Chapter 25 Electromagnetic Waves

25.1 The Production of Electromagnetic Waves

25.2 The Propagation of Electromagnetic Waves

25.3 The Electromagnetic Spectrum

25.5 Polarization

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It was the great Scottish physicist James Clerk Maxwell (1831–1879) who showed that electric and magnetic fields fluctuating together can form a propagating wave, appropriately called an **electromagnetic wave**. Sunlight is a mixture of electromagnetic waves having different wavelengths. Each wavelength in the light produces a different color sensation in our eyes, from red to green to violet. The colors are present in the sunlight, in the sense that sunlight is a mixture of different wavelengths. When this mixture strikes an object, different parts of the object reflect certain wavelengths more strongly than others, giving each part its color pattern. Thus, the colors of an object "belong" to the electromagnetic waves that reflect from it. This chapter examines the general properties of electromagnetic waves and explores their many uses in our lives.

Electromagnetic wave   ****

 An electromagnetic wave in a vacuum consists of mutually perpendicular and oscillating electric and magnetic fields. The wave is a transverse wave, since the fields are perpendicular to the direction in which the wave travels. All electromagnetic waves, regardless of their frequency, travel through a vacuum at the same speed, the speed of light c (c = 3.00 x $10^8 m/s$).

The frequency f and wavelength λ (*lambda*) of an electromagnetic wave in a vacuum are related to its speed through the relation
$c = f \lambda$.

Speed of light

 The wave speed of an electromagnetic wave in a dielectric medium is given by v = $1/(\varepsilon_0\mu_0)^{1/2}$, where ε_0 and μ_0 are the permittivity and permeability of the dielectric respectively. Electromagnetic waves cannot propagate within a conductor; they are totally reflected when they strike a conducting surface.
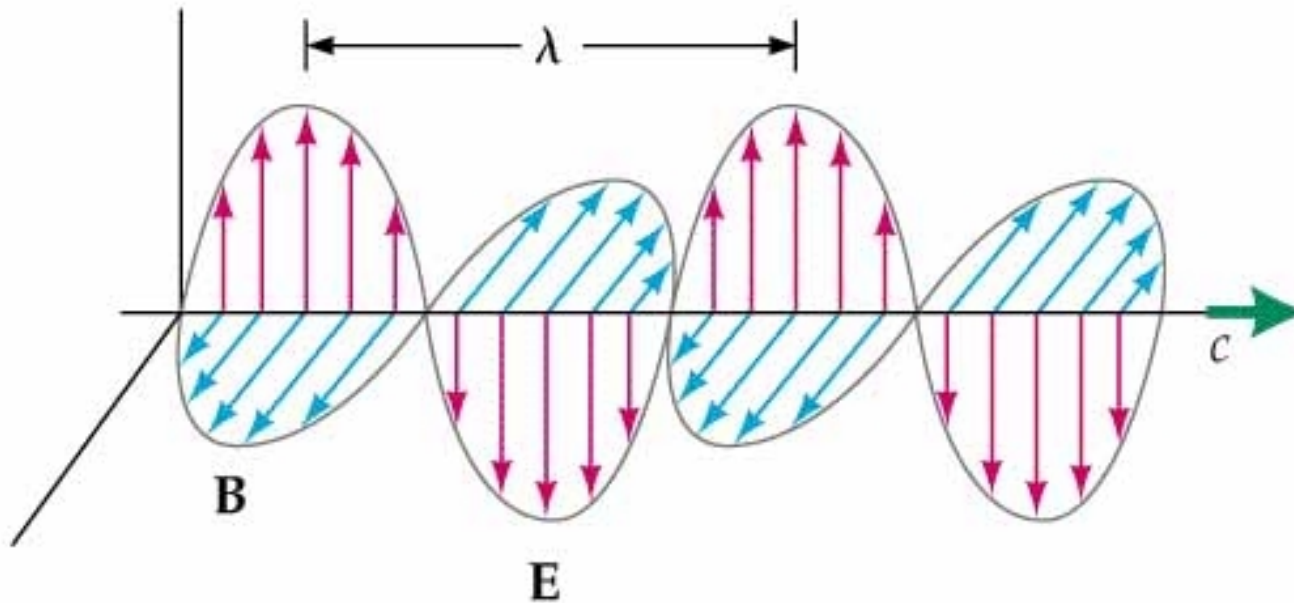
Electric and Magnetic Waves
Electromagnetic Waves

