Modern Physics

Answers to Odd-Numbered Problems

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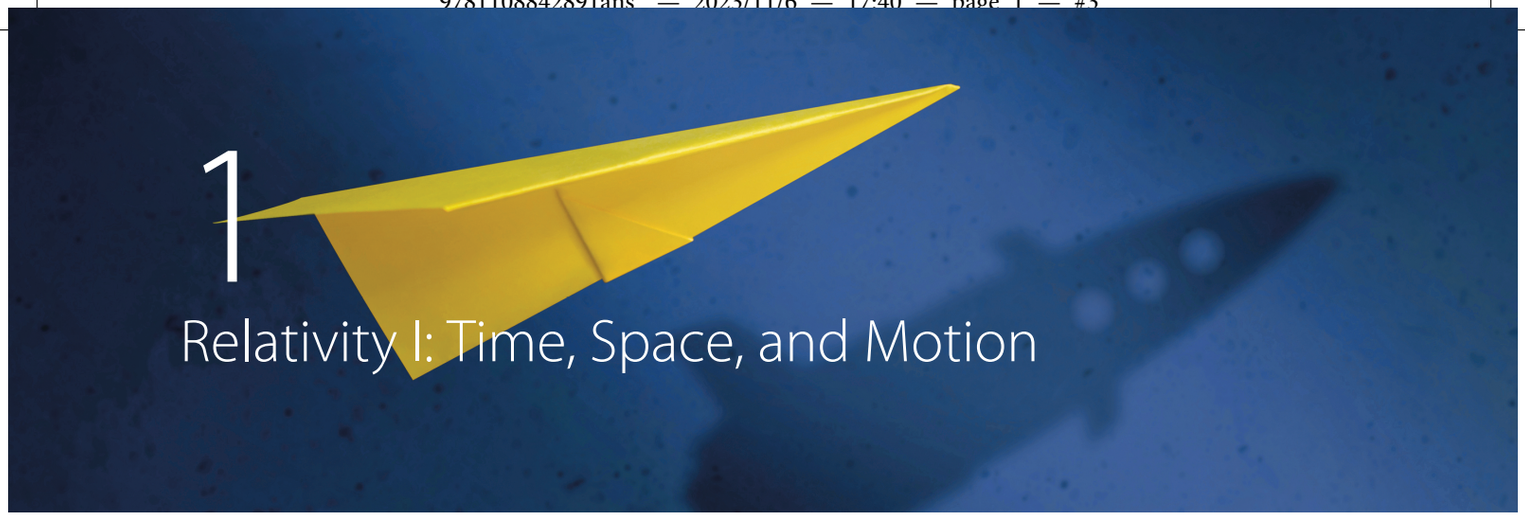


1 Relativity I: Time, Space, and Motion

1.1.3 Questions and Problems: Galilean Relativity

13. (**a**) 25 mph $\hat{j}$

(**b**) 0

(**c**) 50 mph $\hat{j}$

(**d**) -25 mph $\hat{i}$+25 mph $\hat{j}$

15. $t' = t, x' = x-(10\sqrt{3}\,\text{m/s})t, y' = y-(10\,\text{m/s})t, v'_x = v_x-(10\sqrt{3}\,\text{m/s}), v'_y = v_y-(10\,\text{m/s}), a'_x = a_x, a'_y = a_y$

17. $t' = t, a'_x = a_x, a'_y = a_y, v'_x = v_x - u\cos\phi, v'_y = v_y - u\sin\phi, x' = x - (u\cos\phi)t, y' = y - (u\sin\phi)t$

19. (**a**) $x' = (1/3)\sin(24t)$

(**b**) $x = (1/3)\sin(24t) + 8t$

21. (**a**) $v_{C0}t + (1/2)at^2 = x_{T0} + v_T t$

(**b**) $-400\,\text{mi/hr}^2$

23. (**a**) $v_x = v_y = 5/\sqrt{2}$

(**b**) $v_x = 10 + 5/\sqrt{2}, v_y = 5/\sqrt{2}$

(**c**) $x_b(t) = \left(10 + 5/\sqrt{2}\right)t, y_b(t) = \left(5/\sqrt{2}\right)t$

(**d**) $x_c(t) = \left(10/\sqrt{2}\right) + 10t, y_c(t) = 10/\sqrt{2}$

(**e**) $t = 2$

25. (**a**) $a = -a_C, v_x = -a_C t, x = -(1/2)a_C t^2$

1.2.3 Questions and Problems: Einstein's Postulates and Time Dilation

17. (**a**) 2.5 s

(**b**) $\Delta t = 1.5$ s

19. 7.57 years

21. 0.99995 c

23. 8.7 s

25. 7×10^{-6} s

29. (**a**) $5.56 \times 10^{-10}\%$

(**b**) $3.12 \times 10^{-6}\%$

(**c**) 1.3×10^7 m/s

(**d**) A factor of 7100

31. (**a**) $\sqrt{1 + (L/h)^2}$

(**b**) $h = c\Delta t$, $L = u\Delta t'$

(**c**) $\Delta t'/\Delta t = \sqrt{1 + [u\Delta t'/(c\Delta t)]^2}$

1.3.2 Questions and Problems: Length Contraction and Simultaneity

9. (**a**) after

(**b**) before

13. (**a**) 99.99999687 yards

(**b**) 99.5 yards

(**c**) 44 yards

15. (**a**) L

(**b**) 0

19. (**a**) $u = (2\sqrt{2}/3)\,c$

(**b**) $(2\sqrt{2}/3)$ light-seconds

(**c**) $(2\sqrt{2}/9)$ light-seconds

(**d**) (1/3) s

(**e**) (1/9) s

(**f**) (8/9) s

21. (**a**) 0.0048 c

23. (**a**) $L_{app} = L/[\gamma(1 + u/c)]$

25. (**a**) 20 years

(**b**) 9 light-years

(**c**) 8.72 years

(**d**) 4.36 years, 10 years

(**f**) 1.9 years

(**g**) 18.1 years

(**h**) 4.36 years

(**i**) 8.72 years

(**j**) 1.9 years

(**k**) 20 years

1.4.2 Questions and Problems: The Lorentz Transformations

9. 7.56 min, 18.9 light-min

11. (**a**) 33.5 years

21. (**a**) $x' = \gamma(x - ut)$

(**b**) $x = \gamma(x' + ut')$

1.5.3 Questions and Problems: Velocity Transformations and the Doppler Effect

7. (**a**) 0.5 c

(**b**) 0.78 c

(**c**) 1849 THz

9. (**a**) 0.38 c

(**c**) 0.38 c

11. 1.421826 GHz

15. (**a**) $(u_1 + u_2)/(1 + u_1u_2/c^2)$

(**b**) $(4/5)c$

19. (**a**) 20 years

(**b**) 9 light-years

(**c**) 8.7 years

(**d**) 3.923 light-years

(**e**) 4.359 years

(**f**) 1.900 years

(**g**) 0.9945 c

(**h**) 0.0945 c

(**i**) 41.51 years

(**j**) 18.10 years and 4.348 years

(**k**) 20 years and 8.7 years

2 Relativity II: Dynamics

2.1.3 Questions and Problems: Spacetime Diagrams

15. (**a**) A-B is timelike, A-C is spacelike, and B-C is lightlike.

