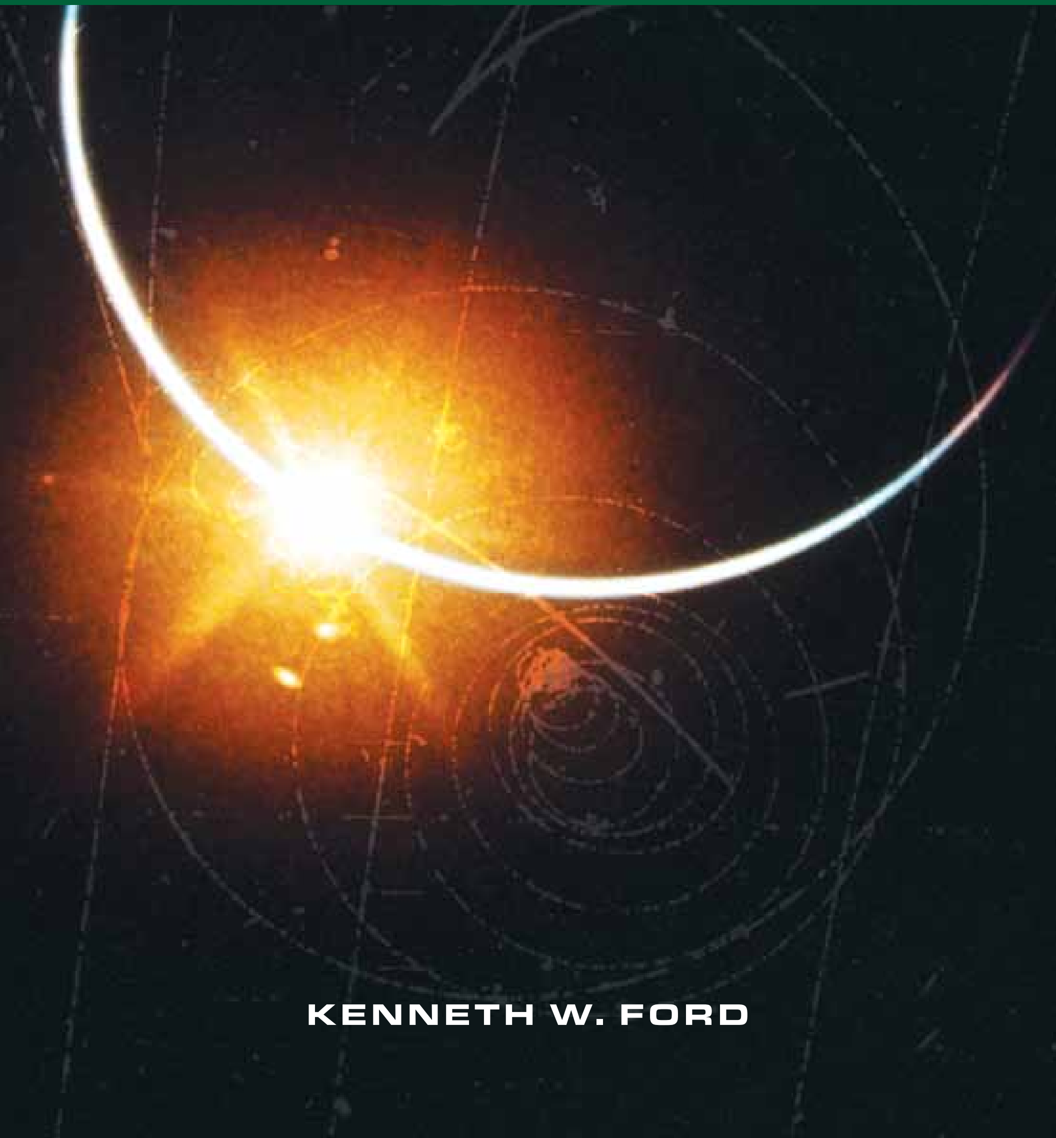
ANSWERS TO EXERCISES IN

BASIC PHYSICS



KENNETH W. FORD

PREFACE

What follows are answers to the exercises in *BASIC PHYSICS,* identical except for a few small changes to the answers provided for the use of instructors shortly after the book's 1968 publication. The changes are the addition of a Table of Contents, altered style for headings, and one altered page reference in the answer to Exercise 15.6 to reflect changed pagination in the 2017 version of the book. These answers may still be of some interest to teachers who buy and use the reissued book.

The reissued book is published by World Scientific. This Manual is provided by H Bar Press. It has been prepared by Adam B. Ford.

KEN FORD
DECEMBER 2016

ORIGINAL NOTE TO INSTRUCTOR

In most of the exercises requiring numerical calculation, numbers have been chosen to be physically meaningful, rather than to lead to elementary arithmetic. Students should therefore be encouraged to develop skill in using the slide rule for multiplication and division. Most numerical answers are given here to three significant figures, although two figures are usually quite sufficient in students' answers.

We have worked hard to reduce errors in this manual to a low level. Undoubtedly a few remain. The author will be most grateful to instructors who call attention to any wrong answers or ambiguous questions.

This manual was prepared by Kenneth W. Ford with the assistance of Harris Benson, David Tang, and John Williams.

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CONTENTS

CHAPTER ONE

1.1. (a)10; (b)5×10^{15}; (c)6.30×10^{7}; (d)3.30×10^{-7}.

1.2. (1)(a)10^{4}yr; (b)10^{7}yr; (c)10^{10}yr. (2)(a)10^{-22} sec; (b)10^{-18}sec; (c)10^{-15}sec.

1.3. About 10^{82} elementary particles; $R \cong 6 \times 10^{13}$cm (or 10^{14} as order of magnitude); comparable in size to one of the largest stars.

1.4. Shrinkage factor 10^{19}: Earth to 10^{-10}cm; atom to 10^{-27}cm.

1.5. Expansion factor 10^{10} (or 2×10^{10}): nucleus to 10^{-2}cm (or 2×10^{-2}cm); man to 2×10^{12}cm (or 4×10^{12}cm).

1.6. (a)time; (c)temperature; (g)disorder. [At this stage, student should not be penalized for omitting (g).]

1.7. (1) and (4). [(5)is debatable.]

1.8. Man's complexity requires that he be constructed from an enormous number of atomic units.

1.12. After 25 sec: A, 3,125 ft; B, 2.5 miles; C, 2,275 ft. Law, $H = Ct^2$. Searching experiment should involve other rockets, other times, both intermediate times and times longer than 20 sec.

CHAPTER TWO

2.1. Alpha particle, no, because constituents known; beta particle, yes, because no known constituents.

2.2. (1)3.3×10^{-14}sec; most particles in table live longer (exceptions, π°, η°, Σ°). (2)10^{-11}cm, less than atomic diameter.

2.3. (1) π°, η, Σ°. (2)Neutron.

2.4. (1)p, 2γ, e^-, $\bar{\nu}_e$, ν_μ, $\bar{\nu}_\mu$. [Note: Early printings contained error in Table 2.1, showing decay $\Lambda^\circ \rightarrow p+\pi^+$ instead of $\Lambda^\circ \rightarrow p+\pi^-$. Student not noticing this error would get e^+, ν_e instead of e^-, $\bar{\nu}_e$ in this list of final products.] (2)The average charge becomes more negative.

2.5. (1)(a)Positive charge curves to the left, negative charge to the right; (b)slower particles leave denser tracks. (2)The electron was negative; spiraling to the right, it lost energy, and accordingly its radius of curvature decreased.

2.8. Three of the combinations form atoms. Only the proton-positron combination does not.

CHAPTER THREE

3.1. Shrinkage factor $2\text{x}10^{14}$: $3\text{x}10^{8}$ miles.

3.2. (1)$8\text{x}10^{5}$cm/sec. (2)Mach 24.

3.3. 150,000 years = $1.5\text{x}10^{5}$years.

3.4. It is less than one mile; time, 3.73 min, or 3 min 44 sec.

3.5. (a)39.37 in/meter; (b)$6.32\text{x}10^{4}$ A.U./light-year; (c)1.467 (ft/sec)/(mile/hr).

3.6. (1)$1.10\text{x}10^{27}$ electrons. (2)About $1.8\text{x}10^{51}$ electrons.

3.7. $6\text{x}10^{58}$ hydrogen atoms (in mass of 10^{35}gm)[or $1.2\text{x}10^{57}$ hydrogen atoms in solar mass of $2\text{x}10^{33}$gm].

3.8. Mass $\sim$ volume $\sim$ (linear dimension)^3; height $\sim$ (linear dimension)^1.

3.9. (1)$4.1\text{x}10^{-9}$erg. (2)(4.1 to 3.3)$\text{x}10^{-7}$cm/sec, for mass range 50 to 75 kg; (2.5 to 3)$\text{x}10^{8}$sec, or 8.0 to 9.5 years.

3.10. 1 erg = 1 gm cm^2/sec^2.

3.11. (1)$(7.5\times10^5/2.68\times10^3)^2 = 7.82\times10^4$. (2)$\frac{1}{2}(v/c)^2 = 3.13\times10^{-10}$.

3.12. (mass energy/kinetic energy) = $2c^2/v^2 = 5\times10^{11}$.

3.13. (1)6.24×10^{18} electrons/coulomb. (2)Yes (20 amp). [However, a student versed in practical matters might know that this overload will not necessarily blow the fuse.]

3.14. (1)5.27×10^{17} e.s.u./gm. (2)Fraction 3.48×10^{-15}.

3.15. (1)No; his mass is constant. (2)Yes; greatest weight standing on earth, least weight standing on moon. (This answer interprets weight as gravitational force, not as reading of scale. Although "weightless" in orbit, he experiences considerable gravitational force in orbit.)

3.17. Comparison of two such clocks, or comparison with earth's orbital period.

CHAPTER FOUR

4.1. The rug experiences an equal and opposite change of charge.

4.2. Yes, in principle. No, in practice. It would require the accumulation of one gram of anti-matter or one gram of certain particles such as neutral pions. Neither is practical. (However, the change of mass in a thermonuclear explosion may exceed one gram.)

4.3. Any direction is possible for one fragment; the other must fly in the opposite direction. Total momentum zero implies equal magnitudes of two momenta. Equal mass and equal momentum imply equal kinetic energy (K.E. = $p^2/2m$).

4.4. The astronaut recoils and slowly spins to preserve zero total momentum and zero total angular momentum.

4.5. (a)Upward from page; (b)upward from page; (c)upward from page. Line joining cars always rotates counterclockwise.

4.6. See Figure 26.5.

4.7. (1)(a)67.5 MeV = 1.08x10^{-4}erg; (b)3.60x10^{-15} gm cm/sec; (c)oppositely directed along same straight line. (2)Energy, momentum, and angular momentum are most directly relevant. (3)Total photon energy would be greater; photon energies and momenta would not necessarily be equal; photons would not be oppositely directed.

4.8. $\mu^+ \rightarrow e^+ + \nu_e + \overline{\nu_\mu}$. Muon-family number, $-1 \rightarrow 0+0-1$; electron-family number, $0 \rightarrow -1+1+0$.

4.9. (1) $n \rightarrow p + e^- + \overline{\nu_e}$. Energy: $m_n > m_p + m_e$. Charge: $0 \rightarrow 1-1+0$. Electron-family number: $0 \rightarrow 0+1-1$. Baryon number: $1 \rightarrow 1+0+0$. (2)Momentum of p + momentum of e define a plane. Only if momentum of $\overline{\nu_e}$ lies in the same plane can three momenta sum to zero.

4.10. $\Sigma^+ \rightarrow p + \pi^\circ$. Energy: $m_\Sigma > m_p + m_\pi$. Angular momentum: $\frac{1}{2} \rightarrow \frac{1}{2}+0$. Charge: $1 \rightarrow 1+0$. Baryon number: $1 \rightarrow 1+0$.

4.11. (a)Violates angular momentum, charge, muon-family number; (b)violates energy, angular momentum, muon-family number; (c)allowed; (d)violates angular momentum, baryon number; (e)violates charge; (f)violates angular momentum, electron-family number.

4.12. (a)Angular momentum: $\frac{1}{2}+\frac{1}{2} \rightarrow \frac{1}{2}+\frac{1}{2}+0+0$. Charge: $0+1 \rightarrow 0+0+1+0$. Baryon number: $1+1 \rightarrow 1+1+0+0$. (d)Angular momentum: $\frac{1}{2}+\frac{1}{2} \rightarrow 1+1$ (O.K. as vector combination). Charge: $1-1 \rightarrow 0+0$. Electron-family number: $-1+1 \rightarrow 0+0$.

4.14. $p+p \rightarrow p+p+\pi^\circ+\pi^\circ$; or $p+p \rightarrow p+p+\pi^+ +\pi^-$, or $p+p \rightarrow p+n+\pi^+ +\pi^\circ$; or $p+p \rightarrow n+n+\pi^+ +\pi^+$, or $p+p \rightarrow p+p+p+\overline{p}$, or $p+p \rightarrow p+p+n+\overline{n}$, or $p+p \rightarrow p+p+\gamma+\gamma$, or $p+p \rightarrow p+\Lambda^\circ+K^+ +\pi^\circ$; or $p+p \rightarrow p+\Sigma^+ +K^\circ+\pi^\circ$; etc.

4.16. A bell-shaped curve of maximum height $R = A/\pi D$ centered at $T = 5+(A/D)$. The formula must fail as D approaches zero. (It is satisfactory at A = 0.)

