29.E: Special Relativity (Exercise)

Conceptual Questions

29.1: Quantization of Energy

1. Give an example of a physical entity that is quantized. State specifically what the entity is and what the limits are on its values.

2. Give an example of a physical entity that is not quantized, in that it is continuous and may have a continuous range of values.

3. What aspect of the blackbody spectrum forced Planck to propose quantization of energy levels in its atoms and molecules?

4. If Planck's constant were large, say 10^{34} times greater than it is, we would observe macroscopic entities to be quantized. Describe the motions of a child's swing under such circumstances.

5. Why don't we notice quantization in everyday events?

29.2: The Photoelectric Effect

6. Is visible light the only type of EM radiation that can cause the photoelectric effect?

7. Which aspects of the photoelectric effect cannot be explained without photons? Which can be explained without photons? Are the latter inconsistent with the existence of photons?

8. Is the photoelectric effect a direct consequence of the wave character of EM radiation or of the particle character of EM radiation? Explain briefly.

9. Insulators (nonmetals) have a higher BE than metals, and it is more difficult for photons to eject electrons from insulators. Discuss how this relates to the free charges in metals that make them good conductors.

10. If you pick up and shake a piece of metal that has electrons in it free to move as a current, no electrons fall out. Yet if you heat the metal, electrons can be boiled off. Explain both of these facts as they relate to the amount and distribution of energy involved with shaking the object as compared with heating it.

29.3 Photon Energies and the Electromagnetic Spectrum

11. Why are UV, x rays, and γ rays called ionizing radiation?

12. How can treating food with ionizing radiation help keep it from spoiling? UV is not very penetrating. What else could be used?

13. Some television tubes are CRTs. They use an approximately 30-kV accelerating potential to send electrons to the screen, where the electrons stimulate phosphors to emit the light that forms the pictures we watch. Would you expect x rays also to be created?

14. Tanning salons use "safe" UV with a longer wavelength than some of the UV in sunlight. This "safe" UV has enough photon energy to trigger the tanning mechanism. Is it likely to be able to cause cell damage and induce cancer with prolonged exposure?

15. Your pupils dilate when visible light intensity is reduced. Does wearing sunglasses that lack UV blockers increase or decrease the UV hazard to your eyes? Explain.

16. One could feel heat transfer in the form of infrared radiation from a large nuclear bomb detonated in the atmosphere 75 km from you. However, none of the profusely emitted x rays or γ rays reaches you. Explain.

17. Can a single microwave photon cause cell damage? Explain.

18. In an x-ray tube, the maximum photon energy is given by $hf = qV$. Would it be technically more correct to say $hf = qV + BE$, where BE is the binding energy of electrons in the target anode? Why isn't the energy stated the latter way?

29.4: Photon Momentum

19. Which formula may be used for the momentum of all particles, with or without mass?

20. Is there any measurable difference between the momentum of a photon and the momentum of matter?

21. Why don't we feel the momentum of sunlight when we are on the beach?

29.6: The Wave Nature of Matter

22. How does the interference of water waves differ from the interference of electrons? How are they analogous?

23. Describe one type of evidence for the wave nature of matter.

24. Describe one type of evidence for the particle nature of EM radiation.

29.7: Probability and The Heisenberg Uncertainty Principle

25. What is the Heisenberg uncertainty principle? Does it place limits on what can be known?

29.8: The Particle-Wave Duality Reviewed

26. In what ways are matter and energy related that were not known before the development of relativity and quantum mechanics?

Problems & Exercises

29.1: Quantization of Energy

27. A LiBr molecule oscillates with a frequency of $1.7 \times 10^{13} Hz$.

(a) What is the difference in energy in eV between allowed oscillator states?

(b) What is the approximate value of n for a state having an energy of 1.0 eV?

Solution
(a) 0.070 eV
(b) 14

28. The difference in energy between allowed oscillator states in HBr molecules is 0.330 eV. What is the oscillation frequency of this molecule?

