16.9: Electromagnetic Waves (Answer)

Check Your Understanding

16.1. It is greatest immediately after the current is switched on. The displacement current and the magnetic field from it are proportional to the rate of change of electric field between the plates, which is greatest when the plates first begin to charge.

16.2. No. The changing electric field according to the modified version of Ampère's law would necessarily induce a changing magnetic field.

16.3. (1) Faraday's law, (2) the Ampère-Maxwell law

16.4. a. The directions of wave propagation, of the **E** field, and of **B** field are all mutually perpendicular.

b. The speed of the electromagnetic wave is the speed of light $c = 1/\sqrt{\varepsilon_0 \mu_0}$ independent of frequency.

c. The ratio of electric and magnetic field amplitudes is $E/B = c$.

16.5. Its acceleration would decrease because the radiation force is proportional to the intensity of light from the Sun, which decreases with distance. Its speed, however, would not change except for the effects of gravity from the Sun and planets.

16.6. They fall into different ranges of wavelength, and therefore also different corresponding ranges of frequency.

Conceptual Questions

1. The current into the capacitor to change the electric field between the plates is equal to the displacement current between the plates.

3. The first demonstration requires simply observing the current produced in a wire that experiences a changing magnetic field. The second demonstration requires moving electric charge from one location to another, and therefore involves electric currents that generate a changing electric field. The magnetic fields from these currents are not easily separated from the magnetic field that the displacement current produces.

5. in (a), because the electric field is parallel to the wire, accelerating the electrons

7. A steady current in a dc circuit will not produce electromagnetic waves. If the magnitude of the current varies while remaining in the same direction, the wires will emit electromagnetic waves, for example, if the current is turned on or off.

9. The amount of energy (about $100 W/m^2$) is can quickly produce a considerable change in temperature, but the light pressure (about $3.00 \times 10^{-7} N/m^2$) is much too small to notice.

11. It has the magnitude of the energy flux and points in the direction of wave propagation. It gives the direction of energy flow and the amount of energy per area transported per second.

13. The force on a surface acting over time Δt is the momentum that the force would impart to the object. The momentum change of the light is doubled if the light is reflected back compared with when it is absorbed, so the force acting on the object is twice as great.

15. a. According to the right hand rule, the direction of energy propagation would reverse.

b. This would leave the vector $\vec{S}$, and therefore the propagation direction, the same.

17. a. Radio waves are generally produced by alternating current in a wire or an oscillating electric field between two plates;

b. Infrared radiation is commonly produced by heated bodies whose atoms and the charges in them vibrate at about the right frequency.

19. a. blue;

b. Light of longer wavelengths than blue passes through the air with less scattering, whereas more of the blue light is scattered in different directions in the sky to give it is blue color.

21. A typical antenna has a stronger response when the wires forming it are orientated parallel to the electric field of the radio wave.

23. No, it is very narrow and just a small portion of the overall electromagnetic spectrum.

25. Visible light is typically produced by changes of energies of electrons in randomly oriented atoms and molecules. Radio waves are typically emitted by an ac current flowing along a wire, that has fixed orientation and produces electric fields pointed in particular directions.

27. Radar can observe objects the size of an airplane and uses radio waves of about 0.5 cm in wavelength. Visible light can be used to view single biological cells and has wavelengths of about $10^{-7} m$.

29. ELF radio waves

31. The frequency of 2.45 GHz of a microwave oven is close to the specific frequencies in the 2.4 GHz band used for WiFi.

Problems

33. $B_{ind} = \frac{\mu_0}{P2\pi r} I_{ind} = \frac{\mu_0}{2\pi r} \varepsilon_0 \frac{\partial \Phi_E}{\partial t} = \frac{\mu_0}{2\pi r} \varepsilon_0 (A \frac{\partial E}{\partial t}) = \frac{\mu_0}{2\pi r} \varepsilon_0 A (\frac{1}{d} \frac{dV(t)}{dt}) = \frac{\mu_0}{2\pi r} [\frac{\varepsilon_0 A}{d}][\frac{1}{C} \frac{dQ(t)}{dt}] = \frac{\mu_0}{2\pi r} \frac{dQ(t)}{dt}$ because $C = \frac{\varepsilon_0 A}{d}$

35. a. $I_{res} = \frac{V_0 sin\omega t}{R}$;

b. $I_d = CV_0 \omega cos\omega t$;

c. $I_{real} = I_{res} + \frac{dQ}{dt} = \frac{V_0 sin\omega t}{R} + CV_0 \frac{d}{dt} sin\omega t = \frac{V_0 sin\omega t}{R} + CV_0 \omega cos\omega t$; which is the sum of I_{res} and I_{real}, consistent with how the displacement current maintaining the continuity of current.

