## *End-of-Chapter Exercises*

Exercises 1 – 12 are primarily conceptual questions, with a particular emphasis on polarized light, designed to test whether you understand the main concepts of the chapter.

1. Many automobile manufacturers are now working on collision avoidance, or collision mitigation, systems. Such systems sense an impending collision, and can warn the driver, start applying the brakes, and/or cause the seat belts to tighten. Using the principles of physics covered in this chapter, describe how such a system might sense an impending collision.

2. Polarizing sunglasses are generally somewhat expensive, so you are a little surprised to find a stall at an indoor market advertising polarizing sunglasses for $10. Using two pairs of the sunglasses, however, you can quickly test to see whether they are really polarized. What can you do?

3. A police officer who is traveling at a constant velocity of 80 km/h north measures a frequency difference of +2800 Hz for waves that reflect from a southbound car, with the frequency difference stated relative to the frequency of the waves emitted by the officer's radar gun. If the officer aims her radar gun at a different car that, like the officer, is traveling north at 80 km/h, what frequency difference will the officer observe between the reflected and emitted waves?

4. A police officer who is traveling at a constant velocity of 80 km/h north measures a frequency difference of +2800 Hz for waves that reflect from a southbound car, with the frequency difference stated relative to the frequency of the waves emitted by the officer's radar gun. After the two vehicles pass one another, and assuming each vehicle maintains its velocity, what will be the frequency difference observed by the officer if she points her radar gun back toward the receding car?

5. Light from the Sun is unpolarized, but when sunlight scatters from molecules in the Earth's atmosphere, it can become at least partly polarized. The most extreme case is when sunlight is scattered through an angle of 90°, in which the scattered light is linearly polarized in a direction that is perpendicular to both the original direction of propagation and the direction the light travels after changing direction. Polarizing sunglasses are designed to block light that is polarized horizontally. Armed with all this information, in which of the following cases would you expect the sky to look darker when you look straight up at a clear sky while wearing your polarizing sunglasses? Explain your answer. Case 1 – the Sun is low in the sky behind you. Case 2 – you turn 90° so the Sun is off to one side.

6. A vertically polarized beam of light with an intensity I_o is incident on a polarizing filter. The transmission axis of the filter is initially vertical, as shown in Figure 22.10. Keeping the polarizing filter perpendicular to the direction of the incident light at all times, the polarizing filter is rotated a full rotation (360˚). Which of the six graphs in Figure 22.10 correctly shows the intensity of the light emerging from the polarizer, as a function of the angle of the polarizer's transmission axis? Explain your answer.
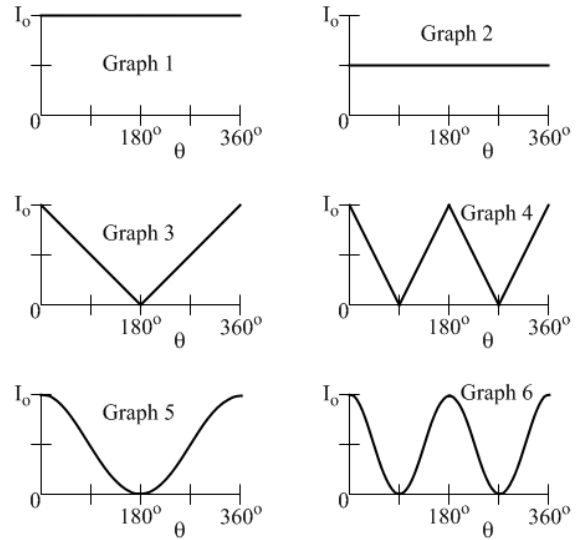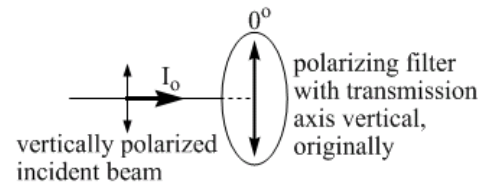
7. Return to the situation described in Exercise 6, and shown in Figure 22.10. Now answer the question when unpolarized light with an intensity of I_o is incident on the polarizer.

