CHAPTER 22: Electromagnetic Waves

Answers to Questions

1. If the direction of travel for the EM wave is north and the electric field oscillates east-west, then the magnetic field must oscillate up and down. For an EM wave, the direction of travel, the electric field, and the magnetic field must all be perpendicular to each other.

2. No, sound is not an electromagnetic wave. Sound is a mechanical (pressure) wave. The energy in the sound wave is actually oscillating the medium in which it travels (air, in this case). The energy in an EM wave is contained in the electric and magnetic fields and it does not need a medium in which to travel.

3. Yes, EM waves can travel through a perfect vacuum. The energy is carried in the oscillating electric and magnetic fields and no medium is required to travel. No, sound waves cannot travel through a perfect vacuum. A medium is needed to carry the energy of a mechanical wave such as sound and there is no medium in a perfect vacuum.

4. When you flip a light switch on, the electrons in the filament wire need to move to light the bulb, and these electrons need to receive energy to begin to move. It does take some time for the energy to travel through the wires from the switch to the bulb, but the time is extremely minimal, since the energy travels with the EM fields in the wire at nearly the speed of light. It also takes a while for the EM (light) waves to travel from the bulb to your eye, again at the speed of light, and so very little time passes. Some delay can usually be detected by your eyes due to the fact that the filament takes a little time to heat up to a temperature that emits visible light. Also, depending on the inductance of the circuit, a small amount of time could be added to the delay in your seeing the light go on (inductance acts like an electrical inertia). Thus, no, the light does not go on immediately when you flip the light switch, but the delay is very small.

5. The wavelengths of radio and TV signals are much longer than visible light. Radio waves are on the order of 3 m – 30,000 m. TV waves are on the order of 0.3 m – 3 m. Visible waves are on the order of 10^{-7} m.

6. It is not necessary to make the lead-in wires to your speakers the exact same length. Since energy in the wires travels at nearly the speed of light, the difference in time between the signals getting to the different speakers will be too small for your ears to detect. [Making sure the resistance of your speaker wires is correct is much more important.]

7. Wavelength of 10^3 km: Sub-radio waves (or very long radio waves; for example, ELF waves for submarine communication fall into this category). Wavelength of 1 km: Radio waves. Wavelength of 1 m: TV signals and microwaves. Wavelength of 1 cm: microwaves and satellite TV signals. Wavelength of 1 mm: microwaves and infrared waves. Wavelength of 1 μm: infrared waves.

8. Yes, radio waves can have the same frequencies as sound waves. These 20 – 20,000 Hz EM waves would have extremely long wavelengths (for example, ELF waves for submarine communication) when compared to the sound waves. A 5000 Hz sound wave has a wavelength of about 70 mm, while a 5000 Hz EM wave has a wavelength of about 60 km.

9. Two TV or two radio stations can be broadcast on the same carrier frequency, but if both signals are of similar strength in the same locality, the signals will be "scrambled". The carrier frequency is used by the receiver to distinguish between different stations. Once the receiver has locked on to a particular carrier frequency, its circuitry then does the work of demodulating the information being carried on that carrier frequency. If two stations had the same carrier frequency, the receiver would try to decipher both signals at once and you would get jumbled information instead of a clear signal.

10. The receiver antenna should also be vertical for obtaining the best reception. The oscillating carrier electric field is up-and-down, so a vertical antenna would "pick up" that signal better, since the electrons in the metal antenna would be forced to oscillate up and down along the entire length of the vertical antenna and creating a stronger signal. This is analogous to polarized light, as discussed in chapter 24.

11. Diffraction effects (the bending of waves around the edge of an object) are only evident when the size of the wavelength of the wave is larger than the size of the object. AM waves have wavelengths that are on the order of 300 m long, while FM waves have wavelengths on the order of 3 m long. Buildings and hills are much larger than FM waves, and so FM waves will not diffract around the buildings and hills. Thus the FM signal will not be received behind the hills or buildings. On the other hand, these objects are smaller than AM waves, and so the AM waves will diffract around them easily. The AM signal can be received behind the objects.

12. Cordless phones utilize EM waves when sending information back and forth between the phone (the part you hold up to your ear/mouth) and its base (where the base is sitting in your house and it is physically connected to the wire phones lines that lead outside to the phone company's network). These EM waves are usually very weak (you can't walk very far away from your house before you lose the signal) and use frequencies such at 49 MHz, 900 MHz, 2.4 GHz or 5 GHz. Cell phones utilize EM waves when sending information back and forth between the phone and the nearest tower in your geographical area (which could be miles away from your location). These EM waves need to be much stronger than cordless phone waves (the batteries are usually much more sophisticated and expensive) and use frequencies of 850 MHz or 1.2 GHz. [Cell phones also have many more channels than cordless phones, so more people can be talking using the same carrier frequency.]

13. Transmitting Morse code by flashing a flashlight on and off is an AM wave. The amplitude of the carrier wave is increasing/decreasing every time you turn the flashlight on and off. The frequency of the carrier wave is visible light, which is approximately 10^{14} Hz.

