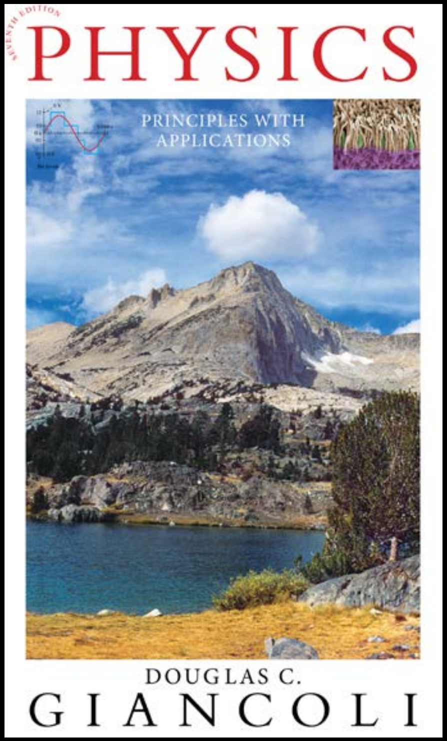
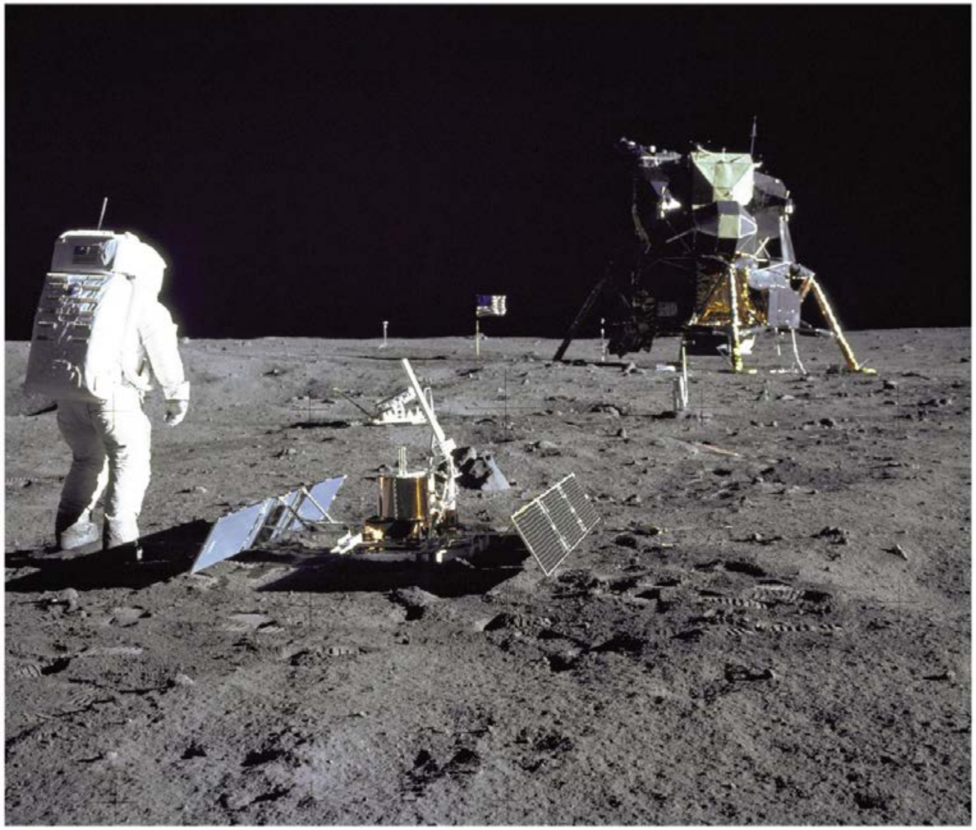


Lecture PowerPoints

Chapter 22
Physics: Principles with Applications, 7th edition
Giancoli

Chapter 22
Electromagnetic Waves



Contents of Chapter 22

- Changing Electric Fields Produce Magnetic Fields; Maxwell's Equations
- Production of Electromagnetic Waves
- Light as an Electromagnetic Wave and the Electromagnetic Spectrum
- Measuring the Speed of Light
- Energy in EM Waves
- Momentum Transfer and Radiation Pressure
- Radio and Television; Wireless Communication

22-1 Changing Electric Fields Produce Magnetic Fields; Maxwell's Equations

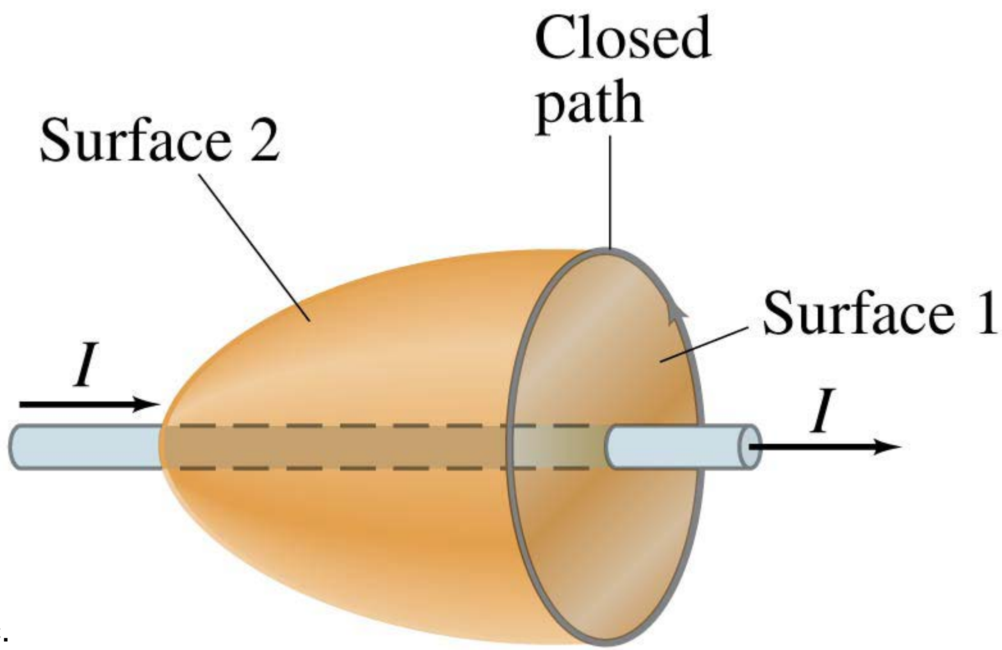
Maxwell's equations are the basic equations of electromagnetism. They involve calculus; here is a summary:

