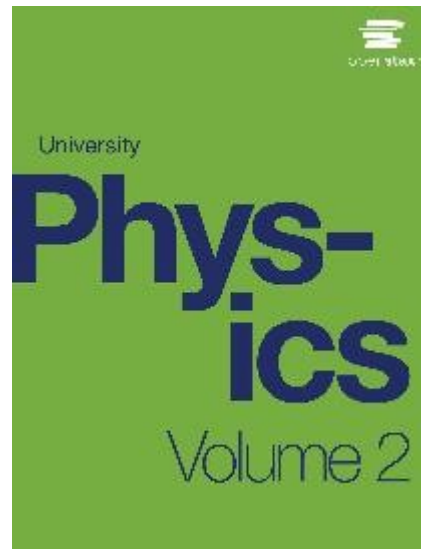


UNIVERSITY PHYSICS

Chapter 16 ELECTROMAGNETIC WAVES

PowerPoint Image Slideshow



Maxwell's equations

$$\oint_C \vec{E} \cdot d\vec{A} = \frac{q_{\text{enclosed}}}{\epsilon_0} \leftrightarrow \vec{\nabla} \cdot \vec{E} = \frac{\rho}{\epsilon_0}$$

$$\oint_C \vec{B} \cdot d\vec{A} = 0 \leftrightarrow \vec{\nabla} \cdot \vec{B} = 0$$

$$\oint_C \vec{B} \cdot d\vec{S} = \mu_0 (I + I_d) \leftrightarrow \vec{\nabla} \times \vec{B} = \mu_0 \vec{J} + \frac{1}{c^2} \frac{\partial \vec{E}}{\partial t}$$

$$\oint_C \vec{E} \cdot d\vec{S} = \frac{-d\Phi_m}{dt} \leftrightarrow \vec{\nabla} \times \vec{E} = \frac{-\partial \vec{B}}{\partial t}$$

Gauss's law for electricity

$$\oint_C \vec{E} \cdot d\vec{A} = \frac{q_{\text{enclosed}}}{\epsilon_0} \leftrightarrow \vec{\nabla} \cdot \vec{E} = \frac{\rho}{\epsilon_0}$$

Gauss's law for magnetism

$$\oint_C \vec{B} \cdot d\vec{A} = 0 \leftrightarrow \vec{\nabla} \cdot \vec{B} = 0$$

Ampere's law

$$\oint_C \vec{B} \cdot d\vec{S} = \mu_0 (I + I_d) \iff \vec{\nabla} \times \vec{B} = \mu_0 \vec{J} + \frac{1}{c^2} \frac{\partial \vec{E}}{\partial t}$$

$$I_d = \epsilon_0 \frac{d\Phi_E}{dt}$$

$$\Phi_E = \int \int_{\text{Surface } S} \vec{E} \cdot d\vec{A}$$

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

Faraday's law

$$\oint_C \vec{E} \cdot d\vec{S} = \frac{-d\Phi_m}{dt} \leftrightarrow \vec{\nabla} \times \vec{E} = \frac{-\partial \vec{B}}{\partial t}$$

Electromagnetic waves

Start with no point charges

$$\vec{\nabla} \cdot \vec{E} = 0 \quad \vec{\nabla} \cdot \vec{B} = 0 \quad \vec{\nabla} \times \vec{B} = \frac{1}{c^2} \frac{\partial E}{\partial t} \quad \vec{\nabla} \times \vec{E} = -\frac{\partial B}{\partial t}$$

Plug in a trial solution. Note the derivative in the direction of \mathbf{E} must be zero.

$$\vec{E} = E_0 \cos(kx - \omega t) \hat{y}$$

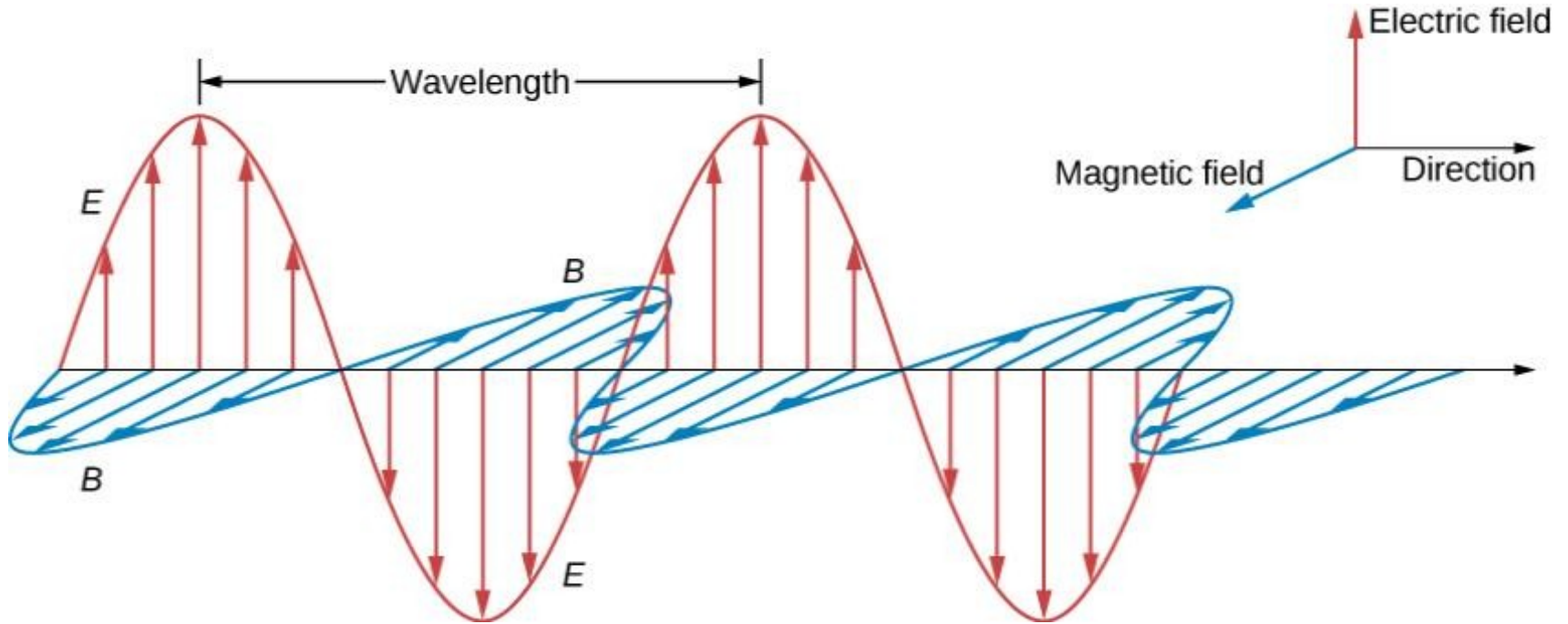
$$\vec{\nabla} \times \vec{B} = \frac{1}{c^2} \frac{\partial}{\partial t} E_0 \cos(kx - \omega t) \hat{y}$$