8. Return to the situations described in Exercises 6 and 7. The polarizer's transmission axis will now be rotated steadily from 0°, as shown in Figure 22.10, to 180°. Plot a graph of the polarization angle of the light that emerges from the polarizer as a function of the angle of the polarizer's transmission axis if the incident light is (a) polarized vertically, as shown in Figure 22.10, and (b) unpolarized.

Figure 22.10: Light is incident on a polarizer, with the transmission axis of the polarizer initially oriented vertically. Six possible graphs of the intensity of the transmitted light, as a function of the angle of the polarizer's transmission axis, measured from the vertical, are also shown. For Exercises 6 – 8.

9. You have three polarizers. Polarizer A has its transmission axis parallel to the vertical; polarizer B has its transmission axis at 30° to the vertical, and polarizer C has its transmission axis at 90° to the vertical. You are using a light source that emits linearly polarized light that is polarized at 45° to the vertical. Using one, two, or all three of the polarizers, how many different arrangements can you come up with so that no light emerges from the last polarizer? List the various arrangements.

10. Return to the situation described in Exercise 9. Now, your goal is to have the light pass through all three of the polarizers, and emerge from the last polarizer with the maximum possible intensity. (a) In what order do you arrange the polarizers now? Give all possible arrangements that produce maximum intensity. (b) If the intensity of the incident light is 720 W/m², what is the intensity of the light emerging from the third polarizer in the sequence?

11. Return to the situation described in Exercises 10, which involves the three polarizers in Exercise 9. Answer the questions from Exercise 10, if the incident light is unpolarized.

12. Light that is either unpolarized or linearly polarized is incident on a single polarizer. As you rotate the polarizer about an axis parallel to the direction of propagation of the light, you observe that the intensity of the light emerging from the polarizer stays constant. Is the incident light unpolarized or linearly polarized? Explain how you know.

Exercises 13 – 17 deal with the electromagnetic spectrum and EM waves.

13. Do a web search for the "United States Frequency Allocation Chart." The chart shows how different parts of the spectrum are used for various purposes in the United States. Compare the parts of the spectrum reserved for broadcasting AM and FM radio. Which of these parts is wider? Explain your answer.

14. The United States government mandated the replacement of analog television broadcasts with digital television broadcasts. In addition to providing a better TV viewing experience for consumers, eliminating the analog broadcasts freed up a 60 MHz-wide band of the spectrum for other uses. A government-run auction of pieces of this part of the spectrum brought in $19.6 billion. Do some research regarding this issue and write a couple of paragraphs about what you learn.

15. One section of the electromagnetic spectrum is known as "VHF." (a) What does this stand for? (b) What frequency range does the VHF band cover? (c) What are typical uses of waves in the VHF band of the spectrum?

16. Electromagnetic waves associated with hydrogen, with a wavelength of 21.1 cm, have been an important tool in astronomy. Do some research about how a tiny hydrogen atom produces EM waves of such a large wavelength, and about how such waves are used by astronomers. Write a couple of paragraphs regarding what you learn.

17. A typical red helium-neon laser pointer emits light with a wavelength of 632 nm. (a) What is the corresponding frequency of this light? (b) If you shine the beam at a wall 1 meter away from the laser pointer, how many wavelengths fit in this 1 m distance?

Exercises 18 – 22 involve energy, momentum, and radiation pressure.

18. A particular laser pointer emits a beam with an average power of 3.00 mW, and the beam has a circular cross-section with a diameter of 4.00 mm. The beam is linearly polarized. Determine (a) the intensity of the laser beam, (b) the amplitude of the oscillating electric field in the laser beam, and (c) the amplitude of the oscillating magnetic field in the laser beam.

19. The Earth's magnetic field has a strength of about 5×10^{-5} T. If this is the amplitude of the oscillating magnetic field in a linearly polarized EM wave, what is the amplitude of the oscillating electric field in the wave? Comment on the size of your answer.