29. A physicist is watching a 15-kg orangutan at a zoo swing lazily in a tire at the end of a rope. He (the physicist) notices that each oscillation takes 3.00 s and hypothesizes that the energy is quantized.

(a) What is the difference in energy in joules between allowed oscillator states?

(b) What is the value of n for a state where the energy is 5.00 J?

(c) Can the quantization be observed?

Solution
(a) $2.21 \times 10^{34} J$
(b) 2.26×10^{34}
(c) No

29.2: The Photoelectric Effect

30. What is the longest-wavelength EM radiation that can eject a photoelectron from silver, given that the binding energy is 4.73 eV? Is this in the visible range?

Solution
263 nm

31. Find the longest-wavelength photon that can eject an electron from potassium, given that the binding energy is 2.24 eV. Is this visible EM radiation?

32. What is the binding energy in eV of electrons in magnesium, if the longest-wavelength photon that can eject electrons is 337 nm?

Solution
3.69 eV

33. Calculate the binding energy in eV of electrons in aluminum, if the longest-wavelength photon that can eject them is 304 nm.

34. What is the maximum kinetic energy in eV of electrons ejected from sodium metal by 450-nm EM radiation, given that the binding energy is 2.28 eV?

Solution
0.483 eV

35. UV radiation having a wavelength of 120 nm falls on gold metal, to which electrons are bound by 4.82 eV. What is the maximum kinetic energy of the ejected photoelectrons?

36. Violet light of wavelength 400 nm ejects electrons with a maximum kinetic energy of 0.860 eV from sodium metal. What is the binding energy of electrons to sodium metal?

Solution
2.25 eV

37. UV radiation having a 300-nm wavelength falls on uranium metal, ejecting 0.500-eV electrons. What is the binding energy of electrons to uranium metal?

38. What is the wavelength of EM radiation that ejects 2.00-eV electrons from calcium metal, given that the binding energy is 2.71 eV? What type of EM radiation is this?

Solution
(a) 264 nm
(b) Ultraviolet

39. Find the wavelength of photons that eject 0.100-eV electrons from potassium, given that the binding energy is 2.24 eV. Are these photons visible?

40. What is the maximum velocity of electrons ejected from a material by 80-nm photons, if they are bound to the material by 4.73 eV?

Solution
$1.95 \times 10^6 m/s$

41. Photoelectrons from a material with a binding energy of 2.71 eV are ejected by 420-nm photons. Once ejected, how long does it take these electrons to travel 2.50 cm to a detection device?

42. A laser with a power output of 2.00 mW at a wavelength of 400 nm is projected onto calcium metal.

(a) How many electrons per second are ejected?

(b) What power is carried away by the electrons, given that the binding energy is 2.71 eV?

Solution
(a) $4.02 \times 10^{15}/s$
(b) 0.256 mW

43. (a) Calculate the number of photoelectrons per second ejected from a $1.00-mm^2$ area of sodium metal by 500-nm EM radiation having an intensity of $1.30 kW/m^2$ (the intensity of sunlight above the Earth's atmosphere).

(b) Given that the binding energy is 2.28 eV, what power is carried away by the electrons?

(c) The electrons carry away less power than brought in by the photons. Where does the other power go? How can it be recovered?

44. *Unreasonable Results*

Red light having a wavelength of 700 nm is projected onto magnesium metal to which electrons are bound by 3.68 eV.

(a) Use $KE_e = hf - BE$ to calculate the kinetic energy of the ejected electrons.

(b) What is unreasonable about this result?

(c) Which assumptions are unreasonable or inconsistent?

Solution
(a) $-1.90 eV$
(b) Negative kinetic energy
(c) That the electrons would be knocked free.

45. *Unreasonable Results*

(a) What is the binding energy of electrons to a material from which 4.00-eV electrons are ejected by 400-nm EM radiation?

(b) What is unreasonable about this result?

(c) Which assumptions are unreasonable or inconsistent?