Each component:

$$\frac{\partial B_y}{\partial z} = \frac{\partial B_z}{\partial y} \quad \frac{\partial B_x}{\partial y} = \frac{\partial B_y}{\partial x} \quad \frac{\partial B_x}{\partial z} - \frac{\partial B_z}{\partial x} = \frac{E_0 \omega \sin(kx - \omega t)}{c^2}$$

$$B_z = \frac{E_0 k \omega \cos(kx - \omega t)}{c^2} = \frac{E_0}{c} \cos(kx - \omega t)$$

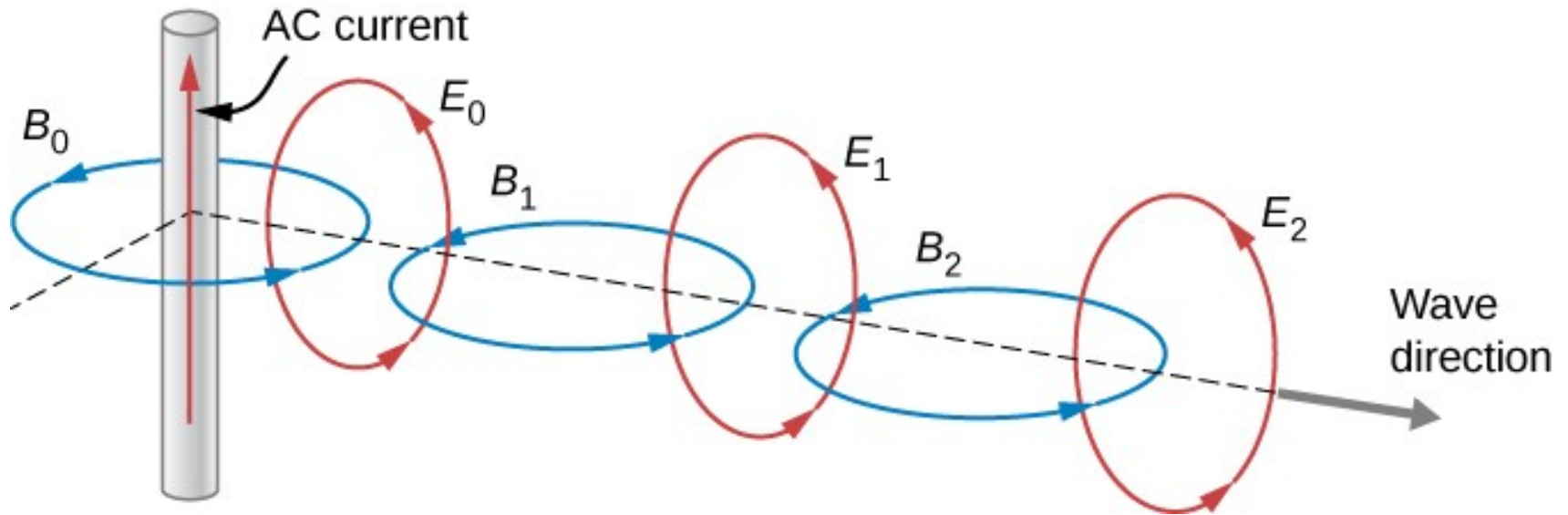
FIGURE 16.8



The plane wave solution of Maxwell's equations has the B field directly proportional to the E field at each point, with the relative directions shown.