20. A highly reflective low-density cylinder is being held motionless in mid-air by a laser beam that is directed vertically upward, and which reflects off one of the two circular faces of the cylinder. The beam is large enough that the entire face of the cylinder is uniformly illuminated. The cylinder has a height h, a cross-sectional area A, and a density of 200 kg/m^3. (a) Sketch a free-body diagram of the cylinder. (b) Apply Newton's Second Law, and show that it does not matter what the area A is. (c) Find the height of the cylinder, if the intensity of the laser beam is 1.5×10^7 W/m^2.

21. The sails on a solar sailboat far above the Earth's atmosphere are oriented so that they reflect sunlight through an angle of 90°, with all the reflected light going off in the same direction. (a) In what direction, relative to the direction of the incident light, is the force exerted by the radiation pressure on the sailboat? (b) Sketch a diagram to show the direction of the incident light, the reflected light, and the force.

22. At the location of Earth in the solar system, the intensity of sunlight is about 1300 W/m^2. The sail on a solar sailboat far above the Earth's atmosphere, but the same distance from the Sun that the Earth is, is circular with a radius of 500 m. The sail is 100% reflective, and is oriented to maximize the force associated with radiation pressure. (a) Calculate the force associated with radiation pressure on the sail. (b) Assuming that the gravitational force exerted on the sailboat by the Sun is the only other force acting on the sailboat, determine the mass the sailboat must have to experience no net force. (c) If the sailboat's mass is actually just 80% of the value you calculated above, determine its acceleration.

Exercises 23 – 27 involve the Doppler effect for electromagnetic waves.

23. How fast would you have to be driving toward a red traffic light for the light to appear green to you? Assume that the wavelength emitted by the red light is 630 nm, and that you will see the light as green if the wavelength you observe is 530 nm.

24. A baseball scout sitting directly behind home plate aims a radar gun at the baseball thrown by the pitcher. The radar gun gives a speed of 160 km/h for the pitch, just slightly less than 100 miles per hour. If the radar gun emits EM waves that have a frequency of exactly 12 GHz, what is the shift in frequency for (a) the waves reaching the moving baseball, and (b) the waves returning to the radar gun after reflecting from the baseball?

25. In the lab, hydrogen gas excited by a high voltage gives off light of particular wavelengths. One of these wavelengths is 435 nm. When an astronomer looks at the spectrum of wavelengths emitted by a distant star, however, she determines that this same line in the spectrum is shifted to a wavelength of 456 nm. (a) Is the star moving toward us or away from us? (b) What is the relative velocity of the star with respect to us?

26. As of the summer of 2010, the women's world-record tennis serve of 130 miles per hour was held jointly by the Dutch player Brenda Schultz-McCarthy, for a serve hit in Cincinnati in 2006, and the American player Venus Williams, for a serve hit in Zurich in 2008. Assuming the speed of each serve was measured by a radar gun that was directly in line with the ball's path, what was the magnitude of the frequency shift between the emitted and reflected waves, if the radar gun emits waves of exactly 22 GHz?

27. You are called to testify in court as an expert witness in a case involving a man who was pulled over for speeding by a police officer who was in a moving police car when she recorded the man's speed on her radar gun. The officer testifies that she was traveling at 50 km/h north on a road that has a speed limit of 100 km/h, and that she observed the man's car traveling south on the road, moving toward her. The officer testifies that her radar gun measured a frequency difference of +1400 Hz for the waves reflecting from the man's car, and that when she uses the radar gun to measure speeds when she is at rest, a frequency difference of +1400 Hz corresponds to a speed of 160 km/h. The police officer had written the man a speeding ticket for traveling at 160 km/h in a 100 km/h zone. How fast was the man traveling in his car, and do you think he deserves the speeding ticket?

Exercises 28 – 32 are designed to give you practice applying the method for solving problems involving polarized light.

