Chapter 2: The Electromagnetic Spectrum

Practice, page 413

1. The word *radiation* is similar to the word *radius*. This makes sense because the types of radiation in the photograph travel out from the Sun along paths that could each be described as a radius drawn from the centre of the Sun.

2. **a.** No, cosmic rays cannot be classified as a form of electromagnetic radiation because electromagnetic radiation consists only of electric and magnetic fields travelling at right angles to each other. Cosmic rays consist of a stream of positively charged particles.

b. **Light is a type of electromagnetic radiation that can be detected by human eyes. People see starlight because it travels from the stars to Earth. In other words, every time you see a star, you are looking at electromagnetic radiation from that star.**

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3. You could detect the radiant heat with the heat-sensitive nerve cells in your fingertips or your face. You could detect the visible light emitted by the light bulb with the light-sensitive nerve cells on the retina at the back of your eye.

4. Unlike sound waves or water waves, light does not need matter to vibrate and transmit energy. The energy in a light wave is transmitted through the vibrations of electric and magnetic fields. Since electric and magnetic fields are not a form of matter and are able to exist in a vacuum, light energy is able to pass through the near vacuum from the hot filament to the glass of the bulb.

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5. **a.** number of wavelengths $= 4\ \lambda$

distance $= 115\ \mu$m

$\lambda = ?$

$4\ \lambda = 115\ \mu\text{m}$

$\lambda = \dfrac{115\ \mu\text{m}}{4}$

$= 28.8\ \mu\text{m}$

The wavelength of the electromagnetic radiation is 28.8 μm.

b. number of wavelengths $= 5\ \lambda$

distance $= 408$ km

$\lambda = ?$

$5\ \lambda = 408$ km

$\lambda = \dfrac{408\text{ km}}{5}$

$= 81.6$ km

The wavelength of the radiation is 81.6 km.

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6. a. number of cycles = 740

$$\text{time for cycles to pass} = 100 \text{ ms} \times \frac{1 \text{ s}}{1000 \text{ ms}}$$
$$= 1.00 \times 10^{-3} \text{ s}$$

$f = ?$

$$f = \frac{\text{number of cycles}}{\text{time for cycles to pass}}$$
$$= \frac{740}{1.00 \times 10^{-3} \text{ s}}$$
$$= 7.40 \times 10^{5} \text{ Hz}$$

The frequency of the radio waves is 7.40×10^5 Hz or 740 kHz.

b. number of cycles = 2450

$$\text{time for cycles to pass} = 1.00 \ \mu\text{s} \times \frac{1 \text{ s}}{1 \times 10^{6} \ \mu\text{s}}$$
$$= 1.00 \times 10^{-6} \text{ s}$$

$f = ?$

$$f = \frac{\text{number of cycles}}{\text{time for cycles to pass}}$$
$$= \frac{2450}{1.00 \times 10^{-6} \text{ s}}$$
$$= 2.45 \times 10^{9} \text{ Hz}$$

The frequency of the microwaves is 2.45×10^9 Hz or 2.45 GHz.

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7. a. $f = 960 \text{ kHz}$
$= 960 \times 10^{3} \text{ Hz}$

$c = 3.00 \times 10^{8} \text{ m/s}$

$\lambda = ?$

$$c = \lambda f$$
$$\lambda = \frac{c}{f}$$
$$= \frac{3.00 \times 10^{8} \text{ m/s}}{960 \times 10^{3} \text{ Hz}}$$
$$= 313 \text{ m}$$

The wavelength of the radio waves is 313 m.

b. If a city block is about 100 m long, it would take about three city blocks to contain one wavelength of this radio wave.