Electromagnetic waves are created by accelerating charges
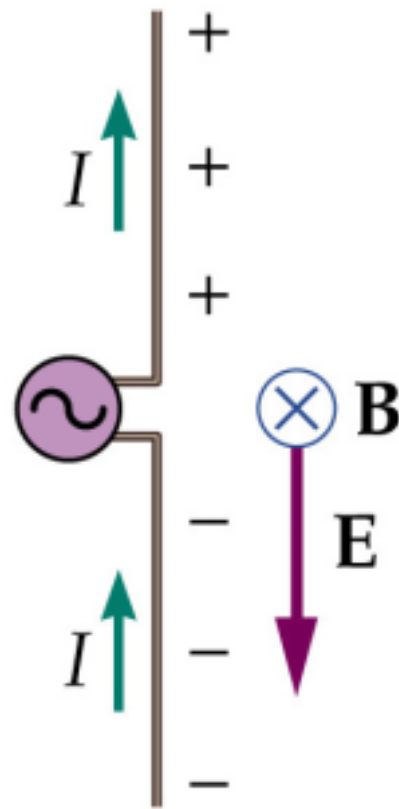Example: oscillating source with two wires attached (antenna)
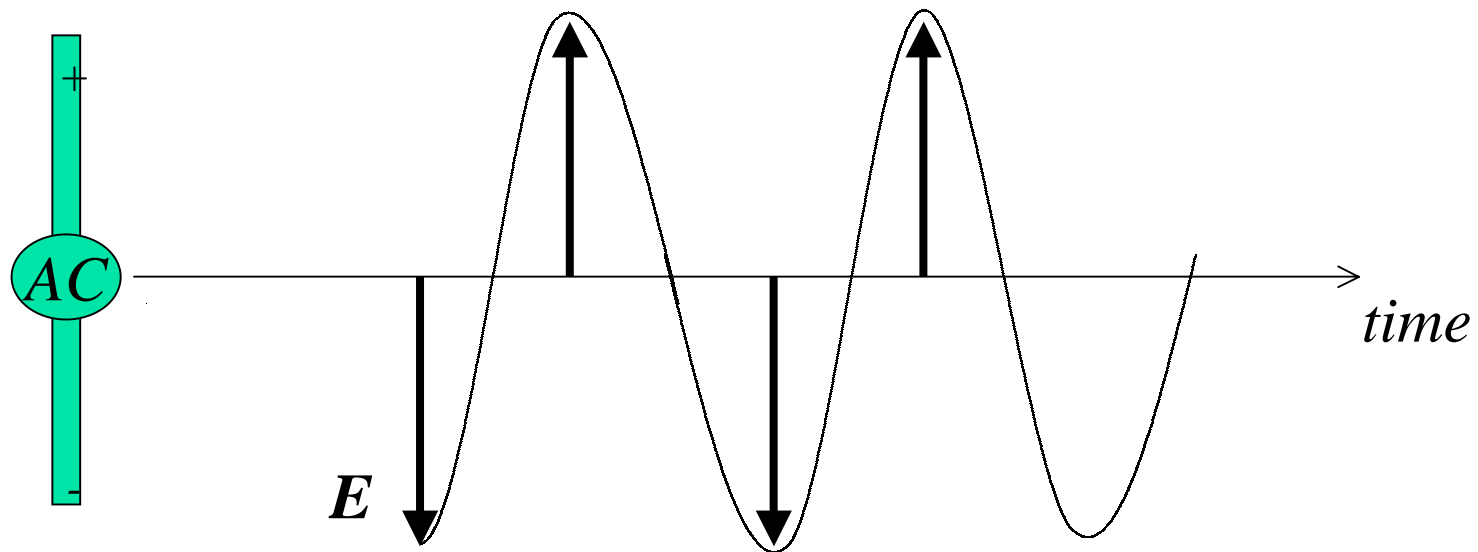
Electric field
• or × Magnetic field

B

E

(b)

# Figure 25–2 Field directions in an electromagnetic wave

- At a time when the electric field produced by the antenna points downward, the magnetic field points into the page. In general, the electric and magnetic fields in an electromagnetic wave are always at right angles to each other.

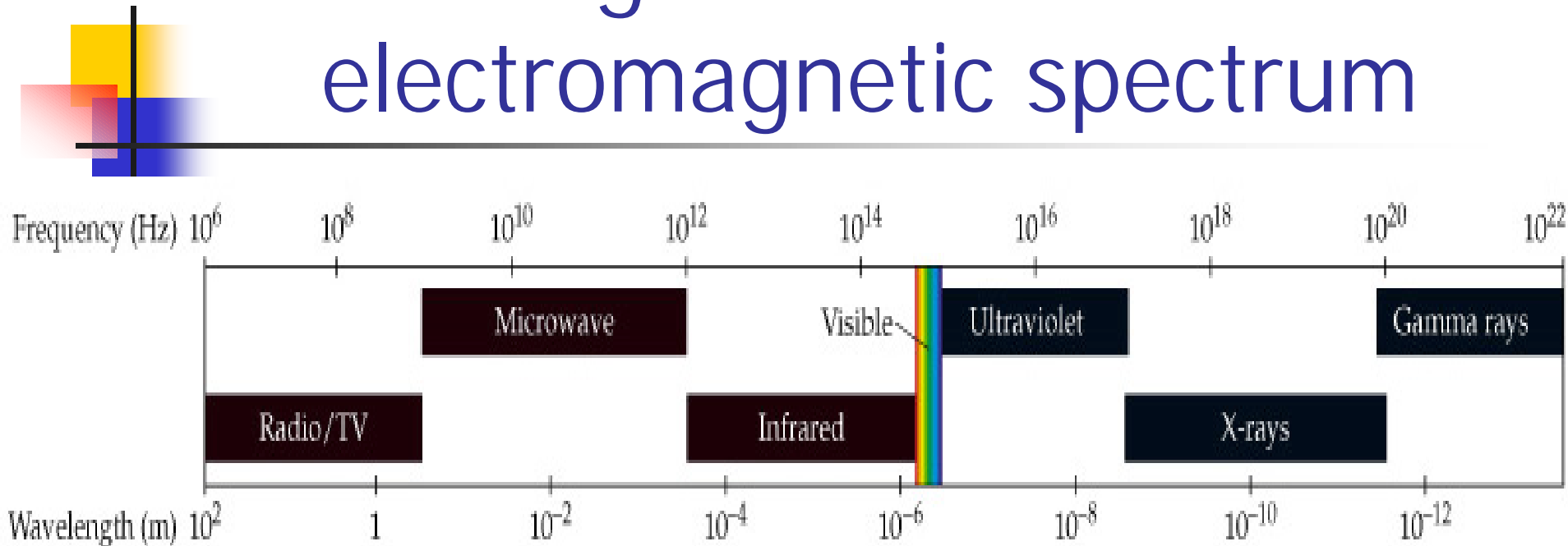# Figure 25–3 The right-hand rule applied to an electromagnetic wave
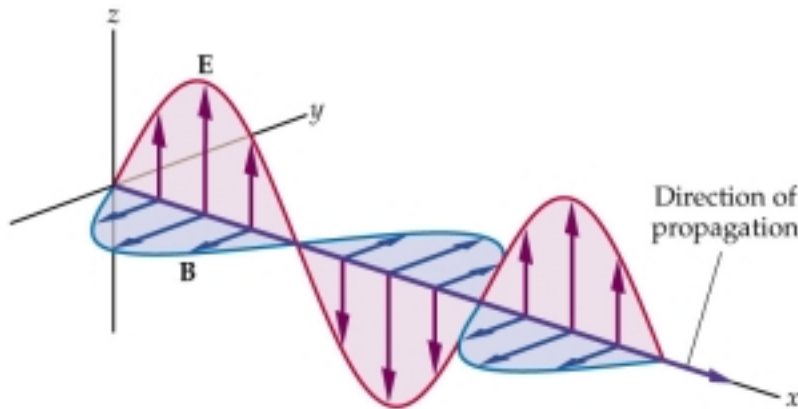
- An electromagnetic wave propagating in the positive x direction. Note that E and B are perpendicular to each other and in phase. The direction of propagation is given by the thumb of the right hand, after pointing the fingers in the direction of E and curling them toward B.