1. Gauss's law relates electric field to charge
2. A law stating there are no magnetic "charges"
3. A changing electric field produces a magnetic field
4. A magnetic field is produced by an electric current, and also by a changing electric field

22-1 Changing Electric Fields Produce Magnetic Fields; Maxwell’s Equations

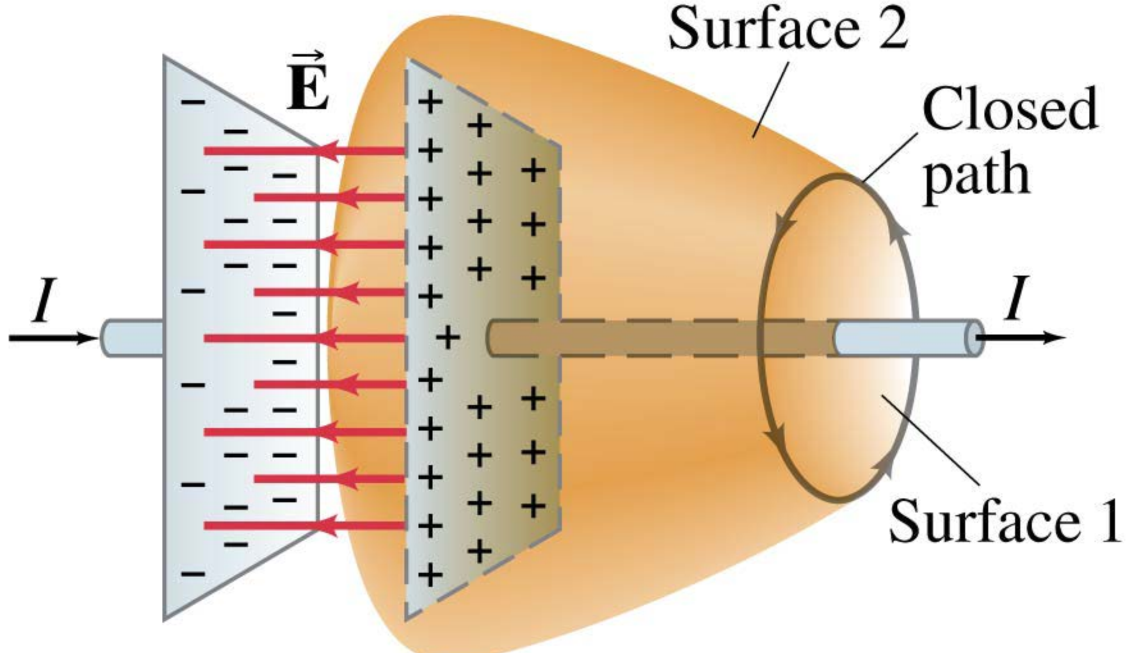
Only one part of this is new—that a changing electric field produces a magnetic field.

Ampère’s law relates the magnetic field around a current to the current through a surface.



22-1 Changing Electric Fields Produce Magnetic Fields; Maxwell's Equations

In order for Ampère's law to hold, it can't matter which surface we choose. But look at a discharging capacitor; there is a current through surface 1 but none through surface 2:



22-1 Changing Electric Fields Produce Magnetic Fields; Maxwell's Equations

Therefore, Ampère's law is modified to include the creation of a magnetic field by a changing electric field—the field between the plates of the capacitor in this example.

