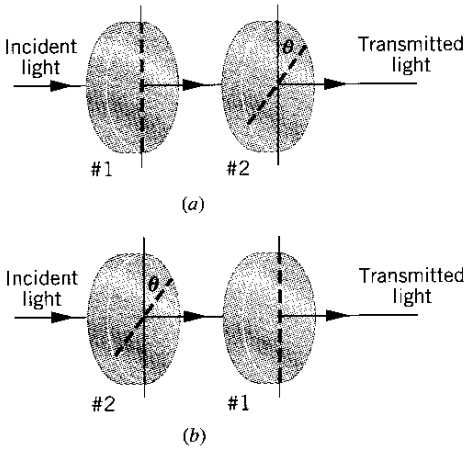
surement, can the astronomer tell whether the star is moving away from the earth or whether the earth is moving away from the star? Explain.

7. Is there any real difference between a polarizer and an analyzer? In other words, can a polarizer be used as an analyzer, and vice versa?

8. Malus' law applies to the setup in Figure 24.20, which shows the analyzer rotated through an angle θ and the polarizer held fixed. Does Malus' law apply when the analyzer is held fixed and the polarizer is rotated? Give your reasoning.

9. In Example 7, we saw that, when the angle between the polarizer and analyzer is 63.4°, the intensity of the transmitted light drops to one-tenth of that of the incident unpolarized light. What happens to the light intensity that is not transmitted?

10. Light is incident from the left on two pieces of polarizing material, 1 and 2. As part *a* of the drawing illustrates, the transmission axis of material 1 is along the vertical direction, while that of material 2 makes an angle of θ with respect to the vertical. In part *b* of the drawing the two polarizing materials are interchanged. (a) Assume that the incident light is unpolarized and determine whether the intensity of the transmitted light in part *a* is greater than, equal to, or less than that in part *b*. (b) Repeat part (a), assuming that the incident light is linearly polarized along the vertical direction. Justify your answers to both parts (a) and (b).



11. You are sitting upright on the beach near a lake on a sunny day, wearing Polaroid sunglasses. When you lie down on your side, facing the lake, the sunglasses don't work as well as they did while you were sitting upright. Why not?

PROBLEMS

ssm Solution is in the Student Solutions Manual. www Solution is available on the World Wide Web at http://www.wiley.com/college/cutnell
This icon represents a biomedical application.

Section 24.1 The Nature of Electromagnetic Waves

1. ssm In astronomy, distances are often expressed in light-years. One light-year is the distance traveled by light in one year. The distance to Alpha Centauri, the closest star other than our own sun that can be seen by the naked eye, is 4.3 light-years. Express this distance in meters.

2. (a) Neil A. Armstrong was the first person to walk on the moon. The distance between the earth and the moon is 3.85×10^8 m. Find the time it took for his voice to reach earth via radio waves. (b) Determine the communication time for the first person who will some day walk on Mars, which is 5.6×10^{10} m from earth at the point of closest approach.

3. For an FM radio station broadcasting at a frequency of 88.0 MHz, the capacitance in Figure 24.5 must be adjusted to a value of 33.0×10^{-12} F. Assuming the inductance does not change, determine the value of the capacitance for an FM station broadcasting at 108.0 MHz.

4. An AM station is broadcasting a radio wave whose frequency is 1400 kHz. The value of the capacitance in Figure 24.5 is 8.4×10^{-11} F. What must be the value of the inductance in order that this station can be tuned in by the radio?

***5. ssm** Equation 16.3, $y = A \sin(2\pi ft - 2\pi x/\lambda)$, gives the mathematical representation of a wave oscillating in the y direction and traveling in the positive x direction. Let y in this equation equal the electric field of an electromagnetic wave traveling in a vacuum. The maximum electric field is $A = 156$ N/C, and the frequency is $f = 1.50 \times 10^8$ Hz. Plot a graph of the electric field strength versus position, using for x the following values: 0, 0.50, 1.00, 1.50, and 2.00 m. Plot this graph for (a) a time $t = 0$ s and (b) a time t that is one-fourth of the wave's period.