4.17. (a) and (b). Consider an interval Δt during which just one pair shake hands. If both were in the odd group, both join the even group. If both were in the even group, both join the odd group. If one was in the even group and one in the odd group, both change groups. For the first two possibilities, the number in each group changes by two. For the third possibility, the number in each group does not change. Oddness or evenness of each group is preserved.

CHAPTER FIVE

5.1. (1)3.3×10^{-19}sec. (2)1.80×10^{13}cm = 1.12×10^{8} miles. (3)c = 9.84×10^{8} ft/sec = 1.86×10^{5} miles/sec = 6.71×10^{8} miles/hr = 3×10^{4}cm/microsec. (4)f = 3×10^{10}sec^{-1}; 2.24×10^{4}cm; 6.0×10^{14}sec^{-1}.

5.2. n = 20. $N = 2^n$.

5.3. Both.

5.5. Vector analysis; mechanics (esp. celestial mechanics); group theory; statistics; possibly numerical arithmetic.

5.6. (1)Rotations about different axes, sealing a container and heating its contents, drinking and driving, etc. (2)Displacements in space, spending two sums of money, accelerating and decelerating, etc.

5.7. A-B = X may be defined by B+X = A (what X, added to B, gives A?). A/B = X may be defined by BX = A (what X, multiplied by B, gives A?). Subtraction generalizes positive integers to all integers and zero. Division generalizes positive integers to positive rational numbers.

5.8. (1)

	+1	-1	$\sqrt{-1}$	$-\sqrt{-1}$
+1	+1	-1	$\sqrt{-1}$	$-\sqrt{-1}$
-1	-1	+1	$-\sqrt{-1}$	$\sqrt{-1}$
$\sqrt{-1}$	$\sqrt{-1}$	$-\sqrt{-1}$	-1	1
$-\sqrt{-1}$	$-\sqrt{-1}$	$\sqrt{-1}$	+1	-1

(2) $\sqrt{-1}$.

5.9. (a)$7+4\epsilon$; (b)$-2+2\epsilon$; (c)$-21-10\epsilon$; (d) ϵ; (e)$1-\epsilon$.

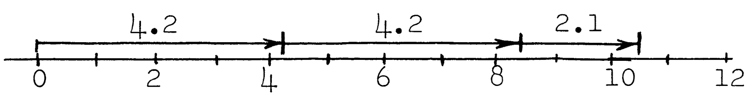
5.10. Seven crossings. This is certainly mathematics. It is probably not science, but opinions may legitimately differ. The mode of reasoning is scientific.

5.11. Every domino covers a red and a black square. Thirty-one dominoes cover 31 red and 31 black squares, leaving 1 red and 1 black uncovered, but diagonally opposite corners have the same color. This is mathematics. Solutions less elegant than this "color" solution are possible.

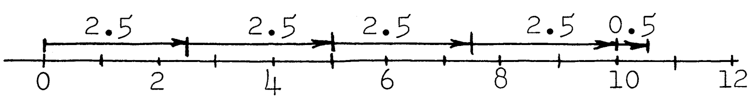
5.12. Precision tests of the theorems of Euclidean geometry (e.g. sum of internal angles of triangle equals 180 deg) would show the surface to be non-Euclidean.

CHAPTER SIX

6.2.



or



6.3. Numerical: (b), (d), (h); vector: (a), (c), (g); neither: (e), (f).

6.4. None. All are numerical quantities without direction.

6.5. (1)(a)2; (b)0; (c) $\sqrt{2} = 1.414$. (2)60 deg between their directions.

6.6. Δv has magnitude 1.414×10^3 cm/sec, and is directed to the southeast.

6.7. F_3 has magnitude 6 dynes and is directed approximately 60 deg south of west.

6.8. From a direction 18.4 deg (arc tan 0.333) west of north at a speed of 3.16×10^3 cm/sec.

6.9. Ground speed 240 miles/hr; direction 62.2 deg east of north.

6.10. (1)30 deg west of north. (2)86.6 miles/hr.

6.11. Position vector components are 12m to east, 5m to south; magnitude is 13m.

6.14. $a = 810$ cm/sec^2, about 0.83g. This is reasonable on a banked track. It is possible, but somewhat questionable, on a level surface.

6.15. (1)$a = 2\pi C/T^2 = 242$ cm/sec$^2 \cong 0.25$g.
(2)Altitude = 3,960 mi; period = 240 min.

6.16. 1.02×10^5 cm = 0.634 mile. Optional: Angle of bank = 45 deg.

6.17. The velocity vector must be turned through a given angle in half the time; this accounts for one factor of two increase in acceleration. Being doubled in magnitude, the velocity vector requires twice the change of velocity to turn through a given angle; this accounts for the other factor of two.

6.18. The velocity vector has the same magnitude, but rotates at only half its previous rate. The acceleration is therefore halved.

6.19. Tangential to circle, opposite to direction of velocity vector.

6.20. (1)$F_{1x} = 100$ dynes, $F_{1y} = 0$; $F_{2x} = 0$, $F_{2y} = 100$ dynes; $F_{3x} = 70.7$ dynes, $F_{3y} = 70.7$ dynes.
(2)$F_{Tx} = 170.7$ dynes, $F_{Ty} = 170.7$ dynes.
(3)$F_T = 241$ dynes; direction is northeast.

6.21. Airplane velocity relative to air: $v_{px} = 212$ mile/hr, $v_{py} = 212$ mile/hr. Wind velocity:

$v_{wx} = 0$, $v_{wy} = -100$ mile/hr. Airplane velocity relative to ground: $v_x = 212$ mile/hr, $v_y = 112$ mile/hr; $v = 240$ mile/hr.

6.22. (1)0.0698 radian/min = 1.16×10^{-3} radian/sec. (2)524 radian/sec.

6.23. 30 radian/sec; 4.78 revolutions per sec.

6.24. (a)1.745×10^{-3} radian/sec; (b)1.45×10^{-4} radian/sec; (c)58.7 radian/sec; (d)1.99×10^{-7} radian/sec.

6.25. (a)0; (b)0; (c) $-\sqrt{\frac{1}{2}} = -0.707$; (d)1.0.

6.28. (1)None are equal; $\mathbf{B}$ and $\mathbf{D}$ have equal magnitude; $\mathbf{A}$ and $\mathbf{B}$ have same direction; $\mathbf{C}$ is directed opposite to $\mathbf{A}$ and $\mathbf{B}$. (2)Sum $\mathbf{S}$: $S_x = -5$, $S_y = 5$. (3)$\mathbf{A}$-$\mathbf{C}$.

6.29. (1)$A_x = 2.00$, $A_y = 2.00$; $B_x = 1.732$, $B_y = 1.00$. (2)Sum $\mathbf{S}$: $S_x = 3.73$, $S_y = 3.00$; $S = 4.78$, angle 38.8 deg above x-axis. (3)Difference $\mathbf{D}$: $D_x = 0.268$, $D_y = 1.00$; $D = 1.035$, angle 75 deg above x-axis.

6.30. (2)$C_x = 9.20$, $C_y = 7.00$; $D_x = 7.93$, $D_y = 5.00$. (3)No, since $\mathbf{A}$ and $\mathbf{B}$ are not parallel (or antiparallel).

6.31. Method 1: Final vectors $\mathbf{p}_1$ and $\mathbf{p}_2$ form the sides of a 45-45-90 triangle. Therefore $p_1 = p_2$. Method 2: $p_{1y} + p_{2y} = 0$ (y-axis to north); therefore $|p_{1y}| = |p_{2y}|$. Since $\mathbf{p}_1$ and $\mathbf{p}_2$ make the same angle with the north-south line, $p_1 = p_2$.

6.32. 30 deg on the other side of the extended track of the pion (90 deg to the track of the kaon).

6.33. (1)750 cm/sec. (2)650 cm/sec.

6.34. Yes, at least one neutral particle was produced, to conserve momentum. If one, its momentum was 51.3 units at an angle of about 257 deg to the positive x-axis. Yes, two neutral particles might have been produced.

6.35. It is equivalent to three numerical equations, or it specifies the equality of directions as well as magnitudes.

6.37. 10(b-a).

CHAPTER SEVEN

7.1. (1)$m\ell t^{-1}$. (2)gm cm/sec. (3)$[Ft] = m\ell t^{-2} \times t = m\ell t^{-1}$.

7.2. $[Fv] = m\ell t^{-2} \times \ell t^{-1} = m\ell^2 t^{-3}$; $[E/t] = m\ell^2 t^{-2}/t = m\ell^2 t^{-3}$. 1 dyne = 1 erg/cm.

7.3. 16,700 miles/hr.

7.4. (a)3.00×10^{10}cm/sec; (b)91.44 cm; (c)3.156×10^{3}sec; (d)7.87×10^{3}cm^3/sec; (e)975 cm/sec^2.

7.5. $\ell = Fm^{-1}t^2$.

7.6. Dimension $m\ell^{-1}t^{-1}$; unit gm/(cm sec).

7.7. C = 0.30G; C = PG.

7.8. 1 credit-hour = 4.50×10^4 classroom-seconds.

7.10. 3,632 cm^3.

7.13. Cm^2/sec (or ft^2/hr, or acres/day, etc.).

7.14. Cubic, $V = L^3$. (2)(length)^2.

7.16. Component of velocity in direction of positive displacement.

7.17. Uniformly accelerated motion (a = 500 cm/sec^2) for 4 sec, followed by constant speed motion (v = 2,000 cm/sec).

7.19. Slope is similar exponential curve reflected across time axis to negative values; slope of slope is positive and proportional to original curve.

7.20. Fit of the points to a smooth curve suggests that experimental uncertainty is probably overestimated; error bars are probably too long.

7.21. $1/\sqrt{n}$. Fourfold.

7.22. About 15 to 25 cm/sec.

7.23. (a)(5.1 to 6.1)$\times 10^{-9}$sec, for 5 to 6 ft; (b)5.36$\times 10^{-6}$sec; (c)3.156$\times 10^{7}$sec.

7.24. (1)$\ell = v^2a^{-1}$; $t = va^{-1}$. (2)For example: speed of light; acceleration of gravity at fixed point on earth, or acceleration of moon at particular point in its orbit.

7.25. (2)Maximum slope is at lowest values of H and M; the slope in the vicinity of the lowest plotted point is about 5 cm/kg. (3)At H = 35cm, M ≅ 1.5 kg; at H = 175cm, M ≅ 70 to 75 kg.

7.26. (2)At t = 0, v ≅ 30 cm/sec (31.4 cm/sec exact); at t = 1/8 sec, v ≅ 20 to 25 cm/sec (22.2 cm/sec exact); at t = 1/4 sec, v = 0; at t = 1/2 sec, v ≅ 30 cm/sec, opposite direction (31.4 cm/sec exact). (3)1.0.

7.27. (2)(a)$v_{min} = 0$ at $t = 0$; (b)v_{max} = 150 mile/hr at $t = \infty$; (c)$a_{min} = 0$, at $t = \infty$; (d)$a_{max} \cong$ 20 to 30 (miles/hr)/sec (exact 25(miles/hr)/sec), at t = 0. [Other units: a_{max} = 36.7 ft/sec^2 = 9.0$\times 10^4$ miles/hr^2 = 1,120 cm/sec^2 = 1.14g.]

7.28. (1)Error ≅ ±1% (±0.8% to ±1.6% acceptable).

(2)

Trial	v_C/v_B
1	1.411
2	1.426
3	1.392
4	1.431
Average	1.415

It is consistent to assume v_C/v_B = constant within experimental error. (3)$n = \frac{1}{2}$.

CHAPTER EIGHT

8.1. 10^5 dynes, vertically upward.

8.2. (1)$v = 1.5$ cm/sec. (2)$x_o = 2$ cm. (3)$x = 17$ cm.

8.3. (2)$v_{av} \cong 8$ to 9 m/sec.

8.4. (1)$a_x = -50$ cm/sec^2. (2)$v_x = -100$ cm/sec.
(3)No. (4)$x_{max} = 100$ cm.

8.5. $v_{av} = v_o + \frac{1}{2}at$; $v_{av} = \frac{x-x_o}{t}$; $x = x_o + v_{av}t = x_o + v_ot + \frac{1}{2}at^2$.

8.6. 5.63 cm/sec^2.

8.7. (1)102 gm. (2)0.903 sec. (3)443 cm/sec.

8.8. (1)100 cm/sec. (2)5×10^6cm/sec$^2 \cong 5{,}000$g.
(3)2×10^{-5}sec.

8.9. (2)(a)6.86×10^7 dynes; (b)zero; (c)zero.

8.10. 2×10^6 dynes.

8.11. $m = 1.33\times10^6$gm; 2,940 lb. Optional: Because of friction, the actual mass is less than these figures.

8.12. (1)140 cm/sec^2 = g/7. (2)280 cm/sec.
(3)2.07 sec.

8.14. Approximate mass-independence of T implies $K \sim m$; K is constant for variable x for a given pendulum. Optional: $T \sim \sqrt{\ell}$.

8.15. For origin at earth center, $r_{c.o.m.} = r_{moon}[m_m/(m_m + m_e)] = (239{,}000 \text{ miles}) \times (7.34\times10^{25}\text{gm}/605\times10^{25}\text{gm}) = 2{,}900$ miles.

8.16. (1)At $x = 5$, $y = 2$. (2)At $x = 3$, $y = 2$.

8.17. (1)0.646 A from C, 0.484 A from O.
(2)2.25×10^4cm/sec, upward.

8.18. They accelerate apart relative to their center of mass. The center of mass continues in orbit, at or near the spacecraft.