Figure 25–5 Electromagnetic waves and the line of sight
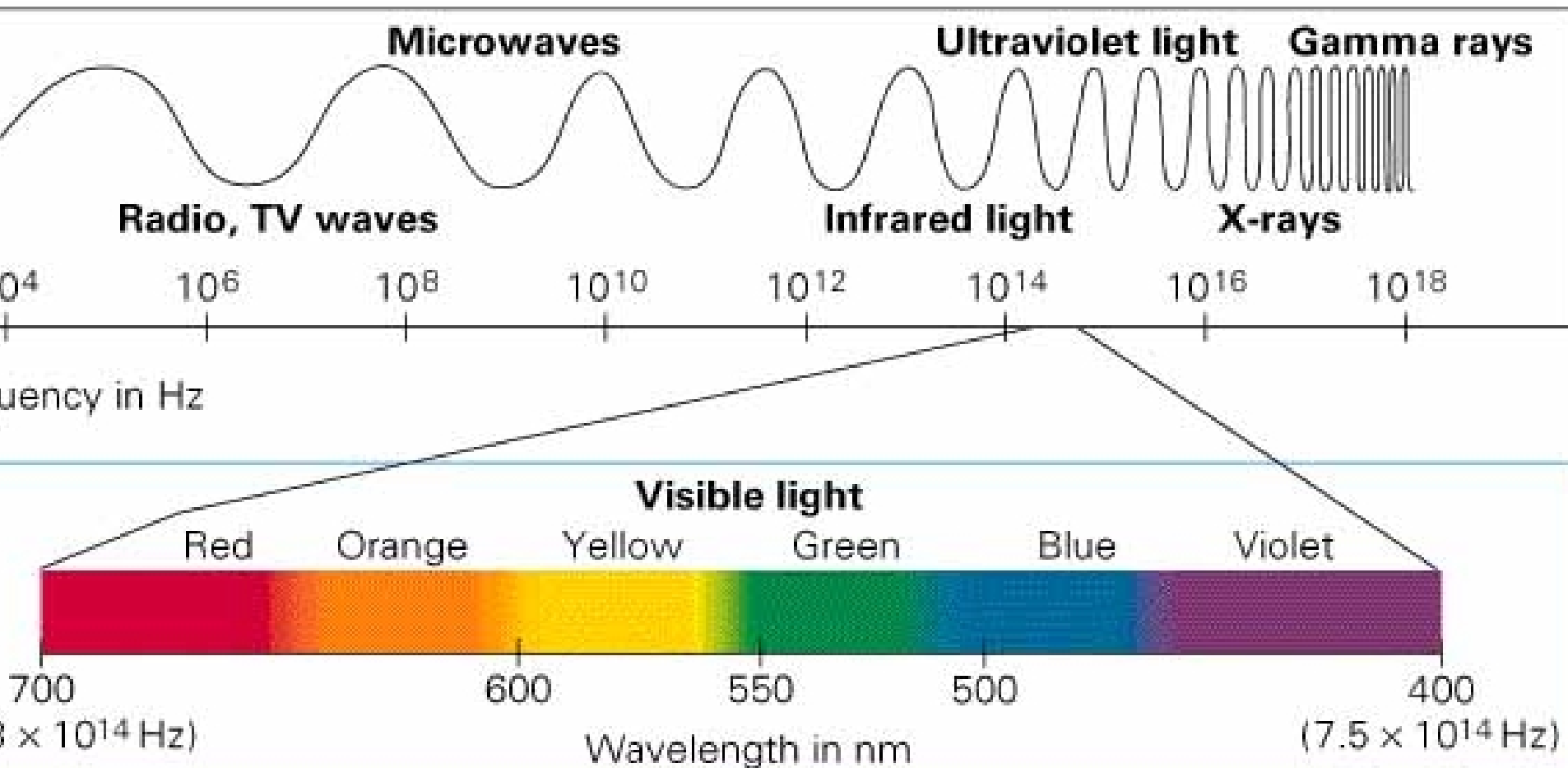