28. Light that is linearly polarized in a direction of 20° to the vertical is incident on a polarizer that has its transmission axis at 50° to the vertical. (a) What is the angle between the polarization direction of the light and the transmission axis of the polarizer? (b) If the incident light has an intensity of 400 W/m², what is the intensity of the light emerging from the polarizer? (c) At what angle, measured from the vertical, is the polarization direction of the light emerging from the polarizer?

29. Linearly polarized light, with an intensity of $I_0 = 600$ W/m² is incident on a sequence of two polarizers. The transmission axis of the first polarizer is at 40° from the vertical, while the transmission axis of the second polarizer is at 70° from the vertical, as shown in Figure 22.11. The polarization direction of the light is also at 70° to the vertical. (a) What is the angle between the polarization direction of the light and the transmission axis of the first polarizer? (b) Determine the intensity of the light emerging from the first polarizer. (c) Determine the angle at which the light is polarized when it emerges from the first polarizer. (d) What is the angle between the polarization direction of the light when it emerges from the first polarizer and the transmission axis of the second polarizer? (e) Determine the intensity of the light emerging from the second polarizer.
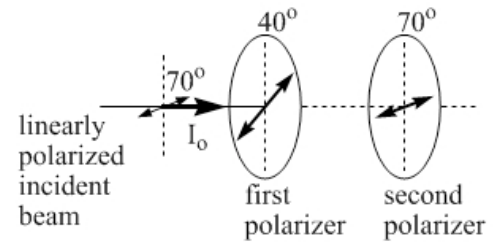
Figure 22.11: A set of two polarizers for light to pass through, for Exercises 29 and 30.

30. Repeat Exercise 29, with the incident light being unpolarized instead. You can skip part (a), which does not make sense when the light is unpolarized.

31. Unpolarized light, with an intensity of $I_0 = 720$ W/m², is incident on a sequence of three polarizers. The transmission axes of the three polarizers with respect to the vertical are, in order, 90° from the vertical, 30° from the vertical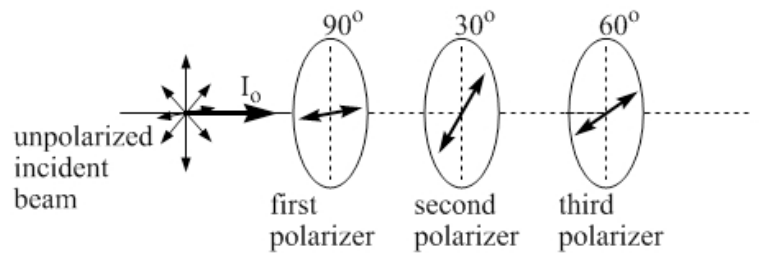, and 60° from the vertical, as shown in Figure 22.12. (a) Determine the intensity of the light emerging from the first polarizer. (b) Determine the angle at which the light is polarized when it emerges from the first polarizer. (c) What is the angle between the polarization direction of the light when it emerges from the first polarizer and the transmission axis of the second polarizer? (d) Determine the intensity of the light emerging from the second polarizer. (e) Determine the angle at which the light is polarized when it emerges from the first polarizer. (f) What is the angle between the polarization direction of the light when it emerges from the second polarizer and the transmission axis of the third polarizer? (g) Determine the intensity of the light emerging from the third polarizer.

Figure 22.12: A set of three polarizers for light to pass through, for Exercises 31 and 32.

32. Repeat Exercise 31, with the incident light being linearly polarized at 90° to the vertical instead.

Exercises 33 – 35 involve practical applications of electromagnetic waves.

33. A typical Doppler radar system, used in weather forecasting, uses an antenna to emit a pulse of EM waves lasting for 1 microsecond. The antenna then listens for the next millisecond to pick up any reflected signals, such as those from distant thunderclouds. What is the range of such a radar system? In other words, what is the maximum distance a weather system can be from the antenna for the antenna to pick up reflected signals from it within the 1 millisecond window?