37. $1.77 \times 10^{-3} A$

39. $I_d = (7.97 \times 10^{-10} A) sin(150t)$

41. 499 s

43. 25 m

45. a. 5.00 V/m;

b. $9.55 \times 10^8 Hz$;

c. 31.4 cm;

d. toward the +**x**-axis;

e. $B = (1.67 \times 10^{-8} T) cos[kx - (6 \times 10^9 s^{-1})t + 0.40]\hat{k}$

47. $I_d = \pi \varepsilon_0 \omega R^2 E_0 sin(kx - \omega t)$

49. The magnetic field is downward, and it has magnitude $2.00 \times 10^{-8} T$.

51. a. $6.45 \times 10^{-3} V/m$;

b. 394 m

53. 11.5 m

55. $5.97 \times 10^{-3} W/m^2$

57. a. $E_0 = 1027 V/m, B_0 = 3.42 \times 10^{-6} T$;

b. $3.96 \times 10^{26} W$

59. $20.8 W/m^2$

61. a. $4.42 \times 10^{-6} W/m^2$;

b. $5.77 \times 10^{-2} V/m$

63. a. $7.47 \times 10^{-14} W/m^2$;

b. $3.66 \times 10 -^{13} W$;

c. 1.12 W

65. $1.99 \times 10^{-11} N/m^2$

67. $F = ma = (p)(\pi r^2), p = \frac{ma}{\pi r^2} = \frac{\varepsilon_0}{2E_0^2}$

$$E_0 = \sqrt{\frac{2ma}{\varepsilon_0 \pi r^2}} = \sqrt{\frac{2(10^{-8} kg)(0.30 m/s^2)}{(8.854 \times 10^{-12} C^2/N \cdot m^2)(\pi)(2 \times 10^{-6} m)^2}}$$

$$E_0 = 7.34 \times 10^6 V/m$$

69. a. $4.50 \times 10^{-6} N$;

b. it is reduced to half the pressure, $2.25 \times 10^{-6} N$

71. a. $W = \frac{1}{2} \frac{\pi^2 r^4}{mc^2} I^2 t^2$;

b. $E = \pi r^2 It$

73. a. $1.5 \times 10^{18} Hz$;

b. X-rays

75. a. The wavelength range is 187 m to 556 m.

b. The wavelength range is 2.78 m to 3.41 m.

77. $P' = (\frac{12m}{30m})^2 (100mW) = 16mW$

79. time for 1 bit = 1.27×10^{-8} s, difference in travel time is 5.34×10^{-8} s

81. a. $1.5 \times 10^{-9} m$;

b. $5.9 \times 10^{-7} m$;

c. $3.0 \times 10^{-15} m$

83. $5.17 \times 10^{-12} T$, the non-oscillating geomagnetic field of 25–65 μT is much larger

85. a. $1.33 \times 10^{-2} V/m$;

b. $4.34 \times 10^{-11} T$;

c. $3.00 \times 10^8 m$

87. a. $5.00 \times 10^6 m$;

b. radio wave;

c. $4.33 \times 10^{-5} T$

Additional Problems

89. $I_d = (10N/C)(8.845 \times 10^{-12} C^2/N \cdot m^2)\pi(0.03m)^2(5000) = 1.25 \times 10^{-5} mA$

91. $3.75 \times 10^7 km$, which is much greater than Earth's circumference

93. a. 564 W;

b. $1.80 \times 10^4 W/m^2$;

c. $3.68 \times 10^3 V/m$;

d. $1.23 \times 10^{-5} T$

95. a. $5.00 \times 10^3 W/m^2$;

b. $3.88 \times 10^{-6} N$;

c. $5.18 \times 10^{-12} N$

97. a. $I = \frac{P}{A} = \frac{P}{4\pi r^2} \propto \frac{1}{r^2}$;

b. $I \propto E_0^2, B_0^2 \Rightarrow E_0^2, B_0^2 \propto \frac{1}{r^2} \Rightarrow E_0, B_0 \propto \frac{1}{r}$

99. Power into the wire= $\int \vec{S} \cdot d\vec{A} = (\frac{1}{\mu_0} EB)(2\pi r L) = \frac{1}{\mu_0} (\frac{V}{L})(\frac{\mu_0 i}{2\pi r})(2\pi r L) = iV = i^2 R$

101. 0.431

103. a. $1.5 \times 10^{11} m$;

b. $5.0 \times 10^{-7} s$;

c. 33 ns

105. $sound: \lambda_{sound} = \frac{v_s}{f} = \frac{343 m/s}{20.0 Hz} = 17.2 m$

$radio: \lambda_{radio} = \frac{c}{f} = \frac{3.00 \times 10^8 m/s}{1030 \times 10^3 Hz} = 291 m; or 17.1 \lambda_{sound}$

Challenge Problems

107. a. $0.29 \mu m$;

b. The radiation pressure is greater than the Sun's gravity if the particle size is smaller, because the gravitational force varies as the radius cubed while the radiation pressure varies as the radius squared.

c. The radiation force outward implies that particles smaller than this are less likely to be near the Sun than outside the range of the Sun's radiation pressure.