Summary

James Clerk Maxwell synthesized an elegant theory in which all electric and magnetic phenomena could be described using four equations, now called **Maxwell's equations**. They are based on earlier ideas, but Maxwell added one more—that a changing electric field produces a magnetic field.

Maxwell's theory predicted that transverse **electromagnetic** (EM) **waves** would be produced by accelerating electric charges, and these waves would propagate (move) through space at the speed of light, given by the formula

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

The oscillating electric and magnetic fields in an EM wave are perpendicular to each other and to the direction of propagation. These waves are waves of fields, not matter, and can propagate in empty space.

The wavelength λ and frequency f of EM waves are related to their speed c by

$$c = \lambda f, \qquad \textbf{(22–4)}$$

just as for other waves.

After EM waves were experimentally detected, the idea that light is an EM wave (of very high frequency) became generally accepted. The **electromagnetic spectrum** includes EM waves of a wide variety of wavelengths, from microwaves and radio waves to visible light to X-rays and gamma rays, all of which travel through space at a speed $c = 3.0 \times 10^8\,\text{m/s}$.

[*The average *intensity* (W/m^2) of an EM wave is

$$\bar{I} = \frac{1}{2}\epsilon_0 c E_0^2 = \frac{1}{2}\frac{c}{\mu_0}B_0^2 = \frac{1}{2}\frac{E_0 B_0}{\mu_0}, \qquad \textbf{(22–8)}$$

where E_0 and B_0 are the peak values of the electric and magnetic fields, respectively, in the wave.]

[*EM waves carry momentum and exert a *radiation pressure* proportional to the intensity I of the wave.]

Questions

1. The electric field in an EM wave traveling north oscillates in an east–west plane. Describe the direction of the magnetic field vector in this wave.
2. Is sound an electromagnetic wave? If not, what kind of wave is it?
3. Can EM waves travel through a perfect vacuum? Can sound waves?
4. When you flip a light switch on, does the light go on immediately? Explain.
5. Are the wavelengths of radio and television signals longer or shorter than those detectable by the human eye?
6. When you connect two loudspeakers to the output of a stereo amplifier, should you be sure the lead-in wires are equal in length so that there will not be a time lag between speakers? Explain.
7. In the electromagnetic spectrum, what type of EM wave would have a wavelength of 10^3 km? 1 km? 1 m? 1 cm? 1 mm? 1 μm?
8. Can radio waves have the same frequencies as sound waves (20 Hz–20,000 Hz)?
* 9. Can two radio or TV stations broadcast on the same carrier frequency? Explain.
* 10. If a radio transmitter has a vertical antenna, should a receiver's antenna (rod type) be vertical or horizontal to obtain best reception?
* 11. The carrier frequencies of FM broadcasts are much higher than for AM broadcasts. On the basis of what you learned about diffraction in Chapter 11, explain why AM signals can be detected more readily than FM signals behind low hills or buildings.
* 12. Discuss how cordless telephones make use of EM waves. What about cell phones?
* 13. A lost person may signal by flashing a flashlight on and off using Morse code. This is actually a modulated EM wave. Is it AM or FM? What is the frequency of the carrier, approximately?

Problems

22–1 Changing $\vec{E}$ Produces $\vec{B}$

* 1. (II) At a given instant, a 1.8-A current flows in the wires connected to a parallel-plate capacitor. What is the rate at which the electric field is changing between the plates if the square plates are 1.60 cm on a side?
* 2. (II) A 1200-nF capacitor with circular parallel plates 2.0 cm in diameter is accumulating charge at the rate of 35.0 mC/s at some instant in time. What will be the magnitude of the induced magnetic field 10.0 cm radially outward from the center of the plates? What will be the magnitude of the field after the capacitor is fully charged?

22–2 EM Waves

3. (I) If the magnetic field in a traveling EM wave has a peak magnitude of 17.5 nT at a given point, what is the peak magnitude of the electric field?
4. (I) In an EM wave traveling west, the B field oscillates vertically and has a frequency of 80.0 kHz and an rms strength of 6.75×10^{-9} T. What are the frequency and rms strength of the electric field, and what is its direction? [*Hint*: see Fig. 22–7.]

22–3 and 22–4 EM Spectrum and Speed

5. (I) What is the frequency of a microwave whose wavelength is 1.60 cm?
6. (I) What is the wavelength of a 29.75×10^9-Hz radar signal?
7. (I) An EM wave has frequency 9.66×10^{14} Hz. What is its wavelength, and how would we classify it?
8. (I) An EM wave has a wavelength of 650 nm. What is its frequency, and how would we classify it?
9. (I) How long does it take light to reach us from the Sun, 1.50×10^8 km away?