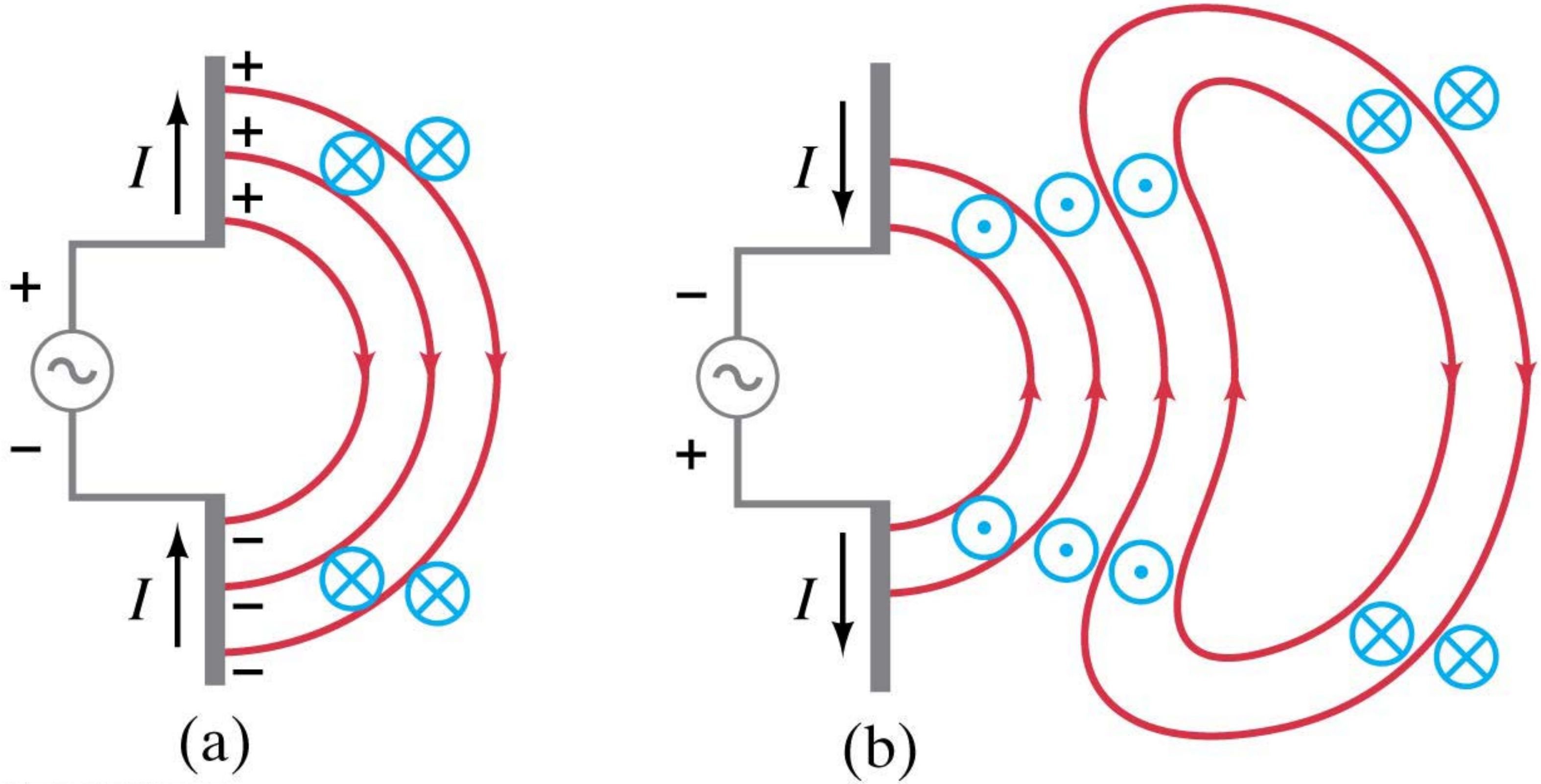
22-2 Production of Electromagnetic Waves

Since a changing electric field produces a magnetic field, and a changing magnetic field produces an electric field, once sinusoidal fields are created they can propagate on their own.

These propagating fields are called electromagnetic waves.

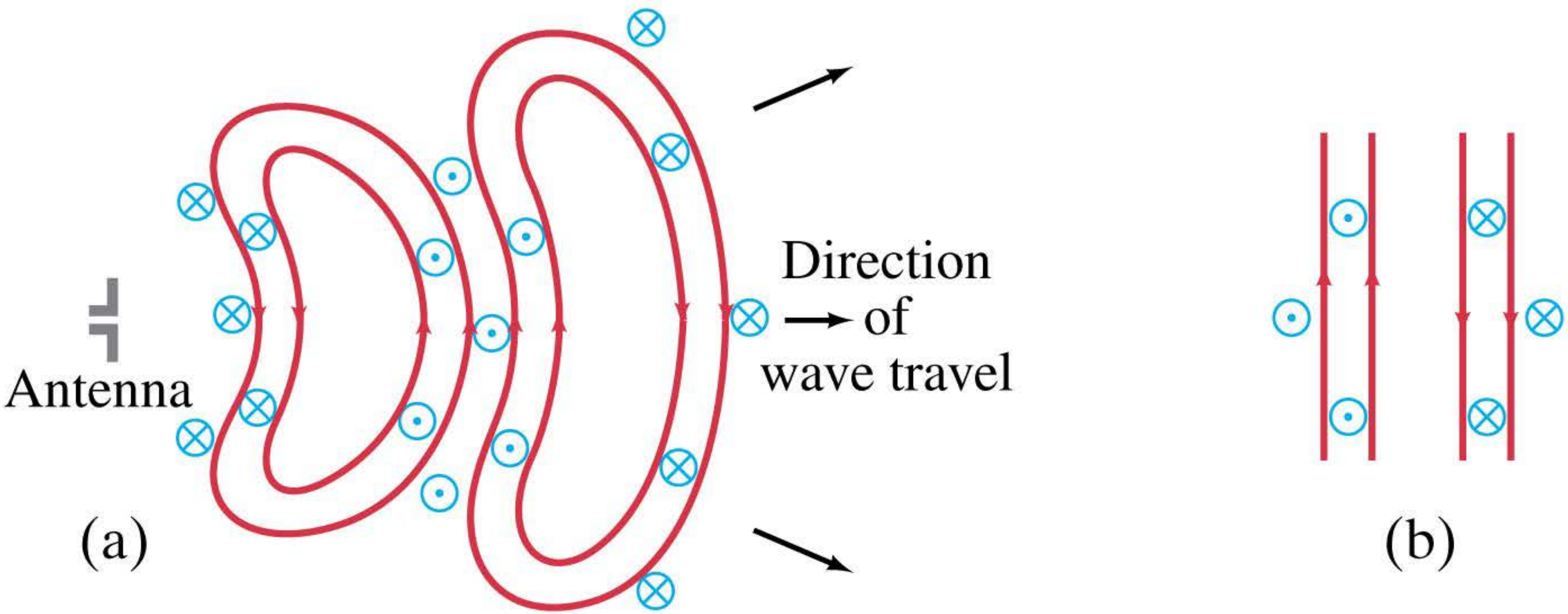
22-2 Production of Electromagnetic Waves