****6.** A flat coil of wire is used with an LC-tuned circuit as a receiving antenna. The coil has a radius of 0.25 m and consists of 450 turns. The transmitted radio wave has a frequency of 1.2 MHz. The magnetic field of the wave is parallel to the normal to the coil and has a maximum value of 2.0×10^{-13} T. Using Faraday's law of electromagnetic induction and the fact that the magnetic field changes from zero to its maximum value in one-quarter of a wave period, find the magnitude of the average emf induced in the antenna during this time.

Section 24.2 The Electromagnetic Spectrum

7. A truck driver is broadcasting at a frequency of 26.965 MHz with a CB (citizen's band) radio. Determine the wavelength of the electromagnetic wave being used.

8. Determine the range of wavelengths for FM radio waves with frequencies between 88.0 and 108.0 MHz.

9. ssm www Television sets sometimes use a "rabbit-ears" antenna. A rabbit-ears antenna consists of a pair of metal rods. The length of each rod can be adjusted to be one-quarter of a wave-

length of an electromagnetic wave whose frequency is 60.0 MHz. How long is each rod?

10. Magnetic resonance imaging or MRI (see Section 21.7) and positron emission tomography or PET scanning (see Section 32.6) are two medical diagnostic techniques. Both employ electromagnetic waves. For these waves, find the ratio of the MRI wavelength (frequency = 6.38×10^7 Hz) to the PET scanning wavelength (frequency = 1.23×10^{20} Hz).

11. ssm The human eye is most sensitive to light having a frequency of about 5.5×10^{14} Hz, which is in the yellow-green region of the electromagnetic spectrum. How many wavelengths of this light can fit across the width of your thumb, a distance of about 2.0 cm?

12. TV channel 3 (VHF) broadcasts at a frequency of 63.0 MHz. TV channel 23 (UHF) broadcasts at a frequency of 527 MHz. Find the ratio (VHF/UHF) of the wavelengths for these channels.

***13.** Section 17.5 deals with transverse standing waves on a string. Electromagnetic waves also can form standing waves. In a standing wave pattern formed from microwaves, the distance between a node and an adjacent antinode is 0.50 cm. What is the microwave frequency?

Section 24.3 The Speed of Light

14. Ghost images are formed in a TV picture when the electromagnetic wave from the broadcasting antenna reflects from a building or other large object and arrives at the TV set shortly after the wave coming directly from the broadcasting antenna. If the reflected wave arrives 5.0×10^{-7} s after the direct wave, what is the difference in the distances traveled by the two waves?

15. ssm Two astronauts are 1.5 m apart in their spaceship. One speaks to the other. The conversation is transmitted to earth via electromagnetic waves. The time it takes for sound waves to travel at 343 m/s through the air between the astronauts equals the time it takes for the electromagnetic waves to travel to the earth. How far away from the earth is the spaceship?

16. Review Conceptual Example 3 before attempting this problem. The brightest star in the night sky is Sirius, which is at a distance of 8.3×10^{16} m. When we look at this star, how far back in time are we seeing it? Express your answer in years. (There are $365\frac{1}{4}$ days in one year.)

17. Figure 24.11 illustrates Michelson's setup for measuring the speed of light with the mirrors placed on Mt. San Antonio and Mt. Wilson in California, which are 35 km apart. Using a value of 3.00×10^8 m/s for the speed of light, find the minimum angular speed (in rev/s) for the rotating mirror.

18. A communications satellite is in a synchronous orbit that is 3.6×10^7 m directly above the equator. The satellite is located midway between Quito, Equador, and Belém, Brazil, two cities almost on the equator that are separated by a distance of 3.5×10^6 m. Find the time it takes for a telephone call to go by way of satellite between these cities. Ignore the curvature of the earth.

***19. ssm** A mirror faces a cliff, located some distance away. Mounted on the cliff is a second mirror, directly opposite the first mirror and facing toward it. A gun is fired very close to the first mirror. The speed of sound is 343 m/s. How many times does the flash of the gunshot travel the round-trip distance between the mirrors before the echo of the gunshot is heard?

***20.** A celebrity holds a press conference, which is televised live. A television viewer hears the sound picked up by a microphone directly in front of the celebrity. This viewer is seated 2.3 m from the television set. A reporter at the press conference is located 4.1 m from the microphone and hears the words directly *at the very same instant* that the television viewer hears them. Using a value of 343 m/s for the speed of sound, determine the maximum distance between the television viewer and the celebrity.