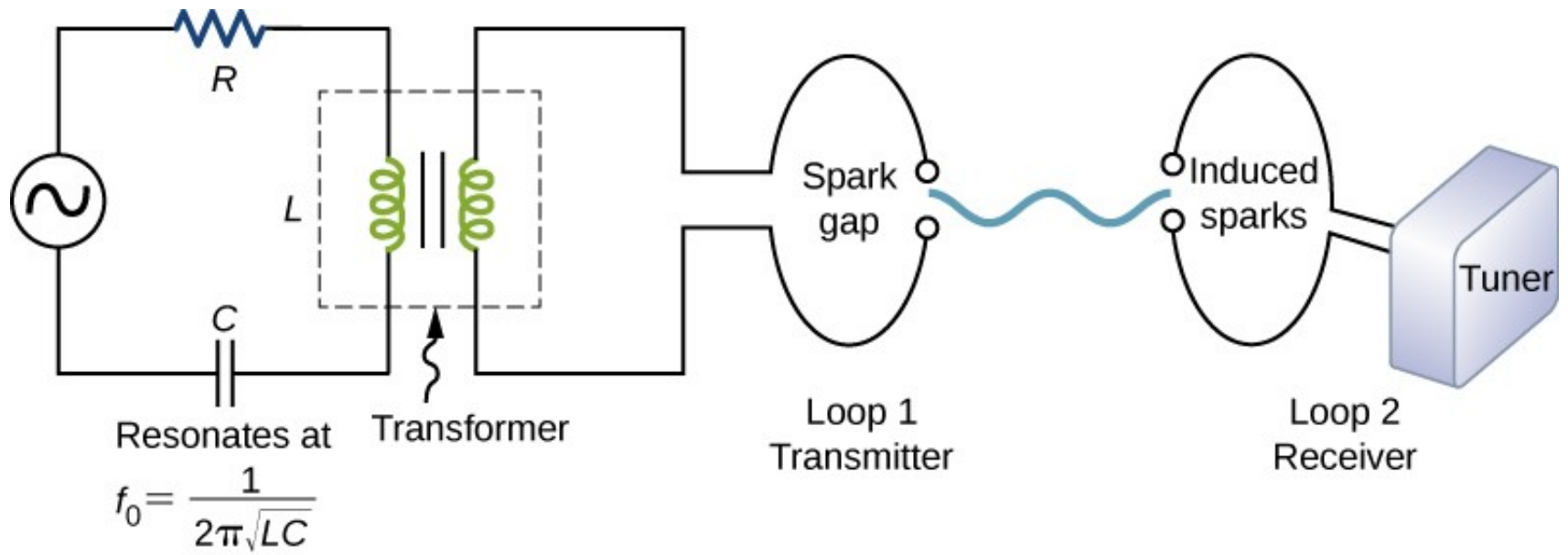
Oscillating fields

FIGURE 16.4



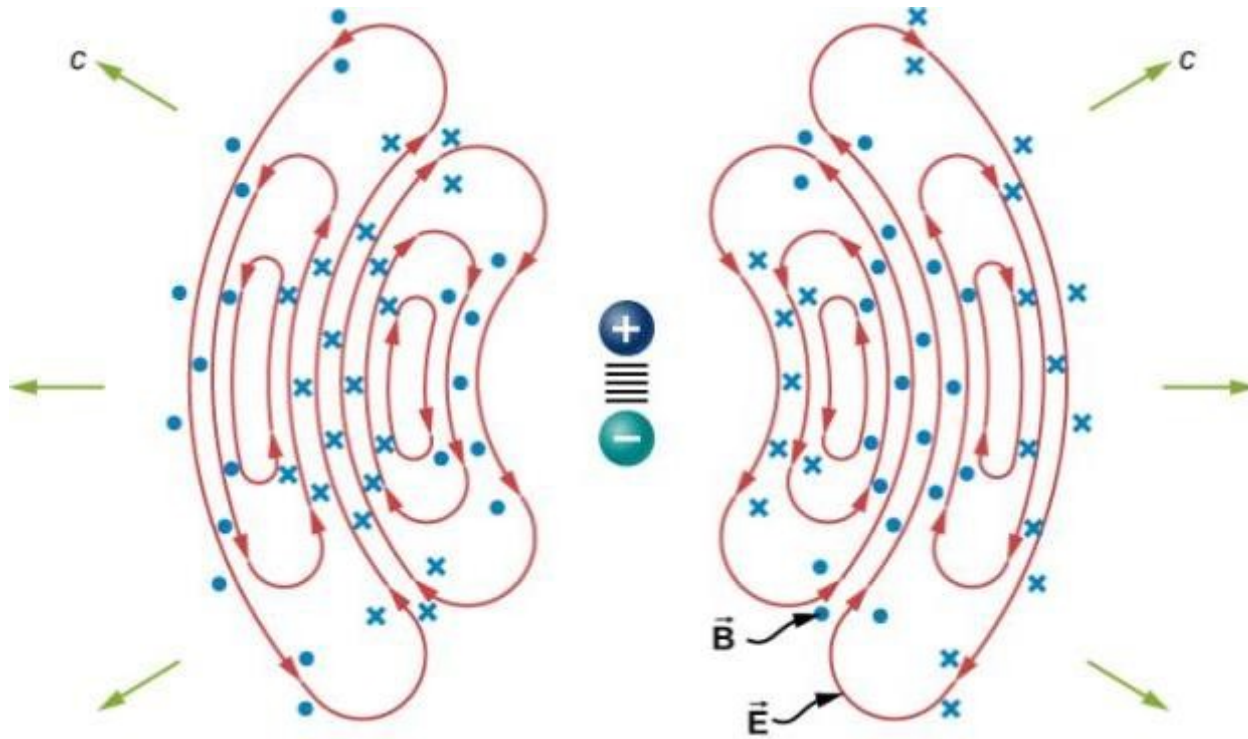
How changing \mathbf{E} and \mathbf{B} fields propagate through space.

FIGURE 16.5



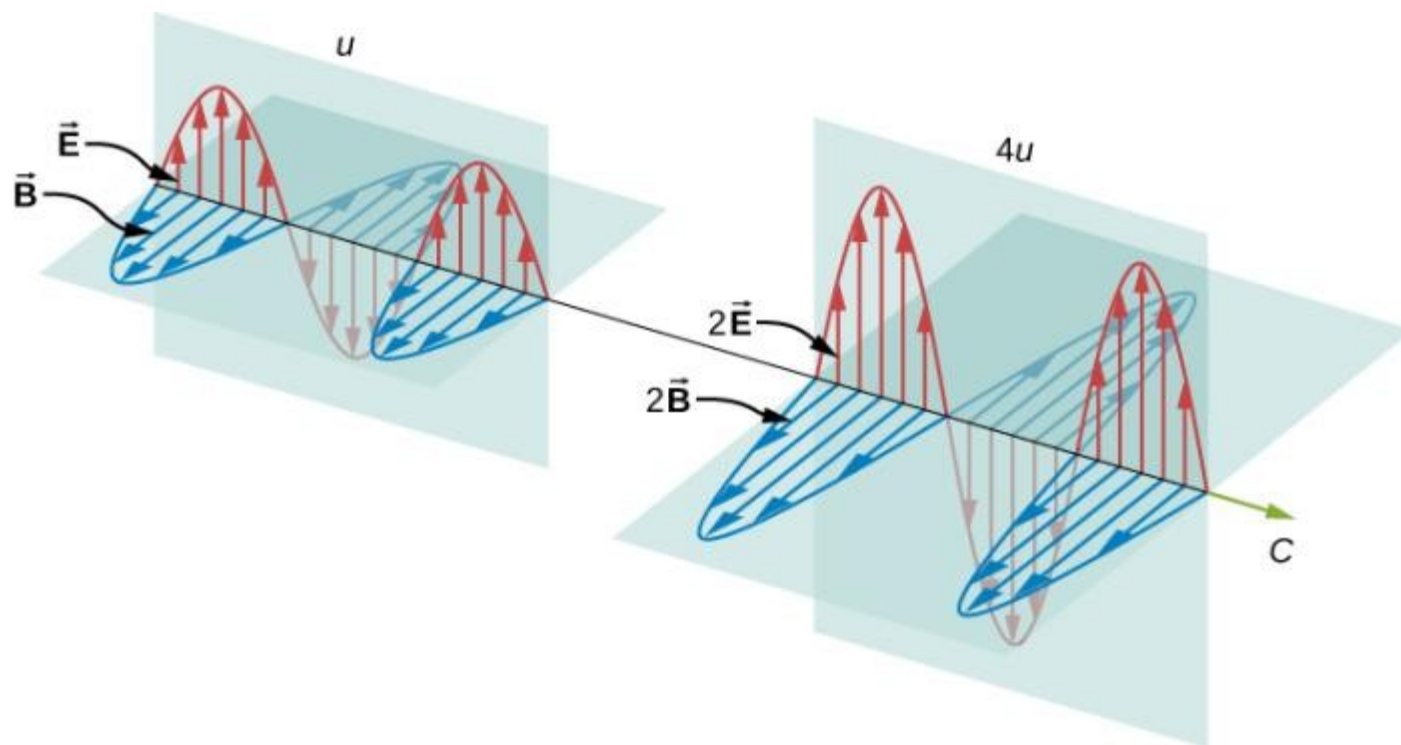
The apparatus used by Hertz in 1887 to generate and detect electromagnetic waves.

FIGURE 16.9



The oscillatory motion of the charges in a dipole antenna produces electromagnetic radiation.