Zero radiation

I

I

Maximum radiation
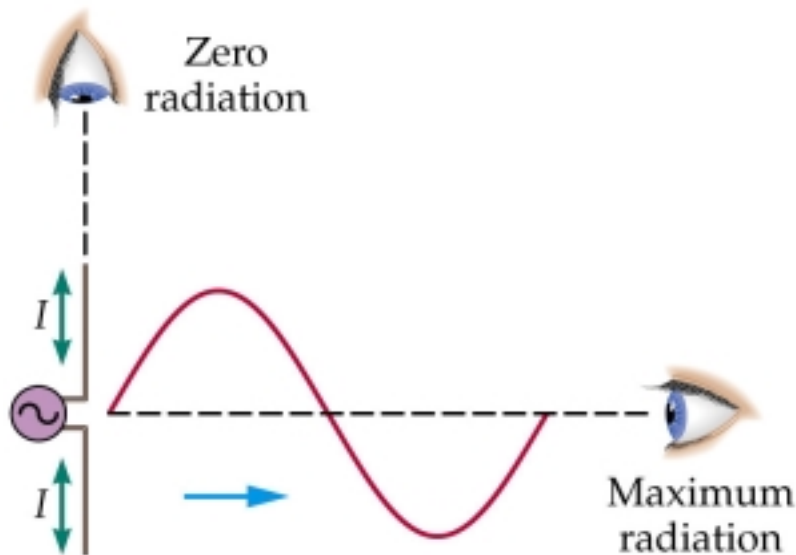
- Electromagnetic radiation is greatest when charges accelerate at right angles to the line of sight. Zero radiation is observed when the charges accelerate along the line of sight. These observations apply to electromagnetic waves of all frequencies.

Figure 25–8 The electromagnetic spectrum

Frequency (Hz)	10^6	10^8	10^{10}	10^{12}	10^{14}	10^{16}	10^{18}	10^{20}	10^{22}

Microwave

Visible

Ultraviolet

Gamma rays

Radio/TV

Infrared

X-rays

Wavelength (m)	10^2	1	10^{-2}	10^{-4}	10^{-6}	10^{-8}	10^{-10}	10^{-12}

- Note that the visible portion of the spectrum is relatively narrow. The boundaries between various bands of the spectrum are not sharp, but instead are somewhat arbitrary.

Microwaves

Ultraviolet light   **Gamma rays**

Radio, TV waves   **Infrared light**   **X-rays**

| 10^4 | 10^6 | 10^8 | 10^{10} | 10^{12} | 10^{14} | 10^{16} | 10^{18} |

…uency in Hz

Visible light

Red   Orange   Yellow   Green   Blue   Violet

| 700 | | 600 | 550 | 500 | | 400 |

$… \times 10^{14}$ Hz)   Wavelength in nm $(7.5 \times 10^{14}$ Hz)

There are lots of different types of electromagnetic waves.
They differ only by their frequency or wavelength.
They are named according to their frequency or wavelength

Microwaves are high frequency radio waves

Infrared waves (lower frequency than red light)

Ultraviolet waves (higher frequency than violet light)

VUV

X-rays

Gamma-rays – very very high frequency

Red light from pointer has a frequency near
4.5×10^{14} Hz

What is the wavelength of this red light?

$c = f\lambda$ or $\lambda = c/f = (3 \times 10^8$ m/s$)/(4.5 \times 10^{14}$ Hz$)$
$= 0.667 \times 10^{-6}$ m $= 667$ nm

The speed of light is pretty fast but IT IS FINITE.

Nothing can exceed the speed of light.

All electromagnetic waves travel at the same speed:

$c=3x10^8$ m/s – the speed of light (in a vacuum).

Stars are pretty far from earth!

Astronomical distances usually measured in light years.
1 light year – how many meters?
Some supernova took place at a distance of $1.66x10^{21}$ m from earth.
How long ago did the explosion occur before we see it on earth?