8. a. $\lambda = 16.5 \text{ cm} \times \frac{1 \text{ m}}{100 \text{ cm}}$
$= 0.165 \text{ m}$

$c = 3.00 \times 10^{8} \text{ m/s}$

$f = ?$

$$c = \lambda f$$
$$f = \frac{c}{\lambda}$$
$$= \frac{3.00 \times 10^{8} \text{ m/s}}{0.165 \text{ m}}$$
$$= 1.82 \times 10^{9} \text{ Hz}$$

The frequency of this digital cellphone is 1.82×10^9 Hz or 1.82 GHz.

b. Answers will vary. The following response shows one possible answer.

$$\text{height} = 1.85 \text{ m} \qquad \text{number of wavelengths} = \frac{\text{height}}{\text{wavelength}}$$

$$\lambda = 0.165 \text{ m} \qquad = \frac{1.85 \text{ m}}{0.165 \text{ m}}$$

$$= 11.2$$

The height of 1.85 m corresponds to 11.2 wavelengths.

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9. The electric field is the part of the radio wave that causes the electrons in the car's antenna to vibrate.

10. a. The car's antenna must be located outside the car or built into its windshield so that the radio waves are able to penetrate through to the antenna and cause the electrons in the antenna to vibrate. If the antenna was located inside the car, the metal body of the car would shield the radio waves from the antenna.

b. When a car passes under a highway overpass, the concrete and reinforced steel within the overpass act as a shield, absorbing the energy of the radio waves. This means that there is no energy left to stimulate a signal in the antenna.

11. $\Delta t = 50 \text{ a} \times \frac{365 \text{ d}}{1 \text{ a}} \times \frac{24 \text{ h}}{1 \text{ d}} \times \frac{3600 \text{ s}}{1 \text{ h}}$

$= 1.5768 \times 10^9 \text{ s}$

$c = 3.00 \times 10^8 \text{ m/s}$

$\Delta d = ?$

$V = \frac{\Delta d}{\Delta t}$

$c = \frac{\Delta d}{\Delta t}$

$\Delta d = c\Delta t$

$= \left(3.00 \times 10^8 \text{ m/s}\right)\left(1.5768 \times 10^9 \text{ s}\right)$

$= 4.73 \times 10^{17} \text{ m}$

A radio wave can travel 4.73×10^{17} m in 50 years.

Practice, page 423

12. $f = 2450 \text{ MHz} \times \frac{1 \times 10^6 \text{ Hz}}{1 \text{ MHz}}$

$= 2.450 \times 10^9 \text{ Hz}$

$c = 3.00 \times 10^8 \text{ m/s}$

$\lambda = ?$

$c = \lambda f$

$\lambda = \frac{c}{f}$

$= \frac{3.00 \times 10^8 \text{ m/s}}{2.450 \times 10^9 \text{ Hz}}$

$= 0.122 \text{ m}$

The wavelength of the microwaves is 0.122 m.

13. Microwaves are a form of electromagnetic wave, so they consist of electric fields and magnetic fields travelling at right angles to one another. Left inside a microwave oven, the electrons in the fork begin to vibrate in response to the highly intense and varying electric fields within the oven. In this way, the fork responds similarly to the antenna of a radio—the charges vibrate in response to the electric fields. However, the microwaves inside a microwave oven are much more intense because they are confined to a small space. The result is that some of the charges move from the fork into the nearby air, producing electric sparks.

Practice, page 424

14. a. The molecules in the human body are warm; thus, they are in a constant state of motion. The motion of these molecules within the body produces infrared radiation.

b. $\lambda = 10\ \mu\text{m} \times \frac{1 \times 10^{-6}\ \text{m}}{1\ \mu\text{m}}$

$= 1.0 \times 10^{-5}\ \text{m}$

$c = 3.00 \times 10^{8}\ \text{m/s}$

$f = ?$

$c = \lambda f$

$f = \frac{c}{\lambda}$

$= \frac{3.00 \times 10^{8}\ \text{m/s}}{1.0 \times 10^{-5}\ \text{m}}$

$= 3.0 \times 10^{13}\ \text{Hz}$

The frequency of the infrared radiation emitted by the body is 3.0×10^{13} Hz.