(**b**) A-B: $\sqrt{8}$ ls, A-C: i$\sqrt{8}$ ls, and B-C: 0

(**c**) $\sqrt{8}$ s

19. (**b**) 5 s

(**c**) Less

(**d**) Less

23. (**a**) 4 years

(**d**) 5, 3.2

2.2.3 Questions and Problems: Momentum and Energy

11. (**a**) 90 billion Joules

(**b**) 900 gallons

13. (**a**) 1.78×10^{-16} kg

(**b**) $\gamma = 10^{11}$

(**c**) 29 seconds

15. $v_A = -(1/26)c$, $v_B = (11/14)c$

17. (**a**) $\gamma \approx 1 + \frac{1}{2}\frac{v^2}{c^2} + \frac{3}{8}\frac{v^4}{c^4}$

(**b**) $\vec{p} \approx m\vec{v}$

(**c**) $\vec{p} \approx m\vec{v} + \left(\frac{mv^2}{2c^2}\right)\vec{v}$

(**d**) $E \approx mc^2 + (1/2)mv^2$

(**e**) $E \approx mc^2 + (1/2)mv^2 + (3/8)m(v^4/c^2)$

2.3.3 Questions and Problems: Mass and Energy (and the Speed of Light Squared)

15. (**a**) $-(15/17)c$

(**b**) $(25/8)mc^2$

(**c**) $-(3/5)c$

(**d**) $(25/8)mc^2$

(**f**) $(5/2)m$

17. (**a**) $(8/3)mc^2$

(**b**) $(4/3)mc$

(**c**) $M = (4/\sqrt{3})m$, $V = c/2$

19. 7×10^{13} J

21. No change in mass. $\Delta p \approx 0.756\ mc$, $\Delta E \approx 0.512\ mc^2$

23. (**a**) $v = 10$ m/s

(**b**) 150,000 kg m^2/s^2

(**c**) 1,350,000 kg m^2/s^2

(**d**) $\Delta m = 1.33 \times 10^{-11}$ kg

25. $E_{ph}c/(E_{ph} + m_0c^2)$

27. 30,000 m/s

29. $\theta \approx 36.87^\circ$

2.4.3 Questions and Problems: Four-Vectors

15. $\mathbf{P} = \left(2m_ec/\sqrt{3}, m_ec/\sqrt{3}, 0, 0\right)$

17. (**a**) $-(35/37)c$

(**b**) $E'_B = (37/12)mc^2$, $p'_B = -(35/12)mc$

(**c**) $((5/3)mc, -(4/3)mc, 0, 0)$

(**d**) $((37/12)mc, -(35/12)mc, 0, 0)$

19. mc

21. (**a**) $E' = \gamma(E - up_x)$, $p'_x = \gamma(p_x - uE/c^2)$

25. (**a**) $(\gamma mc, \gamma mv)$

27. (**b**) $\mathbf{F} = \gamma\vec{F}$

2.5.2 Questions and Problems: The Michelson–Morley Experiment

9. (**a**) 2.7×10^{-9} m

(**b**) 10^{-8} periods

3 The Quantum Revolution I: From Light Waves to Photons

3.1.2 Questions and Problems: Interference

15. (**b**) Constructive

(**d**) Destructive

(**f**) Constructive

17. (**b**) 2π (or any multiple of it)

(**c**) π (or any odd multiple of it)

21. (**a**) One possible answer is:

$$y(x) = \begin{cases} 0 & 0 \leq x \leq 2\pi \\ -\sin x & 2\pi < x < 3\pi \\ 0 & 3\pi \leq x \leq 6\pi \end{cases}$$

(**b**) Destructive

23. Constructive

25. $\approx 0.113\,\text{m}$

27. (**a**) $\lambda = \sqrt{26} - 5 \approx 0.1\,\text{m}$

(**b**) $\lambda = 2\left(\sqrt{26} - 5\right) \approx 0.2\,\text{m}$

29. (**a**) $A = 1/3, \lambda = 6\pi, k = 1/3$

3.2.3 Questions and Problems: The Young Double-Slit Experiment

9. (**a**) Possible answers include 0, 3 cm, and 6 cm.

(**b**) Possible answers include 1.5 cm, 4.5 cm, and 7.5 cm.

11. Destructive

15. (**a**) $\lambda L/(4d)$

(**c**) 2.8 mm

17. (**a**) destructively

(**b**) destructively

(**c**) dark

3.4.3 Questions and Problems: Blackbody Radiation and the Ultraviolet Catastrophe

11. 1.7×10^{19} photons per second

13. (**a**) 2/3, or 67%

(**b**) 4/5, or 80%

15. $4\pi a/(c^3 b^3)$

17. (**a**) $4.6 k_B T$

(**b**) $0.55 k_B T$

19. (**a**) $E_w = 0.15711 k_B T$

(**b**) $E_w = 0.15719 k_B T$

21. $E_w = 0.90 k_B T$

23. $k_B T$

27. (**a**) 1.2×10^{10} J/m^3

(**b**) $\approx 1/4,000,000$

(**c**) 46%

31. 1.7×10^{13} Hz, infrared

33. (**a**) $T \approx 2900$ K, 2600°C, 4800°F.

35. $8\pi \nu^2 k_B T/c^3$

37. $\rho = 8\pi hc \displaystyle\int_0^\infty \frac{1}{\lambda^5 \left(e^{hc/(k_B \lambda T)} - 1\right)} \, d\lambda$

(**a**) $p = a\pi/L$

(**b**) $k = b\pi/L$, $q = d\pi/L$

(**c**) $\nu = \dfrac{c}{2L}\sqrt{a^2 + b^2 + d^2}$

(**d**) $E_{total} = 2 \displaystyle\int_0^{\pi/2} \int_0^{\pi/2} \int_0^\infty E_w(r, \theta, \phi) \, r^2 \sin\theta \, dr \, d\theta \, d\phi$

(**e**) $\pi \displaystyle\int_0^\infty r^2 E_w(r) \, dr$

(**f**) $\dfrac{8L^3\pi}{c^3} \displaystyle\int_0^\infty \nu^2 E_w(\nu) d\nu$

3.5.3 Questions and Problems: The Photoelectric Effect

11. (**a**) $K_{max} = h\nu - w_0$

13. (**a**) 1.6×10^{-19} J

(**b**) 8.0×10^{14} Hz

15. (**a**) 0.25 s

(**b**) No

17. (**a**) 4×10^{-19} J

(**b**) 1.5×10^{20}

(**c**) 7.5×10^{21}

19. (**a**) 10^{15} Hz

(**c**) 4.25 eV

21. Between 6.598×10^{-34} and 6.610×10^{-34} J. This doesn't quite include the modern value but is very close.

3.6.2 Questions and Problems: Further Photon Phenomena

13. 47,000 Kelvin

19. 0%, 1%, and 3.42%, respectively.