29.3 Photon Energies and the Electromagnetic Spectrum

46. What is the energy in joules and eV of a photon in a radio wave from an AM station that has a 1530-kHz broadcast frequency?

Solution
$6.34 \times 10^{-9} eV, 1.01 \times 10^{-27} J$

47. (a) Find the energy in joules and eV of photons in radio waves from an FM station that has a 90.0-MHz broadcast frequency.

(b) What does this imply about the number of photons per second that the radio station must broadcast?

48. Calculate the frequency in hertz of a 1.00-MeV γ-ray photon.

Solution
$2.42 \times 10^{20} Hz$

49. (a) What is the wavelength of a 1.00-eV photon?

(b) Find its frequency in hertz.

(c) Identify the type of EM radiation.

50. Do the unit conversions necessary to show that $hc = 1240 eV \cdot nm$, as stated in the text.

Solution

$$hc = (6.62607 \times 10^{-34} J \cdot s)(2.99792 \times 10^{8} m/s)(\frac{10^{9} nm}{1 m})(\frac{1.00000 eV}{1.60218 \times 10^{-19} J}) = 1239.84 eV \cdot nm \approx 1240 eV \cdot nm$$

51. Confirm the statement in the text that the range of photon energies for visible light is 1.63 to 3.26 eV, given that the range of visible wavelengths is 380 to 760 nm.

52. (a) Calculate the energy in eV of an IR photon of frequency $2.00 \times 10^{13} Hz$.

(b) How many of these photons would need to be absorbed simultaneously by a tightly bound molecule to break it apart?

(c) What is the energy in eV of a γ ray of frequency $3.00 \times 10^{20} Hz$?

(d) How many tightly bound molecules could a single such γ ray break apart?

Solution
(a) 0.0829 eV
(b) 121
(c) 1.24 MeV
(d) 1.24×10^{5}

53. Prove that, to three-digit accuracy, $h = 4.14 \times 10^{-15} eV \cdot s$, as stated in the text.

54. (a) What is the maximum energy in eV of photons produced in a CRT using a 25.0-kV accelerating potential, such as a color TV?

(b) What is their frequency?

Solution
(a) $25.0 \times 10^{3} eV$
(b) $6.04 \times 10^{18} Hz$

55. What is the accelerating voltage of an x-ray tube that produces x rays with a shortest wavelength of 0.0103 nm?

56. (a) What is the ratio of power outputs by two microwave ovens having frequencies of 950 and 2560 MHz, if they emit the same number of photons per second?

(b) What is the ratio of photons per second if they have the same power output?

Solution
(a) 2.69
(b) 0.371

57. How many photons per second are emitted by the antenna of a microwave oven, if its power output is 1.00 kW at a frequency of 2560 MHz?

58. Some satellites use nuclear power.

(a) If such a satellite emits a 1.00-W flux of γ rays having an average energy of 0.500 MeV, how many are emitted per second?

(b) These γ rays affect other satellites. How far away must another satellite be to only receive one γ ray per second per square meter?

Solution
(a) $1.25 \times 10^{13} photons/s$
(b) 997 km

59. (a) If the power output of a 650-kHz radio station is 50.0 kW, how many photons per second are produced?

(b) If the radio waves are broadcast uniformly in all directions, find the number of photons per second per square meter at a distance of 100 km. Assume no reflection from the ground or absorption by the air.

60. How many x-ray photons per second are created by an x-ray tube that produces a flux of x rays having a power of 1.00 W? Assume the average energy per photon is 75.0 keV.

Solution
$8.33 \times 10^{13} photons/s$

61. (a) How far away must you be from a 650-kHz radio station with power 50.0 kW for there to be only one photon per second per square meter? Assume no reflections or absorption, as if you were in deep outer space.

(b) Discuss the implications for detecting intelligent life in other solar systems by detecting their radio broadcasts.

62. Assuming that 10.0% of a 100-W light bulb's energy output is in the visible range (typical for incandescent bulbs) with an average wavelength of 580 nm, and that the photons spread out uniformly and are not absorbed by the atmosphere, how far away would you be if 500 photons per second enter the 3.00-mm diameter pupil of your eye? (This number easily stimulates the retina.)