Solutions to Problems

1. The current in the wires must also be the displacement current in the capacitor. We find the rate at which the electric field is changing from

$$I_D = \varepsilon_0 A\left(\frac{\Delta E}{\Delta t}\right);$$

$$1.8\,\text{A} = \left(8.85\times10^{-12}\ \text{F/m}\right)\left(0.0160\,\text{m}\right)^2\left(\frac{\Delta E}{\Delta t}\right)$$, which gives $\boxed{7.9\times10^{14}\ \text{V/m}\bullet\text{s}.}$

2. The current in the wires is the rate at which charge is accumulating on the plates and must also be the displacement current in the capacitor. Because the location is outside the capacitor, we can use the expression for the magnetic field of a long wire:

$$B = \left(\frac{\mu_0}{4\pi}\right)\frac{2I}{R} = \frac{\left(10^{-7}\,\text{T}\bullet\text{m/A}\right)2\left(35.0\times10^{-3}\,\text{A}\right)}{\left(0.100\,\text{m}\right)} = \boxed{7.00\times10^{-8}\,\text{T.}}$$

After the capacitor is fully charged, all currents will be zero, so the magnetic field will be $\boxed{\text{zero.}}$

3. The electric field is

$$E = cB = \left(3.00\times10^{8}\,\text{m/s}\right)\left(17.5\times10^{-9}\,\text{T}\right) = \boxed{5.25\,\text{V/m.}}$$

4. The frequency of the two fields must be the same: $\boxed{\text{80.0 kHz.}}$
The rms strength of the electric field is

$$E_{\text{rms}} = cB_{\text{rms}} = \left(3.00\times10^{8}\,\text{m/s}\right)\left(6.75\times10^{-9}\,\text{T}\right) = \boxed{2.03\,\text{V/m.}}$$

The electric field is perpendicular to both the direction of travel and the magnetic field, so the electric field oscillates along the $\boxed{\text{horizontal north-south line.}}$

5. The frequency of the microwave is

$$f = \frac{c}{\lambda} = \frac{\left(3.00\times10^{8}\,\text{m/s}\right)}{\left(1.60\times10^{-2}\,\text{m}\right)} = \boxed{1.88\times10^{10}\,\text{Hz.}}$$

6. The wavelength of the radar signal is

$$\lambda = \frac{c}{f} = \frac{\left(3.000\times10^{8}\,\text{m/s}\right)}{\left(29.75\times10^{9}\,\text{Hz}\right)} = \boxed{1.008\times10^{-2}\,\text{m.}}$$

7. The wavelength of the wave is

$$\lambda = \frac{c}{f} = \frac{\left(3.00\times10^{8}\,\text{m/s}\right)}{\left(9.66\times10^{14}\,\text{Hz}\right)} = 3.11\times10^{-7}\,\text{m} = \boxed{311\,\text{nm.}}$$

This wavelength is just outside the violet end of the visible region, so it is $\boxed{\text{ultraviolet.}}$

$\boxed{8.}$ The frequency of the wave is

$$f = \frac{c}{\lambda} = \frac{\left(3.00\times10^{8}\,\text{m/s}\right)}{\left(650\times10^{-9}\,\text{m}\right)} = \boxed{4.62\times10^{14}\,\text{Hz.}}$$

This frequency is just inside the red end of the visible region, so it is $\boxed{\text{visible.}}$

9. The time for light to travel from the Sun to the Earth is

$$\Delta t = \frac{L}{c} = \frac{\left(1.50\times10^{11}\,\text{m}\right)}{\left(3.00\times10^{8}\,\text{m/s}\right)} = 5.00\times10^{2}\,\text{s} = \boxed{8.33\,\text{min.}}$$

10. The radio frequency is

$$f = \frac{c}{\lambda} = \frac{\left(3.0\times10^{8}\,\text{m/s}\right)}{\left(49\,\text{m}\right)} = \boxed{6.1\times10^{6}\,\text{Hz.}}$$

11. We convert the units:

$$d = (4.2\text{ ly})(3.00\times10^{8}\text{ m/s})(3.16\times10^{7}\text{ s/yr}) = \boxed{4.0\times10^{16}\text{ m.}}$$

12. The distance that light travels in one year is

$$d = (3.00\times10^{8}\text{ m/s})(3.156\times10^{7}\text{ s/yr}) = \boxed{9.47\times10^{15}\text{ m.}}$$

13. (*a*) If we assume the closest approach of Mars to Earth, we have

$$\Delta t = \frac{L}{c} = \frac{(227.9\times10^{9}\text{ m} - 149.6\times10^{9}\text{ m})}{(3.000\times10^{8}\text{ m/s})} = \boxed{261\text{s.}}$$

(*b*) If we assume the farthest approach of Mars to Earth, we have

$$\Delta t = \frac{L}{c} = \frac{(227.9\times10^{9}\text{ m} + 149.6\times10^{9}\text{ m})}{(3.000\times10^{8}\text{ m/s})} = \boxed{1260\text{s.}}$$

14. The eight-sided mirror would have to rotate 1/8 of a revolution for the succeeding mirror to be in position to reflect the light in the proper direction. During this time the light must travel to the opposite mirror and back. Thus the angular speed required is

$$\omega = \frac{\Delta\theta}{\Delta t} = \frac{\left(\frac{2\pi\text{ rad}}{8}\right)}{\left(\frac{2L}{c}\right)} = \frac{(\pi\text{ rad})c}{8L}$$

$$= \frac{(\pi\text{ rad})(3.00\times10^{8}\text{ m/s})}{8(3.5\times10^{3}\text{m})} = \boxed{3.4\times10^{3}\text{ rad/s}}\ (3.2\times10^{4}\text{ rev/min}).$$

15. The mirror must rotate at a minimum rate of

$$\omega = \frac{\left(\frac{1}{6}\text{revolutions}\right)}{t}, \text{where } t = \frac{(2)(12\text{ m})}{(3.0\times10^{8}\text{ m/s})} = 8.0\times10^{-8}\text{ s.}$$

Thus $\omega = \dfrac{\left(\frac{1}{6}\text{revolutions}\right)}{(8.0\times10^{-8}\text{ s})} = \boxed{2.1\times10^{6}\text{ revolutions/s.}}$