21. 5.877×10^{-11} m, 6.33×10^{-11} m

23. 4.1×10^{-26} J

25. 3 nm

27. 2×10^{-15} J

29. $E_C \approx E_{ph}/3400$

31. 298, 772, 069 m/s

33. (**a**) $E = mc^2/\sqrt{1 - v^2/c^2}$

(**b**) approaches ∞

35. $\nu_f = \dfrac{m_e c^2}{m_e c^2 + h\nu_0(1 - \cos\theta)}\nu_0$

37. 2.2×10^{20} Hz

4 The Quantum Revolution II: Matter and Wavefunctions

4.1.2 Questions and Problems: The Bohr Model

15. $R_H/4 \approx 2.75 \times 10^6\,m^{-1}$

17. 118,000 K

19. 0.03%

23. (**a**) $v = e/\sqrt{4\pi\epsilon_0 m_e r}$

(**b**) $L = e\sqrt{m_e r/(4\pi\epsilon_0)}$

(**c**) $r = 4\pi\epsilon_0 n^2\hbar^2/(e^2 m_e)$, $v = e^2/(4\pi\epsilon_0 n\hbar)$, KE$= m_e e^4/(32\pi^2\epsilon_0^2 n^2\hbar^2)$

25. (**a**) $\Delta E = \dfrac{m_e e^4}{2(4\pi\epsilon_0)^2\hbar^2}\left(\dfrac{1}{n_1^2} - \dfrac{1}{n_2^2}\right)$

(**b**) $f = \dfrac{m_e e^4}{64\pi^3\epsilon_0^2\hbar^3 c}\left(\dfrac{1}{n_1^2} - \dfrac{1}{n_2^2}\right)$

(**c**) $R_H = \dfrac{m_e e^4}{64\pi^3\epsilon_0^2\hbar^3 c}$

27. (**b**) $E = (1/2)nh\omega/\pi$

4.2.2 Questions and Problems: Matter Waves

13. (**a**) 7 Million m/s

(**b**) ≈ 140 V

15. $\lambda_{electron} = 6.23 \times 10^{-9}$ m, $\lambda_{neutron} = 1.45 \times 10^{-10}$ m

17. (**a**) 1.2×10^{-5} m

(**b**) 1.2×10^{-7} m

19. 8.7×10^{-10} m

21. $6.35 \times 10^{-34}\,kg\,m^2/s - 6.99 \times 10^{-34}\,kg\,m^2/s$. Yes.

23. 1.2×10^8 V

25. (**a**) $\sqrt{h^2 + (x + w/2)^2} - \sqrt{h^2 + (x - w/2)^2}$

(**b**) $L = xw/\sqrt{h^2 + x^2}$

(**c**) $L = w \sin\phi$

4.3.3 Questions and Problems: Wavefunctions and Position Probabilities

11. $1/\sqrt{3}$

13. **(a)** $\pm\sqrt{23}/6$

(b) $i\sqrt{23}/6$

(b) $23/36$

15. **(a)** Not normalizable

(b) $\sqrt{2/k}$

17. $1/\sqrt{L}$

19. $\sqrt{k/\pi}$

21. **(a)** 2

(b) $3/4$

(c) $1/25$

(d) 2

23. **(a)** $1{,}000{,}000P_1$

4.4.2 Questions and Problems: The Heisenberg Uncertainty Principle

13. **(a)** x_0

(b) 0

(d) One over distance squared.

(f) ψ_1, ψ_2.

15. **(a)** $\Delta p = \hbar/L$

(b) $\hbar/(2L)$

(c) $\hbar^2/(8mL^2)$

17. **(b)** $L/\sqrt{3}$

19. **(b)** $-e^2/(4\pi\epsilon_0 R)$

(c) $\Delta p_x \geq \hbar/(2R)$

(d) $\langle p_x \rangle = \hbar/(4R)$

(e) $KE = 3\hbar^2/(32m_e R^2)$

21. **(a)** $\Delta E \geq 2 \times 10^{-6}\,eV$

(b) $\Delta\nu \approx 5 \times 10^8\,Hz$

23. **(a)** $\Delta x = \dfrac{1}{2\sqrt{k}}$

(b) $\hbar\sqrt{k}$

(c) $\hbar/2$

5 The Schrödinger Equation

5.1.2 Questions and Problems: Force and Potential Energy

9. (**d**) $-GM_{Sun}m_{object}/r^2$

11. (**a**) $d^2x/dt^2 = -k/m$

(**b**) $x = -k/(2m)t^2 + At + B$

(**c**) $x = -k/(2m)t^2 + x_0$

13. (**a**) J/m^2, or kg/s^2

(**b**) $F = -kx$

(**d**) $x = 0$

5.2.2 Questions and Problems: Energy Eigenstates and the Time-Independent Schrödinger Equation

11. (**a**) E_4

(**b**) (**i**) $3/10$

(**ii**) 0

(**c**) $\int_{-\infty}^{\infty} A_5^2|\psi_5(x)|^2dx = 1$

(**d**) $|c_1|^2 + |c_2|^2 + |c_3|^2 + |c_4|^2 + |c_5|^2 = 1$

13. (**a**) $A = 1/\sqrt{5}$, $P(E = E_1) = 1/5$.

(**b**) $B = 1/\sqrt{3}$, $P(E = E_1) = 1/3$.

15. (**a**) $U = (1/2)kx^2$

(**b**) $-\dfrac{\hbar^2}{2m}\dfrac{d^2\psi}{dx^2} + \dfrac{1}{2}kx^2\psi(x) = E\psi(x)$

17. (**a**) $E = (3\hbar/2)\sqrt{k/m}$

(**b**) $\int_{-\infty}^{\infty} B^2x^2e^{-\sqrt{km}\,x^2/\hbar} = 1$

(**c**) $E = (\hbar/2)\sqrt{k/m}$ with probability $2/7$ and $E = (3\hbar/2)\sqrt{k/m}$ with probability $5/7$

19. (**a**) $E = U_0$

(**b**) No

(**c**) No

5.3.3 Questions and Problems: The Infinite Square Well

11. $\psi(x) = \sqrt{1/L}\sin(n\pi x/(2L))$, $E = \hbar^2\pi^2 n^2/(8mL^2)$

13. **(a)** $(1/2)\psi_1 + (1/\sqrt{2})\psi_2 + (1/2)\psi_3$

(b) $E = \pi^2\hbar^2/(2mL^2)$ with probability $1/4$, $E = 2\pi^2\hbar^2/(mL^2)$ with probability $1/2$, and $E = 9\pi^2\hbar^2/(2mL^2)$ with probability $1/4$

(c) The same energy you found the first time.

17. $A = \sqrt{2/L}$

5.4.3 Questions and Problems: Other Bound States

11. **(a)** $\dfrac{d^2\psi}{dx^2} + (2E - x^2)\psi = 0$

17. **(a)** zero

(b) $0 < x < L : \psi(x) = A\sin\left(\dfrac{\sqrt{2mE}}{\hbar}x\right) + B\cos\left(\dfrac{\sqrt{2mE}}{\hbar}x\right)$

$x \geq L : \psi(x) = Ce^{x\sqrt{2m(U_0-E)}/\hbar} + De^{-x\sqrt{2m(U_0-E)}/\hbar}$