Solution
181 km

63. *Construct Your Own Problem*

Consider a laser pen. Construct a problem in which you calculate the number of photons per second emitted by the pen. Among the things to be considered are the laser pen's wavelength and power output. Your instructor may also wish for you to determine the minimum diffraction spreading in the beam and the number of photons per square centimeter the pen can project at some large distance. In this latter case, you will also need to consider the output size of the laser beam, the distance to the object being illuminated, and any absorption or scattering along the way.

29.4: Photon Momentum

64. (a) Find the momentum of a 4.00-cm-wavelength microwave photon.

(b) Discuss why you expect the answer to (a) to be very small.

Solution
(a) $1.66 \times 10^{-32} kg \cdot m/s$
(b) The wavelength of microwave photons is large, so the momentum they carry is very small.

65. (a) What is the momentum of a 0.0100-nm-wavelength photon that could detect details of an atom?

(b) What is its energy in MeV?

66. (a) What is the wavelength of a photon that has a momentum of $5.00 \times 10^{-29} kg \cdot m/s$?

(b) Find its energy in eV.

Solution
(a) 13.3 μm
(b) $9.38 \times 10^{-2} eV$

67. (a) A γ-ray photon has a momentum of $8.00 \times 10^{-21} kg \cdot m/s$. What is its wavelength?

(b) Calculate its energy in MeV.

68. (a) Calculate the momentum of a photon having a wavelength of $2.50 \mu m$.

(b) Find the velocity of an electron having the same momentum. (c) What is the kinetic energy of the electron, and how does it compare with that of the photon?

Solution
(a) $2.65 \times 10^{-28} kg \cdot m/s$
(b) 291 m/s
(c) electron $3.86 \times 10^{-26} J$, photon $7.96 \times 10^{-20} J$, ratio 2.06×10^{6}

69. Repeat the previous problem for a 10.0-nm-wavelength photon.

70. (a) Calculate the wavelength of a photon that has the same momentum as a proton moving at 1.00% of the speed of light.

(b) What is the energy of the photon in MeV?

(c) What is the kinetic energy of the proton in MeV?

Solution
(a) $1.32 \times 10^{-13} m$
(b) 9.39 MeV
(c) $4.70 \times 10^{-2} MeV$

71. (a) Find the momentum of a 100-keV x-ray photon.

(b) Find the equivalent velocity of a neutron with the same momentum.

(c) What is the neutron's kinetic energy in keV?

72. Take the ratio of relativistic rest energy, $E = \gamma mc^2$, to relativistic momentum, $p = \gamma mu$, and show that in the limit that mass approaches zero, you find $E/p = c$.

Solution
$E = \gamma mc^2$ and $P = \gamma mu$, so

$$\frac{E}{P} = \frac{\gamma mc^2}{\gamma mu} = \frac{c^2}{u}.$$

As the mass of particle approaches zero, its velocity u will approach c, so that the ratio of energy to momentum in this limit is

$$\lim_{m \to 0} \frac{E}{P} = \frac{c^2}{c} = c$$

which is consistent with the equation for photon energy.

73. *Construct Your Own Problem*

Consider a space sail such as mentioned in Example. Construct a problem in which you calculate the light pressure on the sail in N/m^2 produced by reflecting sunlight. Also calculate the force that could be produced and how much effect that would have on a spacecraft. Among the things to be considered are the intensity of sunlight, its average wavelength, the number of photons per square meter this implies, the area of the space sail, and the mass of the system being accelerated.

74. *Unreasonable Results*

A car feels a small force due to the light it sends out from its headlights, equal to the momentum of the light divided by the time in which it is emitted.

(a) Calculate the power of each headlight, if they exert a total force of $2.00 \times 10^{-2} N$ backward on the car.

(b) What is unreasonable about this result?

(c) Which assumptions are unreasonable or inconsistent?