8.19. The center of mass is uniformly accelerated. It gains a velocity increment of 40 cm/sec.

8.20. (1)Law of force: $F = Km_G$. Law of motion: $F = m_I a$. Therefore $a = Km_G/m_I \sim m_G/m_I$. (2)At a given location, $a \sim m_G/m_I$ = constant for all bodies.

8.21. $a = v^2/r = \omega^2 r = (2\pi/86{,}400\ \text{sec})^2 \times 6.38\times10^8\ \text{cm} = 3.4\ \text{cm/sec}^2$. The average radius of curvature of motion for a point on the surface is less than the radius of the earth.

8.22. (1)Zero force; no acceleration. (2)5.4×10^5 dynes, supplied by track.

8.23. (1)2×10^3 cm/sec. (2)Speed decreases; angular velocity increases.

8.24. (1) a(top) = 980 cm/sec^2 = g; a(bottom) = 2,940 cm/sec^2 = 3g. (2)v(top) = 8.85×10^3 cm/sec (=198 miles/hr); v(bottom) = 1.53×10^4 cm/sec (= 343 miles/hr).

8.25. 1.96×10^{-13} cm; the effect is insignificant.

8.26. $v_x = v_{xo}$; $v_z = v_{zo} - gt$. $z_{max} = v_{zo}^2/2g$.

8.27. The actual range is greater; the earth curves away to permit longer flight.

8.28. Time to rise = time to fall, so maximum height is reached at half of the total time. Since v_x = constant, this is also the midpoint of the horizontal distance.

8.29. (1)No, it falls only 5×10^{-10} cm. (2)1.7×10^3 cm. (3)10^{-4} sec.

8.30. (1)$x_C = (v_o - v_C)t + \frac{1}{2}gt^2 = -200\,t + \frac{1}{2}gt^2$. (2)t = 0.408 sec. (3)204 cm below A. (4)Upward with initial speed 200 cm/sec.

8.31. Projected altitude, $y_p = v_{yo}\,t$; actual altitude,

$y = v_{yo}t - \frac{1}{2}gt^2$; difference, $\Delta y = y_p - y = \frac{1}{2}gt^2$, which is the same as the distance of fall of the can.

8.32. (1)t^{-1}. (2)A is x_o, the x-coordinate at t = 0. (4)F = Kx, with K > 0.

CHAPTER NINE

9.1. (1)1.7×10^{-15}gm cm/sec. (2)5×10^{-10} dyne = 5×10^{-10} (gm cm/sec)/sec.

9.2. (1)1.2×10^{7} dynes. (2)5.83 sec.

9.3. (a)4.5×10^{-16}gm cm/sec, horizontally to the right; (b)1.5×10^{-16}gm cm/sec, horizontally to the right; (c)3.36×10^{-16}gm cm/sec, at an angle of 26.6 deg above the horizontal.

9.5. 9.8×10^{8} dynes.

9.6. a = 2.68×10^{-20} cm/sec^2. Motion in one hour, 1.7×10^{-13}cm, comparable to the size of an elementary particle.

9.8. (Notation of Figure 9.4) $F_1 = 2.36\times10^{7}$ dynes, upward; $F_2 = 1.18\times10^{7}$ dynes, downward; $F_G = 0.98\times10^{7}$ dynes, downward. Net upward force, 2.0×10^{6} dynes.

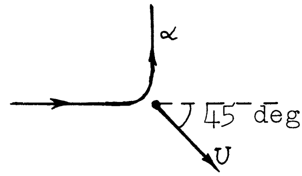
9.9. (a)mg; (b)mg. (Both about 5 to 8×10^{7} dynes.)

9.10. 47.3 miles/hr in direction of motion of truck. Velocity change of car = 127 miles/hr; velocity change of truck = 12.7 miles/hr.

9.11. (a)They will rebound with equal and opposite speed; (b) they will stop and remain at rest. Momentum is conserved for both.

9.12. Zero.

9.13. $v = 2.5 \times 10^{7}$ cm/sec.



9.14. (1)$p_o^{2} = p_1^{2} + p_2^{2}$; $p_o = 2mv_o$, $p_1 = p_2 = mv_1 = mv_2$; therefore $4v_o^{2} = 2v_1^{2}$, $v_1 = \sqrt{2}\, v_o$.

Answer of equation 9.39 is high by 0.13%.

(2)$p_{1y} + p_{2y} = 0$. $p_{1y} = p_1 \cos(45\text{ deg}) = 0.707p_1$; $p_{2y} = p_2 \cos(135\text{ deg}) = -0.707p_2$. Therefore $0.707(p_1 - p_2) = 0$; $p_1 = p_2$.

9.15. (1)5.89×10^{-15} gm cm/sec, directed at 30 deg to pion flight direction. (2)2.12×10^{10} cm/sec. <u>Optional</u>: 1.73×10^{10} cm/sec.

9.16. (2)During the acceleration, the exhaust speed relative to a fixed frame varies from $v_{ex} - v_1$ to $v_{ex} - v_2$. This variation can be ignored only if $v_2 - v_1$ is much less than v_{ex}.

9.17. (a)2×10^{6} gm; (b)2×10^{6} gm.

9.18. (1) $\Delta p = 2.3 \times 10^{5}$ gm cm/sec; 13%. (2)It was imparted to the air.

9.19. 12.5 miles/hr, directed 36.9 deg north of east; it is the same before, during, and after collision.

9.20. (1)10m from car 1, 15m from car 2. (2)120 cm/sec. (3)Same.

9.21. (1)Momentum conservation requires equal and opposite velocities after the collision, but it says nothing about the magnitude of each velocity or about direction. (2)Total momentum is always conserved. The momentum of the two balls is possibly not conserved if they interact with something else during their collision.

9.22. (1)Each second a mass χ of propellant gains momentum χv_{ex}, or $\Delta p/\Delta t = \chi v_{ex}$. Downward force of the rocket on the exhaust is therefore $F_{ER} = \chi v_{ex}$. By Newton's third law, upward force of the exhaust on the rocket is $F_{RE} = F_{ER} = \chi v_{ex}$. (2)$2.45 \times 10^5$ gm/sec.

9.23. Self acceleration of systems is a main point.

CHAPTER TEN

10.1. (a)1.67×10^{-9} gm cm^2/sec, upward from page; (b)8.35×10^{-10} gm cm^2/sec, directed upward from page; (c)zero.

10.2. Solution is analogous to that for torque in Figure 10.12.

10.3. (1)3 radians/sec. (2)1.5×10^6 gm cm^2/sec.

10.4. (1)Zero. (2)1.58×10^8 gm cm^2/sec. (3)With respect to the boy, gravitational force exerts a torque on the stone.

10.5. $L = 2\pi mR^2 \cos\theta / T$ = instantaneous magnitude, directed at angle θ to the earth's axis.

10.6. (1)Vertically upward. (2)Horizontally to the right.

10.8. (1)6.33×10^{-27} gm cm^2/sec $= 6\hbar$ (2) $7\hbar$ maximum.

10.9. Angle of 30 deg to a radial line, or 60 deg to the rim.

10.10. 2.25×10^9 gm cm^2/sec.

10.11. For example, current-carrying wire near magnet: Forces on wire and magnet are equal and opposite, but not directed along same line. (Question inappropriate for this chapter.)

10.12. (1)4.9×10^7 dyne cm. (2)0.0817 radian $\cong$ 4.7 deg.

10.13. (1)Inward toward the page. (2)$L = mv_0 b$. (3)$v = \frac{1}{2}v_0$.

10.14. Hand must move so that hand is not at the center of the circle traced out by the moving weight.

10.15. Change of engine angular momentum produces an opposite change of automobile angular momentum. An engine without this effect is possible in principle; it would require counter-rotating parts.

10.16. Yes, the day would lengthen slightly, since lesser angular velocity would be required for the same angular momentum.

10.17. (1) 9.6×10^6 gm cm^2/sec. (2) For $m \cong 70$ kg, $r \cong 15$ cm, $\omega \cong 0.6$ radian/sec (order of magnitude sufficient).

10.18. (1) Nothing. (2) Turntable rotates counter-clockwise, seen from above. (3) Turntable stops rotating. (4) Turntable rotates counter-clockwise, seen from above, half as fast as in (2).

10.19. 1.027.

10.20. Consider, for example, front paws extended, rear paws retracted. Counter-rotation with equal and opposite angular momentum of parts produces a greater angular change in rear. Reversal of paws and opposite counter-rotation leads to a net rotation of the whole cat.

10.21. Exhaust acquires angular momentum opposite to the angular momentum acquired by the rocket (relative to the center of the earth).

10.22. Astronaut and bicycle turn end over end. Angular momentum is conserved. Stopping the wheels stops the whole rotation.

10.23. (1) He exerts a downward torque. This tends to tilt the horizontal angular momentum vector, and with it the axle, away from the horizontal. (2) This does not violate Newton's third law. The total internal force in the system of boy plus wheel is zero. Optional: Left handle "wants" to go up, right handle down.

10.24. (1) Upward force of support, acting at pulley. Downward forces of gravity, acting at monkey and counterweight. (2) Zero. (3) Angular momentum conservation requires the counterweight to move up at the same speed as the monkey. The rope moves at speed v, up on the left, down on the right.

10.25. $F_1 = mgw/2h$. F_2 makes angle arc tan(w/2h) with the vertical.

10.26. (1)The force produces no net torque with respect to the center of the planet (therefore its spin is constant) and no net torque with respect to the force center (therefore its orbital angular momentum is constant). (2)See discussion on page 366.

CHAPTER ELEVEN

11.1. (a)100 cm/sec; (b)250 cm; (c)5×10^9 ergs; (d)5×10^9 ergs.

11.2. (1)Force is perpendicular to the direction of motion ($F_{\parallel} = 0$). (2)Constant: speed, kinetic energy, potential energy, angular momentum, magnitude of momentum, radius; changing: velocity vector, momentum vector, angle.

11.3. $a = F_A/m$; $v^2 = 2as$, or $s = v^2/2a = v^2m/2F$; then $Fs = \frac{1}{2}mv^2$.

11.4. (1)2.96×10^9 cm/sec. (2)$F_{AV} = 2\times10^{-9}$ dyne.

11.5. (1)Work on air in distance Δs is $\Delta W = F\Delta s$. Divide by Δt. $\Delta W/\Delta t = F\Delta s/\Delta t$, or $P = Fv$. (2)4.2×10^{11} ergs/sec = 42 kilowatts.

11.6. Two particles of equal and opposite momentum moving along the same straight line.

11.7. (1)4.59×10^5 cm. (2)3.57×10^5 cm.

11.8. (1)5.99×10^{11} ergs. (2)407 cm. (3)$h = v^2/2g$.

11.9. Energy conservation: $\frac{1}{2}m(v_x^2 + v_y^2) + mgy = \frac{1}{2}m(v_{xo}^2 + v_{yo}^2)$. Since $v_x = v_{xo}$ = constant, $\frac{1}{2}mv_y^2 + mgy = \frac{1}{2}mv_{yo}^2$. At the peak, $v_y = 0$, and $mgy_{max} = \frac{1}{2}mv_{yo}^2 = \frac{1}{2}m(v_o \sin\theta)^2$. Thus y_{max} =

$v_o^2 \sin^2\theta/2g$. For $\theta = 0$, horizontal motion, no altitude gain. For $\theta = 90$ deg, vertical motion, answer reduces to Equation 11.28.

11.10. Rope must be pulled through 4 cm to raise lower pulleys 1 cm.

11.11. (1) M.A. $= 2\pi R/d$. (2) $\pi R/d$.

11.12. (1) Component of $F = mg \sin\theta$; $a = g \sin\theta$; $v = \sqrt{2as} = \sqrt{2g \sin\theta\, L} = \sqrt{2gy}$ (since $y = L \sin\theta$). (2) $\frac{1}{2}mv^2 = mgy$; $v = \sqrt{2gy}$. Evidently method 2 is more attractive.

11.13. (1) 1.98×10^4 cm/sec. (2)(a) K.E. $\cong 0$, P.E. $= 0$ (arbitrary choice); (b) K.E. $= 0$, P.E. $= mgh$; (c) K.E. $= 2mgh$, P.E. $= 0$.

11.14. (1) P.E. $= e\mathcal{E}x$. (2) Yes.

11.15. (1) 2.0×10^{-9} cm = 0.2 A. (2) 2.83×10^5 cm/sec. (3) $x = 0$.

11.16. (1) Horizontal line at positive energy. (2) A horizontal line segment touching neither the earth nor the P.E. curve.

11.17. (1) 30 MeV. (2) K.E. = 0, P.E. = 30 MeV.

11.18. (a) 0.0209 eV; (b) 1.90 eV; (c) 4.70×10^6 eV = 4.70 MeV; (d) 3.12×10^8 eV = 312 MeV.

11.19. (1) 30 kilotons. (2) 470 gm.

11.20. (1) 4.5×10^{21} ergs = 107 kilotons. (2) 4.6×10^8 cm = 4,600 km.

11.21. m_H less than $m_p + m_e$ by 2.42×10^{-32} gm; fractional mass change 1.45×10^{-8}.

11.22. Acid dissolving latched pin has greater mass and greater temperature, since latched pin had more total energy (effects imperceptible in practice).

11.23. 1.6×10^{21} ergs; 1.78 gm.

11.24. 2.42×10^{21} ergs; 2.69 gm. Sum of masses of separate electrons = 0.91 gm; mass difference, 1.78 gm.