(e) $\tan\left(\dfrac{\sqrt{2mE}}{\hbar}L\right) = -\sqrt{\dfrac{E}{U_0 - E}}$

19. **(b)** 1.98×10^{-7} eV

5.5.3 Questions and Problems: Complex Numbers

11. $2\sqrt{2}\,i$

13. **(a)** $-1 + 2i$

(b) $\sqrt{5}$

(c) $(4 - 7i)/(2 + 3i)$

(d) 5

(e) $\sqrt{5}$

15. **(a)** $1 + 7i$

(b) $|p| = |z_1||z_2|$

(c) $\phi_p = \phi_{z_1} + \phi_{z_2}$

5.6.3 Questions and Problems: Time Evolution of a Wavefunction

11. **(a)** $\sqrt{2/L}\sin(2\pi x/L)e^{-2i\hbar\pi^2 t/(mL^2)}$

(b) $(2/L)\sin^2(2\pi x/L)$

(c) $2\hbar^2\pi^2/(mL^2)$

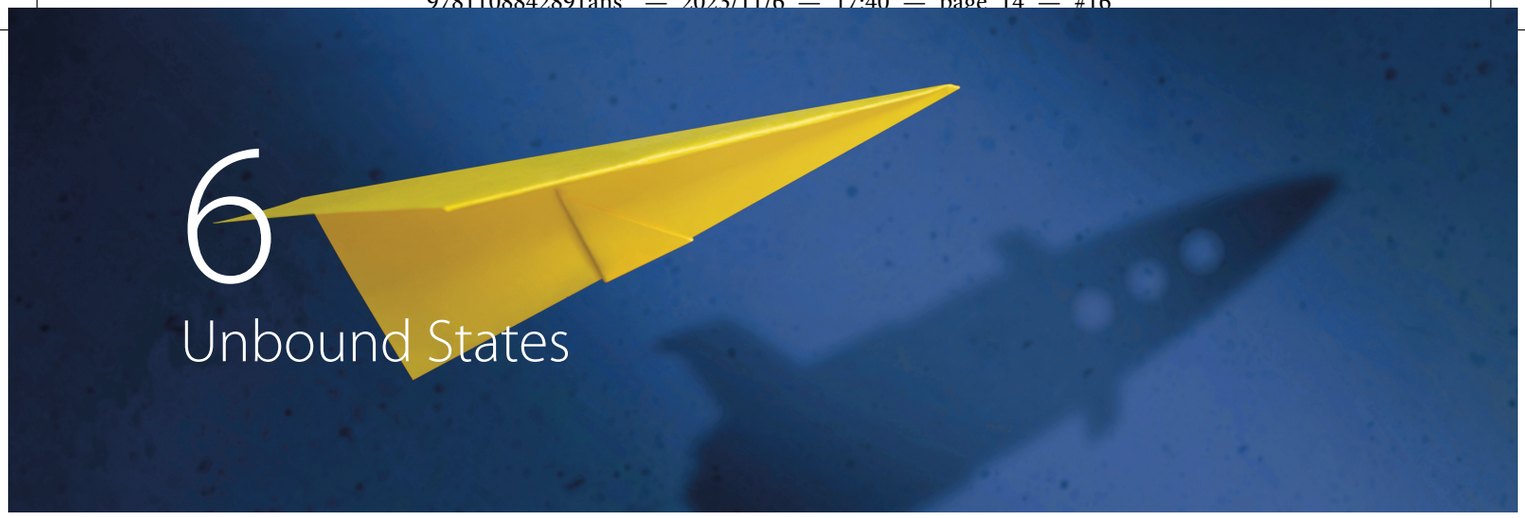
(a) $\sqrt{2/L}\left[(1/2)\sin(2\pi x/L)e^{-2i\hbar\pi^2 t/(mL^2)} + (\sqrt{3}/2)\sin(5\pi x/L)e^{-25i\hbar\pi^2 t/(2mL^2)}\right]$

(**b**) $\frac{1}{L}\left[\frac{1}{2}\sin^2\left(\frac{2\pi}{L}x\right)+\frac{3}{2}\sin^2\left(\frac{5\pi}{L}x\right)+\sqrt{3}\sin\left(\frac{2\pi}{L}x\right)\sin\left(\frac{5\pi}{L}x\right)\cos\left(\frac{21\hbar\pi^2}{2mL^2}t\right)\right]$

(**c**) $4mL^2/(21\hbar\pi)$

(**d**) $2\hbar^2\pi^2/(mL^2)$ with probability 1/4 and $25\hbar^2\pi^2/(2mL^2)$ with probability 3/4

15. $|\Psi(x,t)|^2 = A^2\left(\psi_1^2+\psi_2^2-2\cos\left[\frac{t(E_1-E_2)}{\hbar}\right]\right)$



6 Unbound States

6.1.3 Questions and Problems: Standing Waves, Traveling Waves, and Partial Derivatives

15. (**a**) $5\sin(2\pi t)$

(**f**) $\lambda = 6, T = 1, k = \pi/3, \nu = 1$

17. (**a**) 4

(**b**) 0

(**c**) 2

(**d**) -16

19. (**a**) $\lambda = 0.5, k = 4\pi, \nu = 1/10$

(**b**) negative

(**c**) zero

(**d**) $y(x) = 15\sin(4\pi x)\cos(\pi t/5)$

21. 0.78 m

25. (**a**) $y_R(x,t) = A\sin(kx - \omega t)$

(**b**) $y_L(x,t) = A\sin(kx + \omega t)$

(**d**) $x = n\pi/k$

27. (**d**) $k = n\pi/L$

6.2.3 Questions and Problems: Free Particles and Fourier Transforms

15. (**a**) $A = 1/\sqrt{2L}$

(**b**) $\hat{\psi}(k) = -\dfrac{1}{2ki\sqrt{\pi L}}\left(e^{-ikL} - e^{ikL}\right)$

(**c**) $\hat{\psi}(k) = \sin(kL)/\sqrt{\pi Lk^2}$

(**f**) $\displaystyle\int_{-2/L}^{2/L} \frac{\sin^2(kL)}{\pi Lk^2}dk$

(**g**) 86%

6.3.2 Questions and Problems: Momentum Eigenstates

11. (**a**) $\psi_1(x) = -(i/\sqrt{2L})(e^{ip_1 x/\hbar} - e^{ip_2 x/\hbar})$ where $p_1 = \pi\hbar/L$ and $p_2 = -\pi\hbar/L$

(**b**) $p = \pm\pi\hbar/L$ with equal probability

(**c**) $\pi\hbar/L$

13. (**a**) One example is $e^{-(3x/L)^2}$.

(**b**) Closer

(**c**) $[18/(\pi L^2)]^{1/4}$

(**d**) Higher

(**e**) $\left[L^2/(18\pi)\right]^{1/4} e^{-L^2k^2/36}$

(**g**) 25%

6.4.3 Questions and Problems: Phase Velocity and Group Velocity

11. (**a**) $v_g = (1/2)\sqrt{g/k}$

13. (**a**) both 1

(**b**) $|\psi(x)|^2 = 2 + 2\cos(0.1\pi x)$

6.5.3 Questions and Problems: Scattering and Tunneling

17. (**a**) $A + B = C$, $A - B = iC\sqrt{(U_0 - E)/E}$

19. (**c**) $\psi(x) = \begin{cases} Ae^{i(\sqrt{2m(E-U_0)}/\hbar)x} + Be^{-i(\sqrt{2m(E-U_0)}/\hbar)x} & x < 0 \\ Ce^{i\left(\sqrt{2mE}/\hbar\right)x} + De^{-i\left(\sqrt{2mE}/\hbar\right)x} & x \geq 0 \end{cases}$

(**d**) D

(**e**) $A + B = C$, $A - B = C\sqrt{E/(E - U_0)}$

(**a**) $\left(\dfrac{\sqrt{1 - U_0/E} - 1}{\sqrt{1 - U_0/E} + 1}\right)^2$

(**d**) 1

21. (**e**) $|B/A|^2$

23. (**b**) $1 - \left|\dfrac{B}{A}\right|^2 = \dfrac{4E(E - U_0)}{4E(E - U_0)\cosh^2\left(\sqrt{2m(U_0 - E)}\,L/\hbar\right) + (2E - U_0)^2 \sinh^2\left(\sqrt{2m(U_0 - E)}\,L/\hbar\right)}$

6.6.3 Questions and Problems: The Time-Dependent Schrödinger Equation

9. $f(x,t) = (A\sin[kx] + B\cos[kx])\left(C\sin\left[(k/\sqrt{\beta})t\right] + D\cos\left[(k/\sqrt{\beta})t\right]\right)$

7 The Hydrogen Atom

7.1.2 Questions and Problems: Quantum Numbers of the Hydrogen Atom

7. (**a**) $-1/16$ Ry, or about -0.850 eV, or -1.4×10^{-19} J

(**b**) $\sqrt{12}\,\hbar$, or 3.65×10^{-34} kg · m^2/s

(**c**) $-3\,\hbar$, or -3.16×10^{-34} kg · m^2/s

(**d**) 3/16 Ry, or 2.55 eV, or 4.1×10^{-19} J

7.2.3 Questions and Problems: The Schrödinger Equation in Three Dimensions

11. (**a**) 0.0016

(**b**) 0.0016

(**c**) 0.0079

13. (**a**) equally likely

(**b**) $y > 0$

(**c**) equally likely

17. (**a**) $(1/2)\psi_{3,1,4} + (1/\sqrt{2})\psi_{2,1,2} + (1/2)\psi_{1,4,3}$

(**b**) $E = 13\pi^2\hbar^2/(mL^2)$ and $E = 9\pi^2\hbar^2/(2mL^2)$, each with probability 1/2.