Figure 25-7 Fizeau's experiment to measure the speed of light

Light source — Semitransparent mirror — ω — Notched wheel — d — Mirror
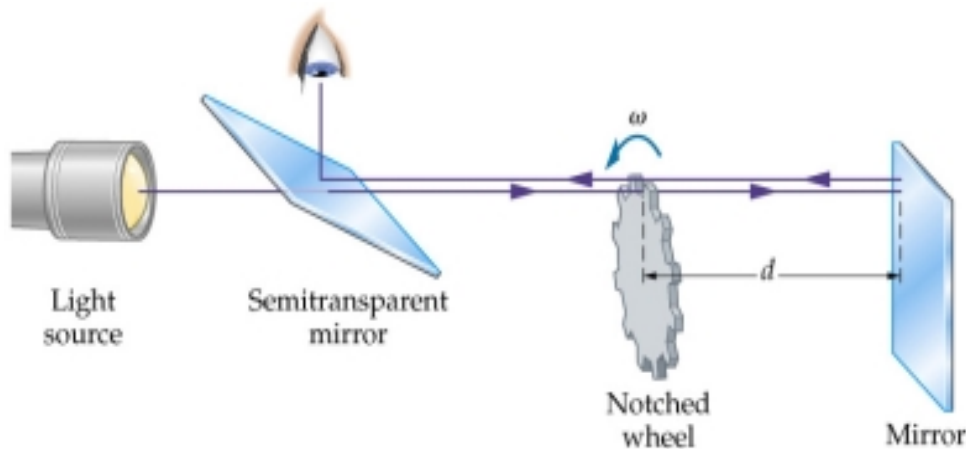
- If the time required for light to travel to the mirror and back is equal to the time it takes the wheel to rotate from one notch to the next, light will pass through the wheel and on to the observer.

Figure 25–11 Polarization of electromagnetic waves
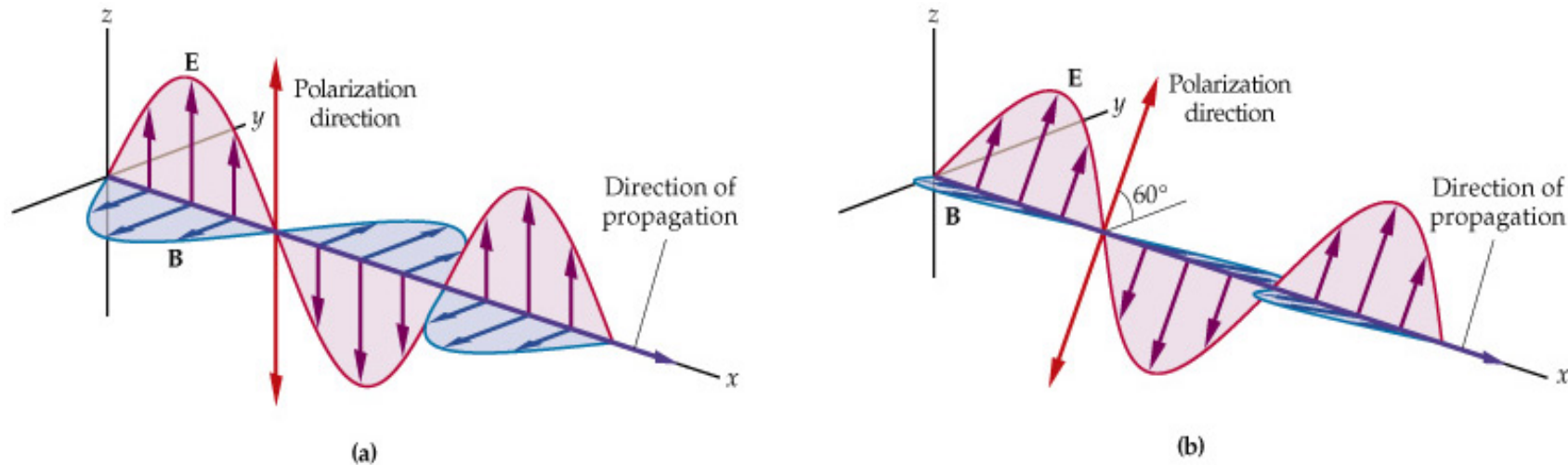
- The polarization of an electromagnetic wave is the direction along which its electric field vector, E, points. The cases shown illustrate (a) polarization in the z direction and (b) polarization in the y-z plane, at an angle of 60° with respect to the y axis.
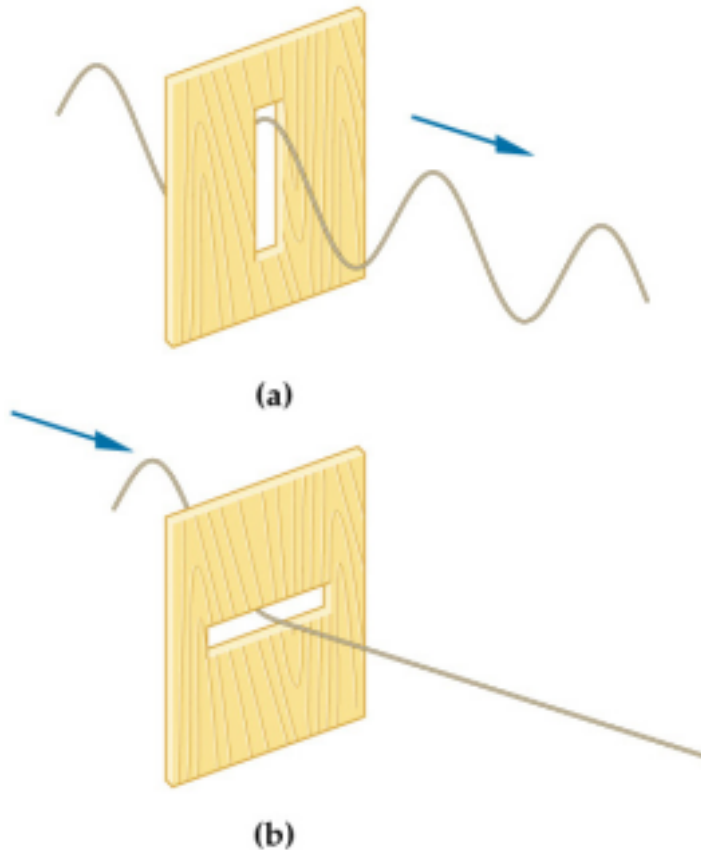
Figure 25–12 Polarized versus unpolarized light