16. If we ignore the time for the sound to travel to the microphone, the time difference is

$$\Delta t = t_{\text{radio}} - t_{\text{sound}} = \left(\frac{d_{\text{radio}}}{c}\right) - \left(\frac{d_{\text{sound}}}{v_{\text{sound}}}\right) = \left(\frac{3000\text{ m}}{3.00\times10^{8}\text{ m/s}}\right) - \left(\frac{50\text{ m}}{343\text{ m/s}}\right) = -0.14\text{s},$$

so the $\boxed{\text{person at the radio hears the voice 0.14 s sooner.}}$

17. The length of the pulse is $\Delta d = c\Delta t$, so the number of wavelengths in this length is

$$N = \frac{(c\Delta t)}{\lambda} = \frac{(3.00\times10^{8}\text{ m/s})(32\times10^{-12}\text{ s})}{(1062\times10^{-9}\text{ m})} = \boxed{9040\text{ wavelengths.}}$$

The time for the length of the pulse to be one wavelength is

$$\Delta t' = \frac{\lambda}{c} = \frac{\left(1062\times10^{-9}\,\text{m}\right)}{\left(3.00\times10^{8}\,\text{m/s}\right)} = 3.54\times10^{-15}\,\text{s} = \boxed{3.54\,\text{fs.}}$$

18. The energy per unit area per unit time is

$$S = \tfrac{1}{2}c\varepsilon_0 E_0{}^2$$
$$= \tfrac{1}{2}\left(3.00\times10^{8}\,\text{m/s}\right)\left(8.85\times10^{-12}\,\text{C}^2/\text{N}\bullet\text{m}^2\right)\left(21.8\times10^{-3}\,\text{V/m}\right)^2 = \boxed{6.31\times10^{-7}\,\text{W/m}^2.}$$

19. The energy per unit area per unit time is

$$S = \frac{cB_{\text{rms}}{}^2}{\mu_0} = \frac{\left(3.00\times10^{8}\,\text{m/s}\right)\left(28.5\times10^{-9}\,\text{T}\right)^2}{\left(4\pi\times10^{-7}\,\text{T}\bullet\text{m/A}\right)} = 0.194\,\text{W/m}^2.$$

We find the time from

$$t = \frac{U}{AS} = \frac{\left(235\,\text{J}\right)}{\left(1.00\times10^{-4}\,\text{m}^2\right)\left(0.194\,\text{W/m}^2\right)} = 1.21\times10^{7}\,\text{s} = \boxed{140\text{ days.}}$$

20. The energy per unit area per unit time is

$$S = c\varepsilon_0 E_{\text{rms}}{}^2$$
$$= \left(3.00\times10^{8}\,\text{m/s}\right)\left(8.85\times10^{-12}\,\text{C}^2/\text{N}\bullet\text{m}^2\right)\left(0.0386\,\text{V/m}\right)^2 = 3.9558\times10^{-6}\,\text{W/m}^2.$$

We find the energy transported from

$$U = AS = \left(1.00\times10^{-4}\,\text{m}^2\right)\left(3.9558\times10^{-6}\,\text{W/m}^2\right)\left(3600\,\text{s/h}\right) = \boxed{1.42\times10^{-6}\,\text{J/h.}}$$

21. Because the wave spreads out uniformly over the surface of the sphere, the power flux is

$$S = \frac{P}{A} = \frac{\left(1200\,\text{W}\right)}{\left[4\pi\left(10.0\,\text{m}\right)^2\right]} = \boxed{0.9549\,\text{W/m}^2.}$$

We find the rms value of the electric field from

$$S = c\varepsilon_0 E_{\text{rms}}{}^2;$$
$$0.9549\,\text{W/m}^2 = \left(3.00\times10^{8}\,\text{m/s}\right)\left(8.85\times10^{-12}\,\text{C}^2/\text{N}\bullet\text{m}^2\right)E_{\text{rms}}{}^2,\ \text{which gives } E_{\text{rms}} = \boxed{19.0\,\text{V/m.}}$$

22. The energy per unit area per unit time is

$$S = \frac{P}{A} = c\varepsilon_0 E_{\text{rms}}{}^2;$$
$$\frac{\left(12.8\times10^{-3}\,\text{W}\right)}{\left[\frac{\pi}{4}\left(1.75\times10^{-3}\,\text{m}\right)^2\right]} = \left(3.00\times10^{8}\,\text{m/s}\right)\left(8.85\times10^{-12}\,\text{C}^2/\text{N}\bullet\text{m}^2\right)E_{\text{rms}}{}^2,$$

which gives $E_{\text{rms}} = \boxed{1.42\times10^{3}\,\text{V/m.}}$

The rms value of the magnetic field is

$$B_{\text{rms}} = \frac{E_{\text{rms}}}{c} = \frac{\left(1420\,\text{V/m}\right)}{\left(3.00\times10^{8}\,\text{m/s}\right)} = \boxed{4.72\times10^{-6}\,\text{T.}}$$

23. The radiation from the Sun has the same intensity in all directions, so the rate at which it reaches the Earth is the rate at which it passes through a sphere centered at the Sun:

$$P = S4\pi R^2 = \left(1350\,\text{W/m}^2\right)4\pi\left(1.5\times10^{11}\,\text{m}\right)^2 = \boxed{3.8\times10^{26}\,\text{W.}}$$

24. (*a*) We find E using

$$E = cB = \left(3.0\times10^8\,\text{m/s}\right)\left(2.5\times10^{-7}\,\text{T}\right) = \boxed{75\,\text{V/m.}}$$