Section 24.4 The Energy Carried by Electromagnetic Waves

21. An industrial laser is used to burn a hole through a piece of metal. The average intensity of the light is $\overline{S} = 1.23 \times 10^9$ W/m^2. What is the rms value of (a) the electric field and (b) the magnetic field in the electromagnetic wave emitted by the laser?

22. Suppose the electric field in an electromagnetic wave has a maximum strength of 1470 N/C. What is the maximum strength of the magnetic field of the wave?

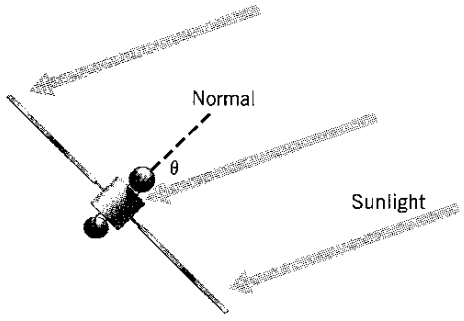
23. ssm The microwave radiation left over from the Big Bang explosion of the universe has an average energy density of 4×10^{-14} J/m^3. What is the rms value of the electric field of this radiation?

24. The electromagnetic wave that delivers a cellular phone call to a car has a magnetic field with an rms value of 1.5×10^{-10} T. The wave passes perpendicularly through an open window, the area of which is 0.20 m^2. How much energy does this wave carry through the window during a 45-s phone call?

25. ssm A future space station in orbit about the earth is being powered by an electromagnetic beam from the earth. The beam has a cross-sectional area of 135 m^2 and transmits an average power of 1.20×10^4 W. What are the rms values of the (a) electric and (b) magnetic fields?

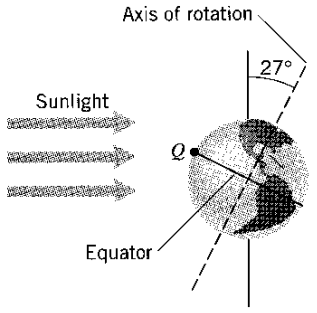
26. The average intensity of sunlight at the top of the earth's atmosphere is 1390 W/m^2. What is the maximum energy that a 25-m $\times$ 45-m solar panel could collect in one hour in this sunlight?

***27.** The drawing shows an edge-on view of the solar panels on a communications satellite. The dashed line specifies the normal to the panels. Sunlight strikes the panels at an angle θ with respect to the normal. If the solar power impinging on the panels is 3200 W when $\theta = 55°$, what is it when $\theta = 35°$?



*28. A heat lamp emits infrared radiation whose rms electric field is $E_{rms} = 2800$ N/C. (a) What is the average intensity of the radiation? (b) The radiation is focused on a person's leg over a circular area of radius 4.0 cm. What is the average power delivered to the leg? (c) The portion of the leg being radiated has a mass of 0.28 kg and a specific heat capacity of 3500 J/(kg·C°). How long does it take to raise its temperature by 2.0 C°? Assume that there is no other heat transfer into or out of the portion of the leg being heated.

*29. **ssm www** The power radiated by the sun is 3.9×10^{26} W. The earth orbits the sun in a nearly circular orbit of radius 1.5×10^{11} m. The earth's axis of rotation is tilted by 27° relative to the plane of the orbit (see the drawing), so sunlight does not strike the equator perpendicularly. What power strikes a 0.75-m² patch of flat land at the equator at point Q?



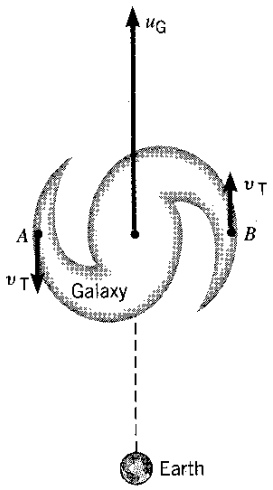
**30. The average intensity of sunlight reaching the earth is 1390 W/m². A charge of 2.6×10^{-8} C is placed in the path of this electromagnetic wave. (a) What is the magnitude of the maximum electric force that the charge experiences? (b) If the charge is moving at a speed of 3.7×10^4 m/s, what is the magnitude of the maximum magnetic force that the charge could experience?