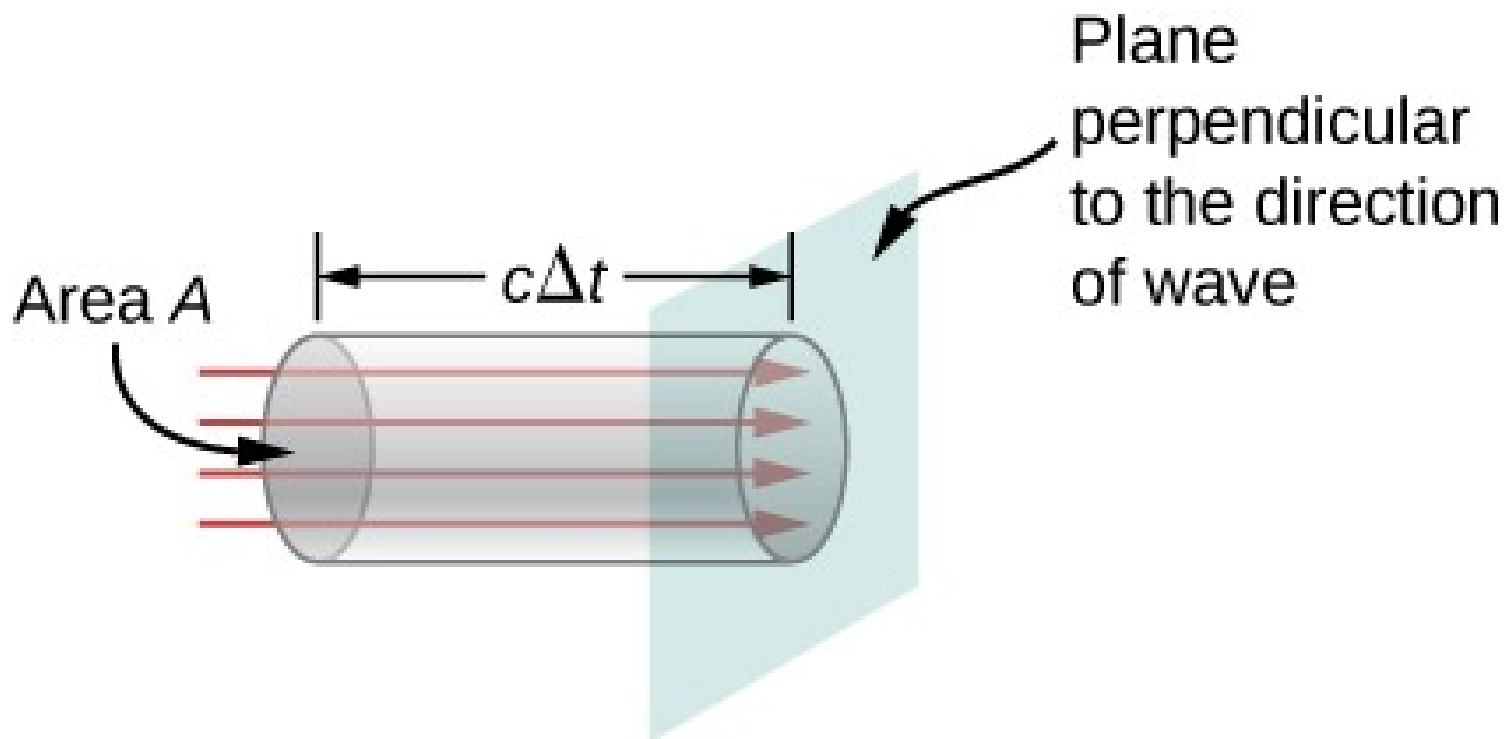
FIGURE 16.10



Energy carried by a wave depends on its amplitude. With electromagnetic waves, doubling the E fields and B fields quadruples the energy density u and the energy flux uc .

$$u = \epsilon_0 E^2 = \frac{B^2}{\mu_0}$$

FIGURE 16.11



The energy $uAc\Delta t$ contained in the electric and magnetic fields of the electromagnetic wave in the volume $Ac\Delta t$ passes through the area A in time Δt .