15. a. The sources of infrared radiation include the infrared remote control, the solar radiation coming in the window, and the warm objects in the room (the hot bowl of popcorn and the two people watching TV).

b. The infrared-detection circuitry within the TV does not respond to all inputs of infrared radiation. As was demonstrated in the "Observing Coded Signals" activity at the start of this chapter, the signals produced by infrared remote controls are coded in a pulsed format. The bowl of popcorn and the bodies of the people watching TV do not emit infrared radiation in a pulsed format; therefore, these sources would be unable to trigger a response in the TV. The solar radiation coming through the window is not pulsed either, but it could be sufficiently intense that if it shone directly on the infrared detector, it could overwhelm the circuit with a strong signal even though it is not pulsed. This would not cause the TV to begin acting in unpredictable ways, but it could disable the circuit's ability to respond to the signals from the remote control.

Practice, page 428

16. Visible light is produced by hot sources, such as the filaments of light bulbs, the flames of candles, and the surface of the Sun.

17. A photon of red light has many things in common with a photon of violet light. Both photons consist of electric and magnetic fields that travel at right angles to one another in an electromagnetic wave. The fact that both photons are a type of EMR means that they travel at the same speed, 3.0×10^{8} m/s, and that they share all the properties common to electromagnetic waves. Both photons can be detected by the human eye and, therefore, both are a part of the visible spectrum. The main differences have to do with wavelength, frequency, and energy. Photons of violet light have a shorter wavelength but a higher frequency and a larger energy content than do photons of red light.

18. The photons from the red and violet ends of the spectrum are absorbed by chlorophyl molecules during photosynthesis. The leaves of most plants look green because photons of green light are not absorbed during photosynthesis and, thus, are reflected or passed through the leaves to people's eyes.

19. A chlorophyl molecule is like an antenna because it is able to absorb light energy in the form of photons and convert that energy into the energy of moving electrons. The leaves of a plant turn toward a light source to expose the maximum surface area and, therefore, the maximum number of chlorophyl molecules to the incoming light photons. This allows the leaves to absorb as much energy as possible.

Practice, page 430

20. UV photons are more hazardous to living tissue than photons of visible light because UV photons have more energy.

21. **a.** A sunblock with homosalate is able to absorb the energy of UVB radiation before it penetrates the skin.

b. A sunblock with zinc oxide is able to absorb the energy of UVA radiation before it penetrates the skin.

c. UVC rays are blocked about 50 km above Earth's surface by a region of the atmosphere called the ozone layer, so there is no need to block these rays with sunblock. If the ozone layer continues to deteriorate, shielding from UVC could become a need.

Practice, page 432

22. The tiny screws appear white in the image because the X-rays are unable to penetrate this material, leaving a shadow on the photographic film.

23. The teeth on the lower left of the X-ray have dark areas inside, indicating that the X-rays were able to penetrate these areas and develop the photographic film. Since dental X-rays are not able to penetrate dense materials, like bone and the hard exterior of teeth, teeth must have soft tissues inside them.

24. $f = 7.1 \times 10^{18}$ Hz

$c = 3.00 \times 10^{8}$ m/s

$\lambda = ?$

$c = \lambda f$

$\lambda = \frac{c}{f}$

$= \frac{3.00 \times 10^{8} \text{ m/s}}{7.1 \times 10^{18} \text{ Hz}}$

$= 4.2 \times 10^{-11}$ m

The wavelength of the X-ray photons is 4.2×10^{-11} m.

25. The doctor would ask the woman if there is a chance that she could be pregnant because the rapidly dividing cells of an unborn child would be very susceptible to damage from X-ray radiation.

2.1 Questions, pages 434 and 435

Knowledge

1. The answer to this question is found on the handout "Summarizing the Characteristics of the Electromagnetic Spectrum—Labelled."

Applying Concepts

2. **a.** $f = 7.2 \times 10^{18}$ Hz

$c = 3.00 \times 10^{8}$ m/s

$\lambda = ?$

$c = \lambda f$

$\lambda = \frac{c}{f}$

$= \frac{3.00 \times 10^{8} \text{ m/s}}{7.2 \times 10^{18} \text{ Hz}}$

$= 4.2 \times 10^{-11}$ m

The wavelength of the X-rays is 4.2×10^{-11} m.

b. The wavelength of this X-ray is smaller than the radius of an electron's orbit around an unexcited hydrogen atom.

