Section 24.1 The Nature of Electromagnetic Waves

1. Which one of the following statements concerning electromagnetic waves is false?
   (a) Electromagnetic waves are longitudinal waves.
   (b) Electromagnetic waves transfer energy through space.
   (c) The existence of electromagnetic waves was predicted by Maxwell.
   (d) Electromagnetic waves can propagate through a material substance.
   (e) Electromagnetic waves do not require a physical medium for propagation.

2. Which one of the following will not generate electromagnetic waves or pulses?
   (a) a steady direct current
   (b) an accelerating electron
   (c) a proton in simple harmonic motion
   (d) an alternating current
   (e) charged particles traveling in a circular path in a mass spectrometer

3. Complete the following sentence: When electrons from a heated filament accelerate through vacuum toward a positive plate,
   (a) only an electric field will be produced.
   (b) only a magnetic field will be produced.
   (c) electromagnetic waves will be produced.
   (d) longitudinal waves will be produced.
   (e) neither electric nor magnetic fields will be produced.

4. The electric field \( E \) of an electromagnetic wave traveling the positive \( x \) direction is illustrated in the figure. This is the wave of the radiation field of an antenna. What is the direction and the phase relative to the electric field of the magnetic field at a point where the electric field is in the negative \( y \) direction?
   Note: The wave is shown in a region of space that is a large distance from its source.
   (a) \(+y\) direction, in phase
   (b) \(-z\) direction, 90° out of phase
   (c) \(+z\) direction, 90° out of phase
   (d) \(-z\) direction, in phase
   (e) \(+z\) direction, in phase

5. A television station broadcasts at a frequency of 86 MHz. The circuit contains an inductor with an inductance \( L = 1.2 \times 10^{-6} \text{ H} \) and a variable-capacitance \( C \). Determine the value of \( C \) that allows this television station to be tuned in.
   (a) \( 2.9 \times 10^{-12} \text{ F} \)
   (b) \( 5.8 \times 10^{-12} \text{ F} \)
   (c) \( 1.8 \times 10^{-11} \text{ F} \)
   (d) \( 3.6 \times 10^{-11} \text{ F} \)
   (e) \( 1.1 \times 10^{-10} \text{ F} \)

Section 24.2 The Electromagnetic Spectrum

6. Which one of the following types of wave is intrinsically different from the other four?
   (a) radio waves
   (b) sound waves
   (c) gamma rays
   (d) ultraviolet radiation
   (e) visible light
7. Which one of the following statements concerning electromagnetic waves is false?
   (a) Electromagnetic waves carry energy.
   (b) X-rays have longer wavelengths than radio waves.
   (c) In vacuum, all electromagnetic waves travel at the same speed.
   (d) Lower frequency electromagnetic waves can be produced by oscillating circuits.
   (e) They consist of mutually perpendicular electric and magnetic fields that oscillate perpendicular to
       the direction of propagation.

8. Which one of the following statements concerning the wavelength of an electromagnetic wave in
   a vacuum is true?
   (a) The wavelength is independent of the speed of the wave for a fixed frequency.
   (b) The wavelength is inversely proportional to the speed of the wave.
   (c) The wavelength is the same for all types of electromagnetic waves.
   (d) The wavelength is directly proportional to the frequency of the wave.
   (e) The wavelength is inversely proportional to the frequency of the wave.

9. Complete the following sentence: The various colors of visible light differ in
   (a) frequency only. (d) frequency and wavelength.
   (b) wavelength only. (e) frequency and their speed in a vacuum.
   (c) their speeds in a vacuum.

10. Note the different types of electromagnetic radiation:
    (1) X-rays
    (2) radio waves
    (3) gamma rays
    (4) visible light
    (5) infrared radiation
    (6) ultraviolet radiation
    Which list correctly ranks the electromagnetic waves in order of increasing frequency?
    (a) 2, 3, 4, 5, 6, 1
    (b) 2, 5, 4, 1, 6, 3
    (c) 2, 5, 4, 6, 1, 3
    (d) 3, 1, 6, 4, 5, 2
    (e) 3, 6, 1, 4, 5, 2

11. Which one of the following colors of visible light has the highest frequency?
    (a) yellow
    (b) red
    (c) green
    (d) blue
    (e) violet