(*b*) Average power per unit area is

$$\bar{I} = \frac{E_0 B_0}{(2\mu_0)} = \frac{\left(75\,\text{V/m}\right)\left(2.5\times10^{-7}\,\text{T}\right)}{\left[2\left(4\pi\times10^{-7}\,\text{N}\bullet\text{s}^2/\text{C}^2\right)\right]} = \boxed{7.5\,\text{W/m}^2.}$$

25. (*a*) The energy emitted in each pulse is

$$U = Pt = \left(2.8\times10^{11}\,\text{W}\right)\left(1.0\times10^9\,\text{s}\right) = \boxed{280\,\text{J.}}$$

(*b*) We find the rms electric field from

$$S = \frac{P}{A} = c\varepsilon_0 E_{\text{rms}}{}^2;$$

$$\frac{\left(2.8\times10^{11}\,\text{W}\right)}{\pi\left(2.2\times10^{-3}\,\text{m}\right)^2} = \left(3.00\times10^8\,\text{m/s}\right)\left(8.85\times10^{-12}\,\text{C}^2/\text{N}\bullet\text{m}^2\right)E_{\text{rms}}{}^2,$$

which gives $E_{\text{rms}} = \boxed{2.6\times10^9\,\text{V/m.}}$

26. We find the pressure

$$P = \frac{\bar{I}}{c} = \frac{100\,\text{W}}{\left[\left(3.0\times10^8\,\text{m/s}\right)4\pi\left(8.0\times10^{-2}\,\text{m}\right)^2\right]} = \boxed{4.1\times10^{-6}\,\text{N/m}^2.}$$

Supposing a 1.0 cm^2 fingertip, the force is

$$F = PA = \left(4.1\times10^{-6}\,\text{N/m}^2\right)\left(1.0\times10^{-4}\,\text{m}^2\right) = \boxed{4.1\times10^{-10}\,\text{N.}}$$

27. (*a*) FM radio wavelengths are

$$\lambda = \frac{c}{f} = \frac{\left(3.0\times10^8\,\text{m/s}\right)}{\left(1.08\times10^8\,\text{Hz}\right)} = \boxed{2.78\,\text{m}} \text{ to}$$

$$\lambda = \frac{c}{f} = \frac{\left(3.0\times10^8\,\text{m/s}\right)}{\left(8.8\times10^7\,\text{Hz}\right)} = \boxed{3.4\,\text{m.}}$$

(*b*) AM radio wavelengths are

$$\lambda = \frac{c}{f} = \frac{\left(3.0\times10^8\,\text{m/s}\right)}{\left(1.7\times10^6\,\text{Hz}\right)} = \boxed{176\,\text{m}} \text{ to}$$

$$\lambda = \frac{c}{f} = \frac{\left(3.0\times10^8\,\text{m/s}\right)}{\left(5.35\times10^5\,\text{Hz}\right)} = \boxed{561\,\text{m.}}$$

28. The cell phone will receive signals of wavelength

$$\lambda = \frac{c}{f} = \frac{(3.0\times10^8\ \text{m/s})}{(1.9\times10^9\ \text{Hz})} = \boxed{0.16\ \text{m.}}$$

29. The frequencies are 940 kHz on the AM dial and 94 MHz on the FM dial. From $c = f\lambda,$ we see that the lower frequency will have the longer wavelength: $\boxed{\text{the AM station.}}$
When we form the ratio of wavelengths, we get

$$\frac{\lambda_2}{\lambda_1} = \frac{f_1}{f_2} = \frac{(94\times10^6\ \text{Hz})}{(940\times10^3\ \text{Hz})} = \boxed{100.}$$

30. The wavelength of Channel 2 is

$$\lambda_2 = \frac{c}{f_2} = \frac{(3.00\times10^8\ \text{m/s})}{(54.0\times10^6\ \text{Hz})} = \boxed{5.56\ \text{m.}}$$

The wavelength of Channel 69 is

$$\lambda_{69} = \frac{c}{f_{69}} = \frac{(3.00\times10^8\ \text{m/s})}{(806\times10^6\ \text{Hz})} = \boxed{0.372\ \text{m.}}$$

31. The resonant frequency is given by

$$f_0^{\ 2} = \left(\frac{1}{2\pi}\right)^2\left(\frac{1}{LC}\right).$$

When we form the ratio for the two stations, we get

$$\left(\frac{f_{02}}{f_{01}}\right)^2 = \frac{C_1}{C_2};$$

$$\left(\frac{1610\ \text{kHz}}{550\ \text{kHz}}\right)^2 = \frac{(2800\ \text{pF})}{C_2}, \text{ which gives } C_2 = \boxed{327\ \text{pF.}}$$

32. We find the capacitance from the resonant frequency:

$$f_0 = \left(\frac{1}{2\pi}\right)\left(\frac{1}{LC}\right)^{\frac{1}{2}};$$

$$96.1\times10^6\ \text{Hz} = \left(\frac{1}{2\pi}\right)\left[\frac{1}{(1.8\times10^{-6}\ \text{H})C}\right]^{\frac{1}{2}}, \text{ which gives } C = 1.5\times10^{-12}\ \text{F} = \boxed{1.5\ \text{pF.}}$$

33. We find the inductance for the first frequency:

$$f_{01} = \left(\frac{1}{2\pi}\right)\left(\frac{1}{L_1 C}\right)^{\frac{1}{2}};$$

$$8 \times 10^6\,\text{Hz} = \left(\frac{1}{2\pi}\right)\left[\frac{1}{L_1\left(840 \times 10^{-12}\,\text{F}\right)}\right]^{\frac{1}{2}},\text{ which gives } L_1 = 3.89 \times 10^{-9}\,\text{H} = 3.89\,\text{nH}.$$