$$\vec{S} = \frac{1}{\mu_0} \vec{E} \times \vec{B}$$

EXAMPLE 16.4

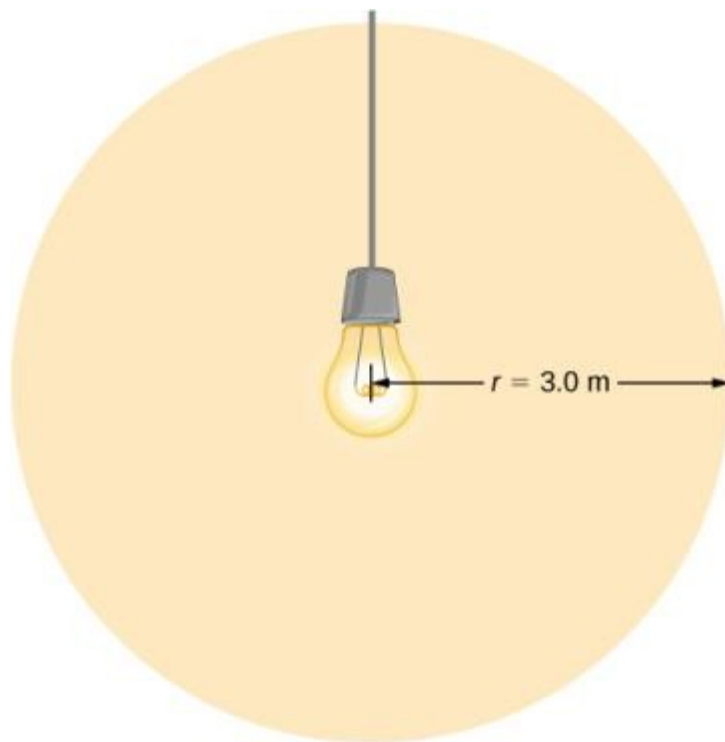
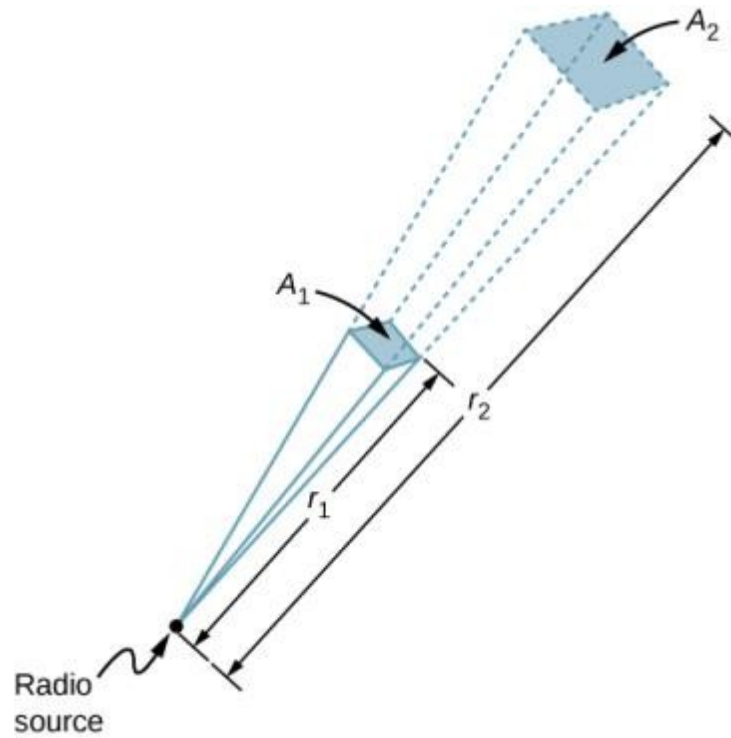
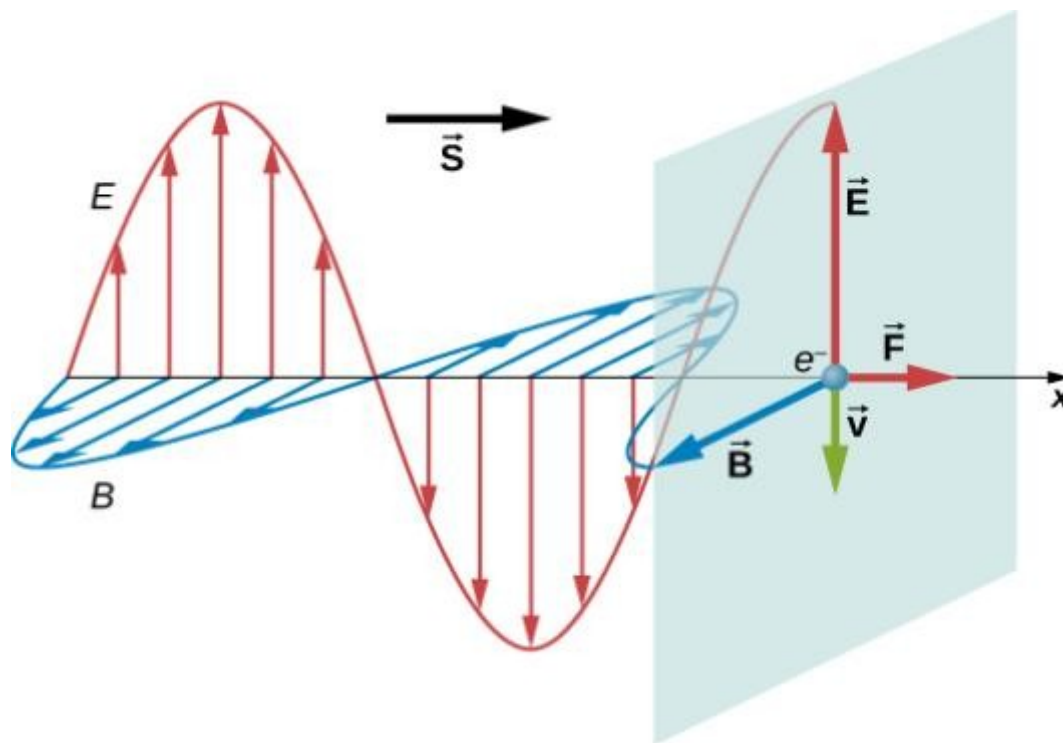


FIGURE 16.12



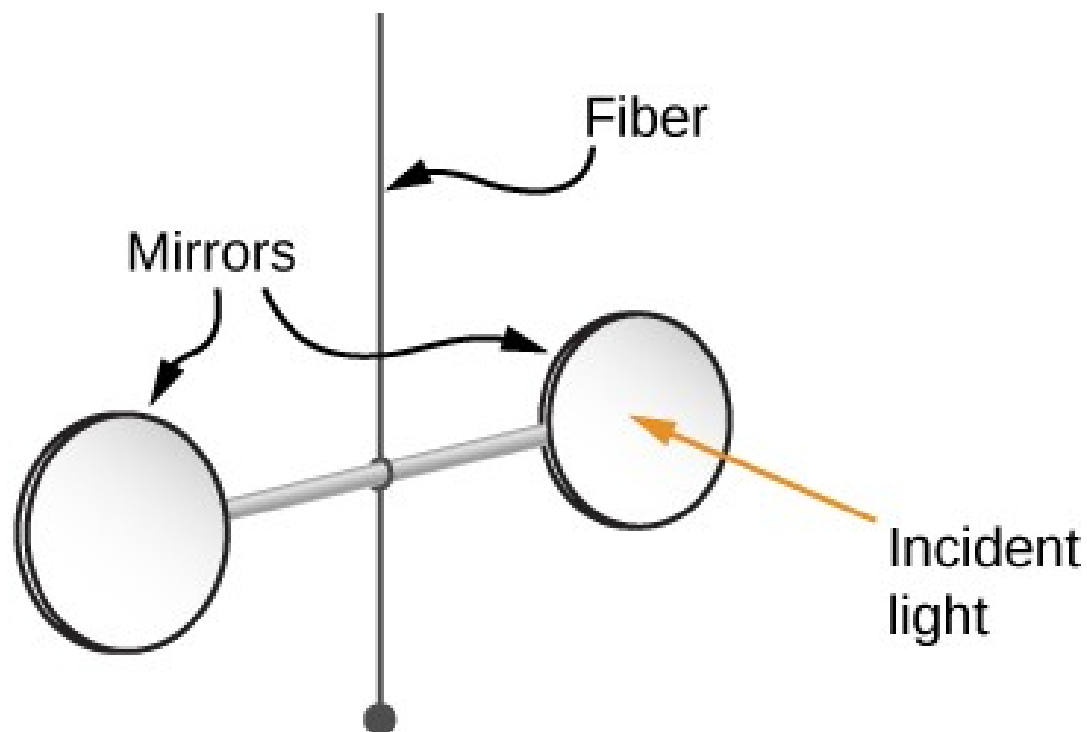
In three dimensions, a signal spreads over a solid angle as it travels outward from its source.

FIGURE 16.13



Electric and magnetic fields of an electromagnetic wave can combine to produce a force in the direction of propagation, as illustrated for the special case of electrons whose motion is highly damped by the resistance of a metal.