Oscillating charges will produce electromagnetic waves:



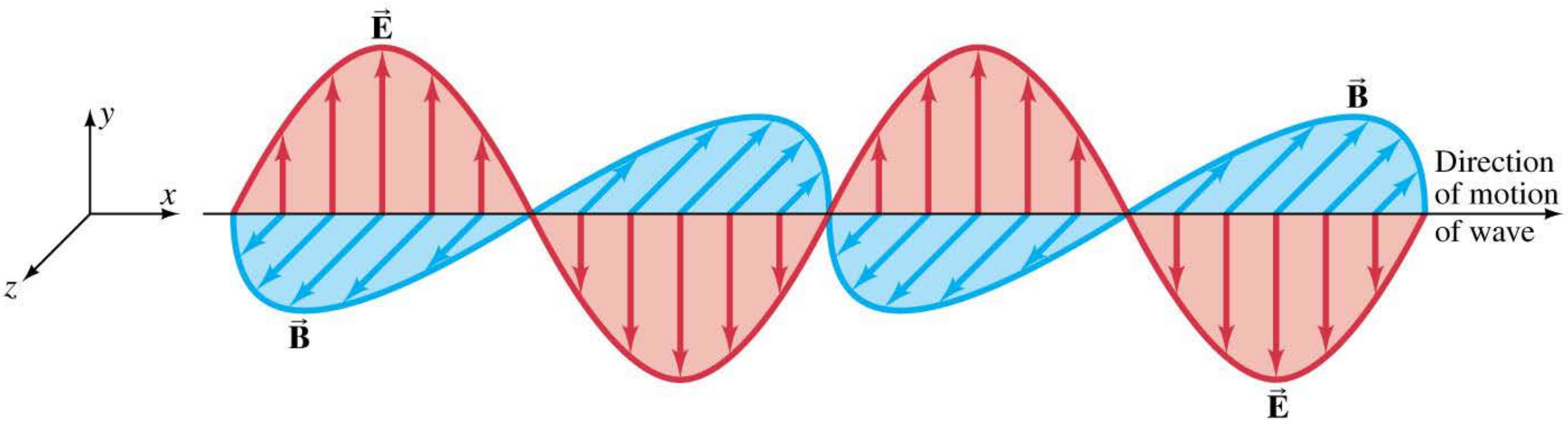
22-2 Production of Electromagnetic Waves

Far from the source, the waves are plane waves:



22-2 Production of Electromagnetic Waves

The electric and magnetic waves are perpendicular to each other, and to the direction of propagation.



22-2 Production of Electromagnetic Waves

When Maxwell calculated the speed of propagation of electromagnetic waves, he found:

$$c = \frac{1}{\sqrt{\epsilon_0 \mu_0}}. \qquad (22\text{-}3)$$

Using the known values of ε_0 and μ_0 gives c = 3.00 x 10^8 m/s.

This is the speed of light in a vacuum.

22-3 Light as an Electromagnetic Wave and the Electromagnetic Spectrum

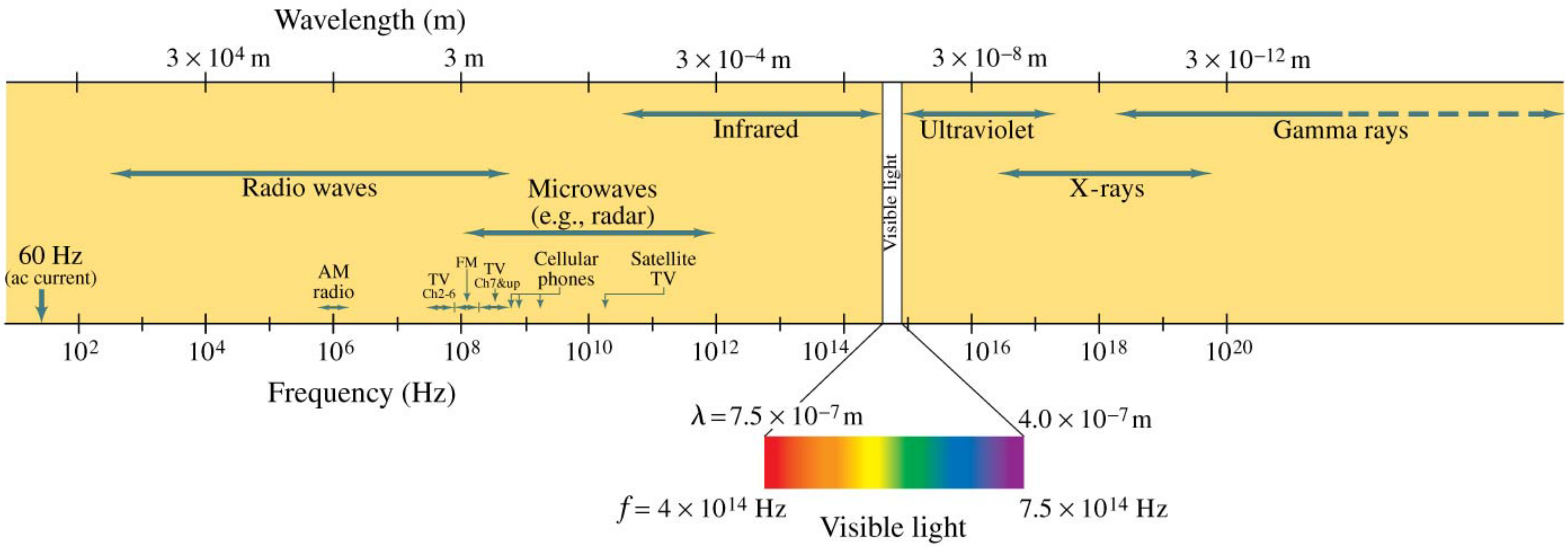
Light was known to be a wave. The production and measurement of electromagnetic waves of other frequencies confirmed that light was an electromagnetic wave as well.