Solution

(a) 3.00×10^6W
(b) Headlights are way too bright.
(c) Force is too large.

29.6: The Wave Nature of Matter

75. At what velocity will an electron have a wavelength of 1.00 m?

Solution

$7.28 \times 10^{-4} m$

76. What is the wavelength of an electron moving at 3.00% of the speed of light?

77. At what velocity does a proton have a 6.00-fm wavelength (about the size of a nucleus)? Assume the proton is nonrelativistic. (1 femtometer = $10^{-15} m$.)

Solution

$6.62 \times 10^7 m/s$

78. What is the velocity of a 0.400-kg billiard ball if its wavelength is 7.50 cm (large enough for it to interfere with other billiard balls)?

79. Find the wavelength of a proton moving at 1.00% of the speed of light.

Solution

$1.32 \times 10^{-13} m$

80. Experiments are performed with ultracold neutrons having velocities as small as 1.00 m/s.

(a) What is the wavelength of such a neutron?

(b) What is its kinetic energy in eV?

81. (a) Find the velocity of a neutron that has a 6.00-fm wavelength (about the size of a nucleus). Assume the neutron is nonrelativistic.

(b) What is the neutron's kinetic energy in MeV?

Solution

(a) $6.62 \times 10^7 m/s$
(b) $22.9 MeV$

82. What is the wavelength of an electron accelerated through a 30.0-kV potential, as in a TV tube?

83. What is the kinetic energy of an electron in a TEM having a 0.0100-nm wavelength?

Solution

15.1 keV

84. (a) Calculate the velocity of an electron that has a wavelength of $1.00 \mu m$.

(b) Through what voltage must the electron be accelerated to have this velocity?

85. The velocity of a proton emerging from a Van de Graaff accelerator is 25.0% of the speed of light.

(a) What is the proton's wavelength?

(b) What is its kinetic energy, assuming it is nonrelativistic?

(c) What was the equivalent voltage through which it was accelerated?

Solution

(a) 5.29 fm
(b) $4.70 \times 10^{-12} J$
(c) 29.4 MV

86. The kinetic energy of an electron accelerated in an x-ray tube is 100 keV. Assuming it is nonrelativistic, what is its wavelength?

87. Unreasonable Results

(a) Assuming it is nonrelativistic, calculate the velocity of an electron with a 0.100-fm wavelength (small enough to detect details of a nucleus).

(b) What is unreasonable about this result?

(c) Which assumptions are unreasonable or inconsistent?

Solution
(a) $7.28 \times 10^{12} m/s$
(b) This is thousands of times the speed of light (an impossibility).
(c) The assumption that the electron is non-relativistic is unreasonable at this wavelength.

29.7: Probability and The Heisenberg Uncertainty Principle

88. (a) If the position of an electron in a membrane is measured to an accuracy of $1.00 \mu m$, what is the electron's minimum uncertainty in velocity?

(b) If the electron has this velocity, what is its kinetic energy in eV?

(c) What are the implications of this energy, comparing it to typical molecular binding energies?

Solution
(a) 57.9 m/s
(b) $9.55 \times 10^{-9} eV$
(c) From [link], we see that typical molecular binding energies range from about 1eV to 10 eV, therefore the result in part (b) is approximately 9 orders of magnitude smaller than typical molecular binding energies.

89. (a) If the position of a chlorine ion in a membrane is measured to an accuracy of $1.00 \mu m$, what is its minimum uncertainty in velocity, given its mass is $5.86 \times 10^{-26} kg$?

(b) If the ion has this velocity, what is its kinetic energy in eV, and how does this compare with typical molecular binding energies?

90. Suppose the velocity of an electron in an atom is known to an accuracy of $2.0 \times 10^{3} m/s$ (reasonably accurate compared with orbital velocities). What is the electron's minimum uncertainty in position, and how does this compare with the approximate 0.1-nm size of the atom?