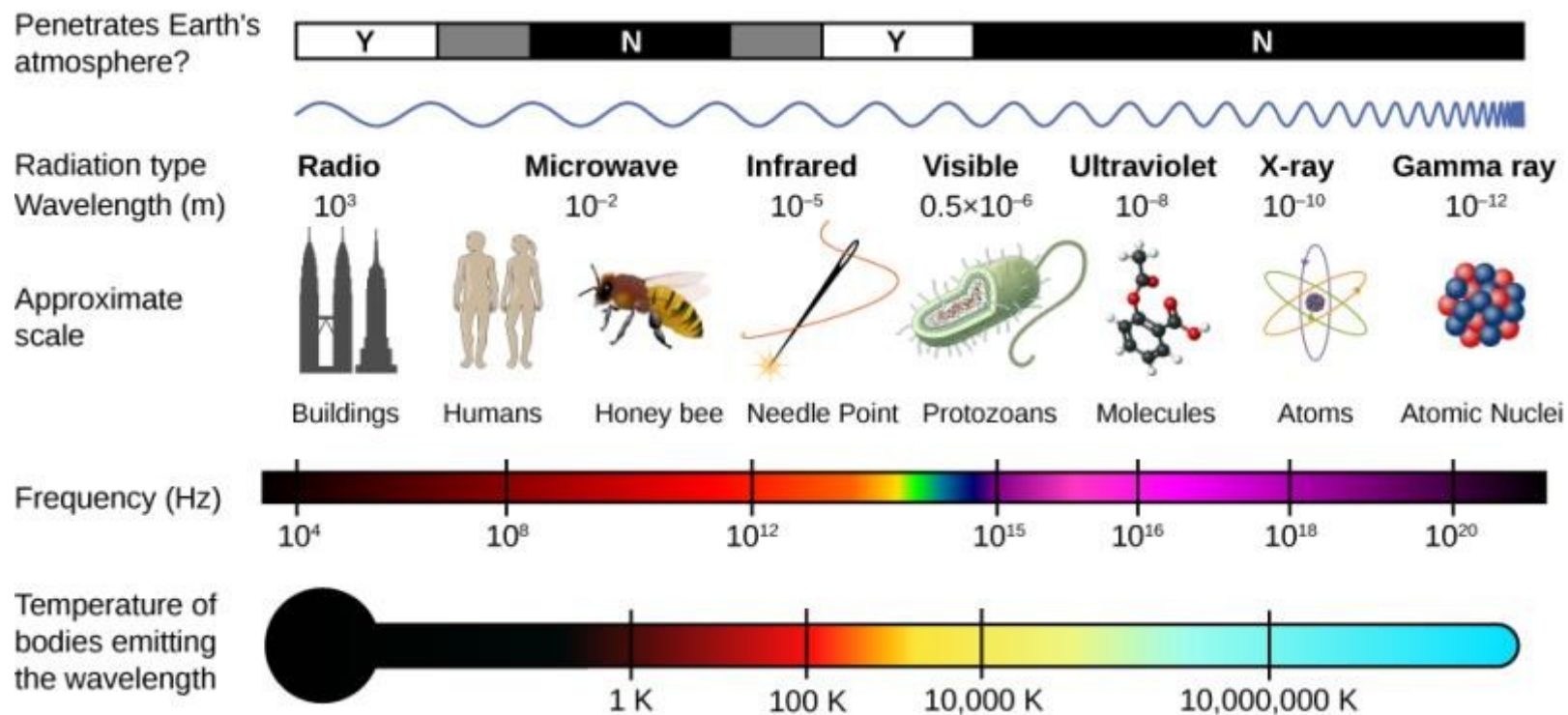
FIGURE 16.14



Simplified diagram of the central part of the apparatus Nichols and Hull used to precisely measure radiation pressure and confirm Maxwell's prediction.

Applications

FIGURE 16.17



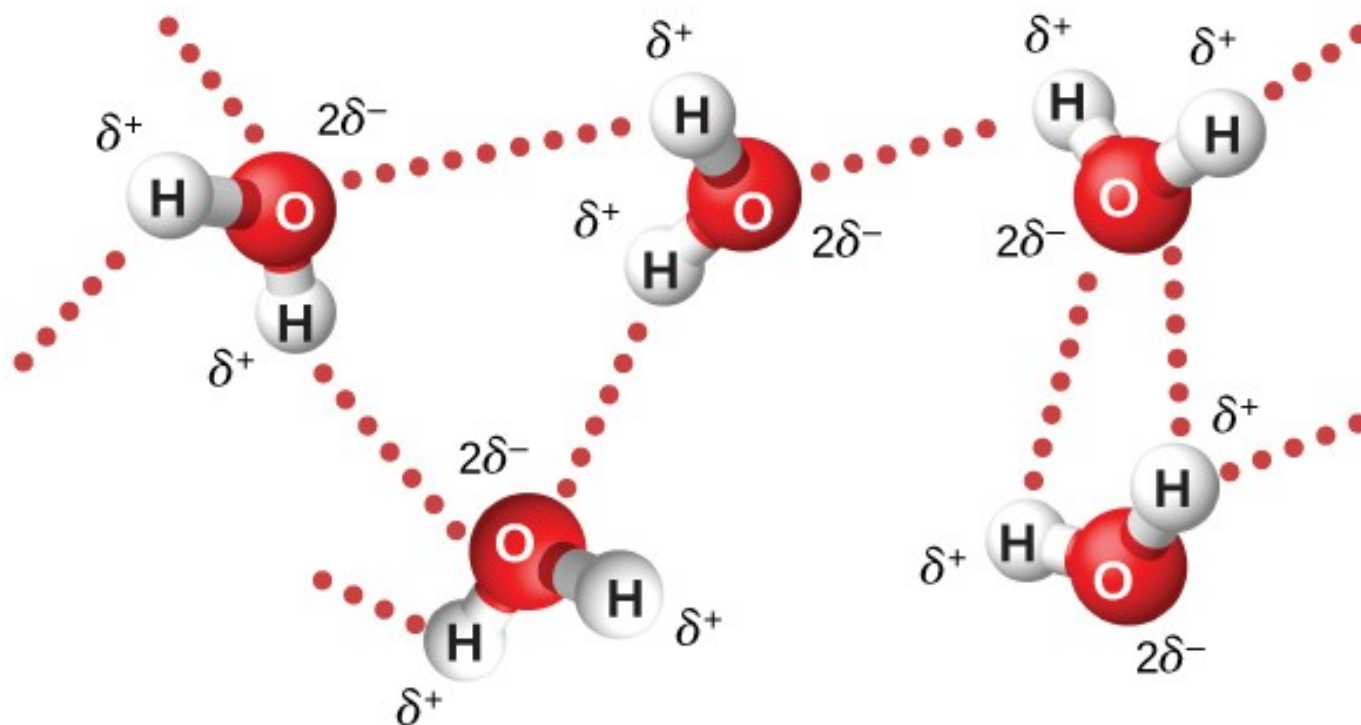
The electromagnetic spectrum, showing the major categories of electromagnetic waves.

FIGURE 16.18

Electromagnetic waves are used to carry communications signals by varying the wave's amplitude (AM), its frequency (FM), or its phase.