34. LASIK (Laser Assisted in Situ Keratomileusis) is now a common eye surgery in which a laser is used to remove a thin layer of cornea, correcting vision in the eye so glasses or contacts do not need to be worn. Typically, a laser known as an excimer laser is used, with a wavelength of 193 nm, which has been shown to produce high-quality incisions in the delicate tissue of the eye. (a) In what section of the electromagnetic spectrum does a wavelength of 193 nm place this laser? (b) If such a laser has a power of 4.0 milliwatts, and is turned on for pulses lasting 20 ns each, how much energy is delivered by the laser to the eye in each pulse?

35. In February of 2007, researchers at the Lawrence Livermore National Laboratory reported that their Solid State Heat Capacity Laser had operated at a record 67 kW average power. (a) How many times larger is this than the power of a typical laser pointer, of approximately 3 mW? The researchers also reported that, with the laser operating at 25 kW and with a beam size of 2.5 cm^2, it took 7 seconds to burn a hole through a 2.5–centimeter thick piece of steel. In this mode of operation, what is (b) the beam's average intensity, and (c) the magnitude of the beam's peak electric field?

General problems and conceptual questions

36. In addition to developing Maxwell's equations, which summarize important features of electricity, magnetism, electromagnetism, and electromagnetic waves, James Clerk Maxwell added much to our understanding of other physical phenomena. Do some research about Maxwell, and write a couple of paragraphs about his other contributions to science.

37. Do some research to create a timeline for the development of Maxwell's equations. In addition to other events and scientists you may want to include, mention specifically the work of Ampère, Coulomb, Faraday, Hertz, and Maxwell, and state where the work of each of these scientists is placed on the timeline.

38. A key part of Maxwell's insights into what the wave solutions to Maxwell's equations meant was Maxwell's knowledge of the speed of light in vacuum, as measured by other scientists. Do some research about our understanding of the value of the speed of light, and the scientists who contributed to this understanding, and then write a couple of paragraphs regarding the evolution of our knowledge about the speed of light.

39. The intensity of sunlight reaching the top of the Earth's atmosphere is about 1300 W/m^2, at a distance of 150 million km from the Sun. Estimate the Sun's power output.

40. How long does light take to reach Earth after leaving the Sun?

41. You are watching a lightning storm from the safety of your home. When you observe a particular flash of lightning, you slowly count the seconds until you hear the thunder associated with the flash. The two are 9 seconds apart. (a) How far away was the lightning, assuming a speed of sound of 340 m/s? (b) What is a general rule to convert seconds to kilometers for lightning? (c) Does the same rule apply to fireworks?

42. You see your friend 100 m away down the street. If you yell back and forth, your conversation will be affected by the speed of sound, which is 340 m/s. If, instead, you use your cell phone to call her on her cell phone, the conversation is relayed via a communications satellite that is 36000 km above you. What is the delay between a sound leaving your mouth and its arrival at your friend's ear if (a) you yell, or (b) you use your cell phone? (c) How far would you have to be from your friend for the delays to be equal?

43. The intensity of sunlight reaching the top of the Earth's atmosphere is about 1300 W/m^2. Use that number to estimate the intensity of sunlight at the location of (a) Mercury, (b) Venus, (c) Mars, and (d) Jupiter.

44. In Essential Question 22.3, we determined that the acceleration of a particular solar sailboat was 3×10^{-4} m/s^2 when the sailboat was the same distance the Earth is from the Sun. Assume the sailboat was released from rest from that location. (a) If this sailboat then traveled directly away from the Sun, what would its acceleration be when it got to the same distance from the Sun that Mars is? (b) Estimate the sailboat's average acceleration during the period while it travels from Earth's orbit to Mar's orbit. Then use your value of the average acceleration to estimate (c) the time the sailboat takes to cover this distance, and (d) the sailboat's speed when it arrives at Mar's orbit.

45. While giving a lecture, your professor absent-mindedly shines his laser pointer out into the audience. When the students point this out, the professor claims that the laser's intensity is less than that of sunlight. Typically, bright sunlight has an intensity of about 1000 W/m^2. Your professor's laser pointer has a power of 4.0 mW, and a beam diameter of 3.0 mm. What is the intensity of light emitted by the laser pointer? Use your answer to comment on the professor's assertion about the brightness of the pointer.