Solution
29 nm,
290 times greater

91. The velocity of a proton in an accelerator is known to an accuracy of 0.250% of the speed of light. (This could be small compared with its velocity.) What is the smallest possible uncertainty in its position?

92. A relatively long-lived excited state of an atom has a lifetime of 3.00 ms. What is the minimum uncertainty in its energy?

Solution
$1.10 \times 10^{-13} eV$

93. (a) The lifetime of a highly unstable nucleus is $10^{-20} s$. What is the smallest uncertainty in its decay energy?

(b) Compare this with the rest energy of an electron.

94. The decay energy of a short-lived particle has an uncertainty of 1.0 MeV due to its short lifetime. What is the smallest lifetime it can have?

Solution
$3.3 \times 10^{-22} s$

95. The decay energy of a short-lived nuclear excited state has an uncertainty of 2.0 eV due to its short lifetime. What is the smallest lifetime it can have?

96. What is the approximate uncertainty in the mass of a muon, as determined from its decay lifetime?

Solution
$2.66 \times 10^{-46} kg$

97. Derive the approximate form of Heisenberg's uncertainty principle for energy and time, $\Delta E \Delta t \approx h$, using the following arguments: Since the position of a particle is uncertain by $\Delta x \approx \lambda$, where λ is the wavelength of the photon used to examine it, there is an uncertainty in the time the photon takes to traverse Δx. Furthermore, the photon has an energy related to its wavelength, and it can transfer some or all of this energy to the object being examined. Thus the uncertainty in the energy of the object is also related to λ. Find Δt and ΔE; then multiply them to give the approximate uncertainty principle.

29.8: The Particle-Wave Duality Reviewed

98. *Integrated Concepts*

The 54.0-eV electron in [link] has a 0.167-nm wavelength. If such electrons are passed through a double slit and have their first maximum at an angle of 25.0°, what is the slit separation d?

Solution
0.395 nm

99. *Integrated Concepts*

An electron microscope produces electrons with a 2.00-pm wavelength. If these are passed through a 1.00-nm single slit, at what angle will the first diffraction minimum be found?

100. *Integrated Concepts*

A certain heat lamp emits 200 W of mostly IR radiation averaging 1500 nm in wavelength.

(a) What is the average photon energy in joules?

(b) How many of these photons are required to increase the temperature of a person's shoulder by $2.0^{\circ}C$, assuming the affected mass is 4.0 kg with a specific heat of $0.83 kcal/kg \cdot {}^{\circ}C$. Also assume no other significant heat transfer.

(c) How long does this take?

Solution
(a) $1.3 \times 10^{-19} J$
(b) 2.1×10^{23}
(c) $1.4 \times 10^{2} s$

101. *Integrated Concepts*

On its high power setting, a microwave oven produces 900 W of 2560 MHz microwaves.

(a) How many photons per second is this?

(b) How many photons are required to increase the temperature of a 0.500-kg mass of pasta by $45.0^{\circ}C$, assuming a specific heat of $0.900 kcal/kg \cdot {}^{\circ}C$? Neglect all other heat transfer.

(c) How long must the microwave operator wait for their pasta to be ready?

102. *Integrated Concepts*

(a) Calculate the amount of microwave energy in joules needed to raise the temperature of 1.00 kg of soup from $20.0^{\circ}C$ to $100^{\circ}C$

.

(b) What is the total momentum of all the microwave photons it takes to do this?

(c) Calculate the velocity of a 1.00-kg mass with the same momentum. (d) What is the kinetic energy of this mass?

Solution
(a) $3.35 \times 10^{5} J$
(b) $1.12 \times 10^{-3} kg \cdot m/s$
(c) $1.12 \times 10^{-3} m/s$
(d) $6.23 \times 10^{-7} J$

103. *Integrated Concepts*

(a) What is γ for an electron emerging from the Stanford Linear Accelerator with a total energy of 50.0 GeV?

(b) Find its momentum.

(c) What is the electron’s wavelength?

104. *Integrated Concepts*

(a) What is γ for a proton having an energy of 1.00 TeV, produced by the Fermilab accelerator?