Section 24.5 The Doppler Effect and Electromagnetic Waves

31. A distant galaxy emits light that has a wavelength of 500.7 nm. On earth, the wavelength of this light is measured to be 503.7 nm. (a) Decide whether this galaxy is approaching or receding from the earth. Give your reasoning. (b) Find the speed of the galaxy relative to the earth.

32. A speeder is pulling directly away and increasing his distance from a police car that is moving at 25 m/s with respect to the ground. The radar gun in the police car emits an electromagnetic wave with a frequency of 7.0×10^9 Hz. The wave reflects from the speeder's car and returns to the police car, where its frequency is measured to be 320 Hz less than the emitted frequency. Find the speeder's speed with respect to the ground.

*33. **ssm** A distant galaxy is simultaneously rotating and receding from the earth. As the drawing shows, the galactic center is receding from the earth at a relative speed of $u_G = 1.6 \times 10^6$ m/s. Relative to the center, the tangential speed is $v_T = 0.4 \times 10^6$ m/s for locations A and B, which are equidistant from the center. When the frequencies of the light coming from regions A and B are measured on earth, they are not the same and each is different from the emitted frequency of 6.200×10^{14} Hz. Find the measured frequency for the light from (a) region A and (b) region B.

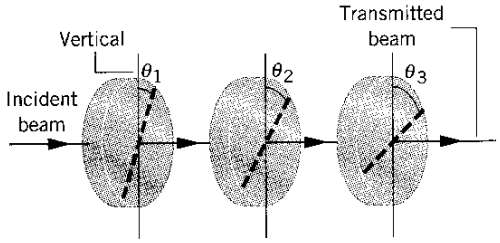


Section 24.6 Polarization

34. Unpolarized light whose intensity is 1.10 W/m² is incident on the polarizer in Figure 24.20. (a) What is the intensity of the light leaving the polarizer? (b) If the analyzer is set at an angle of $\theta = 75°$ with respect to the polarizer, what is the intensity of the light that reaches the photocell?

35. **ssm** Linearly polarized light is incident on a piece of polarizing material. What is the ratio of the transmitted light intensity to the incident light intensity when the angle between the transmission axis and the incident electric field is (a) 25° and (b) 65°?

36. For each of the three sheets of polarizing material shown in the drawing, the orientation of the transmission axis is labeled relative to the vertical. The incident beam of light is unpolarized and has an intensity of 1260.0 W/m². What is the intensity of the beam transmitted through the three sheets when $\theta_1 = 19.0°$, $\theta_2 = 55.0°$, and $\theta_3 = 100.0°$?



37. Polarized light strikes a piece of polarizing material. The incident light is polarized at an angle of 38° relative to the transmission axis of the material. What percentage of the light intensity is transmitted?

38. Review Conceptual Example 8 before solving this problem. Suppose unpolarized light of intensity 150 W/m² falls on the polarizer in Figure 24.22*a*, and the angle θ in the drawing is 30.0°. What is the light intensity reaching the photocell?

*39. **ssm www** More than one analyzer can be used in a setup like that in Figure 24.20, each analyzer following the previous one. Suppose that the transmission axis of the first analyzer is rotated 27° relative to the transmission axis of the polarizer, and that the transmission axis of each additional analyzer is rotated 27° relative to the transmission axis of the previous one. What is the minimum number of analyzers needed, so the light reaching the photocell has an intensity that is reduced by at least a factor of one hundred relative to that striking the first analyzer?

*40. Before attempting this problem, review Conceptual Example 8. The intensity of the light that reaches the photocell in Figure 24.22*a* is 110 W/m², when $\theta = 23°$. What would be the intensity reaching the photocell if the *analyzer* were removed from the setup, everything else remaining the same?

ADDITIONAL PROBLEMS

41. Some of the X-rays produced in an X-ray machine have a wavelength of 2.1 nm. What is the frequency of these electromagnetic waves?

42. A laser emits a narrow beam of light. The radius of the beam is 1.0×10^{-3} m, and the power is 1.2×10^{-3} W. What is the intensity of the laser beam?

43. ssm www The distance between earth and the moon can be determined from the time it takes for a laser beam to travel from earth to a reflector on the moon and back. If the round-trip time can be measured to an accuracy of one-tenth of a nanosecond (1 ns = 10^{-9} s), what is the corresponding error in the earth–moon distance?