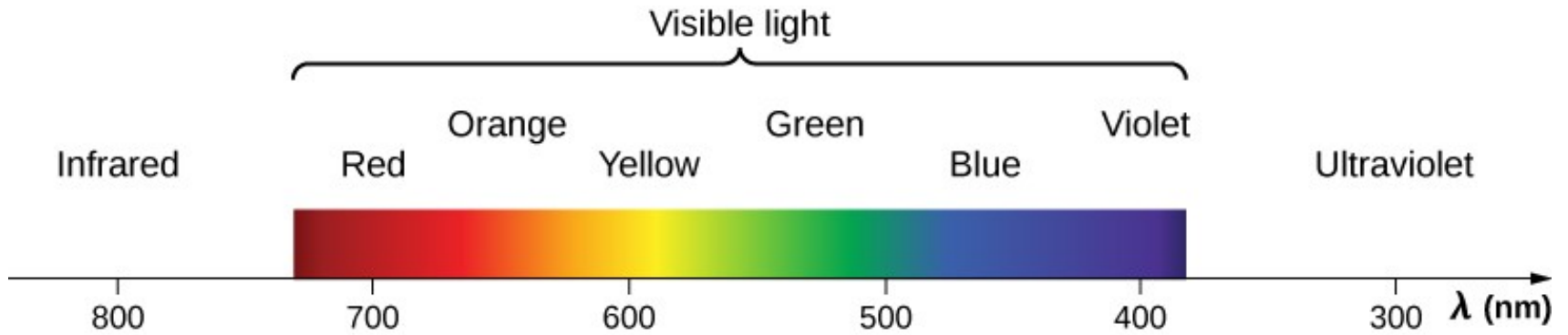


FIGURE 16.19



The oscillating electric field in a microwave oven exerts a torque on water molecules because of their dipole moment, and the torque reverses direction 4.90×10^9 times per second. Interactions between the molecules distributes the energy being pumped into them. The δ^+ and δ^- denote the charge distribution on the molecules.

FIGURE 16.20

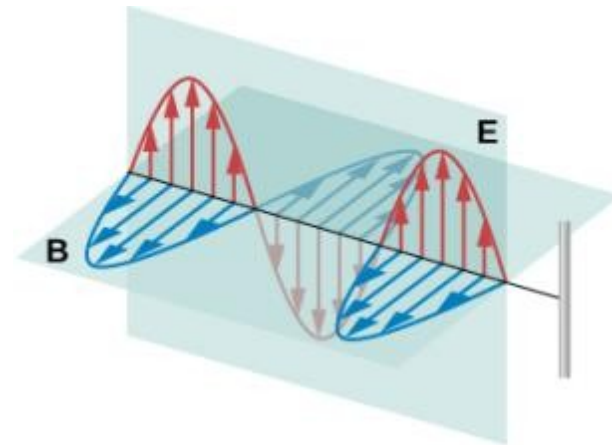


A small part of the electromagnetic spectrum that includes its visible components. The divisions between infrared, visible, and ultraviolet are not perfectly distinct, nor are those between the seven rainbow colors.

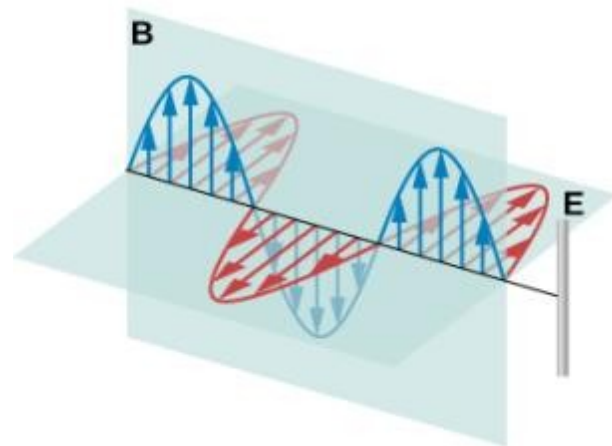
Examples

EXERCISE 5

In which situation shown below will the electromagnetic wave be more successful in inducing a current in the wire? Explain.

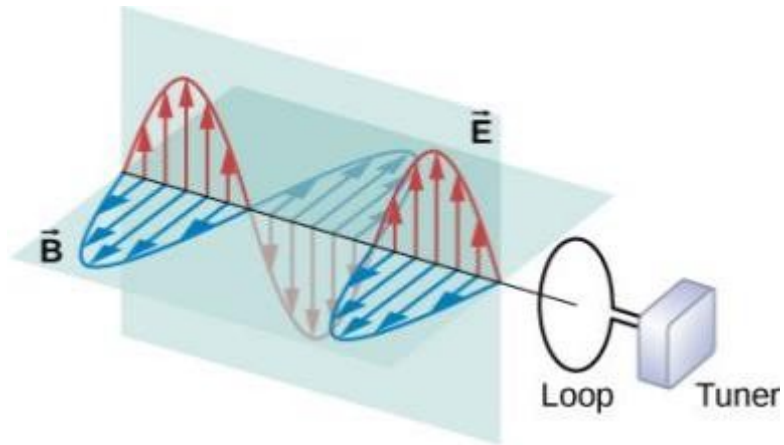


(a)

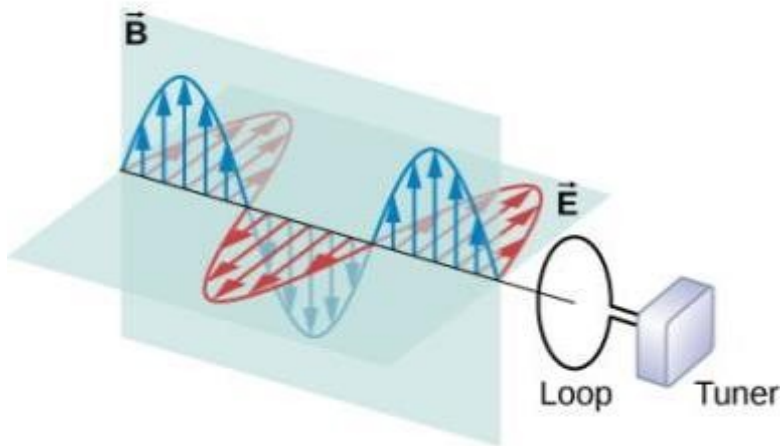


(b)

EXERCISE 6



(a)