11.25. (1)As satellite moves from apogee toward perigee (altitude decreasing). (2)As satellite moves from perigee toward apogee (altitude increasing). (3)Zero. Kinetic energy is the same after one revolution; therefore no net work was done.

11.26. (1)Momentum conservation requires equal magnitudes of two momenta. Since masses are equal, equal momenta imply equal speeds. Energy conservation requires these equal speeds to be the same in all such decays. (2)Kaon might have been moving; kaon might have decayed into 3 or more particles, the others neutral; kaon might have interacted with another system (e.g. a nucleus) at the moment of its decay.

11.27. (1)First particle brought to rest; second particle accelerated to speed v. (2)Equal magnitudes $v/\sqrt{2}$; both velocities at 45 deg to x-axis, on opposite sides of x-axis. Optional: Momentum conservation: $\underset{\sim}{p}_1 + \underset{\sim}{p}_2 = \underset{\sim}{p}$. For equal mass, this implies $\underset{\sim}{v}_1 + \underset{\sim}{v}_2 = \underset{\sim}{v}$. Energy conservation: $\frac{1}{2}mv_1^2 + \frac{1}{2}mv_2^2 = \frac{1}{2}mv^2$, or $v_1^2 + v_2^2 = v^2$. By momentum conservation, $\underset{\sim}{v}_1$, $\underset{\sim}{v}_2$, and $\underset{\sim}{v}$ form the sides of a triangle. By energy conservation, this is a right triangle (Pythagorean theorem).

CHAPTER TWELVE

12.1. (1)3.99×10^8 dynes. (2)3.99×10^8 dynes. (3)399 cm/sec^2. (4)6.67×10^{-20} cm/sec^2.

12.2. (1)0.25 dyne. Ratio of force to weight = 3.40×10^{-9}. (2)For example: Let air move at 100 cm/sec (about 2 miles/hr), striking body area of 5,000 cm^2. Then about 500 gm/sec of air strikes the man. If it loses half its speed (50 cm/sec), its rate of change of momentum is 2.5×10^4 gm cm/sec^2, which is the force of the breeze on the man in dynes (10^5 times greater than the gravitational force of the automobile).

12.3. cm^{3}gm^{-1}sec^{-2}.

12.4. (1)About 5 to $9x10^7$ dynes, for mass range 50 to 90 kg (110 to 200 lb). (2)One quarter of previous answer. (3)7 to 9.5 earth radii, about 28,000 to 38,000 miles, for above mass range.

12.5. Ratio = $2.3x10^{39}$. Gravity plays no role in atomic structure.

12.6. (1)980 cm/sec^2. (2)$7.90x10^5$cm/sec. (3)$5.06x10^3$ sec = 84.4 min. This is about 5 or 6 min less than the period of a typical low-altitude satellite.

12.7. More than 24 cm after an hour (first printing of book). $6.7x10^{-3}$cm after a minute (later printings).

12.8. About $4.4x10^4$sec or 12.2 hours, calculated with initial acceleration. (Note: The correct answer, including increasing acceleration as distance diminishes, is $\frac{1}{4}\pi$ times the above answer, or 9.6 hours. The roughly calculated answer is fairly good because most of the time is spent at large separation.)

12.9. (1)$a = GM_S/r^2$ = 0.59 cm/sec^2. (2)$4.42x10^4$ dynes. His weight is 1,660 times greater.

12.10. Effective mass at half-radius is $M_E/8$. Radius is $\frac{1}{2}R_E$. Force at surface/force at half-radius = $(M_E/R_E^2)/\left[(1/8)M_E/(1/4)R_E^2\right] = 2$.

12.11. The right side of Equation 12.1 depends only on properties of two objects. It is therefore implicit that the force on m_1 contributed by m_2 is independent of other possible masses m_3, m_4, etc. in the vicinity.

12.12. Oscillatory motion with amplitude equal to earth's radius (in fact simple harmonic motion).

12.13. (1)Equal forces in all directions sum to zero. (2)Explanation should make the point that within a given range of angles, there is more mass in the far wall than in the near wall.

12.14. Mercury and Venus. At midnight we see only outward from the earth's orbit. Mercury and Venus are always within the earth's orbit. The geocentric theory may explain the same fact, but not so simply. It requires correlated motion of the sun and inner planets.

12.16.(1)a = 16,445 miles; b = 11,045 miles; c = 12,185 miles. (2)e = 0.741.

12.17.(1)2,090 miles. (2)4.47.

12.18.(2)At perigee, Halley's comet is about 0.6 A. U. from the sun, within the orbit of Venus. At apogee, it is about 35.4 A. U. from the sun, beyond Neptune. (a = 18.0, b = 4.6, c = 17.4)

12.19.Visualize the plane of the satellite's orbit intersecting the earth. Only over the equator is its latitude constant.

12.20.(a)4.0; (b)2.0. The intermediate speed is closer to apogee speed than to perigee speed.

12.21.0.0894 year.

12.22.(a)26,300 miles; (b)88.4 min.

12.23.$v^2 \sim 1/r$.

12.24.(1)Expand $(X + \Delta X)^2$ and $(X + \Delta X)^3$. (2)12 miles.

12.25.(1)1.018. (2)252 min. (3)Answer (1) would be unchanged; it depends only on the conservation of angular momentum. However, Kepler's third law, $T^2 \sim r^3$, depends on the inverse square force law.

12.26.From Equations 12.21 and 12.24, $m_S/m_E = K_E/K_S$. From Kepler's third law, $K_E = T_{sat}^2/a_{sat}^3$ = (for instance) $(89\text{ min})^2/(4{,}100\text{ miles})^3 = 4.14\times10^{-4}$ $\text{sec}^2/\text{miles}^3$. $K_S = T_{earth}^2/a_{earth}^3$ = $(3.156\times10^7\text{sec})^2/(9.3\times10^7\text{ miles})^3 = 1.238\times10^{-9}$ $\text{sec}^2/\text{miles}^3$. Then $m_S/m_E = 3.34\times10^5$. Check: $m_S/m_E = 1.987\times10^{33}/5.98\times10^{27} = 3.32\times10^5$.

12.27.$T^2 = (4\pi^2/GM_J)r^{n+1}$. Only n = 2 gives Kepler's third law.

12.28.(1)a = 2.38 cm/sec^2. a/g = 0.00243. For most purposes, <u>a</u> may be neglected, and F = 0 is a satisfactory approximation. (2)1.72×10^{-3} radian, or about 0.1 deg.

12.29. (1) $v \cong \sqrt{GM_E/R} = \sqrt{gR}$. (2) 23.9. (3) $v/v_{esc} = \sqrt{\frac{1}{2}} = 0.707$.

12.30. (1) 215,000 miles (3.46×10^{10} cm) from center of earth; 23,800 miles (3.83×10^{9} cm) from center of moon. (2) The potential energy is negative. Consider a path starting at the point of zero force and moving away perpendicular to the earth-moon line. Work is required to move along this path to infinity.

12.31. (1) From radius r, $v_{esc} = \sqrt{2GM_E/r}$. (2) From surface, $v_{esc} = \sqrt{2GM_E/R}$. Ratio: $v_{esc}(\text{surface})/v_{esc}(r) = \sqrt{r/R}$. (3) At altitude $h = 3R$ = 11,900 miles.

12.32. (1) P.E. $= -GM_EM_S/r$. (2) K.E. $= GM_EM_S/2r$ (most easily derived from $mv^2/r = F$, or $\frac{1}{2}mv^2 = \frac{1}{2}Fr$). (3) E = K.E. + P.E. $= -GM_EM_S/2r$, so energy needed to reach zero energy is $\Delta E = +GM_EM_S/2r$. (4) Reason as in Section 12.9. From Equation 12.41, $\frac{1}{2}M_EV_{esc}^2 - GM_EM_S/r = 0$, or $V_{esc} = \sqrt{2GM_S/r}$.

12.33. (1) $V_{esc} = 4.21\times10^{6}$ cm/sec. (2) Ratio is 1.41 (it is $\sqrt{2}$). (3) $V_{esc}/v_{esc} = 3.76$. Getting to Neptune is very much more difficult than getting to the moon. The energy ratio is $(3.76)^2 \cong 14$.

12.34. Direct force measurements in the manner of Cavendish (Figure 12.14) could be used to define gravitational mass. One standard is needed, such as an object defined to be 1 kg, and the gravitational constant G is arbitrary. It could be set exactly equal to 6.67×10^{-8} dyne cm^2/gm^2 to keep the new mass scale similar to the old. The dyne must be defined in terms of equal masses a known distance apart.

12.35. (1) Two small rockets of equal and opposite thrust could be fired to produce a net torque, but no net force, on the rocket. Upon completion of the turn, the rotation could be stopped by firing another such pair of rockets, opposite in effect to the first pair. (2) The retro-rocket decreases the speed, the energy, and the angular momentum of the spacecraft. Given less speed at a given point, the craft will arc closer to the earth in the rest of its orbit than if the retro-rocket had not been fired. If it is able to complete a full orbit, it will return to the same altitude where the retro-rocket was fired. The greatest deviation from the previous orbit will be at the opposite point. The retro-rocket is most effective if fired at apogee, because this will produce the greatest decrease of its perigee.

12.36. (1) 8×10^{17} dyne cm. (2) 9.6×10^{19} gm cm^2/sec. (3) $v_o = \sqrt{gR^2/r} = 7.05\times10^5$ cm/sec, $L_o = 5.64\times10^{21}$ gm cm^2/sec, (K.E.)$_o$ = 2.49×10^{18} ergs. (4) $\Delta L/L_o = \Delta v/v_o = 0.0170$. $v = 7.17\times10^5$ cm/sec, $L = 5.74\times10^{21}$ gm cm^2/sec, K.E. = 2.57×10^{18} ergs. (5) The new orbit is outside the previous circle except where the thrust was applied. It is an ellipse with perigee = 8×10^8 cm. (6)(a) The new orbit would be an ellipse with apogee = 8×10^8 cm, inside the previous circle except at one point; (b) the new orbit would be an ellipse with apogee greater than 8×10^8 cm and perigee less than 8×10^8 cm, going both outside and inside the previous circle.

12.37. <u>Exact:</u> Half-period, by Equation 8.28 is $t = \frac{1}{2}T = \pi\sqrt{m/K}$. By Equation 8.24 and Figure 12.5, $K = mg/R$. Therefore $t = \pi\sqrt{R/g} = 2{,}530$ sec = 42.2 min. (Note this is the <u>same</u> as the half-period of a low-altitude satellite.) <u>Approximate</u>: (a) One might guess the time to be of the same order as a satellite half-period. (b) One might approximate the average acceleration as $a \cong \frac{1}{2}g$, and use $s = \frac{1}{2}at^2$ to get the time from the surface to the center = $2\sqrt{R/g}$, or the total time, $t = 4\sqrt{R/g}$ (high by 28%). (c) One might approximate the motion as having acceleration g for a distance R/2, then free coasting with speed $\sqrt{Rg}$ for a distance R, then having deceleration g for a distance R/2. This approximation yields $t = 3\sqrt{R/g}$ (low by 5%).

12.38. (1)Kepler's laws summarize planetary observations and do not, by themselves, lead to predictions or explanations of other kinds of phenomena. (2)Earth satellites are governed by the same laws of motion as the earth, and experience exactly the same kind of force as the earth, differing in magnitude only by a constant factor.

12.39. (1)A straight line of slope -2g/R with value $a = g$ at $h = 0$. (2)At the point $r = R$, both graphs have identical acceleration. For r somewhat greater than R, both agree as to rate of change of acceleration with height. (3)An experiment at large r would easily reveal the difference. The modified formula predicts zero acceleration at $h = \frac{1}{2}R$, and repulsion by the earth at greater altitudes. Optional: The correct formula may be written $a = gR^2/r^2$. Write $r = R + h$. Then $a = g/(1 + h/R)^2$. Use the expansion $(1 + x)^{-2} \cong 1 - 2x$ for small x to obtain $a \cong g(1 - 2h/R) = g - 2gh/R$, valid for h much less than R.

CHAPTER THIRTEEN

13.1. $P = \frac{212}{180} P_o - \frac{32}{180} P_1 + \frac{P_1 - P_o}{180} T =$

$\frac{1}{180}(212\ P_o - 32P_1 + (P_1 - P_o)T) \cong$

$1.1778\ P_o - 0.1778\ P_1 + 0.005556(P_1 - P_o)T.$

13.2. (1)$T(^oC) = (5/9)[T(^oF)-32]$.

(2)

^oF	^oC
0	-17.78
32	0
68	20
80	26.67
98.6	37.00

(3)-459.67^oF.

13.3. $T(^oR) = (9/5)T(^oK)$.

13.4. (1)Pressure; or length (the height of a mercury column). (2)In mechanics: The reaction definition of mass, for instance, uses length and time concepts; the spring definition of force uses length.

13.5. Refer, for instance, to the standard, C^{12}. One atom of C^{12} has m = 12 a.m.u. (definition of the a.m.u.). One mole of C^{12} has m = 12 gm (definition of the mole). Therefore atoms/mole = a.m.u./gm.

13.6. (1)7.59×10^{24} molecules = 12.6 moles. (2)25.2 moles of H, 12.6 moles of O. (3)100.8 moles of neutrons.

13.7. (1)28.96 gm. (2)0.78x28 + 0.21x32 + 0.01x40 = 28.96. (3)This supports the ideal-gas behavior of air.

13.8. $m = M.W./N_0$.