12. What is the correct order, beginning with shortest wavelength and extending to the longest
    wavelength, of the following colors in the visible light spectrum: blue, green, red, violet, and
    yellow?
    (a) red, yellow, blue, green, violet
    (b) violet, blue, yellow, red, green
    (c) red, yellow, green, blue, violet
    (d) violet, blue, green, yellow, red
    (e) red, blue, violet, green, yellow

13. When a radio telescope observes a region of space between two stars, it detects electromagnetic
    radiation that has a wavelength of 0.21 m. This radiation was emitted by hydrogen atoms in
    the gas and dust located in that region. What is the frequency of this radiation?
    (a) $7.1 \times 10^{10}$ Hz
    (b) $2.1 \times 10^{14}$ Hz
    (c) $3.0 \times 10^{8}$ Hz
    (d) $6.9 \times 10^{11}$ Hz
    (e) $1.4 \times 10^{9}$ Hz

14. An FM radio station generates radio waves that have a frequency of 95.5 MHz. The frequency of
    the waves from a competing station have a frequency of 102.7 MHz. What is the difference in
    wavelength between the waves emitted from the two stations?
    (a) 0.22 m
    (b) 0.45 m
    (c) 0.84 m
    (d) 2.4 m
    (e) 42 m
15. Which one of the following wavelengths is in the infrared range of the electromagnetic spectrum?
   (a) 100 mm  (c) 400 m  (e) 20 µm
   (b) 100 nm  (d) 2 × 10^{-15} m

Section 24.3 The Speed of Light

16. Which one of the following scientists did not attempt to measure the speed of light?
   (a) Galileo  (c) Fizeau  (e) Michelson
   (b) Newton  (d) Foucault

17. A radio wave sent from the surface of the earth reflects from the surface of the moon and returns to the earth. The elapsed time between the generation of the wave and the detection of the reflected wave is 2.6444 s. Determine the distance from the surface of the earth to the surface of the moon. Note: The speed of light is 2.9979 × 10^8 m/s.
   (a) 3.7688 × 10^8 m  (c) 3.9638 × 10^8 m  (e) 7.9276 × 10^8 m
   (b) 3.8445 × 10^8 m  (d) 4.0551 × 10^8 m

18. The average distance between the surface of the earth and the surface of the sun is 1.49 × 10^{11} m. How much time, in minutes, does it take for light leaving the surface of the sun to reach the earth?
   (a) zero minutes  (c) 8.3 min  (e) 500 min
   (b) 2.9 × 10^{-3} min  (d) 74 min

19. A cellular telephone transmits electromagnetic waves at a frequency of 935 MHz. What is the wavelength of these waves?
   (a) 0.0106 m  (c) 0.642 m  (e) 2.40 m
   (b) 0.321 m  (d) 1.22 m

20. A distant space probe is programmed to emit a radio signal toward Earth at regular time intervals. One such pulse arrives on Earth 2.92 s after it is emitted from the probe. What is the approximate distance from the Earth to the probe?
   (a) 8.76 × 10^8 m  (c) 6.94 × 10^8 m  (e) 3.50 × 10^8 m
   (b) 7.40 × 10^8 m  (d) 4.12 × 10^8 m

Section 24.4 The Energy Carried by Electromagnetic Waves

21. Which one of the following statements concerning the energy carried by an electromagnetic wave is true?
   (a) The energy is carried only by the electric field.
   (b) More energy is carried by the electric field than by the magnetic field.
   (c) The energy is carried equally by the electric and magnetic fields.
   (d) More energy is carried by the magnetic field than by the electric field.
   (e) The energy is carried only by the magnetic field.

22. The amplitude of the electric field component of an electromagnetic wave is increased from E to 4E. What is the corresponding change in the intensity of the wave?
   (a) The intensity is unchanged by the increase in E.
   (b) The intensity increases by a factor of sixteen.
   (c) The intensity increases by a factor of four.
   (d) The intensity decreases by a factor of four.
   (e) The intensity decreases by a factor of sixteen.
23. The peak value of the electric field component of an electromagnetic wave is \( E \). At a particular instant, the intensity of the wave is of 0.020 W/m\(^2\). If the electric field were increased to 5\( E \), what would be the intensity of the wave?