The frequency of an electromagnetic wave is related to its wavelength:

$$c = \lambda f, \qquad (22\text{-}4)$$

22-3 Light as an Electromagnetic Wave and the Electromagnetic Spectrum

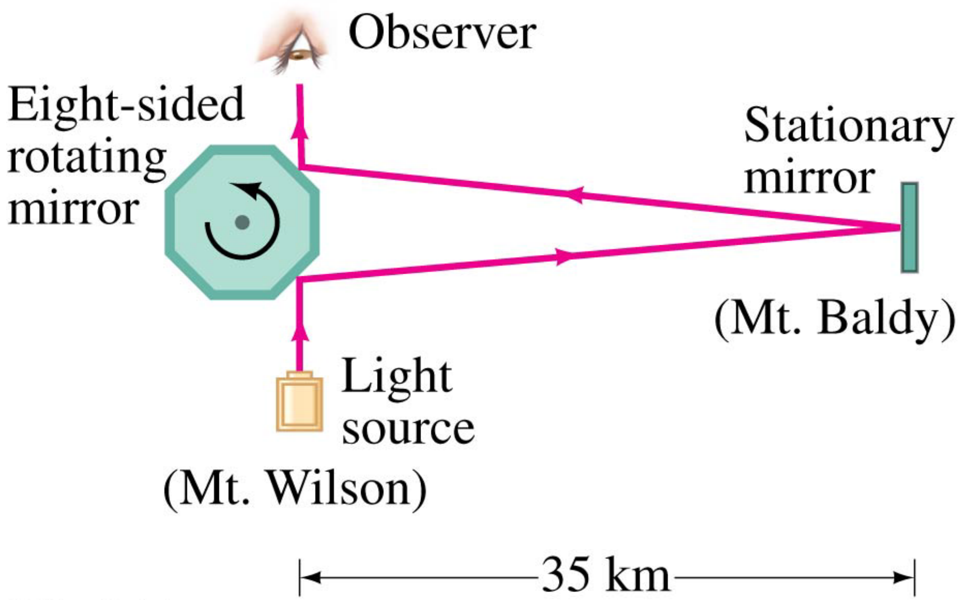
Electromagnetic waves can have any wavelength; we have given different names to different parts of the electromagnetic spectrum.



22-4 Measuring the Speed of Light

The speed of light was known to be very large, although careful studies of the orbits of Jupiter's moons showed that it is finite.

One important measurement, by Michelson, used a rotating mirror:



22-4 Measuring the Speed of Light

Over the years, measurements have become more and more precise; now the speed of light is defined to be:

$$c = 2.99792458 \times 10^{8}\ \text{m/s}$$

This is then used to define the meter.

22-5 Energy in EM Waves

Energy is stored in both electric and magnetic fields, giving the total energy density of an electromagnetic wave:

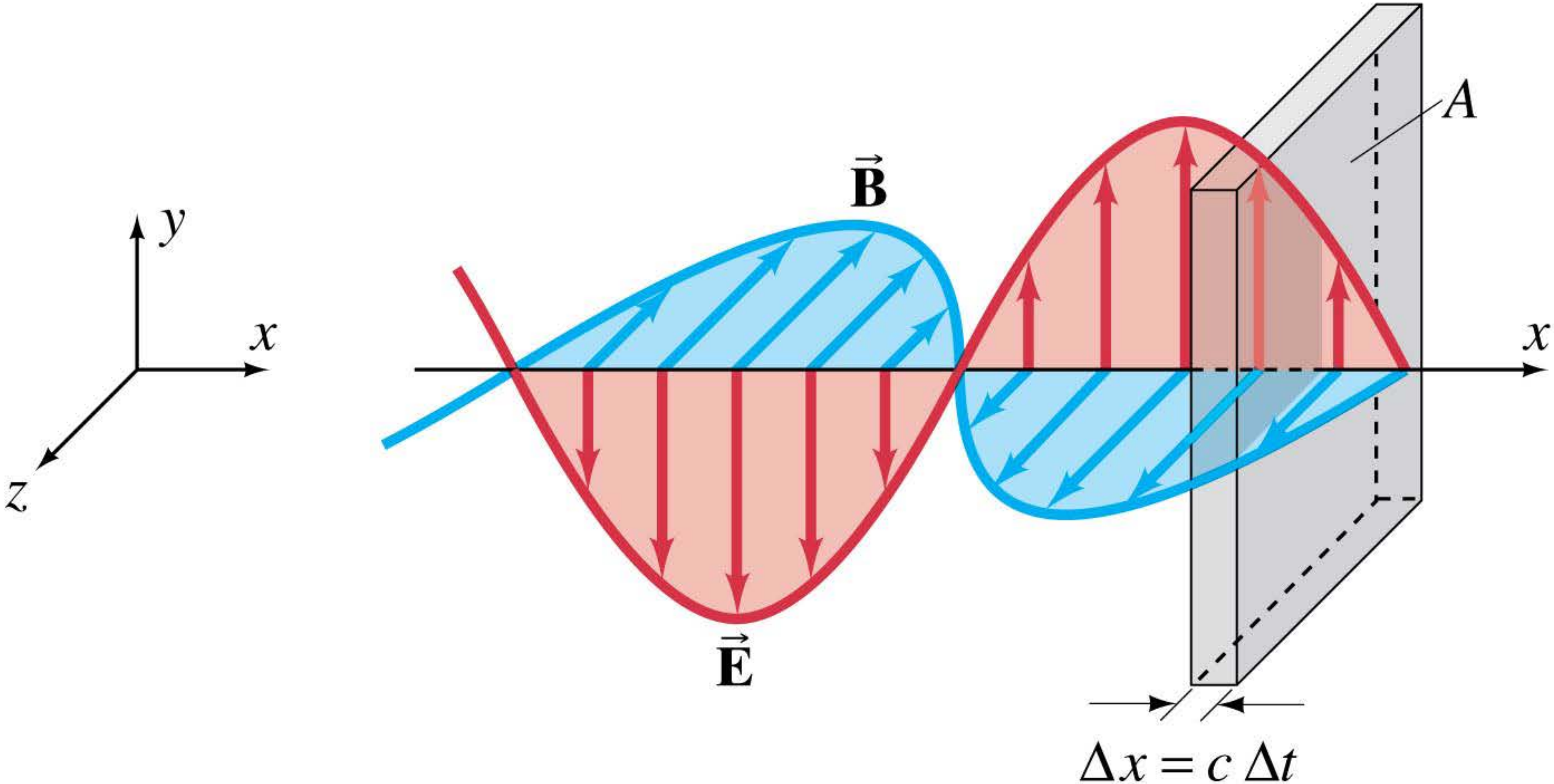
$$u = u_E + u_B = \frac{1}{2}\epsilon_0 E^2 + \frac{1}{2}\frac{B^2}{\mu_0}. \qquad (22\text{-}5)$$

Each field contributes half the total energy density.

$$u = \frac{1}{2}\epsilon_0 E^2 + \frac{1}{2}\frac{\epsilon_0 \mu_0 E^2}{\mu_0} = \epsilon_0 E^2. \qquad (22\text{-}6a)$$

22-5 Energy in EM Waves

This energy is transported by the wave.



22-5 Energy in EM Waves

The energy transported through a unit area per unit time is called the intensity:

$$I = \epsilon_0 c E^2 = \frac{c}{\mu_0} B^2 = \frac{EB}{\mu_0}. \qquad (22\text{-}7)$$

Its average value is given by:

$$\overline{I} = \frac{1}{2} \epsilon_0 c E_0^2 = \frac{1}{2} \frac{c}{\mu_0} B_0^2 = \frac{E_0 B_0}{2\mu_0}. \qquad (22\text{-}8)$$

22-6 Momentum Transfer and Radiation Pressure

In addition to carrying energy, electromagnetic waves also carry momentum. This means that a force will be exerted by the wave.

The radiation pressure is related to the average intensity. It is a minimum if the wave is fully absorbed:

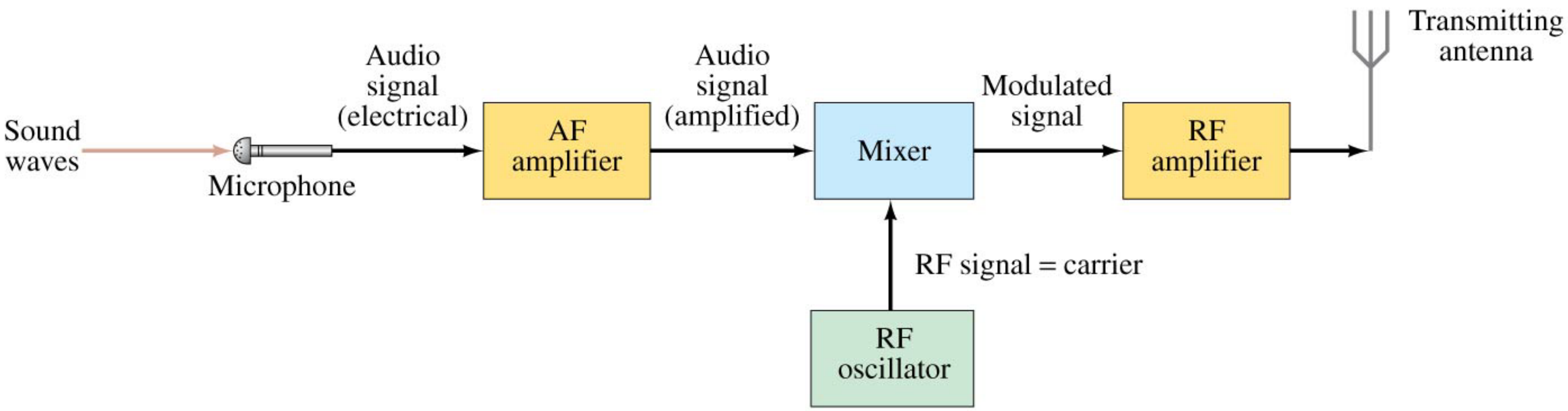
$$P = \frac{\overline{I}}{c}. \qquad (22\text{-}10a)$$