Polarization direction

Polarized beam

Propagation direction

(a)

Unpolarized beam

Propagation direction
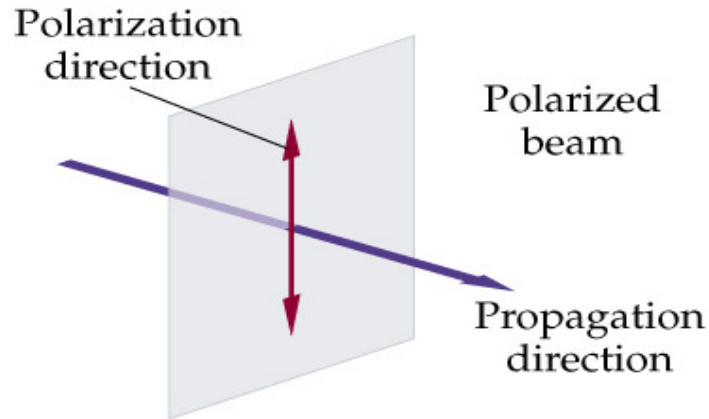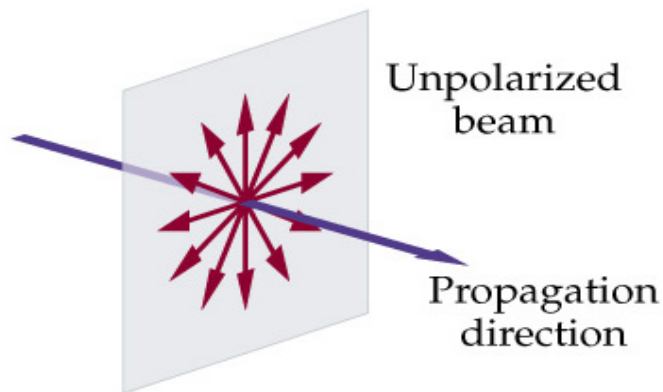
(b)

- A beam of light that is (a) polarized in the vertical direction and (b) unpolarized.

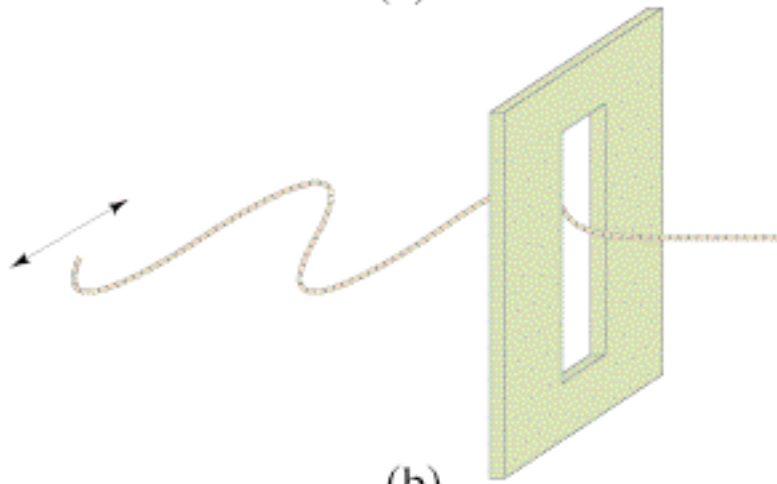# Figure 25–13 A mechanical analog of a polarizer

(a)

(b)

- (a) The polarization of the wave is in the same direction as the polarizer; hence, the wave passes through unaffected. (b) The polarization of the wave is at right angles to the direction of the polarizer. In this case the wave is absorbed.
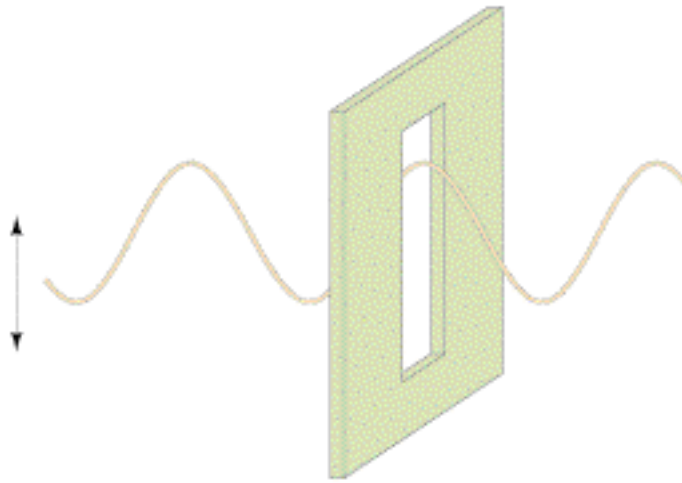
(a)