(a) 0.020 W/m\(^2\)    (c) 0.25 W/m\(^2\)    (e) 1.0 W/m\(^2\)
(b) 0.10 W/m\(^2\)    (d) 0.50 W/m\(^2\)

24. An electromagnetic wave has an electric field with peak value 250 N/C. What is the average intensity of the wave?

(a) 0.66 W/m\(^2\)    (c) 83 W/m\(^2\)    (e) 170 W/m\(^2\)
(b) 0.89 W/m\(^2\)    (d) 120 W/m\(^2\)

25. An electromagnetic wave has an electric field with peak value 250.0 N/C. What is the average energy delivered to a surface with area 2.00 m\(^2\) by this wave in one minute?

(a) 83.1 J    (c) 2490 J    (e) 9960 J
(b) 166 J    (d) 4980 J

26. An incandescent light bulb radiates uniformly in all directions with a total average power of \( 1.0 \times 10^2 \) W. What is the maximum value of the magnetic field at a distance of 0.50 m from the bulb?

(a) \( 8.4 \times 10^{-7} \) T    (c) \( 3.1 \times 10^{-7} \) T    (e) zero tesla
(b) \( 5.2 \times 10^{-7} \) T    (d) \( 1.6 \times 10^{-7} \) T

27. A local radio station transmits radio waves uniformly in all directions with a total power of \( 1.50 \times 10^5 \) W. What is the intensity of these waves when they reach a receiving antenna located 40.0 km from the transmitting antenna?

(a) \( 2.98 \times 10^{-5} \) W/m\(^2\)    (c) \( 9.25 \times 10^{-7} \) W/m\(^2\)    (e) \( 5.60 \times 10^{-10} \) W/m\(^2\)
(b) \( 7.46 \times 10^{-6} \) W/m\(^2\)    (d) \( 1.17 \times 10^{-8} \) W/m\(^2\)

28. A laser uniformly illuminates an area with green light that has an average intensity of 550 W/m\(^2\). What is the rms value of the electric field of this light?

(a) 322 N/C    (c) 455 N/C    (e) 891 N/C
(b) 405 N/C    (d) 643 N/C

29. Electromagnetic waves are radiated uniformly in all directions from a source. The rms electric field of the waves is measured 35 km from the source to have an rms value of 0.42 N/C. Determine the average total power radiated by the source.

(a) \( 4.1 \times 10^5 \) W    (c) \( 3.0 \times 10^6 \) W    (e) \( 1.7 \times 10^7 \) W
(b) \( 8.3 \times 10^5 \) W    (d) \( 7.2 \times 10^5 \) W

Section 24.5 The Doppler Effect and Electromagnetic Waves

30. An astronomer observes electromagnetic waves emitted by oxygen atoms in a distant galaxy that have a frequency of \( 5.710 \times 10^{14} \) Hz. In the laboratory on earth, oxygen atoms emit waves that have a frequency of \( 5.841 \times 10^{14} \) Hz. Determine the relative velocity of the galaxy with respect to the astronomer on earth. \( \text{Note: The speed of light is } 2.9979 \times 10^8 \) m/s.

(a) \( 6.724 \times 10^6 \) m/s, away from earth    (d) \( 4.369 \times 10^4 \) m/s, toward earth
(b) \( 6.724 \times 10^6 \) m/s, toward earth    (e) \( 4.369 \times 10^4 \) m/s, away from earth
(c) \( 2.931 \times 10^6 \) m/s, away from earth
31. What would the speed of an observer be if a red \((4.688 \times 10^{14} \text{ Hz})\) traffic light appeared green \((5.555 \times 10^{14} \text{ Hz})\) to the observer?

(a) \(4.445 \times 10^8 \text{ m/s}\)  
(b) \(2.219 \times 10^8 \text{ m/s}\)  
(c) \(8.438 \times 10^7 \text{ m/s}\)  
(d) \(5.548 \times 10^7 \text{ m/s}\)  
(e) \(2.890 \times 10^6 \text{ m/s}\)

32. A minivan moving at 38 m/s passes an unmarked state police car moving at 24 m/s. The electromagnetic waves produced by the radar gun in the police car have a frequency of \(8.25 \times 10^9 \text{ Hz}\). What is the magnitude of the difference in frequency between the waves emitted by the gun and those that are reflected back from the speeding minivan?