and a maximum if it is fully reflected:

$$P = \frac{2\overline{I}}{c}. \qquad (22\text{-}10b)$$

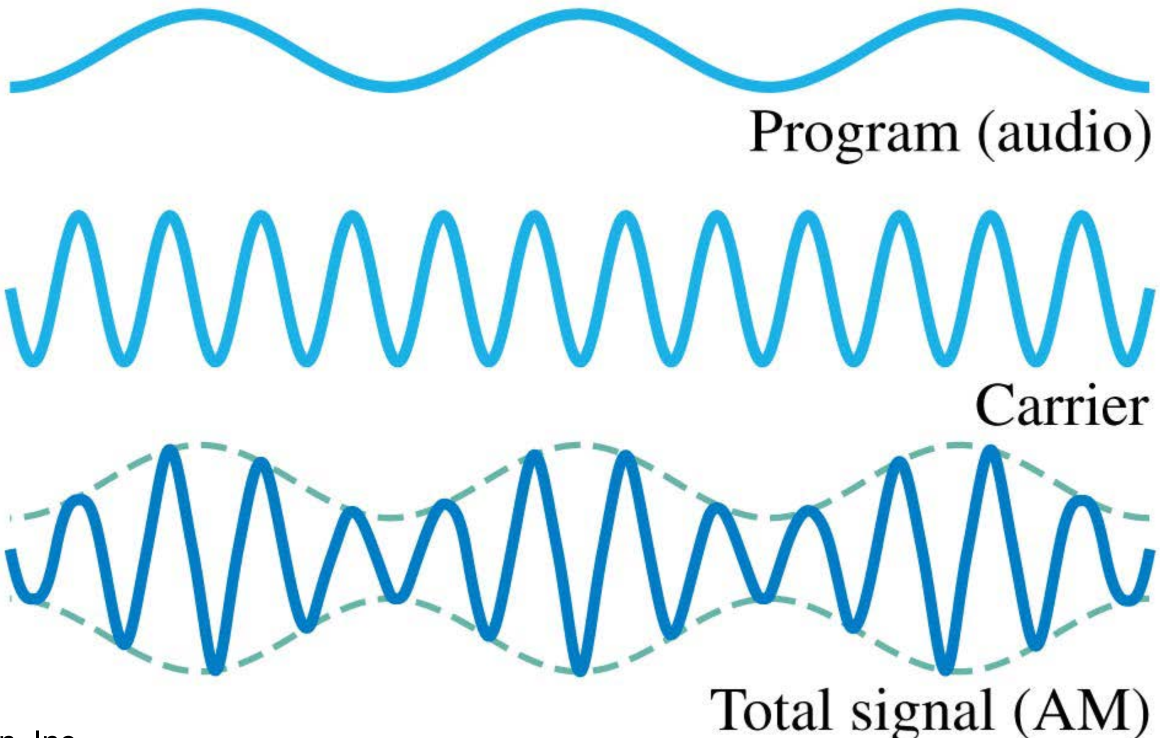
22-7 Radio and Television; Wireless Communication

This figure illustrates the process by which a radio station transmits information. The audio signal is combined with a carrier wave:



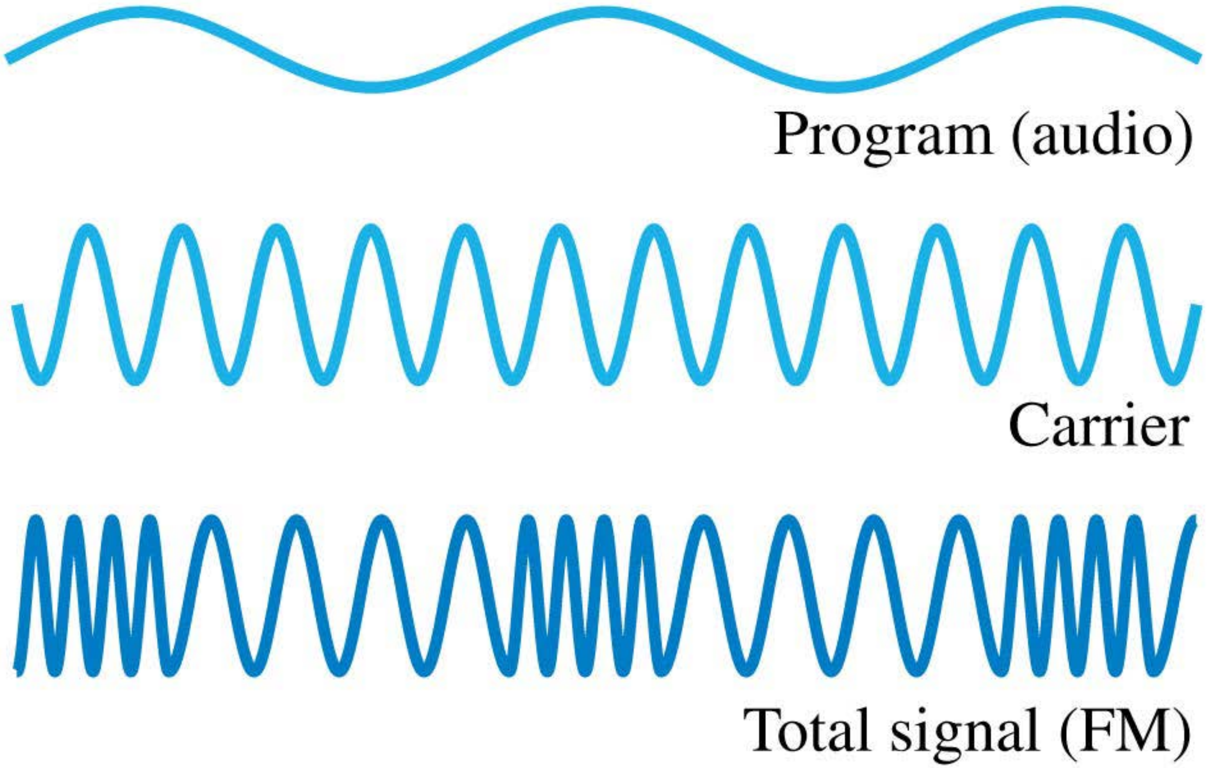
22-7 Radio and Television; Wireless Communication