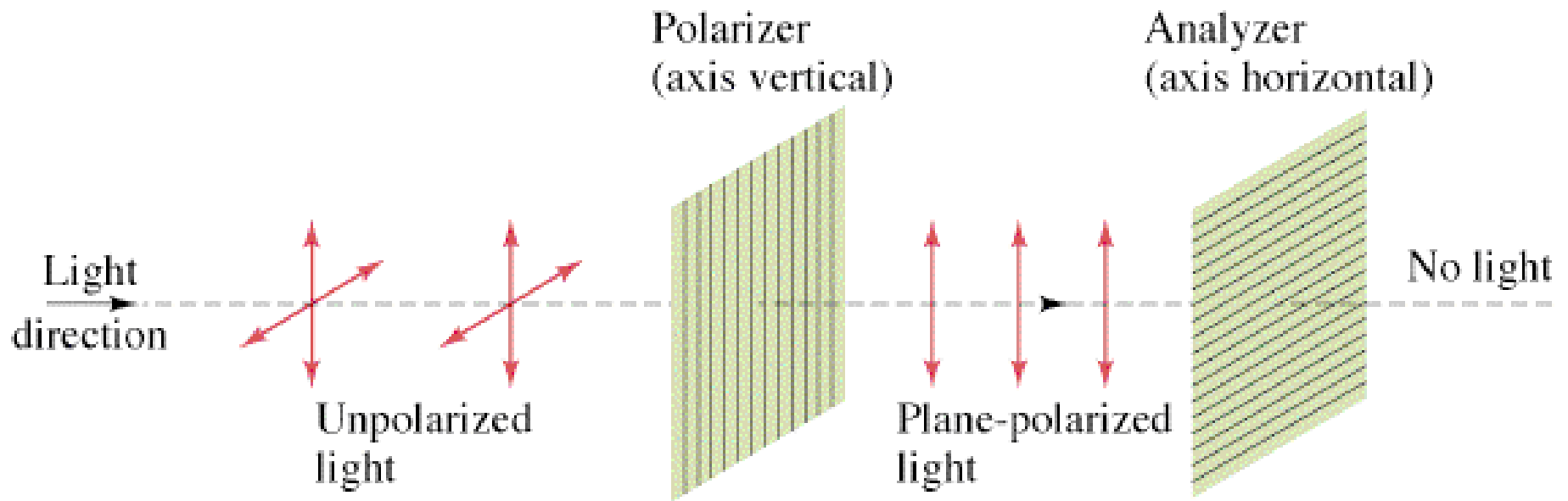100 % transmission

(b)

0 % transmission

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Polarizing materials

Polarizing materials allows only the component of the wave's electric field along one direction to pass through them. The preferred transmission direction for the electric field is called the **transmission axis** of the material. When unpolarized light is incident on a piece of polarizing material, the transmitted polarized light has an intensity that is one-half that of the incident light.

Molecules in the material are aligned in such a way so that only electric fields that are in the same direction as the transmission axis are transmitted.
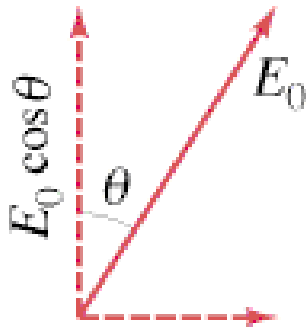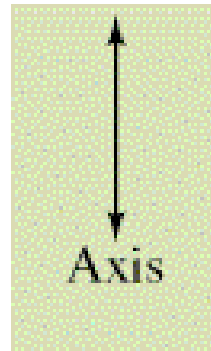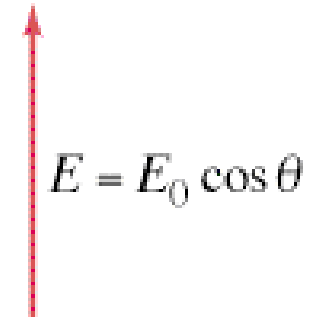
POLARIZATION OFLIGHT WAVES UPON TRANSMISSION
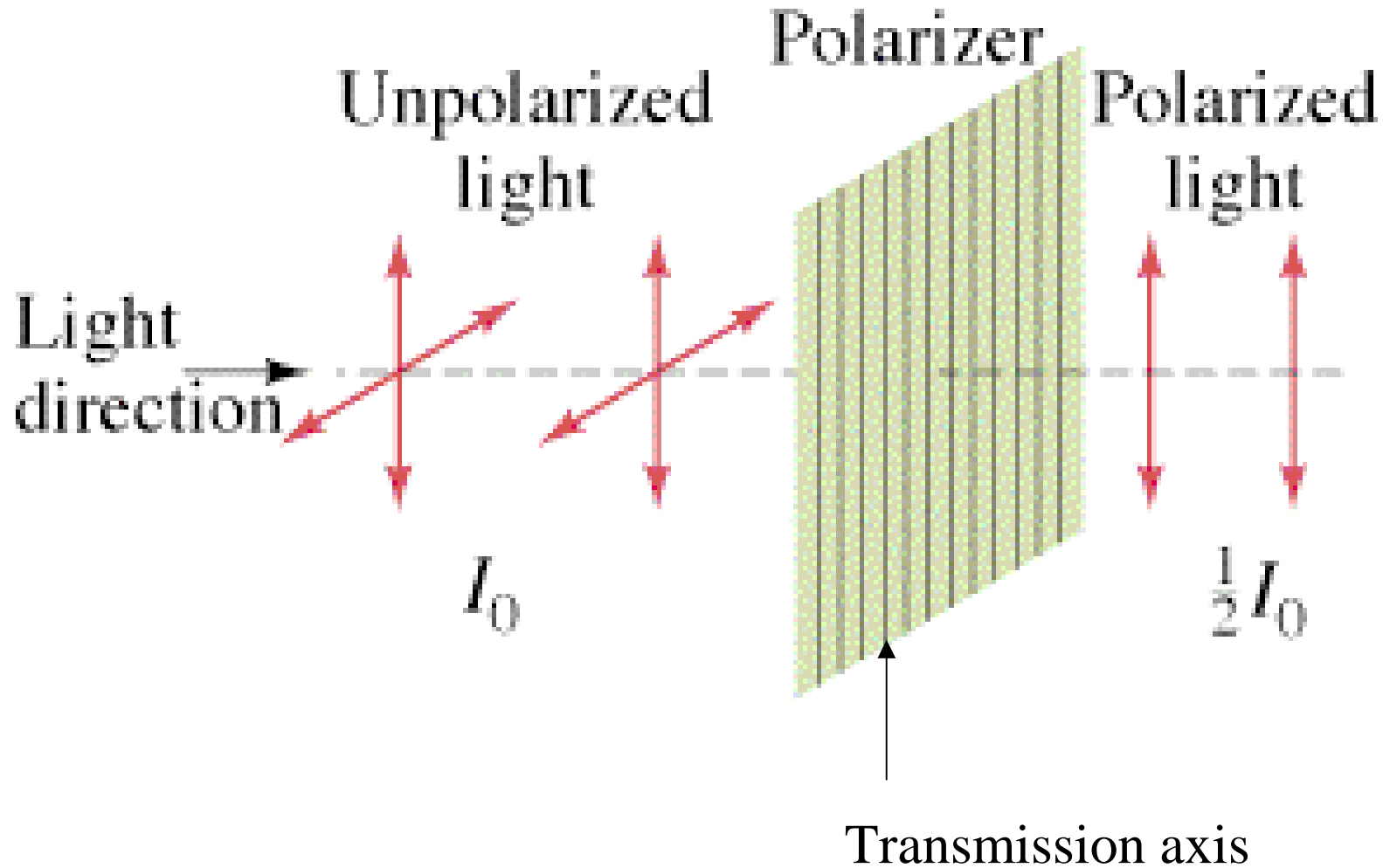
Transmission axis