(a) 180 Hz  
(b) 390 Hz  
(c) 770 Hz  
(d) 1440 Hz  
(e) 2100 Hz

Section 24.6 Polarization

33. The most convincing evidence that electromagnetic waves are transverse waves is that

(a) they can be polarized.  
(b) they carry energy through space.  
(c) they can travel through a material substance.  
(d) they do not require a physical medium for propagation.  
(e) all electromagnetic waves travel with the same speed through vacuum.

34. The magnitude of the magnetic field component of a plane polarized electromagnetic wave traveling in vacuum is given by \(B_y = B_o \sin(k z - \omega t)\). Which one of the following statements concerning this electromagnetic wave is true?

(a) The wavelength is equal to \(k/\omega\).  
(b) The wave propagates in the \(y\) direction.  
(c) The wave is polarized in the \(x\) direction.  
(d) The electric field component vibrates in the \(z\) direction.  
(e) The electric field component has a magnitude of \(E = cB_o \cos(k z - \omega t)\).

35. Light emerges from a polarizer that has its transmission axis located along the \(x\) axis. The light then passes through two additional sheets of polarizing material. It is desired to orient the two sheets so that, after passing through both of them, the electromagnetic wave has the maximum possible intensity and is polarized 90° with respect to the \(x\) axis. How should the transmission axes of the sheets be oriented? Note: the following answers give the angles that the transmission axes make with respect to the \(x\) axis.

<table>
<thead>
<tr>
<th>First polarizing sheet</th>
<th>Second polarizing sheet</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) 45° with respect to the (x) axis</td>
<td>45° with respect to the (x) axis</td>
</tr>
<tr>
<td>(b) 45° with respect to the (x) axis</td>
<td>90° with respect to the (x) axis</td>
</tr>
<tr>
<td>(c) 90° with respect to the (x) axis</td>
<td>45° with respect to the (x) axis</td>
</tr>
<tr>
<td>(d) 30° with respect to the (x) axis</td>
<td>60° with respect to the (x) axis</td>
</tr>
<tr>
<td>(e) 30° with respect to the (x) axis</td>
<td>90° with respect to the (x) axis</td>
</tr>
</tbody>
</table>

36. Unpolarized light of intensity \(S_o\) passes through two sheets of polarizing material whose transmission axes make an angle of 60° with each other as shown in the figure. What is the intensity of the transmitted beam, \(S_t\)?

(a) \(S_o/4\)  
(b) \(S_o/8\)  
(c) \(3S_o/4\)  
(d) \(S_o/16\)  
(e) zero
37. Linearly polarized light is incident on a sheet of polarizing material. The angle between the transmission axis and the incident electric field is 52°. What percentage of the incident intensity is transmitted?
(a) 38%  (c) 52%  (e) 79%
(b) 43%  (d) 62%

38. A linearly polarized beam of light is incident upon a group of three polarizing sheets which are arranged so that the transmission axis of each sheet is rotated by 45° with respect to the preceding sheet as shown.

What fraction of the incident intensity is transmitted?
(a) 1/8  (c) 3/8  (e) 3/4
(b) 1/4  (d) 1/2

39. Unpolarized light with an average intensity of 750.0 W/m² enters a polarizer with a vertical transmission axis. The transmitted light then enters a second polarizer. The light that exits the second polarizer is found to have an average intensity of 125 W/m². What is the orientation angle of the second polarizer relative to the first one?
(a) 54.7°  (c) 29.0°  (e) zero degrees
(b) 19.5°  (d) 70.5°

40. Two polarizing sheets have their transmission axes parallel so that the intensity of unpolarized light transmitted through both of them is a maximum. Through what angle must either sheet be rotated if the transmitted intensity is 25% of the incident intensity?
(a) 15°  (c) 45°  (e) 75°
(b) 30°  (d) 60°