The mixing of signal and carrier can be done two ways. First, by using the signal to modify the amplitude of the carrier (AM):



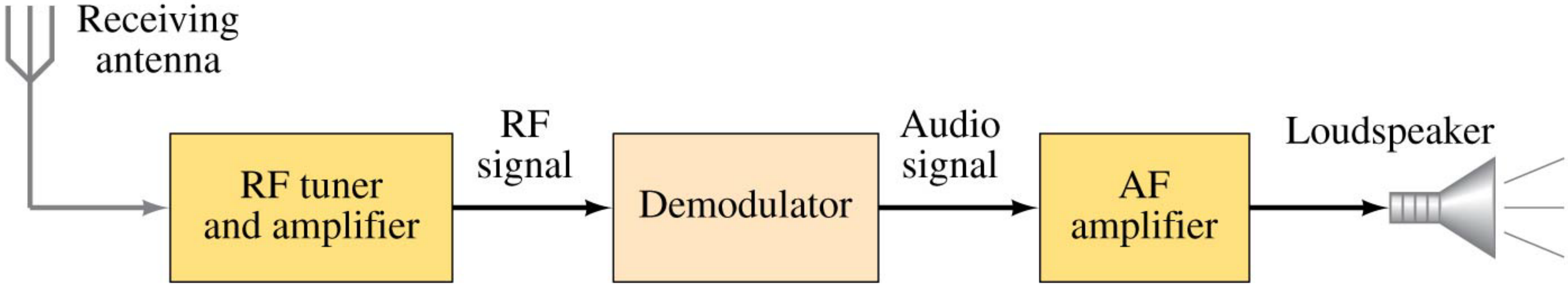
22-7 Radio and Television; Wireless Communication

Second, by using the signal to modify the frequency of the carrier (FM):



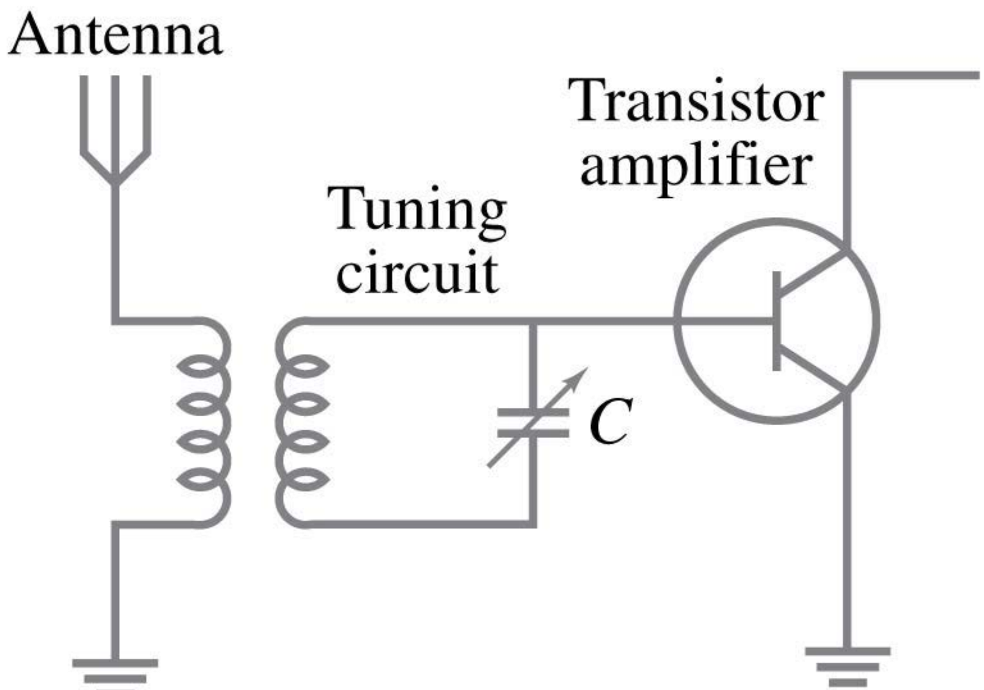
22-7 Radio and Television; Wireless Communication

At the receiving end, the wave is received, demodulated, amplified, and sent to a loudspeaker:



22-7 Radio and Television; Wireless Communication

The receiving antenna is bathed in waves of many frequencies; a tuner is used to select the desired one:



Summary of Chapter 22

- Maxwell's equations are the basic equations of electromagnetism
- Electromagnetic waves are produced by accelerating charges; the propagation speed is given by:

$$c = \frac{1}{\sqrt{\epsilon_0 \mu_0}}.$$

- The fields are perpendicular to each other and to the direction of propagation.

Summary of Chapter 22

- The wavelength and frequency of EM waves are related:

$$c = \lambda f,$$

- The electromagnetic spectrum includes all wavelengths, from radio waves through visible light to gamma rays.