For the second frequency we have

$$f_{02} = \left(\frac{1}{2\pi}\right)\left(\frac{1}{L_2 C}\right)^{\frac{1}{2}};$$

$$108 \times 10^6\,\text{Hz} = \left(\frac{1}{2\pi}\right)\left[\frac{1}{L_2\left(840 \times 10^{-12}\,\text{F}\right)}\right]^{\frac{1}{2}},\text{ which gives } L_2 = 2.59 \times 10^{-9}\,\text{H} = 2.59\,\text{nH}.$$

Thus the range of inductances is $\boxed{2.59\,\text{nH} \le L \le 3.89\,\text{nH}.}$

34. (*a*) The minimum value of *C* corresponds to the higher frequency, so we have

$$f_{01} = \left(\frac{1}{2\pi}\right)\left(\frac{1}{LC_1}\right)^{\frac{1}{2}};$$

$$15.0 \times 10^6\,\text{Hz} = \left(\frac{1}{2\pi}\right)\left[\frac{1}{L\left(82 \times 10^{-12}\,\text{F}\right)}\right]^{\frac{1}{2}},\text{ which gives } L = 1.373 \times 10^{-6}\,\text{H} = \boxed{1.4\,\mu\text{H}.}$$

(*b*) The maximum value of *C* corresponds to the lower frequency, so we have

$$f_{02} = \left(\frac{1}{2\pi}\right)\left(\frac{1}{LC_2}\right)^{\frac{1}{2}};$$

$$14.0 \times 10^6\,\text{Hz} = \left(\frac{1}{2\pi}\right)\left[\frac{1}{\left(1.373 \times 10^{-6}\,\text{H}\right)C_2}\right]^{\frac{1}{2}},\text{ which gives } C_2 = 9.41 \times 10^{-11}\,\text{F} = \boxed{94\,\text{pF}.}$$

35. The rms electric field strength of the beam is given by

$$S = \frac{P}{A} = c\varepsilon_0 E_{\text{rms}}{}^2;$$

$$\frac{\left(10 \times 10^3\,\text{W}\right)}{\left(\pi\left(750\,\text{m}\right)^2\right)} = \left(3.0 \times 10^8\,\text{m/s}\right)\left(8.85 \times 10^{-12}\,\text{C}^2/\text{N}\bullet\text{m}^2\right)E_{\text{rms}}{}^2,$$

which gives $E_{\text{rms}}{}^2 = 2.1314\,\text{V}^2/\text{m}^2$, and $E_{\text{rms}} = \boxed{1.5\,\text{V/m}.}$

36. To produce the voltage over the length of the antenna, we have

$$E_{\text{rms}} = \frac{V_{\text{rms}}}{d} = \frac{\left(1.00 \times 10^{-3}\,\text{V}\right)}{\left(1.60\,\text{m}\right)} = \boxed{6.25\times 10^{-4}\,\text{V/m}.}$$

The rate of energy transport is

$$S = c\varepsilon_0 E_{\text{rms}}{}^2$$
$$= \left(3.00\times10^8\ \text{m/s}\right)\left(8.85\times10^{-12}\,\text{C}^2/\text{N}\bullet\text{m}^2\right)\left(6.25\times10^{-4}\ \text{V/m}\right)^2 = \boxed{1.04\times10^{-9}\ \text{W/m}^2.}$$

37. After the change occurred, we would find out when the change in radiation reached the Earth:

$$\Delta t = \frac{L}{c} = \frac{\left(1.50\times10^{14}\,\text{m}\right)}{\left(3.00\times10^8\ \text{m/s}\right)} = 5.00\times10^2\,\text{s} = \boxed{8.33\,\text{min.}}$$

38. The length in space of a burst is

$$d = ct = \left(3.00\times10^8\ \text{m/s}\right)\left(10^{-8}\text{s}\right) = \boxed{3\,\text{m.}}$$

39. (*a*) The time for a signal to travel to the Moon is

$$\Delta t = \frac{L}{c} = \frac{\left(3.84\times10^8\,\text{m}\right)}{\left(3.00\times10^8\ \text{m/s}\right)} = \boxed{1.28\,\text{s.}}$$

(*b*) The time for a signal to travel to Mars at the closest approach is

$$\Delta t = \frac{L}{c} = \frac{\left(78\times10^9\,\text{m}\right)}{\left(3.00\times10^8\ \text{m/s}\right)} = 260\,\text{s} = \boxed{4.3\,\text{min.}}$$

40. The time consists of the time for the radio signal to travel to Earth and the time for the sound to travel from the loudspeaker:

$$t = t_{\text{radio}} + t_{\text{sound}} = \left(\frac{d_{\text{radio}}}{c}\right) + \left(\frac{d_{\text{sound}}}{v_{\text{sound}}}\right)$$
$$= \left(\frac{3.84\times10^8\,\text{m}}{3.00\times10^8\ \text{m/s}}\right) + \left(\frac{25\,\text{m}}{343\,\text{m/s}}\right) = \boxed{1.35\,\text{s.}}$$

Note that about 5% of the time is for the sound wave.