41. Linearly polarized light is incident upon a polarizing sheet that has a transmission axis parallel to the incident light. The sheet is rotated about its axis through 360° (one complete revolution). At how many positions, including the initial and final positions, will the transmitted intensity be a maximum?
(a) 6  (c) 4  (e) 2
(b) 5  (d) 3

Questions 42 through 45 pertain to the situation described below:
A linearly polarized electromagnetic wave is sent through two sheets of polarizing material. The first sheet, A, is oriented so that its transmission axis makes an angle of 30° with respect to the incident electric field of the wave. The second sheet, B, is oriented so that its transmission axis makes an angle of 90° with the incident electric field of the wave. The incident beam has an electric field of peak magnitude \( E_0 \) and average intensity \( S_0 \).
Chapter 24

Electromagnetic Waves

42. What is the peak value of the electric field amplitude after it goes through sheet A?
   (a) $0.30E_o$   (c) $0.60E_o$   (e) $0.87E_o$
   (b) $0.50E_o$   (d) $0.75E_o$

43. What is the average intensity of the wave after it passes through A?
   (a) $0.30S_o$   (c) $0.60S_o$   (e) $0.86S_o$
   (b) $0.50S_o$   (d) $0.75S_o$

44. What is the average intensity of the wave after it passes through B?
   (a) $0.19S_o$   (c) $0.43S_o$   (e) zero
   (b) $0.34S_o$   (d) $0.50S_o$

45. Suppose that A and B are interchanged so that the wave is first incident upon B. What is the
   average wave intensity after passing through both polarizing sheets?
   (a) $0.19S_o$   (c) $0.43S_o$   (e) zero
   (b) $0.34S_o$   (d) $0.50S_o$

Additional Problems

46. An FM radio station emits an electromagnetic wave which is received by a circuit containing a
   $3.33 \times 10^{-7}$ H inductor and a variable capacitor set at $7.31 \times 10^{-12}$ F. What is the frequency of the
   radio wave?
   (a) $1.02 \times 10^8$ Hz   (c) $1.58 \times 10^8$ Hz   (e) $9.80 \times 10^7$ Hz
   (b) $8.80 \times 10^7$ Hz   (d) $9.40 \times 10^7$ Hz

Questions 47 through 55 pertain to the statement and figure below:

The electromagnetic wave of the radiation field from a wire
antenna travels toward the plane of the paper (which is in the $-z$
direction). At time $t = 0$ s, the wave strikes the paper at normal
incidence. The magnetic field vector at point O in the figure
points in the $-y$ direction and has a magnitude of $4.0 \times 10^{-8}$ T.
The frequency of the wave is $1.0 \times 10^{16}$ Hz.

47. What is the magnitude of the associated electric field $E$ at time $t = 0$ s?
   (a) $7.5 \times 10^{-16}$ N/C   (c) $7.5$ N/C   (e) $7.5 \times 10^{15}$ N/C
   (b) $1.3$ N/C   (d) $12$ N/C

48. What is the direction of the electric field?
   (a) It points in the negative $y$ direction.   (d) It points in the negative $x$ direction.
   (b) It points in the positive $y$ direction.   (e) It points in the positive $x$ direction.
   (c) It points in the negative $z$ direction.

49. What is the direction of polarization of this electromagnetic wave?
   (a) the $x$ direction   (d) $45^\circ$ with respect to the $x$ direction
   (b) the $y$ direction   (e) the wave is not polarized
   (c) the $z$ direction
50. What is the wavelength of this electromagnetic wave?
   (a) 0.33 nm  (c) 20 nm  (e) 40 nm
   (b) 3.3 nm  (d) 30 nm

51. What is the \textit{rms} value of the electric field? Assume that the figure shows the peak value of $B$.
   (a) 7.5 N/C  (c) 17 N/C  (e) $8.5 \times 10^{-16}$ N/C
   (b) 8.5 N/C  (d) $1.1 \times 10^{15}$ N/C

52. What is the \textit{rms} value of the magnetic field? Assume that the figure shows the peak value of $B$.
   (a) $1.0 \times 10^{-8}$ T  (c) $2.8 \times 10^{-8}$ T  (e) $5.7 \times 10^{-8}$ T
   (b) $1.4 \times 10^{-8}$ T  (d) $4.6 \times 10^{-8}$ T