(**c**) The same energy you found the first time.

21. (**a**) $$-\frac{\hbar^2}{2m}\left(\frac{\partial^2\psi}{\partial x^2}T(t) + \frac{\partial^2\psi}{\partial y^2}T(t) + \frac{\partial^2\psi}{\partial z^2}T(t)\right) + U\psi T = i\hbar\psi(x,y,z)\frac{dT}{dt}$$

(**b**) $$-\frac{\hbar^2}{2m}\left(\frac{\partial^2\psi/\partial x^2}{\psi} + \frac{\partial^2\psi/\partial y^2}{\psi} + \frac{\partial^2\psi/\partial z^2}{\psi}\right) + U = i\hbar\frac{dT/dt}{T}$$

27. $f(x,y,z) = e^{-(k+p)y}z^p\left(Ae^{\sqrt{k}\,x} + Be^{-\sqrt{k}\,x}\right)$

29.

$$\psi_{abc}(x,y,z) = A_{abc}\sin\left(\frac{a\pi}{L}x\right)\sin\left(\frac{b\pi}{W}y\right)\sin\left(\frac{c\pi}{H}z\right)$$

$$E_{abc} = \frac{\pi^2\hbar^2}{2m}\left(\frac{a^2}{L^2} + \frac{b^2}{W^2} + \frac{c^2}{H^2}\right)$$

7.3.3 Questions and Problems: Spherical Coordinates

7. (**a**) $(r, \theta, \phi) = (3\sqrt{2}, \pi/2, \phi/4)$

(**b**) $(r, \theta, \phi) = (\sqrt{2}, \pi/4, 0)$

9. (**b**) $\sin\phi = y/\rho$, $\cos\phi = x/\rho$, $\tan\phi = y/x$, $x^2 + y^2 = \rho^2$

(**c**) $\sin\theta = \rho/r$, $\cos\theta = z/r$, $\tan\theta = \rho/z$, $z^2 + \rho^2 = r^2$

11. (**a**) $20r^2$

(**b**) $f(x, y, z) = \left(x^2 + y^2 + z^2\right)^2$

(**c**) $20x^2 + 20y^2 + 20z^2$

(**d**) They are, because $x^2 + y^2 + z^2 = r^2$.

7.4.3 Questions and Problems: Schrödinger's Equation and the Hydrogen Atom

13. (**a**) $r^6 e^{-r/(2a_0)} \left(12a_0 - r\right) / \left(2949120\, a_0^9\right)$

(**b**) One

19. (**a**) 1

(**c**) $2 + 2\cos\phi$

21. (**a**) 0.3

(**b**) $1/2$

23. (**a**) $1/2$

(**b**) $1/2$

(**c**) x-axis

25. (**a**) $1/8$

(**b**) $1/8$

(**c**) 0.097

(**d**) 0.048

7.6.2 Questions and Problems: Spin and the Problem of Measurement

7. (**a**) $\cos^{2N}\left[\pi/(4N)\right]$

(**b**) 1

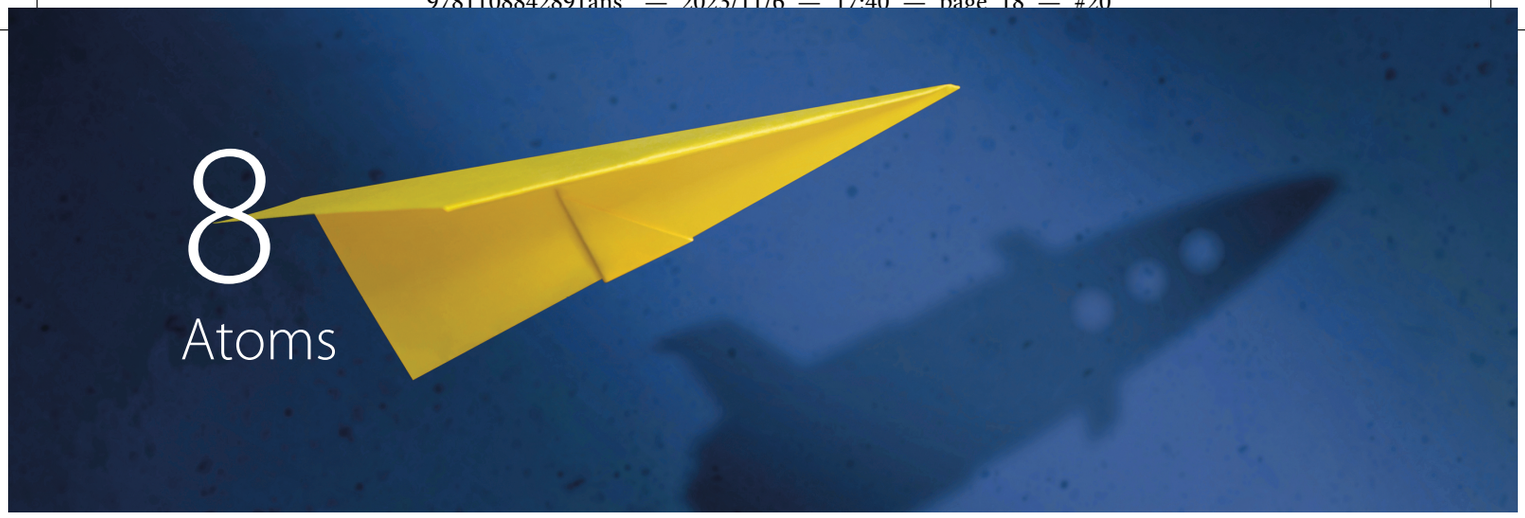
7.7.3 Questions and Problems: Splitting of the Spectral Lines

11. (**a**) 2.6×10^{-9} eV

13. (**a**) $KE \approx p^2/(2m) - p^4/(8m^3c^2)$

(**b**) 13.6 eV

(**c**) 2×10^{-4} eV



8 Atoms

8.1.2 Questions and Problems: The Pauli Exclusion Principle

7. (**a**) $\dfrac{\pi^2\hbar^2}{4mR^2}\sum_{x=1}^{n_{max}}\sum_{y=1}^{n_{max}}\sum_{z=1}^{n_{max}}\left(x^2+y^2+z^2\right)$

(**b**) $E=\dfrac{\pi^2\hbar^2 n_{max}^5}{4mR^2}$

(**c**) $M=2n_{max}^3 m_n$

(**d**) $E=\dfrac{\pi^2\hbar^2}{R^2}\left(\dfrac{M^5}{2^{11}m_n^8}\right)^{1/3}$

(**f**) $E=\dfrac{\pi^2\hbar^2}{R^2}\left(\dfrac{M^5}{2^{11}m_n^8}\right)^{1/3}-\dfrac{3GM^2}{5R}$