41. (*a*) The rms value of the associated electric field is found by

$$u_{\text{avg}} = \varepsilon_0 E_{\text{rms}}{}^2 = 4\times10^{-14}\ \text{J/m}^3 = \left(8.85\times10^{-12}\,\text{C}^2/\text{N}\bullet\text{m}^2\right)E_{\text{rms}}{}^2.$$

Thus $E_{\text{rms}}{}^2 = 4.52\times10^{-3}\ \text{V}^2/\text{m}^2$, and $E_{\text{rms}} = \boxed{0.07\,\text{V/m.}}$

(*b*) A comparable value is found by using the relation

$$\bar{I} = \tfrac{1}{2}\varepsilon_0 c E_0{}^2 = \frac{P}{\left(4\pi r^2\right)}.$$ Solving for r yields

$$r^2 = \frac{P}{\left(2\pi\varepsilon_0 c E_0{}^2\right)} = \frac{10^4\,\text{W}}{\left[2\pi\left(8.85\times10^{-12}\,\text{C}^2/\text{n}\bullet\text{m}^2\right)\left(3\times10^8\ \text{m/s}\right)\left(0.07\sqrt{2}\ \text{V/m}\right)^2\right]}$$
$$= 6.12\times10^7\ \text{m}^2,\ \text{and}\ r = 7.8\times10^3\,\text{m} = \boxed{8\,\text{km.}}$$

42. The light has the same intensity in all directions, so the energy per unit area per unit time over a sphere centered at the source is

$$S = \frac{P_0}{A} = \frac{P_0}{4\pi r^2} = \frac{(95\,\text{W})}{4\pi(2.00\,\text{m})^2} = 1.89\,\text{W/m}^2.$$

We find the electric field from

$$S = \tfrac{1}{2}c\varepsilon_0 E_0{}^2;$$

$$1.89\,\text{W/m}^2 = \tfrac{1}{2}(3.00\times10^8\,\text{m/s})(8.85\times10^{-12}\,\text{C}^2/\text{N}\bullet\text{m}^2)E_0{}^2, \text{ which gives } E_0 = \boxed{37.7\ \text{V/m.}}$$

The magnetic field is

$$B_0 = \frac{E_0}{c} = \frac{(37.7\,\text{V/m})}{(3.00\times10^8\,\text{m/s})} = \boxed{1.26\times10^{-7}\ \text{T.}}$$

43. The radiation from the Sun has the same intensity in all directions, so the rate at which it passes through a sphere centered at the Sun is

$$P = S4\pi R^2.$$

The rate must be the same for the two spheres, one containing the Earth and one containing Mars. When we form the ratio, we get

$$\frac{P_{\text{Mars}}}{P_{\text{Earth}}} = \left(\frac{S_{\text{Mars}}}{S_{\text{Earth}}}\right)\left(\frac{R_{\text{Mars}}}{R_{\text{Earth}}}\right)^2;$$

$$1 = \left(\frac{S_{\text{Mars}}}{1350\,\text{W/m}^2}\right)(1.52)^2, \text{ which gives } S_{\text{Mars}} = 584.3\,\text{W/m}^2.$$

We find the rms value of the electric field from

$$S_{\text{Mars}} = c\varepsilon_0 E_{\text{rms}}{}^2;$$

$$584.3\,\text{W/m}^2 = (3.00\times10^8\,\text{m/s})(8.85\times10^{-12}\,\text{C}^2/\text{N}\bullet\text{m}^2)E_{\text{rms}}{}^2, \text{ which gives } E_{\text{rms}} = \boxed{469\,\text{V/m.}}$$

44. If we curl the fingers of our right hand from the direction of the electric field (south) into the direction of the magnetic field (west), our thumb points down, so the direction of the wave is $\boxed{\text{downward.}}$ We find the electric field from

$$S = \tfrac{1}{2}c\varepsilon_0 E_0{}^2;$$

$$560\,\text{W/m}^2 = \tfrac{1}{2}(3.00\times10^8\,\text{m/s})(8.85\times10^{-12}\,\text{C}^2/\text{N}\bullet\text{m}^2)E_0{}^2, \text{ which gives } E_0 = \boxed{649\,\text{V/m.}}$$

The magnetic field is

$$B_0 = \frac{E_0}{c} = \frac{(649\,\text{V/m})}{(3.00\times10^8\,\text{m/s})} = \boxed{2.16\times10^{-6}\ \text{T.}}$$

45. The wavelength of the AM radio signal is

$$\lambda = \frac{c}{f} = \frac{(3.0\times10^8\,\text{m/s})}{(10^6\,\text{Hz})} = 300\,\text{m}.$$

(*a*) $\tfrac{1}{2}\lambda = \tfrac{1}{2}(300\,\text{m}) = \boxed{150\,\text{m.}}$

(*b*) $\tfrac{1}{4}\lambda = \tfrac{1}{4}(300\,\text{m}) = \boxed{75\,\text{m.}}$

46. We find the magnetic field from

$$S = \tfrac{1}{2}\left(\frac{c}{\mu_0}\right)B_0{}^2;$$

$$1.0\times10^{-4}\ \mathrm{W/m^2} = \tfrac{1}{2}\left[\frac{\left(3.00\times10^{8}\ \mathrm{m/s}\right)}{\left(4\pi\times10^{-7}\ \mathrm{T{\bullet}m/A}\right)}\right]B_0{}^2,\ \text{which gives } B_0 = 9.15\times10^{-10}\,\mathrm{T}.$$

Because this field oscillates through the coil at $\omega = 2\pi f$, the maximum emf is

$$\xi_0 = NAB_0\omega = (380\,\text{turns})\pi(0.011\mathrm{m})^2\left(9.15\times10^{-10}\ \mathrm{T}\right)2\pi\left(810\times10^3\mathrm{Hz}\right) = 6.73\times10^{-4}\,\mathrm{V}.$$