53. What is the intensity of the electromagnetic wave at time $t = 0$ s?
   (a) 0.24 W/m$^2$  (c) 0.48 W/m$^2$  (e) 24 W/m$^2$
   (b) 0.38 W/m$^2$  (d) 0.76 W/m$^2$

54. What is the direction of electromagnetic energy transport?
   (a) the positive $x$ direction  (c) the positive $y$ direction  (e) the negative $z$ direction
   (b) the negative $x$ direction  (d) the negative $y$ direction

55. What is the magnitude of the magnetic field at point $O$ at time $t = 5.0 \times 10^{-17}$ s? \textbf{Note:} Assume that the figure shows the peak value of $B$.
   (a) $1.0 \times 10^{-8}$ T  (c) $3.0 \times 10^{-8}$ T  (e) $5.0 \times 10^{-8}$ T
   (b) $2.0 \times 10^{-8}$ T  (d) $4.0 \times 10^{-8}$ T

**Questions 56 through 66 pertain to the statement and figure below:**

The figure shows the time variation of the magnitude of the electric field of an electromagnetic wave produced by a wire antenna.

56. Determine the \textit{rms} value of the electric field magnitude.
   (a) 7.1 N/C  (c) 14 N/C  (e) 28 N/C
   (b) 12 N/C  (d) 19 N/C

57. What is the peak value of the magnetic field?
   (a) $1.4 \times 10^{-8}$ T  (c) $3.3 \times 10^{-8}$ T  (e) $5.4 \times 10^{-8}$ T
   (b) $2.3 \times 10^{-8}$ T  (d) $4.6 \times 10^{-8}$ T

58. What is the \textit{rms} value of the magnitude of the magnetic field?
   (a) $1.4 \times 10^{-8}$ T  (c) $3.3 \times 10^{-8}$ T  (e) $5.4 \times 10^{-8}$ T
   (b) $2.4 \times 10^{-8}$ T  (d) $4.6 \times 10^{-8}$ T
59. Determine the frequency of the wave.
   (a) $1.0 \times 10^9$ Hz  (c) $2.5 \times 10^8$ Hz  (e) $5.0 \times 10^8$ Hz
   (b) $1.3 \times 10^8$ Hz  (d) $3.8 \times 10^8$ Hz

60. Determine the wavelength of the wave.
   (a) 0.30 m  (c) 0.79 m  (e) 2.3 m
   (b) 0.60 m  (d) 1.2 m

61. What is the average total energy density of this electromagnetic wave?
   (a) $6.2 \times 10^{-11}$ J/m$^3$  (c) $1.1 \times 10^{-10}$ J/m$^3$  (e) $4.4 \times 10^{-10}$ J/m$^3$
   (b) $8.6 \times 10^{-11}$ J/m$^3$  (d) $1.8 \times 10^{-10}$ J/m$^3$

62. What is the average intensity of this electromagnetic wave?
   (a) 0.13 W/m$^2$  (c) 0.33 W/m$^2$  (e) 0.54 W/m$^2$
   (b) 0.26 W/m$^2$  (d) 0.36 W/m$^2$

63. What is the magnitude of the electric field at $t = 3.34 \times 10^{-10}$ s?
   (a) 2.0 N/C  (c) 7.1 N/C  (e) zero N/C
   (b) 5.0 N/C  (d) 10.0 N/C

64. What is the magnitude of the magnetic field at $t = 6.67 \times 10^{-10}$ s?
   (a) $1.7 \times 10^{-8}$ T  (c) $2.9 \times 10^{-8}$ T  (e) zero tesla
   (b) $2.3 \times 10^{-8}$ T  (d) $3.3 \times 10^{-8}$ T

65. What is the magnitude of the magnetic field at $t = 6.0 \times 10^{-9}$ s?
   (a) $1.7 \times 10^{-8}$ T  (c) $2.8 \times 10^{-8}$ T  (e) zero tesla
   (b) $2.3 \times 10^{-8}$ T  (d) $3.3 \times 10^{-8}$ T

66. To which region of the electromagnetic spectrum does this wave belong?
   (a) X-rays  (c) visible light  (e) radio waves
   (b) gamma rays  (d) infrared radiation