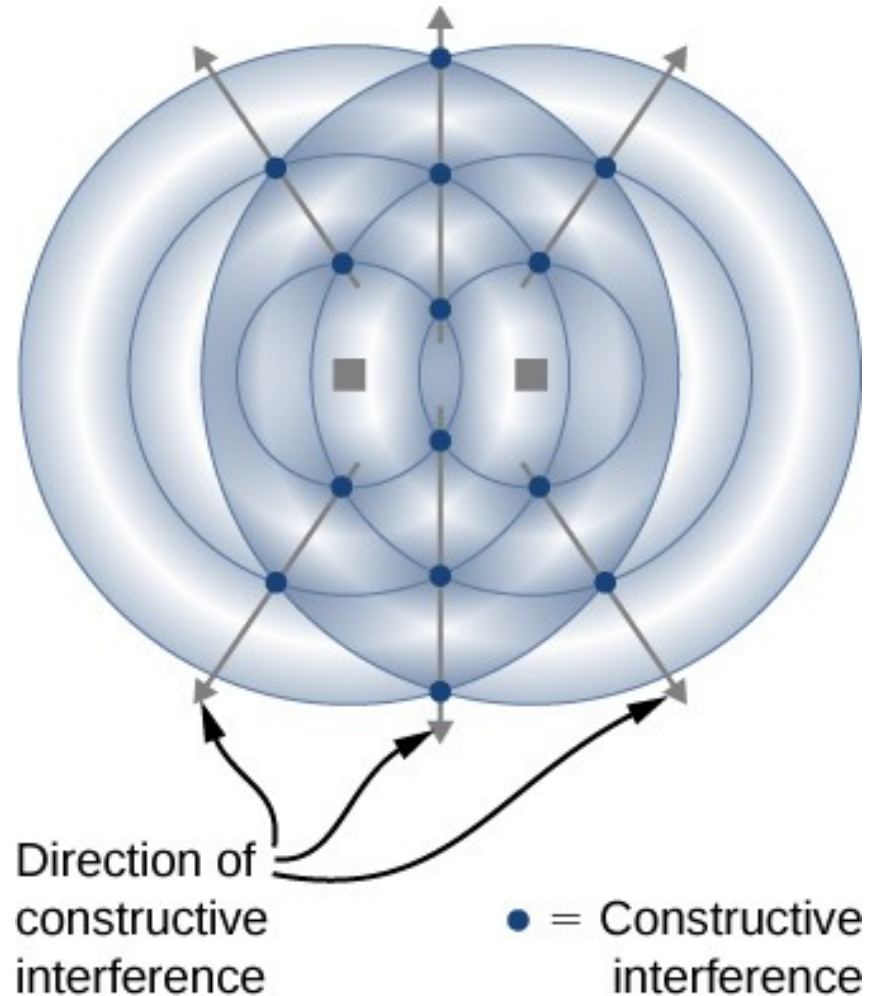


(b)

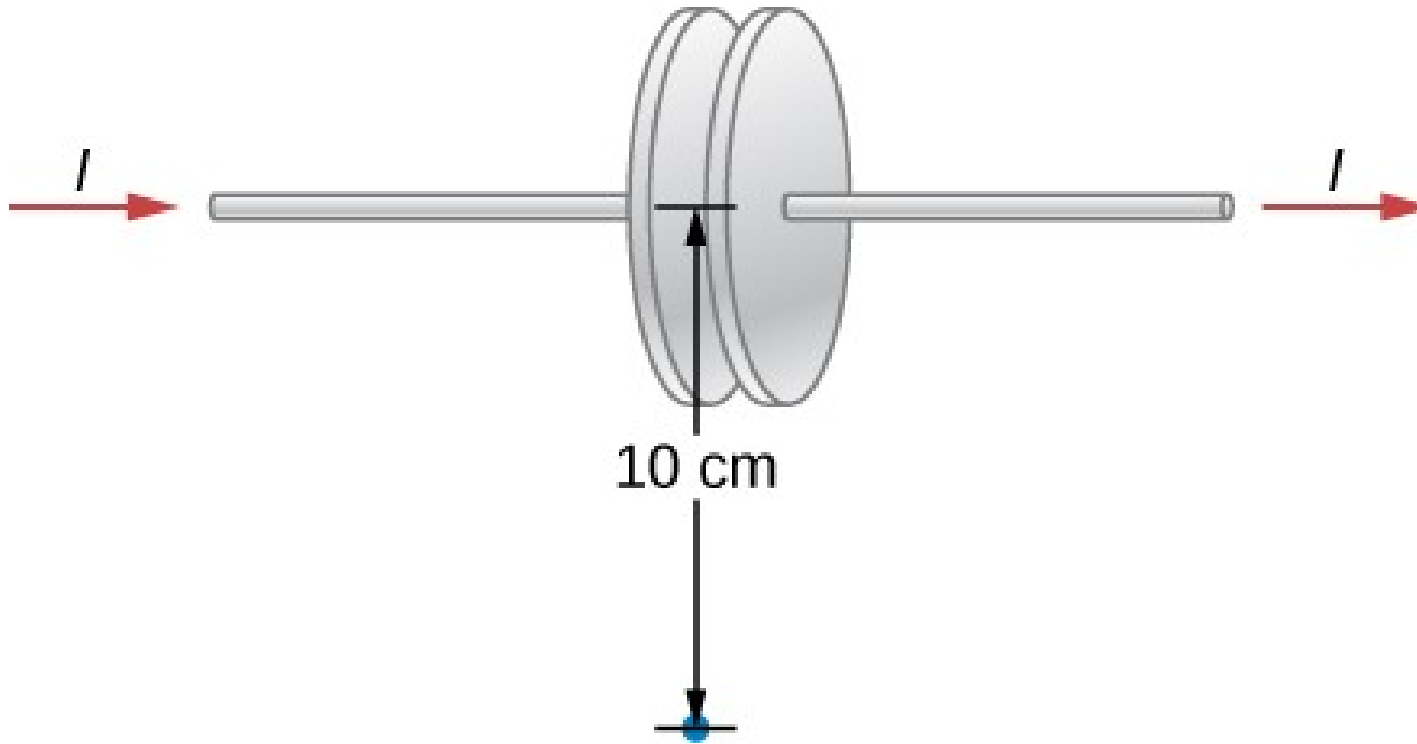
In which situation shown below will the electromagnetic wave be more successful in inducing a current in the loop? Explain.

EXERCISE 8

Shown below is the interference pattern of two radio antennas broadcasting the same signal. Explain how this is analogous to the interference pattern for sound produced by two speakers. Could this be used to make a directional antenna system that broadcasts preferentially in certain directions? Explain.



EXERCISE 36



Suppose the parallel-plate capacitor shown below is accumulating charge at a rate of 0.010 C/s . What is the induced magnetic field at a distance of 10 cm from the capacitor?

EXERCISE 63



A 2.50-m-diameter university communications satellite dish receives TV signals that have a maximum electric field strength (for one channel) of $7.50 \mu\text{V/m}$ (see below). (a) What is the intensity of this wave? (b) What is the power received by the antenna? (c) If the orbiting satellite broadcasts uniformly over an area of $1.50 \times 10^{13} \text{ m}^2$ (a large fraction of North America), how much power does it radiate?



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