3. First Signal

$$\lambda = 19.0 \text{ cm} \times \frac{1 \text{ m}}{100 \text{ cm}}$$
$$= 0.190 \text{ m}$$
$$c = 3.00 \times 10^8 \text{ m/s}$$
$$f = ?$$

$$c = \lambda f$$
$$f = \frac{c}{\lambda}$$
$$= \frac{3.00 \times 10^8 \text{ m/s}}{0.190 \text{ m}}$$
$$= 1.58 \times 10^9 \text{ Hz}$$

The frequency of the first GPS signal is 1.58×10^9 Hz or 1.58 GHz.

Second Signal

$$\lambda = 24.4 \text{ cm} \times \frac{1 \text{ m}}{100 \text{ cm}}$$
$$= 0.244 \text{ m}$$
$$c = 3.00 \times 10^8 \text{ m/s}$$
$$f = ?$$

$$c = \lambda f$$
$$f = \frac{c}{\lambda}$$
$$= \frac{3.00 \times 10^8 \text{ m/s}}{0.244 \text{ m}}$$
$$= 1.23 \times 10^9 \text{ Hz}$$

The frequency of the second GPS signal is 1.23×10^9 Hz or 1.23 GHz.

4. The metal mesh screen reflects the microwaves back inside the oven, ensuring that they don't leave the interior of the oven and create a hazard for people near the oven. The other advantage of keeping the microwaves inside the oven is that all the microwave energy is used to cook the food in the oven.

5. Green plants transform light energy into chemical energy through photosynthesis. The photons used in this process are photons of red light and violet light. This is why the specialized light bulbs used for growing plants indoors tend to emit a reddish-purple colour.

6. The type of EMR that causes skin to tan is UVB. This radiation has a higher frequency than both violet radiation from the visible spectrum and UVA. The higher frequency means that photons of UVB have more energy than photons from the visible spectrum, creating a hazard to the light-sensitive cells at the back of the eye. Goggles are worn to help prevent UVB radiation from entering the eyes of the person tanning.

7. A patient having an X-ray image taken of a broken bone might have this kind of X-ray taken once a decade. The technician who operates the equipment could run through dozens of these procedures a day, adding up to thousands in a year and tens of thousands in a decade. Given these numbers, it is important that the technician not absorb even tiny doses of radiation. For this reason, the technician operates the machine from behind a shielded wall.

8. The following details from the photo support the idea that ultrasound is not a form of ionizing radiation:

- The imaging technology is being used to check the development of an unborn child. Ionizing radiation would never be used for this purpose.
- No shielding is present to protect the ultrasound technician or the mother's tissues that are not involved in the procedure.
- The technician is sitting next to the source of the radiation and he is holding part of it. The technician would maximize the distance between himself and the source if this were a form of ionizing radiation.

9. X-rays are not used to monitor the development of unborn children because the cells in an unborn child are rapidly dividing. This makes these cells vulnerable to the effects of ionizing radiation. In addition, the cells in the child are also differentiating to form different kinds of tissue. If the genetic information in these cells was altered by X-rays, the child's development could be seriously affected.

Practice, page 437

26. a. In the photo, light from the Sun is shown as someone uses a traditional form of transportation to move across the frozen landscape. The EMR from the Sun is not only providing light for the day's activities in this region, it is also providing the whole planet with the energy that supports nearly every food web on the planet. If the person in the photo is hunting, the animals he seeks could not exist, and, therefore, the hunter could not exist if it were not for energy from the Sun.

b. Answers to this question will vary. A sample response is provided.

Electromagnetic radiation from the Sun makes Earth a habitable planet by warming it and by providing sunlight for the green plants that are the foundation for all the food webs. So, when I eat my lunch, you could say that I am using solar energy that has been transformed into chemical energy. I also use EMR from beyond Earth as a source of enjoyment when I am out sledding with my friends on cold winter nights and when I am walking home on warm summer evenings. The visible light from stars is beautiful and it adds greatly to my enjoyment of nighttime activities.