13.9. $u = \rho N_0/M.W.$

13.10.(1)2.69×10^{19} molecules/cm^3 (volume per molecule = 37.2×10^{-21}). Average separation $\cong 3.4 \times 10^{-7}$cm. (2)3.35×10^{22} molecules/cm^3. Average separation $\cong 3.1 \times 10^{-8}$cm. (3)6.02×10^{22} atoms/cm^3. Average spacing $\cong 2.6 \times 10^{-8}$cm. (4)Both solid and liquid are relatively close-packed. (The separation is less in aluminum than in water, but the Al atom is smaller than the H_2O molecule). The spacing in the gas is more than 10 times that in the water.

13.11.(a)A tiny flake of metal dropped into hot liquid, for example; (b)a small chunk of meat in an oven, for example; (c)the core of the earth and the surface of the earth, for example. (For the last example, equilibrium is expected only after many more billions of years.)

13.12.Write Equation 13.8 as $n = PV/RT$. The number of moles depends on P, V, and T, but not on the nature of the gas. All gases obeying this law have the same number n of molecules for the same conditions of P, V, and T.

13.13.Into Equation 13.8, substitute $P = 1.013 \times 10^6$ dyne/cm^2, $n = 1$, $R = 8.31 \times 10^7$ erg/$^\circ$K, and $T = 273^\circ$K to obtain $V = 2.24 \times 10^4$cm^3.

13.14.Density on the winter day is greater by 11%.

13.15.Tag (b) belongs to the largest container, about 11 liters; tag (c) belongs to the smallest container, about 0.28 liter; tag (a) belongs to the intermediate container, about 9 liters. The smallest container would fit in a generous pocket; 0.28 liters is about 10 oz.

13.16. Expansion factor, 1,720.

13.17. (1) $360^\circ K = 87^\circ C$. (2) 6.02×10^{23} molecules (1 mole).

13.18. Air must escape from the house. The number of moles decreases by the fraction 10/293 = 0.0342.

13.19. Height 2.30×10^7 cm = 230 km. Since g changes by about 11% in this height, the approximation is fairly good (to within 6%).

13.20. $(K.E.)_{aver} = \frac{3}{2}kT = \frac{(1.5)(1.38 \times 10^{-16}\ erg/^\circ K)(300^\circ K)}{1.60 \times 10^{-12}\ erg/eV}$

= 0.039 eV.

13.21. 65,000 $^\circ$K.

13.22. About 6×10^5 cm/sec, about 18 times the speed of sound in air. (Since $v \sim \sqrt{T/m}$, it is easiest to use ratios. Temperature ratio gives factor $\sqrt{6000/273} = 4.7$; mass ratio gives factor $\sqrt{29/2} = 3.8$. Net factor $4.7 \times 3.8 \cong 18$.)

13.23. The speed of sound is determined principally by the molecular speed, which depends on molecular mass and temperature, but not on density.

13.24. (a) The lower molecular weight of water gives a factor $\sqrt{29/18} \cong 1.3$. (b) The main part of the increase, however, is due to the close packing of the molecules. To collide with a neighboring molecule, a water molecule need move a distance considerably less than its own diameter. Thus an impulse is transmitted over a distance of one molecular diameter with a motion much less than this distance.

13.25. (1) $v = \sqrt{3RT/M.W.}$. (2) Numerically, at $0^\circ C$, $v = 2.61 \times 10^5/\sqrt{M.W.}$. $v(N_2) = 4.93 \times 10^4$ cm/sec; $v(O_2) = 4.61 \times 10^4$ cm/sec; $v(A) = 4.12 \times 10^4$ cm/sec.

13.26. (1) $v = 1.46 \times 10^5$ cm/sec. This is roughly one fifth the speed of an astronaut in a 90 minute orbit, which is 7.8×10^5 cm/sec. (Approximation: $2\pi R/T = 4 \times 10^9$ cm/5,400 sec.) (2) $1,550^\circ K$.

13.27.(1)In a solid or liquid, the energy required to separate its molecules (binding energy) is greater than the thermal energy of the molecules. (However, individual molecules can have more than average energy and escape.) In a gas, the thermal energy exceeds the weak binding energy. (2)As water evaporates, its molecules separate, a process that requires energy. The surface from which evaporation occurs therefore loses energy; its temperature falls. (3)Friction generates heat which raises the gas temperature and thereby the kinetic energy of its molecules. The more energetic molecules exert more pressure.

13.28.Equation 13.33 is invalid (a) for a total temperature change so great that the specific heat changes appreciably during the heat transfer, or (b) for a change of state during which heat is absorbed or given up without change of temperature.

13.29.(1)92 cal. (2)The energy required for bulk acceleration to Mach 1 is $\frac{1}{2}mv^2 = 5.78\times10^9$ ergs = 138 cal, only slightly greater than the energy to heat it through 100°C.

13.30.s = 0.192 cal/gm °K. (Heat to pan = 2,800 cal.)

13.32.(1)3.54×10^5 cm/sec. (2)2.50×10^5 cm/sec.

13.33.(1)3.23×10^4 cal. (2)32.3°K. (3)It is all transformed into disordered internal energy--in brakes, tires, the rest of the car, the road, and the air.

13.34.It still has but one degree of freedom, since its position is specified by a single coordinate, and it has one mode of motion.

13.35.Initially $E = \frac{5}{2}NkT$. After energy is added, $E' = \frac{5}{2}N'k'T'$. Set $E' = E + \Delta E$, $T' = T + \Delta T$, and note $N' = N$, $k' = k$. Then $E + \Delta E = \frac{5}{2}Nk(T + \Delta T)$.

Subtract the initial equation from this one (left side from left, right side from right) to obtain $\Delta E = \frac{5}{2}Nk\,\Delta T$.

13.36.Specific heat would be (by Equation 13.35) 0.165 cal/gm°K, about six times less than actual specific heat, 1 cal/gm°K. This means that only about one sixth of energy added to water goes into translational degrees of freedom, the rest going into internal excitation of the molecules.

13.37. (1)6. (2)First printing: $s_v = 3k/mJ$. Later printings: No change. (3)The quantum excitation energy of the vibrational mode of motion is greater than typical thermal energies at ordinary temperature, so that this degree of freedom is frozen.

13.38. (1)Start with $\Delta H = sM\Delta T$. Multiply on right by n/n to get $\Delta H = (sM/n)n\Delta T = s'n\Delta T$, where $s' = sM/n = s \times M.W.$ (M.W. = molecular weight = M/n). Thus s′, like s, depends on the nature of the substance, but not on the mass of the sample. (2)$s' = s \times M.W. = \frac{1}{J}\frac{3}{2}\frac{k}{m} \times M.W.$ Use $M.W. = mN_0$, since molecular weight is the mass in gm of 1 mole or the mass of one molecule (m) times the number of molecules in a mole (N_0). The factors of m cancel. Use $R = kN_0$ to obtain $s' = 3R/2J$.

13.39. Finite molecular size causes the gas pressure to be greater than given by Equation 13.23. By successive collisions, momentum is transferred from one wall to another in less time than it would take a free molecule to cover the distance. Or, a signal passes through a molecule faster than it passes between molecules. The Δt of Equation 13.19 is decreased, or the v of Equation 13.23 is increased, and P is increased.

13.40. Intermolecular force causes the gas pressure to be less than given by Equation 13.23. Consider a molecule rebounding from a wall as in Figure 13.7. Only part of its change of momentum is provided by the wall. The rest is provided by forces of attraction to other gas molecules. Thus the force on the wall is less than given by Equation 13.21. (In a solid, the wall need feel no force at all, as a molecule at a surface can be turned back entirely by intermolecular forces.)

13.41. (1)Two possible answers: (a)Temperature is defined in terms of an <u>average</u> kinetic energy of many particles; or, better, (b)temperature is defined in terms of disordered energy, and for a single particle viewed alone, its kinetic energy is ordered, not disordered. (Note, however, that the temperature of a substance can be defined in terms of the time average of the energy of one of its particles if the time is extended over many collisions.) (2)Pressure, for example. Also heat, specific heat, and possibly the volume of a substance.

13.42. For the gases present singly, the pressures would be, by Equation 13.23, $p_1 = N_1m_1v_1^2/3L^3$, $p_2 = N_2m_2v_2^2/3L^3$, $p_3 = N_3m_3v_3^2/3L^3$. Because the temperature is the same (this is the key fact), $m_1v_1^2 = m_2v_2^2 = m_3v_3^2 = 3kT$. Thus $p_1 + p_2 + p_3 = (N_1 + N_2 + N_3)kT/L^3$. For all gases present together, each molecule contributes a force (Equation 13.21) equal to mv^2/L. Because of constant temperature, the combination mv^2 is the same for all molecules in the mixture, even if their masses differ. Thus each contributes an average force $3kT/L$. The total pressure is (Equation 13.23) $P = NkT/L^3$. Since $N = N_1 + N_2 + N_3$, $P = p_1 + p_2 + p_3$.

13.43. (1)For example, if $m = 3.3\text{x}10^{-24}$gm (hydrogen), $v = 2\text{x}10^5$cm/sec, and L = 10 cm, $F_{av} = mv^2/L = 1.3\text{x}10^{-15}$ dyne. (Anything in the range $\sim 10^{-13}$ to 10^{-17} dynes is acceptable.) (2)The momentum change 2mv actually occurs in a time of about 10^{-14} sec (this is $x/v \cong 10^{-9}\text{cm}/10^5\text{cm/sec}$). Thus $F \cong 2mv/10^{-14}\text{sec} \cong 1.3\text{x}10^{-4}$ dyne. (Again several orders of magnitude latitude is acceptable.) (3)Actual force/average force $\cong 10^{11}$ in this example. (10^8 - 10^{14} O.K.) Even the "large" actual force is small by normal standards, ten million times less than the weight of 1 gm.

13.44. (2)0.42 eV/molecule. (3)At 373°K, $\frac{1}{2}mv^2 = \frac{3}{2}kt$ = 0.048 eV, about 9 times less than the heat of vaporization. [Typographical error in first printing, 373°C instead of 373°K; this gives 0.0835 eV.] (4)9.63 eV. (5)Setting kT = 9.6 eV yields $T \cong 110{,}000$ °K, an acceptable answer, although dissociation would in fact occur well below this temperature.

CHAPTER FOURTEEN

14.1. (1)Closest to probability of gambler. Known probability, but not fundamental. (2)Closest to probability of radioactivity, a fundamental probability of nature. (3)Closest to probability of spelunker; unknown magnitude of probability. The first is a thermodynamic probability.

14.2. (1)Curve centered at C = 50 with width $W = 2\sqrt{C} \cong 14$. (2)A poor bet. There is a fairly high probability for any number from 36 to 64, so there is a small probability for any one number. (3)A good bet. There is an even chance to find 50 or less, so there is better than an even chance to find 60 or less.

14.3. (1)1/36 = 0.0278. (2)This is an a priori probability, based on the assumption of equal probability for a die to show any one of its six faces. (3)7, because there are more different ways to produce this total than any other total.

14.4. Answer should cite effects of large statistical fluctuations (non-uniform temperature, pressure, density).

14.5. The simplest answer is that the second law governs spontaneous change. Or a decrease of "available energy" could be cited. Analysis in terms of entropy is almost impossible, but the question is designed to stimulate thought, not to produce a "right" answer.

14.6. (1)From Equation 14.3 and Table 14.3, $\Delta S = k \log(252/1) = 7.63\times10^{-16}$ erg/°K. (2)This is an entropy increase which could have occurred spontaneously.

14.7. (1)5 and 5. (2)Yes. Statistical fluctuations will cause entropy variations.

14.8. Set $P = NP_r$ (P = absolute probability, P_r = relative probability, N = any constant). Then $S = k \log P = k \log N + k \log P_r$. The first term on the right is a constant which will cancel out of expressions for change of entropy or difference of two entropies. (Alternative: $S_2 - S_1 = k \log P_2 - k \log P_1 = k \log(P_2/P_1)$. The ratio P_2/P_1 is the same for absolute or relative probabilities.)

14.9. (1), (3), and (4) violate the second law of thermodynamics. (3) and (4), because of small numbers, might actually happen. [Although improbable, (2) might also happen, but this is unrelated to the second law.]

14.10. For example: refrigerator, freezer, air conditioned room, factory converting raw materials into finished products, living organism manufacturing complex molecules from simple molecules.

14.11. The nutrient material is being oxidized, with a decrease in its available energy. The hen or incubator supplying heat also suffers an increase of entropy.

14.12. The energy is finally distributed as internal energy of air and earth. The proton is brought to thermal velocity, but not to rest. Entropy increases.

14.13. (1) Answer should paraphrase material in Section 14.5. (2) Roughly, from Equation 14.6, ΔS(hot water) = $\Delta H/T = -4{,}540$ cal/308°K, and ΔS(cool water) = +4,540 cal/298°K. ΔS_{total} =

$$4{,}540\left(\frac{1}{298} - \frac{1}{308}\right) \cong 0.5 \text{ cal/}^{\circ}\text{K}.$$

14.14. (1) $\Delta S \cong 4{,}540\left(\frac{1}{273} - \frac{1}{298} - \frac{1}{333} + \frac{1}{308}\right) = 2.5$ cal/°K. (2) This is about five times the entropy increase of Exercise 14.13. Less total entropy increase could be realized by using reservoirs closer in temperature to the water (one greater than 0°C, the other less than 60°C).