44. On a cloudless day, the sunlight that reaches the surface of the earth has an average intensity of about 1.0×10^3 W/m^2. What is the average electromagnetic energy contained in 5.5 m^3 of space just above the earth's surface?

45. The intensity of sunlight at the top of the earth's atmosphere is about 1390 W/m^2. The distance between the sun and earth is 1.50×10^{11} m, while that between the sun and Mars is 2.28×10^{11} m. What is the intensity of sunlight at the surface of Mars?

46. A radio station broadcasts a radio wave whose wavelength is 274 m. (a) What is the frequency of the wave? (b) Is this radio wave AM or FM? (See Figure 24.9.)

47. ssm In the polarizer/analyzer combination in Figure 24.20, 90.0% of the light intensity falling on the analyzer is absorbed. Determine the angle between the transmission axes of the polarizer and the analyzer.

48. Suppose that the police car in Example 6 is moving to the right at 27 m/s, while the speeder is coming up from behind at a speed of 39 m/s, both speeds being with respect to the ground. Assume that the electromagnetic wave emitted by the radar gun has a frequency of 8.0×10^9 Hz. (a) Find the magnitude of the difference between the frequency of the emitted wave and the wave that returns to the police car after reflecting from the speeder's car. (b) Which wave has the greater frequency? Why?

***49.** In a traveling electromagnetic wave, the electric field is represented mathematically as

$$E = E_0 \sin [(1.5 \times 10^{10}\ \text{s}^{-1})\, t - (5.0 \times 10^{1}\ \text{m}^{-1})\, x]$$

where E_0 is the maximum field strength. (a) What is the frequency of the wave? (b) This wave and the wave that results from its reflection can form a standing wave, in a way similar to that in which standing waves can arise on a string (see Section 17.5). What is the separation between adjacent nodes in the standing wave?

***50.** A beam of polarized light has an average intensity of 15 W/m^2 and is sent through a polarizer. The transmission axis makes an angle of 25° with respect to the direction of polarization. Determine the rms value of the electric field of the transmitted beam.

***51. ssm** The mean distance between earth and the sun is 1.50×10^{11} m. The average intensity of solar radiation incident on the upper atmosphere of the earth is 1390 W/m^2. Assuming the sun emits radiation uniformly in all directions, determine the total power radiated by the sun.

***52.** An argon-ion laser produces a cylindrical beam of light whose average power is 0.750 W. How much energy is contained in a 2.50-m length of the beam?

***53.** A tiny source of light emits light uniformly in all directions. The average power emitted is 60.0 W. For a point located 8.00 m away from this source, determine the rms (a) electric and (b) magnetic field strengths in the light waves.

****54.** Suppose that the light falling on the polarizer in Figure 24.20 is partially polarized (average intensity = $\bar{S}_P$) and partially unpolarized (average intensity = $\bar{S}_U$). The total incident intensity is $\bar{S}_P + \bar{S}_U$, and the percentage polarization is $100\bar{S}_P/(\bar{S}_P + \bar{S}_U)$. When the polarizer is rotated in such a situation, the intensity reaching the photocell varies between a minimum value of $\bar{S}_{min}$ and a maximum value of $\bar{S}_{max}$. Show that the percentage polarization can be expressed as $100(\bar{S}_{max} - \bar{S}_{min})/(\bar{S}_{max} + \bar{S}_{min})$.

CONCEPTS & CALCULATIONS

GROUP LEARNING PROBLEMS

Note: Each of these problems consists of Concept Questions followed by a related quantitative Problem. They are designed for use by students working alone or in small learning groups. The Concept Questions involve little or no mathematics and are intended to stimulate group discussions. They focus on the concepts with which the problems deal. Recognizing the concepts is the essential initial step in any problem-solving technique.

55. Concept Questions A certain type of laser puts out light of known frequency. The light, however, occurs as a series of short pulses, each lasting for a time t_0. (a) How is the wavelength of the light related to its frequency? (b) How is the length (in meters) of each pulse related to the time t_0?

Problem A laser puts out a pulse of light that lasts for 2.7×10^{-11} s. The frequency of the light is 5.2×10^{14} Hz. (a) How many wavelengths are there in one pulse? (b) The light enters a pool of water. Its frequency remains the same, but the light slows down to a speed of 2.3×10^8 m/s. How many wavelengths are there now in one pulse?