(**g**) $\dfrac{5\pi^2\hbar^2}{3(2^{8/3})Gm_n^{8/3}M^{1/3}}$

(**h**) $7,578\,\text{m}$

(**i**) $2.5\times10^{-34}\,\text{m}$

8.2.3 Questions and Problems: Energy Levels and Atomic States

11. (**a**) (**i**) 2

(**ii**) 1.5

$3.4\,\text{eV}$

13. 1s, 2s, 2p, 3s, 3p, 4s, 3d, 4p, 5s, 4f, 5d, 6p, 7s, 5f, 6d, 7p

15. sodium

8.4.2 Questions and Problems: X-Ray Spectroscopy and Moseley's Law

7. (**a**) 3 to 2

(**b**) $(13.6\,\text{eV})(Z-10)^2/2^2$

(**c**) $(13.6\,\text{eV})(Z-18)^2/3^2$

(**d**) $(13.6\,\text{eV})\left(\dfrac{(Z-10)^2}{2^2}-\dfrac{(Z-18)^2}{3^2}\right)$

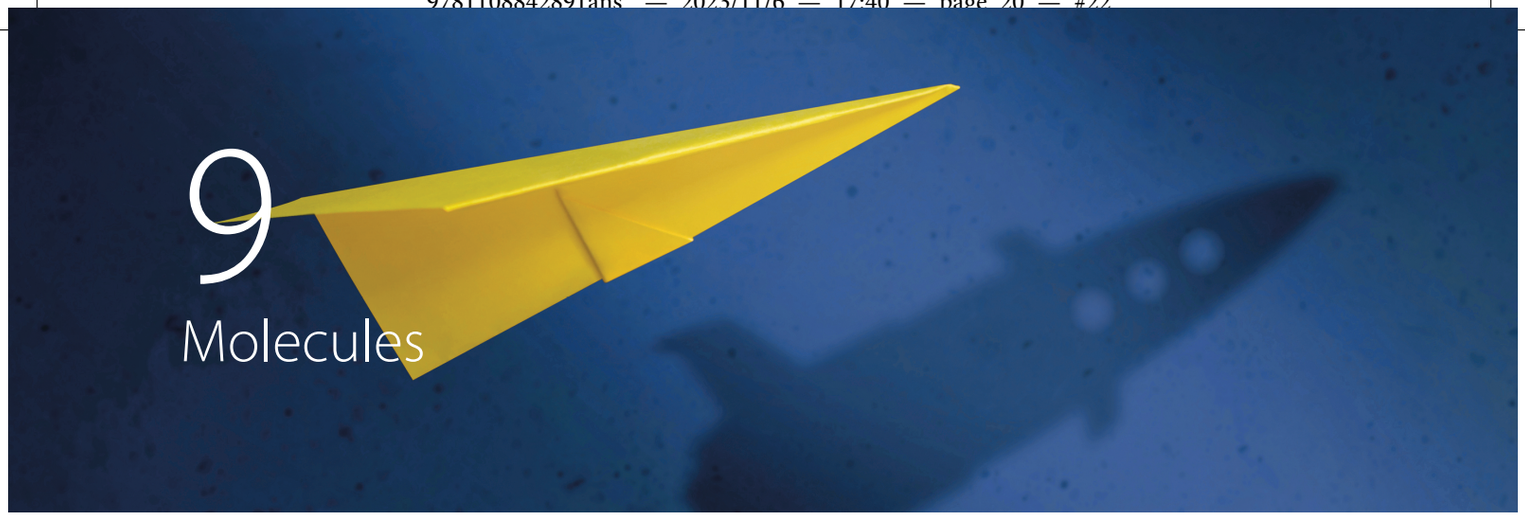
(**e**) 36%

(**f**) Slope $\sqrt{(3.4\,\text{eV})/\text{h}}$, x-intercept Z = 10

9. (**a**) lower

(**b**) higher

11. (**b**) $\lambda = 32$ pm



9 Molecules

9.1.4 Questions and Problems: Ionic and Covalent Bonds

13. (**a**) $r = 8.1 \times 10^{-10}\,\text{m}$

(**b**) 0.56 eV

9.2.2 Questions and Problems: Bonding and Antibonding States

1. (**a**) $-13.6\,\text{eV}$

(**b**) $-13.6\,\text{eV}$

9. (**a**) $U(x,y,z) = -\dfrac{e^2}{4\pi\epsilon_0}\left(\dfrac{1}{\sqrt{x^2+y^2+z^2}} + \dfrac{1}{\sqrt{(x-L)^2+y^2+z^2}}\right)$

(**b**) $\psi_1 = \dfrac{1}{\sqrt{a_0^3\pi}}\, e^{-\sqrt{x^2+y^2+z^2}/a_0}$, $\psi_2 = \dfrac{1}{\sqrt{a_0^3\pi}}\, e^{-\sqrt{(x-L)^2+y^2+z^2}/a_0}$

(**c**) $A = 0.56$, $B = 1.10$

(**d**) $E_S \approx -28.7\,\text{eV}$, $E_D \approx -18.1\,\text{eV}$

(**e**) 13.6 eV

(**f**) 1.5 eV

10 Statistical Mechanics

10.1.3 Questions and Problems: Microstates and Macrostates

9. 3/8

11. (**a**) 1/6

(**b**) 3/10

(**c**) 2/5

13. (**a**) 2^{15}

(**b**) 455

(**c**) Roughly 1 in 72

15. (**a**) 0.66

(**b**) 0.96

(**c**) 0.9999999998, or $1 - 2 \times 10^{-10}$

17. 0.063

10.2.3 Questions and Problems: Entropy and the Second Law of Thermodynamics

13. (**a**) 1140

(**b**) $k_B \ln 1140 = 9.71 \times 10^{-23}$ J/K

(**c**) 184,756

(**d**) $k_B \ln 184756 = 1.67 \times 10^{-22}$ J/K

15. (**a**) 1

(**b**) 2.5

(**c**) 3.5

(**d**) 3.6

(**e**) 10

(**f**) 20,000

17. (**a**) 1

(**b**) 100

(**c**) About 75 million

(**d**) 5×10^{20}

19. (**a**) 3

(**b**) 9

(**c**) $\Omega_A \Omega_B$

(**d**) 1.516×10^{-23}, 3.032×10^{-23}

10.3.3 Questions and Problems: Temperature

13. (**a**) 3.45 k_B, 6.45 k_B

(**b**) $197.91\epsilon/k_B$, $100\epsilon/k_B$

(**c**) 600ϵ

15. (**a**) 0

(**b**) 0

17. 35,000 J/K

19. $C = -\dfrac{(dS/dE)^2}{d^2S/dE^2}$

21. 0, 0

23. (**a**) $S_A = 0$, $S_B = k_B \ln 3$

(**b**) ϵ in A, and 3ϵ in B

(**c**) 1/2

(**d**) 454 K

25. (**a**) $W + Q_C = Q_H$

(**b**) $Q_C/T_C = Q_H/T_H$

(**c**) $T_C/(T_H - T_C)$

(**d**) 0.081 J

27. (**a**) $Q_H = W + Q_C$

(**b**) $Q_C/T_C = Q_H/T_H$

(**c**) $1 - T_C/T_H$

(**d**) 0.1 J

10.4.3 Questions and Problems: The Boltzmann Distribution

11. 32%

13. 88%

15. (**a**) 5.7%

(**b**) 429 K

17. (**a**) 9/13

(**b**) 0.22, or 22%

19. (**b**) 28%

21. (**a**) $P(E_1) = \dfrac{e^{-E_1/(k_B T)}}{e^{-E_0/(k_B T)} + e^{-E_1/(k_B T)}}$