The ξ_{rms} is $\dfrac{\xi_0}{\sqrt{2}} = \dfrac{\left(6.73\times10^{-4}\,\mathrm{V}\right)}{\sqrt{2}} = \boxed{0.48\,\mathrm{mV.}}$

47. (*a*) The energy received by the antenna is

$$U = IAt = \left(1.0\times10^{-13}\ \mathrm{W/m^2}\right)\pi\left(\frac{0.33\,\mathrm{m}}{2}\right)^2(6.0\,\mathrm{h})(3600\,\mathrm{s/h}) = \boxed{1.8\times10^{-10}\ \mathrm{J.}}$$

(*b*) The electric and magnetic field amplitudes are described by

$$\bar{I} = \left(\frac{1}{2}\right)\varepsilon_0 cE_0{}^2 = \left(\frac{1}{2}\right)\left(\frac{c}{\mu_0}\right)B_0{}^2.$$

$$1.0\times10^{-13}\ \mathrm{W/m^2} = \left(\frac{1}{2}\right)\left(8.85\times10^{-12}\,\mathrm{C^2/N{\bullet}m^2}\right)\left(3\times10^{8}\ \mathrm{m/s}\right)E_0{}^2.$$

Solving for E_0 yields $\boxed{E_0 = 8.7\times10^{-6}\ \mathrm{V/m.}}$

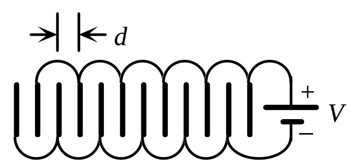
Substitution then gives $B_0 = \dfrac{E_0}{c} = \boxed{2.9\times10^{-14}\,\mathrm{T.}}$

48. To find the average output power we first find the average intensity.

$$\bar{I} = \left(\frac{1}{2}\right)\varepsilon_0 cE_0{}^2 = \left(\frac{1}{2}\right)\left(8.85\times10^{-12}\,\mathrm{C^2/N{\bullet}m^2}\right)\left(3\times10^{8}\ \mathrm{m/s}\right)\left(0.12\,\mathrm{V/m}\right)^2 = 1.9116\times10^{-5}\ \mathrm{W/m^2}.$$

Now $P = \bar{I}A = \left(1.9116\times10^{-5}\ \mathrm{W/m^2}\right)4\pi\left(15\times10^3\mathrm{m}\right)^2 = \boxed{54\,\mathrm{kW.}}$

49. (*a*) We see from the diagram that all positive plates are connected to the positive side of the battery, and that all negative plates are connected to the negative side of the battery, so the 11 capacitors are connected in $\boxed{\text{parallel.}}$



(*b*) For parallel capacitors, the total capacitance is the sum, so we have

$$C_{\min} = 11\left(\frac{\varepsilon_0 A_{\min}}{d}\right)$$

$$= \frac{11\left(8.85\times10^{-12}\,\mathrm{C^2/N{\bullet}m^2}\right)\left(1.0\times10^{-4}\,\mathrm{m^2}\right)}{\left(1.1\times10^{-3}\,\mathrm{m}\right)} = 8.9\times10^{-12}\,\mathrm{F} = 8.9\,\mathrm{pF};$$

$$C_{\max} = 11\left(\frac{\varepsilon_0 A_{\max}}{d}\right)$$

$$= \frac{11\left(8.85\times10^{-12}\,\mathrm{C^2/N{\bullet}m^2}\right)\left(9.0\times10^{-4}\,\mathrm{m^2}\right)}{\left(1.1\times10^{-3}\,\mathrm{m}\right)} = 80\times10^{-11}\,\mathrm{F} = 80\,\mathrm{pF}.$$

Thus the range is $\boxed{8.9\,\mathrm{pF} \le C \le 80\,\mathrm{pF}.}$

(*c*) The lowest resonant frequency requires the maximum capacitance.
We find the inductance for the lowest frequency:

$$f_{01} = \left(\frac{1}{2\pi}\right)\left(\frac{1}{L_1 C_{\max}}\right)^{\frac{1}{2}};$$

$$550\times10^3\,\mathrm{Hz} = \left(\frac{1}{2\pi}\right)\left[\frac{1}{L_1\left(80\times10^{-12}\,\mathrm{F}\right)}\right]^{\frac{1}{2}},\ \text{which gives } L_1 = 1.05\times10^{-3}\,\mathrm{H} = 1.05\,\mathrm{mH}.$$

We must check to make sure that the highest frequency can be reached.
We find the resonant frequency using this inductance and the minimum capacitance:

$$f_{0\max} = \left(\frac{1}{2\pi}\right)\left(\frac{1}{L_1 C_{\min}}\right)^{\frac{1}{2}}$$

$$= \left(\frac{1}{2\pi}\right)\left[\frac{1}{\left(1.05\times10^{-3}\,\mathrm{H}\right)\left(8.9\times10^{-12}\,\mathrm{F}\right)}\right]^{\frac{1}{2}} = 1.64\times10^6\,\mathrm{Hz} = 1640\,\mathrm{kHz}.$$

Because this is greater than the highest frequency desired, the inductor will work.
We could also start with the highest frequency.
We find the inductance for the highest frequency:

$$f_{02} = \left(\frac{1}{2\pi}\right)\left(\frac{1}{L_2 C_{\min}}\right)^{\frac{1}{2}};$$

$$1600\times10^3\,\mathrm{Hz} = \left(\frac{1}{2\pi}\right)\left[\frac{1}{L_2\left(8.9\times10^{-12}\,\mathrm{F}\right)}\right]^{\frac{1}{2}},\ \text{which gives } L_2 = 1.22\times10^{-3}\,\mathrm{H} = 1.22\,\mathrm{mH}.$$