14.15. (1) $\Delta S \cong 4.8/380 = 0.0126$ cal/°K. (2) $\Delta S = 2.39/385 = 0.0062$ cal/°K. (3) $\Delta S = 0$. (4) $\Delta S = -0.0126$ cal/°K. $\Delta S_{total} = +0.0062$ cal/°K, not zero because the steam occupies more volume at the end than at the beginning, thus having greater spatial disorder.

14.16. (1) From Equation 14.14, $W_{max}/H_1 = 0.625$. (2) 1.31×10^7 ergs.

14.17. Use Equation 14.6 (or 14.8) and the discussion on page 446 to argue that for T_2 near zero, very little heat is required to produce a large entropy change.

14.18. 75 ergs.

14.19. (1) 2.58×10^{11} ergs. (2) 107 watts.

14.20. (1) Solve Equation 14.12 for H_1 and substitute in Equation 14.14. (2) $0^{\circ}K < T_2 \leq 250^{\circ}K$.

14.21. $(W_1 + W_2)/H_1 = 1 - (T_3/T_1)$, the same as the efficiency of a single engine.

14.22. (1) Equation 14.17, with revised notation, is $W = H_2\,((T_1/T_2) - 1)$, the same as the equation of Exercise 14.20. Therefore the engine output work is just sufficient to power the refrigerator. (2) By energy conservation for the heat engine, $H_1 = W + H_2$. By energy conservation for the refrigerator, $W + H_2 = H_3$. Therefore $H_1 = H_3$.

14.23. Answer should note extraordinary breadth of application of the second law, and its statistical character which means it need not always be true for small systems.

CHAPTER FIFTEEN

15.1. Student need not know the phrase "electric induction," but should appreciate the principle based on the mobility of charge in most objects.

15.2. (1) The wool acquires equal and opposite charge. (2) Any procedure to measure charge on balloon and wool, or to test that they are equal and opposite.

15.3. 8.2 deg (tangent decreased by factor four).

15.4. (1) 0.189 dyne (repulsive). (2) $p = 1.89 \times 10^{-17}$ gm cm/sec; $v = 1.13 \times 10^{7}$ cm/sec.

15.5. (1) 4.88×10^{8} dynes. (2) 5.42×10^{7} dynes. (3) About 1.3×10^{8} eV = 130 MeV (answers 100-160 MeV satisfactory).

15.6. Argument analogous to that of Figure 12.2, page 287.

15.7. F_1 = 1.25 dynes to left; F_2 = 15.0 dynes to right; F_3 = 13.75 dynes to left.

15.8. (1)Zero. (2)1.63×10^{-3} dyne, to the left. (3)1.79×10^{24} cm/sec^2.

15.9. (1)0.119 dyne, upward. (2)0.0319 dyne, downward. There is no point of zero force (except at infinite distance).

15.10. 1 e.s.u. = 1 $gm^{1/2}\ cm^{3/2}\ sec^{-1}$.

15.11. (1)Call θ the angle between x and r. $F_{2x} = F_2 \cos\theta = \frac{Q_1Q_2}{r^2} \cdot \frac{x}{r}$; $F_{2y} = F_2 \sin\theta = \frac{Q_1Q_2}{r^2} \cdot \frac{y}{r}$.
(2) $\underset{\sim}{F}_2 = Q_1Q_2\, \underset{\sim}{r}/r^3$.

15.12. (1)The explanation should touch on the constancy of K and the inverse square distance dependence. Q and ξ are related by $Q = \sqrt{K}\,\xi$.
(2) $\xi_1^2 + \xi_2^2 + \xi_3^2 + \ldots$ = constant.

15.13. (1)3.42×10^{-12} $\frac{\text{statvolt}}{\text{cm}}$ (or $\frac{\text{e.s.u.}}{\text{cm}^2}$ or $\frac{\text{dyne}}{\text{e.s.u.}}$).
(2)11.9 cm.

15.14. The repulsive electric force between nuclei is least.

15.15. (1)They repel. (2)152.5 dynes, horizontal, away from the other magnet. (3)152.5 dynes, horizontal, toward the other magnet.

15.16. (1)4.17×10^5 statvolt/cm (or dyne/e.s.u.), directed vertically upward. (2)Same as (1). (3)1,250 dynes.

15.17. Q_1 = +20 e.s.u., Q_2 = -20 e.s.u.

15.18. For example: Velocity of moving fluid; force on a distributed charge.

15.19. (1) $\mathcal{E} = 1.92\times10^7$ dyne/e.s.u., directed <u>away</u> from proton. (2) The electric field does not change. The force doubles in magnitude and reverses in direction.

15.20. (1) $\Phi_E = 4\pi Q$. (2) The flux remains constant. (3) Only for the inverse square law does flux have this simple property.

15.21. (1) $Q_3 = -9.90$ e.s.u. $\cong -10$ e.s.u. (2) $\mathcal{E} = 19.9$ ($\cong 20$) dyne/e.s.u. (or statvolt/cm).

15.23. $\mathcal{B} = 0.400$ gauss.

15.24. (a) Compare Equation 15.4 or 15.8 with Equation 15.5 or 15.13; (b) compare Equation 15.6, 15.7, or 15.10 with Equation 15.11, or Equation 15.9 with Equation 15.12, using also the result of part (a).

15.25. Torque, for example.

15.26. (1) $\sqrt{G} = 2.58\times10^{-4}$ g.u./gm, or $1/\sqrt{G} = 3.87\times10^3$ gm/g.u. (2) 20.7 g.u. (3) $F = m_1 m_2/d^2$.

15.27. $r = e^2/mc^2 = 2.82\times10^{-13}$ cm, slightly smaller than an average nucleus, not much larger than an elementary particle.

CHAPTER SIXTEEN

16.1. The field between the wires is (a) weaker if the currents are in the same direction, and (b) stronger if the currents are oppositely directed. This is best shown by a diagram.

16.2. (1) Vertically upward. It is substantially weaker than the force on the north pole (less than half). (2) A net torque acts horizontally to the left.

16.3. Yes, a current is induced, since $\mathcal{B}$ changes. The direction of the induced current is opposite to what is shown in Figure 16.5, since the direction of change of $\mathcal{B}$ is opposite.

16.4. F = 0.9 dyne. It would not be perceptible, being only about 1/1000 the weight of a 1 gm object.

16.5. (a)F = 2.56×10^{-8} dyne; (b)1.81×10^{-8} dyne; (c)zero. $a_{max} = 2.81\times10^{19}$ cm/sec^2.

16.6. (1) $\mathcal{E} = (v/c)\mathcal{B}$. (2)Directed vertically downward. (3)33.3 dyne/e.s.u.

16.7. The force and velocity are perpendicular, and each is constant in magnitude, requirements for uniform circular motion. From mechanics, $a = v^2/r$, $F = mv^2/r$. From the law of magnetic force, $F = vQ'\mathcal{B}/c$. Equate the two expressions for F to get $r = mvc/Q'\mathcal{B} = pc/Q'\mathcal{B}$.

16.8. $v = mgc/e\mathcal{B} = 0.341$ cm/sec.

16.9. (1)Diagram similar to Figure 15.9 (b). (2)(a)Head-on, the electron experiences no force and moves with constant velocity; (b)passing at a distance, the electron is deflected neither toward nor away from the pole, but perpendicular to the line joining it to the pole and perpendicular to its velocity. (The electron may also spiral--it does not move in a plane.)

16.10. (1)3.2×10^{-13} dyne. (2)114 cm. (3)$F_2/F_1 = r_1/r_2 = 2.28\times10^{10}$.

16.11. The angle between velocity and magnetic field for a charged particle approaching the earth decreases with increasing latitude, and the deflecting force also decreases. Consider in particular the limiting case of particles heading straight along the lines of field toward the geomagnetic pole. None are deflected; all strike the earth.

16.12. The absence of electric field is verified by the absence of force on a static charge. The presence of magnetic field is verified by force on a moving charge, force on a current, or force (or torque) on a stationary magnet.

16.13. Fields at A and B have equal magnitude and are directed tangentially around the circle of the tube face, clockwise seen from point C. The magnetic field at C is zero.

16.14. $\mathcal{B} = vQ/cd^2 = 3.2\times10^4$ gauss(directed along the axis of the circle).

16.15. $v = c\mathcal{B}r^2/Ne = 62.5$ cm/sec.

16.16. (a) Zero; (b) 2×10^{-7} gauss; (c) 1.73×10^{-7} gauss.

16.17. (1) $p = re\mathcal{B}/c = 9.6\times10^{-19}$ gm cm/sec. (2) $v \cong 1.05\times10^{9}$ cm/sec; the formula $p = mv$ is approximately valid ($v/c \cong 1/30$). (3) 1.87×10^{-10} gauss. (4) The field created by the electron is vastly smaller than the original field, and oppositely directed.

16.18. The field lines would be circles within the torus, with negligible field outside the coil.

16.19. $I = ev/2\pi r = 4.59\times10^{6}$ e.s.u./sec $= 1.53\times10^{-3}$ amp.

16.20. $F = I_2 \ell \mathcal{B}/c = 2 I_1 I_2 \ell/c^2 r$. The force is attractive, from one wire toward the other.

16.21. (1) 4.38×10^{9} cm/sec (calculated non-relativistically). (2) 45.7 cm. (3) 480 e.s.u./sec = 1.6×10^{-7} amp. (4) 1.6 watts, probably not perceptible (although quite hazardous).

16.22. (1) 3×10^{9} e.s.u./sec. (2) $\mathcal{B} = 2\pi I/cr = 0.105$ gauss. (3) The straight wire should be in the plane of the loop, a distance $d = 38$ cm from the center of the loop, with its current directed opposite to the direction of current in the nearest part of the loop. (Note $d = r(I_2/\pi I_1)$.)

16.23. (1) The first proton, experiencing no force, continues along the axis with constant velocity. (2) In the field of 3.14 gauss, the second proton has an initial radius of curvature of about 0.33 cm. Since this is small compared to 10 cm, the proton executes nearly a circular path in the plane of the loop.

16.24. $mg = I\ell\mathcal{B}/c$; $I = 4.9\times10^{13}$ e.s.u./sec = 1.63×10^{4} amp. The current should flow horizontally from west to east.

16.25. (a) Force on the charge is zero; (b) $F = P'\mathcal{B} = 2IP'/cr$, directed perpendicular to the plane containing the wire and the pole.

16.26. (1) F(top) = F(bottom) = 0; F(right) = $nI\ell\mathcal{B}/c$ into the page; F(left) = $nI\ell\mathcal{B}/c$ out from the page. Torque, $T = 2\ell rnI\mathcal{B}/c = AnI\mathcal{B}/c$, where $A = 2\ell r$ = area. (2)$T = 3.33\times10^6$ dyne cm. (3)Seen from above, the loop turns counterclockwise.

16.27.(1)Force (on negative electron) is to the right. (2)$F = ve\mathcal{B}/c$. (3)Potential has not yet been introduced. Explanation should be in terms of electric forces within the wire produced by pulling electrons to one end of the moving wire segment.

16.28.(1)Force (on negative electron) is from left wing toward right wing. (2)Conventional current flows (temporarily) from the right wing toward the left wing. (3)Displaced charge builds up electric forces which cancel the magnetic force.

16.29.This observer sees a changing magnetic field which induces in the stationary wire segment an electric field directed to the left.

16.30.(1) $\mathcal{E} = \mathcal{B} = \sqrt{8\pi\times\frac{1}{2}\times10^5} = 1.12\times10^3$ (unit of $\mathcal{E}$ is dyne/e.s.u. or statvolt/cm; unit of $\mathcal{B}$ is gauss). (2)$r = \sqrt{e/\mathcal{E}} = 6.55\times10^{-7}$cm. (This is for equal electric field strength. For equal total field energy, the answer is 5.50×10^{-7}cm. Because of somewhat ambiguous wording, either answer should be accepted.)

16.31.(1)$\mathcal{E} = 3.17$ dyne/e.s.u. (2)$a = e\mathcal{E}/m = 1.67\times10^{18}$ cm/sec^2.

16.32.Energy conservation would be violated in a crescendo of downward acceleration and increasing induced current without application of external force.

16.33.Lenz's law acts to counter his motion so that his downward acceleration is less than g.

16.34.(a)The motion causes current to flow from right to left in the wire segment. In the given field (into the page), this current experiences a downward force, opposite to the direction of motion. Without upward external force, the wire segment would decelerate and come to rest. (b)Direct application of Lenz's law: Upward motion (1) induces current (2), which in turn produces downward force (3) opposing the original motion.

16.35. Either Figure 16.5 or Figure 16.22 (a) provides the answer that the induced current is opposite to the inducing current. The explanation in terms of Lenz's law is subtle because the induced current shrinks as the inducing current grows. It is satisfactory to say that the induced current acts to oppose the growth of the magnetic field through the loops.

16.36. A counterclockwise rotation (seen from above) induces in the loop a current which is opposite to the direction of current shown in the diagram. As the given current grows, the counterclockwise rotation will set in to oppose its growth.

16.37. (1) I' is opposite to I. The downward motion of the magnet is equivalent to an upward motion of the wire, which, according to right-and-left rule 1, induces current I' to the left. (2) I' should be less than I. If it were greater, the force on the magnet would reverse, its acceleration would reverse, and the induced current I' would diminish. (I' equal to I is possible in principle, unlikely in practice.)

16.38. (1) An S shape, the upper part of the wire deflecting to the left, the lower part to the right. (2) Total force on magnet vanishes. (3) Torque acts into the page (N pole pushed to right, S pole to left).