10.5.3 Questions and Problems: Some Applications of the Boltzmann Distribution

15. (**b**) 170,000 m/s

17. 1.3 Million K

19. (**a**) $0.015 k_B T$

(**b**) $0.94 k_B T$

(**c**) $k_B T$

23. (**a**) $\sqrt{8 k_B T/(\pi m)}$

(**b**) $\sqrt{3 k_B T/m}$

25. 3.6×10^{10} Hz

10.6.3 Questions and Problems: Quantum Statistics

11. (**a**) 0.60

(**b**) 1/2

(**c**) 0.40

13. (**a**) 1/3

(**b**) 1/2

(**c**) 0

15. (**a**) 2/9

(**b**) 1/10

(**c**) 1

17. 2/3

19. C

21. 125,000

23. (**a**) Occupied: $e^{-(E-\mu)/(k_B T)}/\mathcal{Z}$. Unoccupied: $1/\mathcal{Z}$

(**b**)

$$\frac{1}{\mathcal{Z}} e^{-(E-\mu)/(k_B T)} + \frac{1}{\mathcal{Z}} = 1$$
$$e^{-(E-\mu)/(k_B T)} + 1 = \mathcal{Z}$$

(**b**) $1 + e^{-(E-\mu)/(k_B T)}$

25. (**a**) 1

(**b**) 16

(**c**) 28

(**d**) 2×10^{-19}

27. (**a**) 1/2

(**c**) $\mu \to -\infty$

29. (**a**) 0

(**c**) μ approaches the ground state energy.

31. (**b**) $N = \int_0^{\pi/2} \int_0^{\pi/2} \int_0^{\infty} \overline{n}\, n^2 \sin\theta \, dn \, d\theta \, d\phi$

(**c**) $N = (\pi/2)\int_0^\infty \bar{n}\, n^2 dn$

(**d**) $N = \dfrac{m^{3/2}V}{\pi^2\hbar^3\sqrt{2}}\displaystyle\int_0^\infty \bar{n}\sqrt{E}\, dE$

(**e**) $g(E) = m^{3/2}V\sqrt{E}/\left(\pi^2\hbar^3\sqrt{2}\right)$

(**f**) Any type

10.7.2 Questions and Problems: Blackbody Radiation

9. 11,000 K

11. 6×10^{-6} J

15. (**a**) 822.7 sec

(**b**) 29 hours

17. 650 K

19. (**a**) $P(N) = \dfrac{1}{Z}e^{-Nh\nu/(k_B T)}$

(**b**) $Z = \displaystyle\sum_{N=0}^{\infty} e^{-Nh\nu/(k_B T)}$

(**c**) $\langle E\rangle = \displaystyle\sum_{N=0}^{\infty} \frac{Nh\nu}{Z} e^{-Nh\nu/(k_B T)}$

(**d**) $\langle E\rangle = h\nu \,/\, (e^{h\nu/(k_B T)} - 1)$

21. (**a**) c dt

(**b**) ρ dV

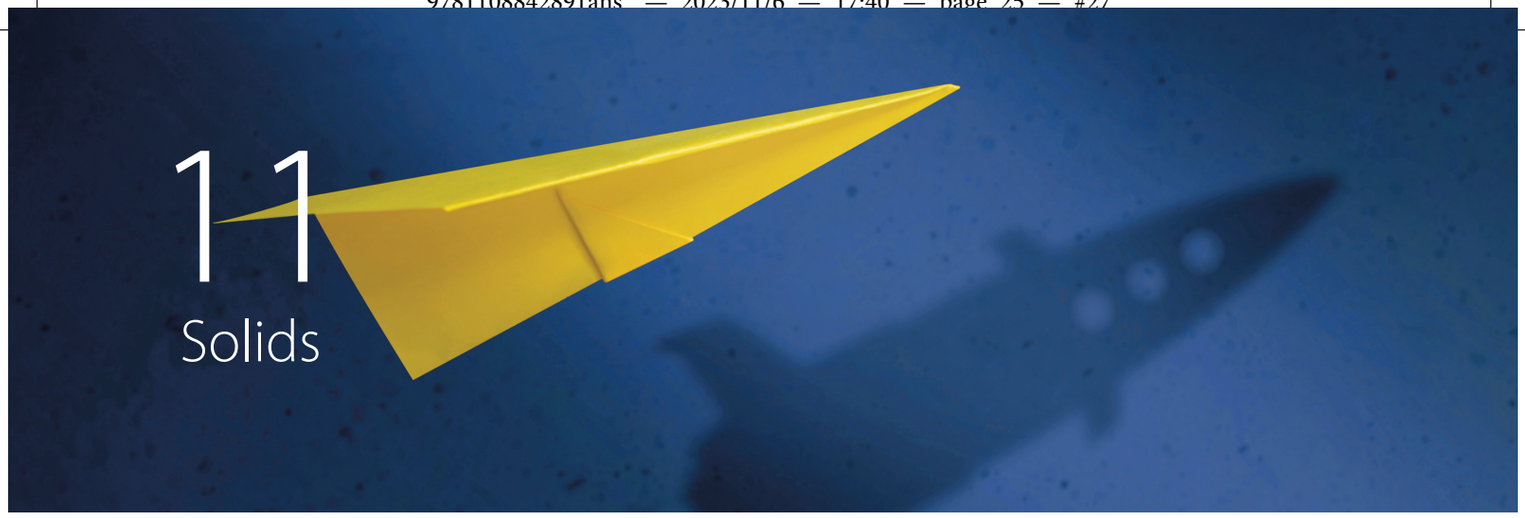
(**b**) $E = c\rho\, dA\, dt/4$

(**c**) $\dfrac{2\pi h}{c^2}\displaystyle\int_0^\infty \frac{\nu^3}{e^{h\nu/(k_B T)} - 1} d\nu$

10.8.3 Questions and Problems: Bose–Einstein Condensation

9. (**a**) 0.67 N

(**d**) N − 0.59



11 Solids

11.1.2 Questions and Problems: Crystals

9. (**a**) $-q^2/(2\pi\epsilon_0 R)$

(**b**) $q^2/(4\pi\epsilon_0 R)$

(**c**) $-q^2/(6\pi\epsilon_0 R)$, $q^2/(8\pi\epsilon_0 R)$

(**d**) $\left(2-\frac{2}{2}+\frac{2}{3}-\frac{2}{4}\ldots\right)\frac{-q^2}{4\pi\epsilon_0 R}$

(**e**) $2\ln 2$

11. (**a**) 2.13, 22%

(**b**) −0.866, 149%

11.2.2 Questions and Problems: Band Structure and Conduction

5. (**a**) 6.1×10^{-47}

(**b**) 1.2×10^{-23}.

7. (**a**) 0.67 m/s

(**b**) 1.39×10^{6} m/s

(**c**) a little over 400 lattice spacings

11.3.3 Questions and Problems: Semiconductors and Diodes

7. (**a**) 5.7×10^{-10}

(**b**) 5.7×10^{-10}

(**c**) About 200,000

11.5.3 Questions and Problems: Why Do Crystals Have a Band Structure?

9. (**a**) less than

(**b**) lower

11.6.2 Questions and Problems: Magnetic Materials

9. (**a**) 0.148 T

(**b**) 5.94×10^{-24} J

11.7.3 Questions and Problems: Heat Capacity

9. (**a**) 24.9 J/(mol · K)

(**b**) 22.25 J/(mol · K)

(**c**) 22.18 J/(mol · K)

11. (**a**) $3Nk_BT$

(**b**) $3Nk_B$

(**c**) 3R

15. 0

12 The Atomic Nucleus

12.1.3 Questions and Problems: What's in a Nucleus?

7. (**a**) 6 MeV

(**b**) 5.5 MeV

(**c**) Nickel (Iron would also be a reasonable answer.)