We must check to make sure that the lowest frequency can be reached.
We find the resonant frequency using this inductance and the maximum capacitance:

$$f_{0\min} = \left(\frac{1}{2\pi}\right)\left(\frac{1}{L_2 C_{\max}}\right)^{\frac{1}{2}}$$

$$= \left(\frac{1}{2\pi}\right)\left[\frac{1}{\left(1.22\times10^{-3}\,\mathrm{H}\right)\left(80\times10^{-12}\,\mathrm{F}\right)}\right]^{\frac{1}{2}} = 509\times10^5\,\mathrm{Hz} = 509\,\mathrm{kHz}.$$

Because this is less than the lowest frequency desired, this inductor will also work.
Thus the range of inductances is $\boxed{1.05\,\text{mH} \le L \le 1.22\,\text{mH.}}$

50. Again using the relationship between average intensity and electric field strength,

$$\bar{I} = \left(\frac{1}{2}\right)\varepsilon_0 c E_0^{\,2} = \left(\frac{1}{2}\right)\left(8.85\times10^{-12}\,\text{C}^2/\text{N}\bullet\text{m}^2\right)\left(3\times10^8\,\text{m/s}\right)\left(0.020\,\text{V/m}\right)^2 = 5.31\times10^{-7}\,\text{W/m}^2.$$

$$25\times10^3\,\text{W} = (5.31\times10^{-7}\,\text{W/m}^2)4\pi r^2.$$

Thus, to receive the transmission one should be within the radius $r = \boxed{61\text{ km.}}$

51. The light has the same intensity in all directions, so the energy per unit area per unit time over a sphere centered at the source is

$$S = \frac{P_0}{A} = \frac{P_0}{4\pi r^2} = \tfrac{1}{2}c\varepsilon_0 E_0^{\,2} = \tfrac{1}{2}c\left(\frac{1}{c^2\mu_0}\right)E_0, \text{ which gives } E_0 = \left(\frac{\mu_0 c P_0}{2\pi r^2}\right)^{\frac{1}{2}}.$$

52. (*a*) The radio waves have the same intensity in all directions, so the energy per unit area per unit time over a sphere centered at the source with a radius of 100 m is

$$S = \frac{P_0}{A} = \frac{P_0}{4\pi r^2} = \frac{\left(500\times10^3\,\text{W}\right)}{4\pi\left(100\,\text{m}\right)^2} = 0.398\,\text{W/m}^2.$$

Thus the power through the area is

$$P = SA = \left(0.398\,\text{W/m}^2\right)\left(1.0\,\text{m}^2\right) = \boxed{0.40\,\text{W.}}$$

(*b*) We find the rms value of the electric field from

$$S = c\varepsilon_0 E_{\text{rms}}^{\,2};$$

$$0.398\,\text{W/m}^2 = \left(3.00\times10^8\,\text{m/s}\right)\left(8.85\times10^{-12}\,\text{C}^2/\text{N}\bullet\text{m}^2\right)E_{\text{rms}}^{\,2}, \text{ which gives } E_{\text{rms}} = \boxed{12\,\text{V/m.}}$$

(*c*) The voltage over the length of the antenna is

$$E_{\text{rms}} = V_{\text{rms}} = E_{\text{rms}}d = \left(12\,\text{V/m}\right)\left(1.0\,\text{m}\right) = \boxed{12\,\text{V.}}$$

53. (*a*) The radio waves have the same intensity in all directions, so the energy per unit area per unit time over a sphere centered at the source with a radius of 100 km is

$$S = \frac{P_0}{A} = \frac{P_0}{4\pi r^2} = \frac{\left(50\times10^3\,\text{W}\right)}{4\pi\left(100\times10^3\,\text{m}\right)^2} = 3.98\times10^{-7}\,\text{W/m}^2.$$

Thus the power through the area is

$$P = SA = \left(3.98\times10^{-7}\,\text{W/m}^2\right)\left(1.0\,\text{m}^2\right) = 3.98\times10^{-7}\,\text{W} = \boxed{0.40\,\mu\text{W.}}$$

(*b*) We find the rms value of the electric field from

$$S = c\varepsilon_0 E_{\text{rms}}^{\,2};$$

$$3.98\times10^{-7}\,\text{W/m}^2 = \left(3.00\times10^8\,\text{m/s}\right)\left(8.85\times10^{-12}\,\text{C}^2/\text{N}\bullet\text{m}^2\right)E_{\text{rms}}^{\,2},$$

which gives $E_{\text{rms}} = \boxed{0.012\,\text{V/m.}}$

(*c*) The voltage over the length of the antenna is

$$E_{\text{rms}} = V_{\text{rms}} = E_{\text{rms}}d = \left(0.012\,\text{V/m}\right)\left(1.0\,\text{m}\right) = \boxed{0.012\,\text{V.}}$$

54. The energy per unit area per unit time is

$$S = \tfrac{1}{2} c\varepsilon_0 {E_0}^2;$$

$$= \tfrac{1}{2}\left(3.00\times10^{8}\ \text{m/s}\right)\left(8.85\times10^{-12}\ \text{C}^2/\text{N}\bullet\text{m}^2\right)\left(3\times10^{6}\ \text{V/m}\right)^2 = 1.20\times10^{10}\ \text{W/m}^2.$$

The power output is

$$P = S4\pi r^2 = \left(1.20\times10^{10}\ \text{W/m}^2\right)4\pi\left(1.0\ \text{m}\right)^2 = \boxed{1.5\times10^{11}\ \text{W.}}$$