(b) Find its momentum.

(c) What is the proton’s wavelength?

Solution
(a) 1.06×10^3
(b) $5.33 \times 10^{-16} kg \cdot m/s$
(c) $1.24 \times 10^{-18} m$

105. *Integrated Concepts*

An electron microscope passes 1.00-pm-wavelength electrons through a circular aperture $2.00 \mu m$ in diameter. What is the angle between two just- resolvable point sources for this microscope?

106. *Integrated Concepts*

(a) Calculate the velocity of electrons that form the same pattern as 450-nm light when passed through a double slit.

(b) Calculate the kinetic energy of each and compare them.

(c) Would either be easier to generate than the other? Explain.

Solution
(a) $1.62 \times 10^3 m/s$
(b) $4.42 \times 10^{-19} J$ for photon, $1.19 \times 10^{-24} J$ for electron, photon energy is 3.71×10^5 times greater
(c) The light is easier to make because 450-nm light is blue light and therefore easy to make. Creating electrons with $7.43 \mu eV$ of energy would not be difficult, but would require a vacuum.

107. *Integrated Concepts*

(a) What is the separation between double slits that produces a second-order minimum at 45.0^o for 650-nm light?

(b) What slit separation is needed to produce the same pattern for 1.00-keV protons.

Solution
(a) $2.30 \times 10^{-6} m$
(b) $3.20 \times 10^{-12} m$

108. *Integrated Concepts*

A laser with a power output of 2.00 mW at a wavelength of 400 nm is projected onto calcium metal.

(a) How many electrons per second are ejected?

(b) What power is carried away by the electrons, given that the binding energy is 2.71 eV?

(c) Calculate the current of ejected electrons.

(d) If the photoelectric material is electrically insulated and acts like a 2.00-pF capacitor, how long will current flow before the capacitor voltage stops it?

109. *Integrated Concepts*

One problem with x rays is that they are not sensed. Calculate the temperature increase of a researcher exposed in a few seconds to a nearly fatal accidental dose of x rays under the following conditions. The energy of the x-ray photons is 200 keV, and 4.00×10^{13} of them are absorbed per kilogram of tissue, the specific heat of which is $0.830 kcal/kg \cdot {}^oC$. (Note that medical diagnostic x-ray machines cannot produce an intensity this great.)

Solution
$3.69 \times 10^{-4} {}^oC$

110. *Integrated Concepts*

A 1.00-fm photon has a wavelength short enough to detect some information about nuclei.

(a) What is the photon momentum?

(b) What is its energy in joules and MeV?

(c) What is the (relativistic) velocity of an electron with the same momentum?

(d) Calculate the electron's kinetic energy.

111. *Integrated Concepts*

The momentum of light is exactly reversed when reflected straight back from a mirror, assuming negligible recoil of the mirror. Thus the change in momentum is twice the photon momentum. Suppose light of intensity $1.00 kW/m^2$ reflects from a mirror of area $2.00 m^2$.

(a) Calculate the energy reflected in 1.00 s.

(b) What is the momentum imparted to the mirror?

(c) Using the most general form of Newton's second law, what is the force on the mirror?

(d) Does the assumption of no mirror recoil seem reasonable?

Solution
(a) 2.00 kJ
(b) $1.33 \times 10^{-5} kg \cdot m/s$
(c) $1.33 \times 10^{-5} N$
(d) yes

112. *Integrated Concepts*

Sunlight above the Earth's atmosphere has an intensity of $1.30 kW/m^2$. If this is reflected straight back from a mirror that has only a small recoil, the light's momentum is exactly reversed, giving the mirror twice the incident momentum.

(a) Calculate the force per square meter of mirror.

(b) Very low mass mirrors can be constructed in the near weightlessness of space, and attached to a spaceship to sail it. Once done, the average mass per square meter of the spaceship is 0.100 kg. Find the acceleration of the spaceship if all other forces are balanced.

(c) How fast is it moving 24 hours later?

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