9. (**c**) About 40 MeV

(**d**) Gamma ray

11. (**a**) 5.3×10^{-20} kg m/s

12.2.2 Questions and Problems: Experimental Evidence for Nuclear Properties

3. (**a**) 12 MeV

(**b**) 39 MeV

5. 38°

12.3.2 Questions and Problems: Nuclear Models

7. 19 MeV

12.4.3 Questions and Problems: Three Types of Nuclear Decay

15. $t_{1/2}(\ln 3)/(\ln 2)$

17. (**a**) $Q = K_\alpha\,(1 + m_\alpha/m_Y)$

(**b**) $K_\alpha = Q(A_X - 4)/A_X$

(**c**) 0.28 MeV

19. (**b**) $K_p = p_p^2/(2m_p)$, $K_e = p_e c$

(**c**) $p^2/(2m_p) + pc = Q$

(**d**) $p = m_p c\left[-1 + \sqrt{2(m_n - m_e)/m_p - 1}\right]$

(**e**) $\frac{1}{2}\left(\sqrt{\frac{2}{m_p}\,(m_n - m_e) - 1} - 1\right)$

12.5.3 Questions and Problems: Fission and Fusion

11. $\mathrm{nd}\sigma_\alpha$

13. (**a**) 5.42×10^{26} MeV

(**b**) 8.5

(**c**) about 43,000 kg

13 Particle Physics

13.1.2 Questions and Problems: Forces and Particles

5. (**a**) 1.25×10^{-14} J

(**b**) 3.86×10^{6} m/s

(**d**) About 4 billion years

13.2.3 Questions and Problems: The Standard Model

17. (**a**) $2\sin^2\theta\cos^2\theta\left[1-\cos\left(\dfrac{t\Delta(m^2)c^4}{2\hbar E_0}\right)\right]$

(**b**) $2\sin^2\theta\cos^2\theta\left[1-\cos\left(\dfrac{L\Delta(m^2)c^3}{2\hbar E_0}\right)\right]$

(**c**) L = 6600 m, P = 84%

13.3.2 Questions and Problems: Detecting Particles

7. $\approx 3 \times 10^{-24}$ s

9. (**a**) 2.1 MeV

(**b**) 0.0031 cm

11. (**a**) 1.2×10^{-20} kg m/s

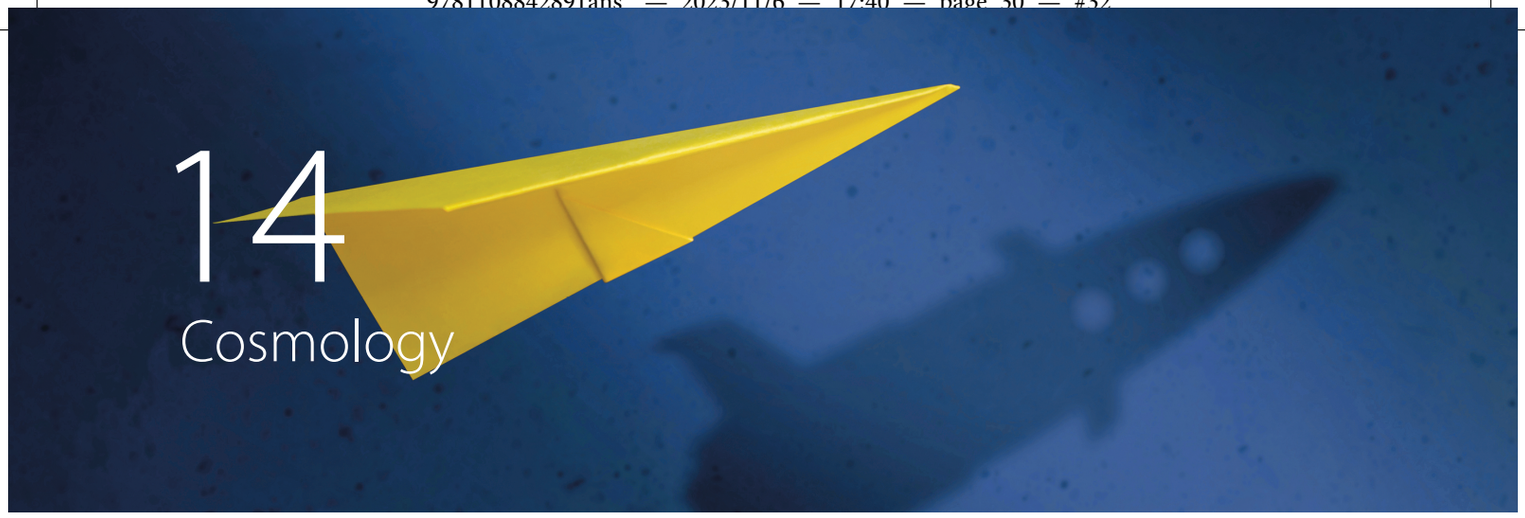
(**d**) 1.2×10^{-18} kg m/s

(**e**) 1.2×10^{-18} kg m/s

(**f**) 4.2×10^{-10} J

(**g**) 1200 MeV/c^2

13. 1582 MeV



14 Cosmology

14.1.2 Questions and Problems: The History of the Universe

9. (**a**) $c^5/(\hbar G^2) = 5 \times 10^{96}\ \mathrm{kg/m^3}$

(**b**) $6.5 \times 10^{-25}\ \mathrm{m}$

14.2.3 Questions and Problems: How Do We Know All That?

11. (**b**) $2D\sin(\theta)/\sin(\Delta\theta)$

(**c**) 1400 light-years

14.3.3 Questions and Problems: Infinite Universe, Finite Universe, Observable Universe

9. (**a**) Δx

(**b**) $2\Delta x$

(**c**) Yes

11. (**a**) $dx/dt = Hx$

(**b**) $x = x_0 e^{Ht}$

13. (**a**) $\dfrac{A_E L}{4\pi R^2}$

(**b**) $A_E L \rho \Delta R$

(**c**) $\dfrac{A_E L}{16\pi R^2}$

(**d**) $A_E L \rho \Delta R$

14.4.3 Questions and Problems: The Friedmann Equations

9. (**a**) $k_{max} = 8\pi G\rho a^2/(3c^4)$

11. (**b**) $r = \left(\dfrac{3\kappa c}{4}\sqrt{\dfrac{3M}{\pi}}\, t + C\right)^{2/3}$

(**d**) $C = 0$

(**e**) 25 billion years

13. $T \ll 4 \times 10^{12}\ \mathrm{K}$

15. $\rho \propto a^{-4}$

17. (**a**) $Hx\,dt$

(**b**) $Hx + c$

(**c**) $dx/dt = 2x/(3t) + c$

(**d**) $x(t) = 3ct + Ct^{2/3}$

(**e**) $3ct$

(**f**) $x(t) = 3ct$

(**g**) 41.4 billion light years

14.5.3 Questions and Problems: Dark Matter and Dark Energy

7. $P < -\rho/3$

9. (**a**) $P = -\rho$

11. $3c^2\Lambda/(8\pi G)$