16.39. The argument should use the fact that $\mathbf{F}$ and therefore $\Delta\mathbf{v}$ are perpendicular to $\mathbf{v}$ at all times, and consider the right triangle formed by $\mathbf{v}$, $\Delta\mathbf{v}$, and $\mathbf{v} + \Delta\mathbf{v}$ in the limit of small $\Delta\mathbf{v}$.

16.40. (1) Use Equations 16.21 and 16.24; force per unit length is $\Delta F/\Delta \ell = 2I_1I_2/c^2d$, attractive for parallel currents, repulsive for anti-parallel currents. (2) Yes; note symmetry of the formula.

16.41. $\mathcal{B} = 2\pi r^2 I/c(r^2 + d^2)^{3/2}$. When d = 0, the denominator becomes r^3, and $\mathcal{B} = 2\pi I/cr$, duplicating Formula 16.23.

16.42. $\mathcal{B} = \frac{32\pi}{5\sqrt{5}} \cdot \frac{nI}{ca}$.

CHAPTER SEVENTEEN

17.1. $[V] = m^{\frac{1}{2}} l^{\frac{1}{2}} t^{-1}$.

17.2. 5.93×10^8 cm/sec.

17.3. $\mathcal{E}$ = 1,500 volts/cm = 5 statvolt/cm (or 5 dyne/e.s.u.).

17.4. (1)20,000 eV, or 20 KeV. (2)8.4×10^9 cm/sec (non-relativistic calculation). (3)8×10^{-9} dyne.

17.5. (1)P = VI = 10^3 watts = 1 kilowatt. (2)500 joules = 5×10^9 ergs. (3)3.12×10^{15} electrons.

17.6. V = 0.867 statvolt = 260 volts. ($\mathcal{E}$ = 2.89 statvolt/cm.)

17.7. (1)2.40×10^{-2} statvolt = 7.20 volts. (2)2.40×10^{-2} statvolt = 7.20 volts. (3)It loses 14.4 eV of potential energy (P.E. changes, for instance, from zero to -14.4 eV).

17.8. (1)It is repelled along a radial line, achieving a final kinetic energy equal to its initial potential energy. (2)K.E. (final) = 1.32×10^7 eV = 13.2 MeV.

17.9. (a) $[I] = m^{1/2} l^{3/2} t^{-2}$; (b) $[R] = l^{-1} t$; (c) $[P] = m l^2 t^{-3}$.

17.10. 13.3 amp.

17.11. (1)500 watts. (2)4.55 amp. (3)24.2 ohms.

17.12. 7.5×10^{18} electrons/sec through the bulb of lower resistance; 3.75×10^{18} electrons/sec through the bulb of higher resistance.

17.13. The equal current through each resistor is based on the assumption that no charge is gained or lost in the circuit (charge conservation) and that no charge accumulates at any point in the circuit (steady unchanging conditions).

17.14. (1)60 ohms. (2)5.45 ohms.

17.15. (1)3.6×10^5 coulombs. (2)4.32×10^6 joules (or 4.32×10^{13} ergs). (3)3.6×10^4 sec = 10 hours.

17.16. (a) About 25 ohms (acceptable range about 10 to 50 ohms, for assumed power of 250 to 1200 watts); (b) about 13 amp (acceptable range about 9 to 18 amp, for assumed power of 1,000 to 2,000 watts); (c) about 20 to 30 kilowatts (a wider range is acceptable if answer is reasonably justified).

17.17. Upper and lower branches each have resistance 2R. The parallel combination of two branches, each of resistance 2R, has resistance R.

17.18. (1)(a) $I_1 = 12/14 = 0.857$ amp, $I_2 = 48/70 = 0.686$ amp, $I_3 = 12/70 = 0.171$ amp; (b) $P_1 = 7.35$ watts, $P_2 = 2.35$ watts, $P_3 = 0.59$ watt. (2) 97.2 hours ($= 3.52\times10^5$ sec). The energy is dissipated as heat in the resistors.

17.19. (1) 2.4×10^6 watts (1.2×10^6 watts in each wire). (2) Fraction 2.4×10^{-2} or 2.4% (total power 10^8 watts). (3) 48,800 volts (600 volt potential drop in each wire). (4) Power loss is reduced by a factor of four (to 6×10^5 watts).

17.20. Key fact is $\mathcal{E} = V/\ell$. Since ℓ = constant, $\mathcal{E} \sim V$. Therefore if $I \sim \mathcal{E}$, $I \sim V$.

17.21. Use $\mathcal{E} = V/\ell$, so $I = A\sigma\mathcal{E} = A\sigma V/\ell = (A\sigma/\ell)V$. But R defined by $I = V/R$, so $R = \ell/A\sigma$.

17.22. (1) 1.325×10^9 cm/sec. (2) Yes, since this formula rests on the definition of potential as energy per unit charge. (3) 0.358 cal/sec (= 1.5 watt).

17.23. (1) $V_{out} = 50$ volts. (2) 4×10^5 ohms. (3) V_{out} increases by 50 volts.

17.24. (1) From Equation 17.51, $\dfrac{v_y}{v_x} = \dfrac{eV_d\ell}{dmv_x^2}$. In the denominator, set $mv_x^2 = 2$ K.E. $= 2eV_a$. The charge e cancels and the desired result is obtained. (2) Sample: $\ell = 2$ cm, $d = 0.5$ cm, $V_d = 50$ volts, $V_a = 500$ volts; $v_y/v_x = 0.2 = \tan\theta$; $\theta = 11.3$ deg.

17.25. $V_d = 50$ volts.

17.26. (1) It is easiest to square both sides of Equation 17.57, then substitute for v^2 from Equation 17.56, to obtain Equation 17.58. (2) 0.151 cm.

17.27. (1) $T = 13.2\times10^{-8}$ sec (from Equation 17.61). (2) 15 MeV (half of the proton energy, since the deuterons have half the speed and twice the mass of the protons). Optional: $T \sim A/Z$; $E \sim Z^2/A$.

17.28. (1) 20 amp. (2) The secondary circuit requires heavier wires, since it carries greater current. (A more complete answer would consider dissipation in the wires, $P = I^2R$.)

17.29. (1) Positively charged particles are accelerated counterclockwise, seen from above. The magnetic field they generate loops upward through the center of the torus, opposing the increase of field produced by the moving magnet. (2) The field created by the circulating charge exerts an upward force on the descending lower end of the magnet (which is its north pole).

17.30. (1) 2×10^{-10} farad = 200 micro-microfarad. (2) Capacitance does not change. (3) Potential doubles.

17.31. A straight line passing through the origin; its slope is $1/C$.

17.32. (1) $I/Q = 1/RC$. (2) I decreases, remaining proportional to Q, since RC = constant. (3) No (since I reaches zero when Q reaches zero).

17.33. The current will diminish gradually. Consideration of energy shows that it must decrease. An abrupt decrease would imply a very large (or infinite) rate of change of magnetic field near the inductor, which in turn would create a very large (or infinite) electric field in the wire to keep the current flowing. (Equation 17.67 might fruitfully be used in the discussion.)

17.34. (1) $f \cong 1$ megacycle (9.9×10^5 sec^{-1}). (2) Method 1: In the period $\Delta t = 1/f$, capacitor charge changes by $\Delta Q = 2Q$ (from $+Q$ to $-Q$). Current is therefore roughly $I = \Delta Q/\Delta t = 2Qf = 2CV/2\pi\sqrt{LC} = (V/\pi)\sqrt{C/L} \cong 5\times10^{-3}$ amp = 5 milliamp. Method 2: From Equation 17.67, peak rate of change of current is $\Delta I/\Delta t = V/L$. In the half-period, $\Delta t = 1/(2f)$, this produces a change of current from zero to I_{max}, $\Delta I \cong I_{max}$. Guess average current

$I = I_{max}/2 = \Delta I/2 = V/(4Lf) = (\pi V/2)\sqrt{C/L} \cong$ 2.5×10^{-2} amp = 25 milliamp. The true maximum current is $V\sqrt{C/L} \cong$ 16 milliamp; the true r.m.s. current is 11 milliamp. Any justified answer from 2.5 milliamp to 50 milliamp should be acceptable.

17.35. Consider protons of equal momentum at A and A'. The one at A moves around to B. The one at A', being in a stronger field, does not follow the dashed curve; instead, it moves inside the dashed curve with smaller radius of curvature, tending to return to the solid curve. A similar argument applies to protons at B and B'. The one at B', being in a weaker field, moves with larger radius of curvature outside the dashed circle, also tending to return to the solid curve.

CHAPTER EIGHTEEN

18.1. (1)$f = 3.3\times10^3 sec^{-1}$ = 3.3 kilocycle. (2)$f = 3\times10^9 sec^{-1}$, in the microwave or radar part of the spectrum.

18.2. (1) $\lambda \cong 250$ cm. (2)$f = 10^7 sec^{-1}$ = 10 megacycle. (3)$v = 3\times10^{10}$ cm/sec; a microwave or radar wave.

18.3. $f = 3.56\times10^5 sec^{-1}$; $\lambda = 8.43\times10^4$ cm = 0.843 km.

18.4. (1)32. (2)$f_{max} \cong 1{,}400\ sec^{-1}$, $f_{min} \cong 44\ sec^{-1}$.

18.5. 27.

18.6. (1)The surface of the metal is subject to a repeating stimulus at the frequency of the sound wave in air. (2)Greater in metal. (3)Longitudinal. (4)Longitudinal.

18.7. (1)$f = 10^{10} sec^{-1}$ = 10 gigacycles. (2)1.5×10^4 cm long, containing 5,000 wave cycles. (3)Nearest object 7,500 cm (round trip time 0.5 microsec); farthest object 1.5×10^7 cm = 150 km (round trip time 1 millisec). Optional: 7.55×10^{18} photons.

18.8. (1)Yes, vertically polarized. (2)Of order 1 sec^{-1} (reasonable range about 0.3 to 5 sec^{-1}).

18.9. (1)About 10^9. (2)(a)1.51×10^{25} photons/sec; (b)1.51×10^{13} photons/sec.

18.10. $f \cong 1.5 \times 10^{21} sec^{-1}$, somewhat greater than the typical frequencies of nuclear gamma rays, but not greatly different. (Answers from 1 to $3 \times 10^{21} sec^{-1}$ acceptable.)

18.11. The fundamental fact is that the oscillating charge must be able to complete a cycle of oscillation in a time equal to $1/f$. As the frequency rises, the distance over which the charge moves must decrease. The speed of light limits the speed of the particle and therefore limits its domain of motion.

18.12. Period of particle oscillation = period of wave $= 1/f \cong d/v$. For the wave (from Equation 18.1), $1/f = \lambda/c$. Equate these to get $\lambda \cong cd/v$. (Argument may also be based on the fact that while the particle moves a distance d, the wave moves a distance $(c/v)d$.)

18.14. (1)The polarization is parallel to the wire. Consider the oscillating field $\mathcal{E}$ within the wire. (2)Yes, for the same reason as the preferential polarization of emitted radiation.

18.15. (1)Transverse. (2)Standing.

18.16. (1)Answer should stress one or both of these facts: (a)The wavelength of light is much less than the width of a single wire; (b)the mechanism of absorption of light is different, involving atoms rather than electrons accelerated over macroscopic distances. (2)This would be an enormous system such as a row of equally spaced skyscrapers.

18.17. The key fact is the congruence of triangles CAA' and A'C'C, based on the equal distances of propagation, A'C' and AC.

18.18. (1)The angle of reflection would be less than the angle of incidence. (2)Its angle of reflection is greater than its angle of incidence (overlooking effects produced by friction and rotation, as with a super-ball).

18.19. Base the argument on time. The time for the paths AC and A'C' are equal, and the time of propagation of the wavelet from B' is exactly half of this time. The radius of the wavelet centered at B' is therefore half of the radius of the wavelet centered at A'. The proof is completed geometrically.

18.20. By the definition of index of refraction, $v_1 = c/n_1$, $v_2 = c/n_2$. Therefore the speed ratio n, defined to be v_1/v_2, is $n = v_1/v_2 = n_2/n_1$. Thus Equation 18.21 takes the form $\sin\theta / \sin\varphi = n_2/n_1$, from which follows $n_1 \sin\theta = n_2 \sin\varphi$. (Alternatively, a new proof may be constructed with the help of a diagram similar to that of Figure 18.19.)

18.22. (1) φ = 22 deg. (2) 2.26×10^{10} cm/sec.

18.23.

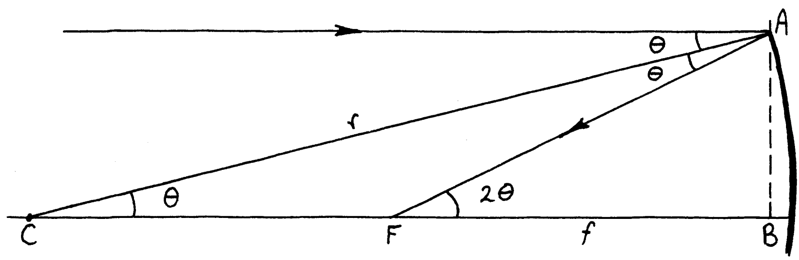
n	φ_{max}
1.0	90 deg
1.2	56.4 deg
1.4	45.6 deg
1.6	38.7 deg
1.8	33.8 deg

18.24. (1) Toward the perpendicular line. (2) Deviated by 8.9 deg (φ = 36.1 deg).

18.25. (1) 2.12×10^{10} cm/sec ($= c/\sqrt{2}$). (2) No, for the speed ratio would be less than 1.41, and the critical angle greater than 45 deg.