56. Concept Questions (a) Suppose that the magnitude E of the electric field in an electromagnetic wave triples. By what factor does

the intensity S of the wave change? (b) The magnitude B of the magnetic field is much smaller than E, because, according to Equation 24.3, $B = E/c$, where c is the speed of light in a vacuum. If B triples, by what factor does the intensity change? Account for your answers.

Problem The magnitude of the electric field of an electromagnetic field increases from 315 to 945 N/C. (a) Determine the intensities for the two values of the electric field. (b) What is the magnitude of the magnetic field associated with each electric field? (c) Determine the intensity for each value of the magnetic field. Make sure your answers are consistent with your answers to the Concept Questions.

57. Concept Questions A source is radiating light waves uniformly in all directions. At a certain distance r from the source a person measures the average intensity of the waves. (a) Does the average intensity increase, decrease, or remain the same as r increases? (b) If the magnitude of the electric field is determined from the average intensity, is the electric field the rms value or the peak value? In both cases, justify your answers.

Problem A light bulb emits light uniformly in all directions. The emitted power is 150.0 W. At a distance of 5.00 m from the bulb, what are (a) the average intensity and the magnitudes of the (b) rms and (c) peak electric fields?

58. Concept Questions An electric charge is placed in a laser beam. Does a stationary charge experience a force due to (a) the electric field and (b) the magnetic field of the electromagnetic wave? Now suppose that the charge is moving perpendicular to the magnetic field of the beam. Does it experience (c) an electric force and (d) a magnetic force? Account for your answers.

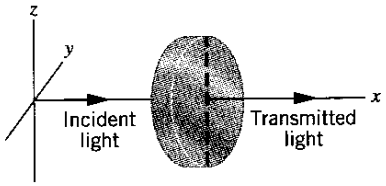
Problem A stationary particle of charge $q = 2.6 \times 10^{-8}$ C is placed in a laser beam whose intensity is 2.5×10^3 W/m^2. Determine the magnitude of the (a) electric and (b) magnetic forces exerted on the charge. If the charge is moving perpendicular to the magnetic field with a speed of 3.7×10^4 m/s, find the magnitudes of the (c) electric and (d) magnetic forces exerted on it. Verify that your answers are consistent with your answers to the Concept Questions.

59. Concept Questions The drawing shows light incident on a polarizer whose transmission axis is parallel to the z axis. The polarizer is rotated clockwise through an angle α between 0 and 90°. While the polarizer is being rotated, does the intensity of the transmitted light increase, decrease, or remain the same if the incident light is (a) unpolarized, (b) polarized parallel to the z axis, and (c) polarized parallel to the y axis? Provide a reason for each of your answers.

Problem The intensity of the incident light is 7.0 W/m^2. Determine the intensity of the transmitted light for each of the six cases shown in the table.

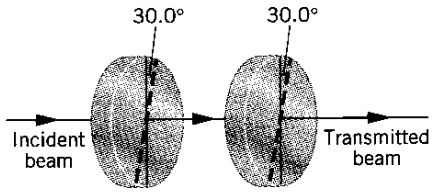
	Intensity of Transmitted Light	
Incident Light	$\alpha = 0°$	$\alpha = 35°$
Unpolarized		
Polarized parallel to z axis		
Polarized parallel to y axis		

Be sure that your answers are consistent with your answers to the Concept Questions.

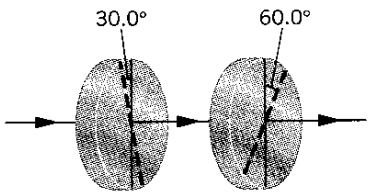


60. Concept Question The drawing shows three polarizer/analyzer pairs. The incident light on each pair is unpolarized and has the same intensity. Rank the pairs according to the intensity of the transmitted light, largest first. Provide reasons for your answers.

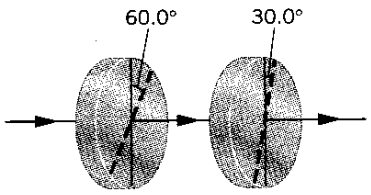
Problem The intensity of the unpolarized incident beam is 48 W/m^2. Find the intensity of the transmitted beams for each of the three cases shown in the drawing. Be sure your answers are consistent with your answer to the Concept Question.



(a)



(b)



(c)