Crossed polarizers

I is proportional to E²

$E_0 \cos \theta$

E_0

θ

Incident beam polarized
at angle θ to the vertical
and has amplitude E_0.

Axis

Vertical
Polaroid

$E = E_0 \cos \theta$

Transmitted wave

$I_T = I_0 \cos^2 \theta$ *Malus' Law*

Light
direction

I_0

$\frac{1}{2}I_0$

$\frac{1}{4}I_0$

$\frac{1}{8}I_0$
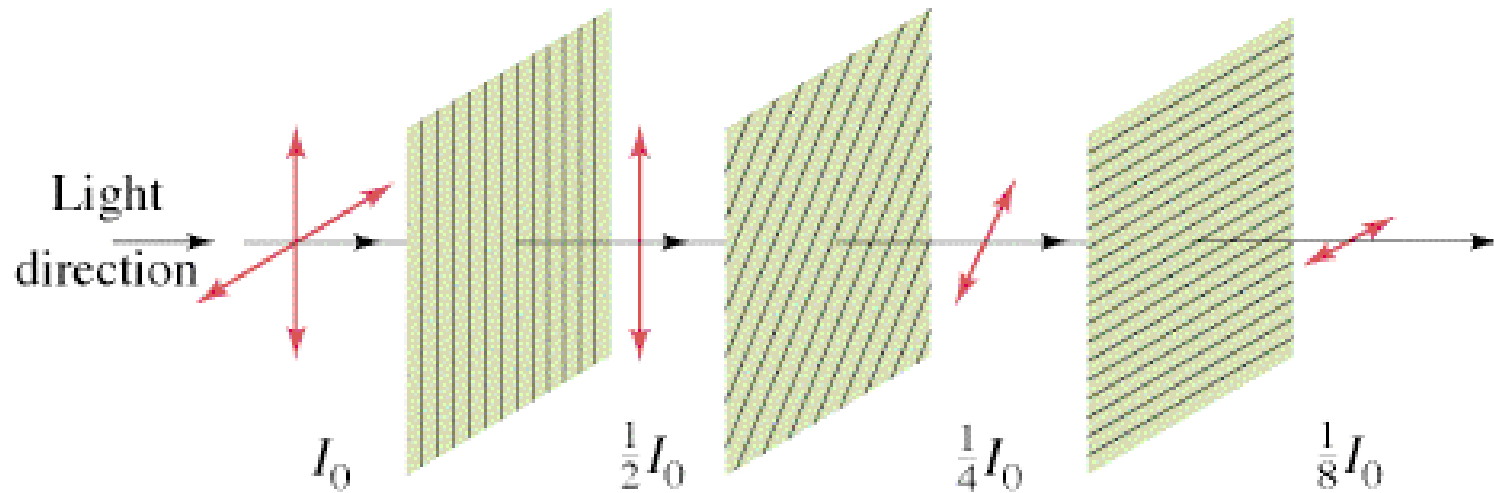
50%
transmission

$I_T = I_i \cos^2 45$
$= I_o/2 \ (1/2) = I_o/4$

$I_T = I_o/4 \ \cos^2 45$
$= I_o/4 \ (1/2) = I_o/8$