27. a. CFCs were introduced to solve the problems created by the flammable compounds that were originally used as refrigerants. CFCs were thought to be a safer alternative. However, when CFCs are carried by winds into the upper atmosphere, these compounds break down and then act to destroy molecules of ozone. Ozone plays a vital role in absorbing UVC radiation, preventing it from reaching Earth's surface. Some scientists are concerned because UVC is a form of ionizing radiation, and if the ozone layer continues to deteriorate, there could be a rise in skin cancers and other health problems related to increased exposure to this radiation.

b. The introduction of GPS technology could have the unintended outcome of causing the young Inuit hunters to become too dependent upon this new technology. In the extreme cold of the arctic winter, GPS technology can be unreliable because it runs on batteries and the display screen can only operate for a few seconds in extreme cold. If their GPS units fail, hunters could be in serious trouble if they did not know the traditional navigation techniques.

c. In the past, the Inuit people have shown remarkable adaptability when it comes to incorporating new technologies into their traditional lifestyle. Examples of the successful inclusion of technology include the adoption of firearms and snowmobiles. Rather than completely abandoning the traditional ways, these technologies became new tools to be gradually incorporated into the mosaic that is traditional ecological knowledge. This focus on interconnectedness is a very useful viewpoint. It helps to reduce the kinds of problems that can occur when a technology is adopted too quickly without considering the long-term implications to the environment and to a community's culture.

Practice, page 440

28. Nuclear fusion reactions within the Sun's core release high-energy gamma photons. As these photons travel outward, they are absorbed and then re-emitted by charged particles that make up the Sun's interior. In each interaction, the charged particle gains a little kinetic energy, so the re-emitted photon has less energy than the incident photon. After a huge number of collisions, the photons that leave the surface of the Sun have the energy of visible and infrared photons rather than gamma photons.

29. a. UV photons are emitted from the lower atmosphere of the Sun.

b. X-ray photons are emitted from solar flares, as well as from the middle and upper atmosphere of the Sun.

c. The characteristic of each region of the Sun that determines the type of EMR emitted is temperature. The higher the temperature, the greater the energy of the emitted photons.

30. a. If detectors are placed on the surface of Earth, astronomers can only study the radiation that is able to travel through Earth's atmosphere. This means that they can only gather data using some types of radio waves, visible light, and the UV and infrared radiation that has wavelengths close to visible light.

b. To avoid the problems associated with the fact that the atmosphere absorbs many types of EMR, the detectors need to be placed above the atmosphere. This could mean placing detectors in orbit by mounting them on satellites. Other options include high-altitude balloons and aircraft.

Practice, page 444

31. a. Kepler designed a refracting telescope. His design uses lenses only.

b. As the light rays pass through the telescope, they switch positions in terms of which one is on the top and which one is on the bottom. This means that if someone was using Kepler's telescope, the object being observed would appear upside down. Galileo's telescope did not have this problem.

32. The pupil is the opening that allows light to pass into the eye. Since an eagle's eyes have such large pupils, the effects of diffraction are reduced, allowing the eagle good resolution for seeing the fine details in distant objects.

Practice, page 447

33. Astronomical observatories for infrared radiation are sometimes located in special aircraft that can fly at high altitudes because Earth's atmosphere absorbs most of the infrared radiation that arrives from sources in space.

34. A radio telescope is a device that can detect EMR from the radio-wave region of the electromagnetic spectrum. The energy in the radio waves is used to produce an electrical signal, which is then used to produce a visible representation of the information contained in the radio waves. Since radio waves have the longest wavelengths of all the types of radiation in the electromagnetic spectrum, the dishes that collect these waves must be very large. In addition, radio waves are the EMR with the lowest energy content. A very large reflecting dish means that more radio-wave energy can be reflected to the detector, allowing for the study of weak signals.