46. The power emitted by the Sun in the form of electromagnetic waves is about 4×10^{26} W. The distance from the Earth to the Sun is about 150 million km. Estimate (a) the intensity of sunlight reaching Earth, and (b) the total energy every second in the sunlight that is incident on the Earth.

47. A particular laser beam has a constant cross-sectional area of 5.0 mm. What is the ratio of the intensity of the beam 1.0 m from the laser to that 4.0 m from the laser?

48. Return to Exercise 47, but now replace the laser beam with a light bulb that emits light uniformly in all directions. What is the ratio of the intensity of the light 1.0 m from the bulb to that 4.0 m from the bulb?

49. A typical 100–W incandescent light bulb emits only about 5% of its energy in the form of visible light. How close would your eye have to be to the filament of a 100–W bulb for the intensity associated with the visible light to be equal to that emitted by a 3.0 mW laser pointer with a beam diameter of 4.0 mm?

50. When a baseball scout aims his radar gun at a stationary car, the radar gun displays a frequency shift of 0 for the difference in frequency between the emitted waves and the reflected waves. (a) Is that what the scout should expect to see for the frequency shift? (b) When the scout aims the radar gun at a car that is moving directly away from him at 60 km/h, the radar gun displays a frequency shift of –720 Hz between the emitted waves and reflected waves. If the gun displays a frequency shift of +1728 Hz when the scout aims the radar gun at a baseball thrown by a pitcher in a high school game, what is the speed of the baseball? The baseball is traveling directly toward the radar gun.

51. A police officer uses a radar gun that emits electromagnetic waves with a frequency of 10.525 GHz (10.525×10^9 Hz). Assume the police officer is at rest, and is aiming the radar gun at vehicles traveling either directly toward, or directly away from, the radar gun. What is the magnitude of the frequency shift between reflected and emitted waves for a vehicle traveling at (a) 60 km/h, (b) 100 km/h, and (c) 150 km/h?

52. Return to the situation described in Exercise 51, and assume the speed limit is 110 km/h, as it is on many Canadian highways. If the police officer observes reflected waves that have a frequency of 2440 Hz below the frequency of the emitted waves, (a) in which direction is the vehicle that reflected the waves moving, (b) what is the vehicle's speed, and (c) should the officer issue a speeding ticket?

53. A police officer, who is at rest, records reflected waves that have a frequency 4200 Hz larger than that of the waves emitted by the officer's radar gun for waves reflecting from a vehicle that is moving at a constant speed of 100 km/h in a direction that is either directly toward or directly away from the officer. (a) In what direction is the vehicle moving? (b) What is the frequency of the officer's radar gun?

54. Light that is either unpolarized or linearly polarized is incident on a single polarizer. The intensity of the light emerging from the polarizer is half that of the incident light. Is the incident light unpolarized or linearly polarized? Explain your answer.

55. Linearly polarized light with an intensity of 240 W/m² is incident on a sequence of two polarizers. The angle between the transmission axes of the two polarizers is 30°. When the incident light is replaced by unpolarized light of the same intensity, the intensity of the light emerging from the second polarizer is the same as with the polarized light. (a) What is the intensity of light emerging from the second polarizer? (b) In the original situation, when the incident light is linearly polarized, what is the angle between the polarization direction of the incident light and the transmission axis of the first polarizer?

56. Repeat part (b) of Exercise 55, except now when the incident polarized light is replaced by unpolarized light of the same intensity, the intensity of the light emerging from the second polarizer is half of the value it is when the polarized light is used.

57. Light passes through two polarizers. The intensity of the light emerging from the second polarizer is 35% of the intensity of the incident light. The incident light is either unpolarized or linearly polarized. Which is it? Explain your answer.

58. Return to the situation described in Exercise 57. (a) If the incident light is unpolarized, determine the angle between the transmission axes of the two polarizers. (b) If the incident light is linearly polarized, determine the range of possible values for the angle between the transmission axes of the two polarizers.