Practice, page 451

35. A continuous spectrum is the full rainbow of colours with no dark lines or bands to interrupt the flow from one colour to the next. The word *continuous* refers to the fact that one colour continues into the next colour, forming an unbroken band of wavelengths.

When observed through a spectroscope, an emission spectrum consists of a series of individual bright lines. Each discrete line corresponds to a particular wavelength of emitted light. Emission spectra are produced when gases under low pressure are energized by an external source, such as the electric current supplied to a gas-discharge tube.

When observed through a spectroscope, an absorption spectrum consists of a pattern of dark lines superimposed on a continuous spectrum. Each dark line corresponds to a wavelength of light that is absorbed. Absorption spectra are produced when light passes through a gas at low pressure. The lines that a particular gas will absorb in its absorption spectrum correspond to the same lines that the gas emits in its emission spectrum.

36. The evidence supporting the idea that the universe is expanding comes from the spectral analysis of the light from remote galaxies. In every case, the pattern of spectral lines has been shifted to the red end of the spectrum. Since red shift indicates that the source of light is moving away from the observer, every remote galaxy in the universe must be moving away from Earth. If remote galaxies are increasing their distance from Earth, the universe must be expanding.

Practice, page 453

37. Referring to the graph "The Continuous Spectra of Stars: Brightness of Emitted Light Versus Wavelength" on page 451, you can see the overall trend is that as the surface temperature of a star rises, the brightness of the emitted light increases and the peak of the curve moves closer to the blue end of the spectrum. So, if a star produces light that is less yellow and more white than the light emitted by the Sun, the surface of this star must have a higher temperature than the surface of the Sun. Similarly, if a star produces light that is more orange than the light emitted by the Sun, the surface of this star must have a lower temperature than the surface of the Sun.

38. The feature that determines the endpoint of a star in stellar evolution is the initial mass of the gas and dust that forms the star. If the initial mass is between 0.1 and 1.4 solar masses, the end result of solar evolution will be a white dwarf. If the initial mass is between 1.4 and 8 solar masses, the end result of solar evolution will be a neutron star. Finally, if the initial mass is greater than 8 solar masses, the end result will be a black hole.

39. A black hole is an area in space with a gravitational field that is so strong that neither matter nor EMR can escape. A telescope is a device designed to detect the light emitted or reflected from distant objects. Since no light is emitted from a black hole, a telescope would be unable to detect it.

2.2 Questions, page 455

Knowledge

1. Answers to this question can be found on the handout "Summarizing Multiwavelength Astronomy—Labelled."

Applying Concepts

2. The spectrum was emitted from a source consisting of excited hydrogen gas and excited boron gas.

3. If a star is moving away from Earth, the spectral lines observed on Earth will shift toward the red end of the spectrum. This is called red shift. If a star is moving toward Earth, the spectral lines observed on Earth will shift toward the blue end of the spectrum. This is called blue shift.

4. Since the star that produced the Crab Nebula involved a supernova, it must have been an intermediate-mass star. An intermediate-mass star begins as a cloud of gas and dust, progresses to form an intermediate-mass star, and eventually forms a supergiant star before exploding as a supernova and forming a neutron star.

5. Each type of EMR yields unique information about the Crab Nebula. By using as many types of EMR as possible, scientists obtain a much richer collection of data than if they studied the Crab Nebula using only one type of radiation.

6. a. The success of an agricultural economy depends upon obtaining the optimal harvest of the crops that are planted. It is important to know the best times of the year to plant the seeds, when to expect the seasonal rains, and when to harvest. Astronomical observations could have provided the ancient Pueblo People (Anasazi) with an accurate way to keep track of these key periods in the growing season.

b. Given that astronomical observations may have played an important role in their agricultural economy, it is likely that they were already routinely looking up to the night sky. It is also likely that the events in the sky were taken quite seriously as their survival was linked to their ability to record and track changes in the positions of constellations. However, unlike everyday occurrences, this astronomical event would have been a truly amazing sight, something completely out of the ordinary. Given these circumstances, it seems only natural to make a record of such an unusual event.