18.26. Surface forces would be one explanation. Student might think of others.

18.27. One method is based on the following diagram.



The radial line CA makes angle θ with the horizontal; the light path line FA makes angle 2θ with the horizontal. $AB/CB = \tan\theta \cong \theta$; $AB/FB = \tan 2\theta \cong 2\theta$; therefore $CB \cong 2(FB)$, or $r \cong 2f$.

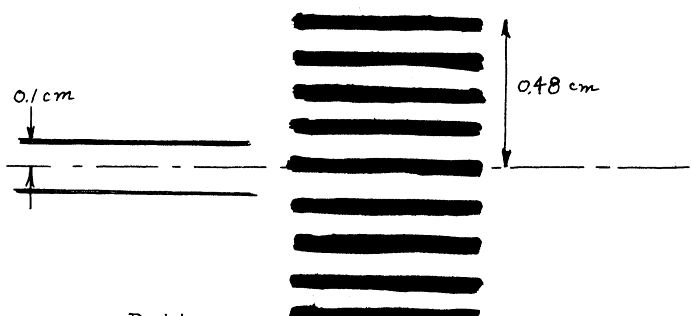
18.28. From $d_1 = 10$ to $d_1 = \infty$, M falls from ∞ to zero, being 1 at $d_1 = 20$, and 0.5 at $d_1 = 30$. From $d_1 = 0$ to $d_1 = 10$, M falls from -1 to $-\infty$. Where M is negative, $|M|$ gives the magnification of the virtual image.

18.29. The key idea, derived from the geometry of Figure 18.30, is that $M = d_2/d_1$. The equation in Exercise 18.41 is converted into $d_1/f = 1 - (1/M)$. This, solved for M, gives $M = 1/(1 - (d_1/f))$.

18.31. The essential idea is the <u>equal</u> path length from all points on the periphery of the disk to the center of the shadow, which implies constructive interference.

18.32. 0.5 micron is 5×10^{-5} cm, just about the same as the wavelength of visible light. A microscope should therefore not reveal details of the shape of the grain.

18.33. (1) $\Delta y = \lambda L/d = 0.12$ cm, fringe spacing; great enough to be visible to the unaided eye. Diagrams for (1) and (2) below.



Pattern if no diffraction

Actual Pattern

(Dark lines here indicate regions of maximum light.)

18.34. For example, set $x_2 = x_1 + \Delta x$. Then $x_2 - x_1 = \Delta x$; infinite percentage error if Δx ignored. Sum: $x_2 + x_1 = 2x_1 + \Delta x = 2x_1(1 + (\Delta x/2x_1))$; fractional error $\Delta x/2x_1$ if Δx ignored.

18.35. For example: two-slit pattern, using Equations 18.43 and 18.44.

18.36.

Source	Wavelength	Sin θ	θ
Hydrogen	6,563 A	0.1641	9.45 deg
Neon	6,402 A	0.1601	9.22 deg
Argon	6,965 A	0.1741	10.03 deg

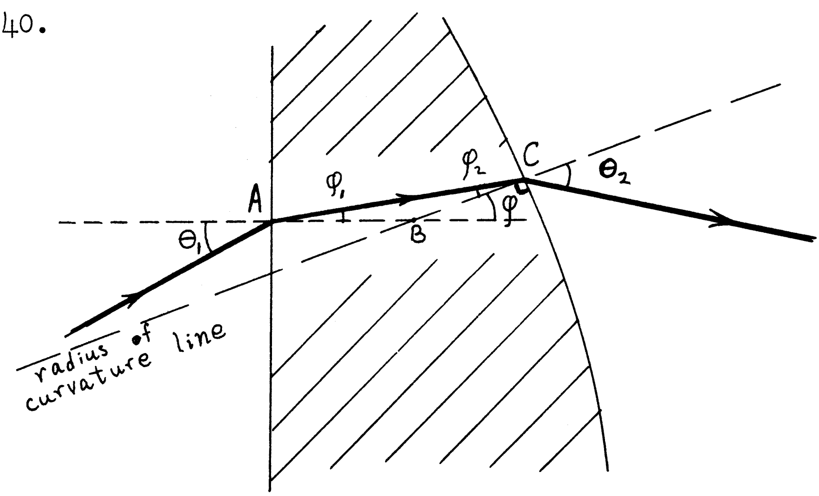
The three lines should be easily distinguishable in a good spectroscope.

18.37. (1) 2.05×10^{-4} cm. (2) 38.2 deg.

18.38. (1) $\Delta f = f_2 - f_1 = \frac{c}{\lambda_2} - \frac{c}{\lambda_1} = \frac{c}{\lambda_2\lambda_1}(\lambda_1 - \lambda_2)$. Set $\lambda_2 - \lambda_1 = \Delta\lambda$, and use $\lambda_1\lambda_2 \cong \lambda_{av}^2$. Then $\Delta f = -c\,\Delta\lambda/\lambda_{av}^2$. (2) $\Delta\lambda = 6\times10^{-8}$ cm, $\lambda_{av} = 5.893\times10^{-5}$ cm, $\Delta f = -5.2\times10^{11}\ \text{sec}^{-1}$; $|\Delta E| = 2.15\times10^{-3}$ eV.

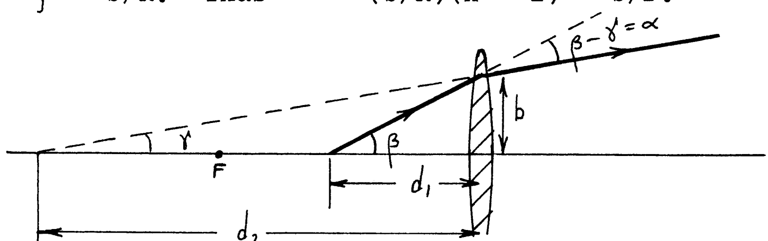
18.39. (1) Near infrared. (2) These K photons are of less energy than the photons of Na D lines. (3) Potassium doublet energy difference greater. Ratio $\Delta E_K/\Delta E_{Na} = (\Delta\lambda_K/\Delta\lambda_{Na})(\lambda_{Na}/\lambda_K)^2 \cong 3.3$.

18.40.



Angle θ_1 is the same as β in Figure 18.28. Angle $\varphi \cong b/R$ (see Figure 18.26 and Equation 18.28). Deflection at the first face = $\theta_1 - \varphi_1$; deflection at the second face = $\theta_2 - \varphi_2$; total deflection, $\alpha = \theta_1 - \varphi_1 + \theta_2 - \varphi_2$. By Snell's law, $\theta_1 \cong n\varphi_1$, $\theta_2 \cong n\varphi_2$, so $\alpha \cong \varphi_1(n - 1) + \varphi_2(n - 1) = (\varphi_1 + \varphi_2)(n - 1)$. From the geometry of the triangle ABC, $\varphi_1 + \varphi_2 = \varphi \cong b/R$. Thus $\alpha \cong (b/R)(n - 1) \cong b/f$.

18.41.



The deflection angle is $\alpha = \beta - \gamma$. For small angles, $\beta \cong b/d_1$ and $\gamma \cong b/d_2$; α is given to be approximately b/f. Therefore $b/f \cong b/d_1 - b/d_2$. Divide by b to obtain $\frac{1}{f} \cong \frac{1}{d_1} - \frac{1}{d_2}$.

CHAPTER NINETEEN

19.2. Yes Consider, for example, an observer moving with the charge; he sees no magnetic field.

19.3. Agreement: (c) and (d). Disagreement: (a) and (b).

19.4. A weight hanging at the end of a string, for instance. Many other possibilities.

19.5. (1)No. (2)Acceleration, force, and laws of motion must be moved from the "Agreement" column to the "Disagreement" column.

19.6. (1)$x' = -vt'$, $y' = h - \frac{1}{2}gt'^2$. (2)$x = 0$, $y = h - \frac{1}{2}gt^2$. (3)The same. (4)Different.

19.7. (1)50 cm/sec^2. (2)$x' = x_o + \frac{1}{2}at'^2$, $x = x_o + vt + \frac{1}{2}at^2$ (where $a = 50$ cm/sec^2).
(3)$t_2 - t_1 = t'_2 - t'_1$; $x_2 - x_1 = x'_2 - x'_1 + v(t_2 - t_1)$.

19.10.(2)From (a) to (b), the airplane moves forward 10^3 cm, one third of distance M_1A. From (b) to (c), the airplane moves forward $3\text{x}10^3$ cm, equal to the distance M_1A. (3)$3\text{x}10^4$ cm/sec (or greater).

19.11.The right triangle in the figure has hypotenuse $\frac{1}{2}v_st$ and sides L and $\frac{1}{2}v_at$. Therefore $\frac{1}{4}v_s{}^2t^2 = L^2 + \frac{1}{4}v_a{}^2t^2$. Solve for t to obtain Formula 19.7.

19.13.(1)The Michelson-Morley experiment, performed repeatedly during the course of a year, would reveal various relative speeds of earth and ether, from which could be deduced the average velocity of the earth through the ether. This in turn would yield the speed and line of direction of the sun relative to the ether. (2)Nothing in Newtonian mechanics limits the speed of an observer. Therefore an observer moving relative to the ether at the speed of light could witness stationary photons in his frame of reference.

CHAPTER TWENTY

20.3. Bartholomew agrees only that the two photons struck simultaneously at the same point. He probably disagrees about (1) the time when this event occurred, and he certainly disagrees about (2) the time interval between this event and the electron emission. He also disagrees (3) that the electron emission and the photon absorption occurred at the same location.

20.4. The ratio v/c must be small compared with 1.

20.5. (1) $\sqrt{1 \pm x} \cong 1 \pm \frac{1}{2}x$. (2) $1/(1 - x) \cong 1 + x$. Optional: $1 + \frac{1}{2}(v/c)^2 + (3/8)(v/c)^4$.

20.6. 3.67 microsec (time dilation factor 1.667).

20.7. 35.4 min (time dilation factor 7.09).

20.8. By about 15% (time dilation factor 1.155).

20.9. Less by 3.29×10^{-4} sec, or 329 microsec (fractional effect, $\frac{1}{2}(v/c)^2 = 2.72 \times 10^{-10}$).

20.10. (1) $v = 0.6c = 1.8 \times 10^{10}$ cm/sec. (2) 2.55×10^{-8} sec. (3) 574 cm.

20.11. The left end of A is opposite a scale reading of 13.4 cm on B (A appears to be 86.6 cm long).

20.12. (1) 1.97 m, or approximately 2m. (2) $|\Delta t'| = v\Delta x'/c^2 = 4.62 \times 10^{-8}$ sec.

20.13. $|\Delta t| = v\,\Delta x/c^2 = 2.67 \times 10^{-7}$ sec.

20.14. According to the train-based observers, the mark at the front of the train was placed 8×10^{-7} sec earlier than the mark at the rear of the train. (In this time the train moved 192 m, so that the train-based observers consider the marks on the ground to be 108 m apart. The ground-based measurement of the distance between the marks is 180 m. These two distances differ by the Lorentz-contraction factor of 0.6.)

20.15. (1) If $\Delta t'$ is positive, the second term in the numerator of Equation 20.7 may be negative and sufficiently large in magnitude to cause Δt and $\Delta t'$ to be of opposite sign. (2) There is agreement on the time sequence if $|\Delta x'| < c\,|\Delta t'|$ (if the spatial separation of events is less than the distance covered by light during their temporal separation).

20.17. (2)(a) $v = 0.8c$; (b) $v = 0.9945c$; (c) $v = 0.9918c$.

20.18. Particle moving toward Jupiter, 0.909c; particle moving toward earth, 0.400c.

20.19. (1) Factor $c^2 - v^2 = (c + v)(c - v)$ and replace $c + v$ by $2c$. (2) Factor is $2.58\text{x}10^{-5}$.

20.22. $\Delta t = 10^{-10}$ sec.

20.25. $\Delta x' = 3\ 10^3$ cm, $\Delta t' = 10^{-7}$ sec; $\Delta x = 9\text{x}10^3$ cm, $\Delta t = 3\text{x}10^{-7}$ sec.

20.26. (a) zero; (b) zero.

20.27. Roles of two observers are reversed. $t_B = t_A/\sqrt{1 - (v/c)^2}$.

20.28. For example, write $(c/v) = 1 + y$, and derive $y = \dfrac{((1 - (v_1/c))(1 - (v_2/c))}{(v_1/c) + (v_2/c)}$, a positive quantity.

20.29. $\sqrt{1 - (v^2/c^2)} = 0.707$. (1) 424 cm. (2) $3\text{x}10^{10}$ cm/sec. (3) The rearward-going photon arrives sooner, by $2.00\text{x}10^{-8}$ sec. (4) I = 600 cm.

20.30. (1) $\Delta x = 2{,}600$ cm, $\Delta t = 9.33\text{x}10^{-8}$ sec. (2) $v = 0.929c = 2.79\text{x}10^{10}$ cm/sec. (3) The interval is time-like. (4) No. Equation 20.7 shows that for any allowable v, Δt and $\Delta t'$ have the same sign.

20.31. (1) $\Delta t' = \dfrac{\Delta t - (v\Delta x/c^2)}{\sqrt{1 - (v^2/c^2)}}$, $\Delta x' = \dfrac{\Delta x - v\Delta t}{\sqrt{1 - (v^2/c^2)}}$.

20.32. (1) Same as answer to 20.31 (1) written above.

CHAPTER TWENTY-ONE

21.1. (a)Time and distance, for example; (b)the speed of light and the four-dimensional interval, for example.

21.2. (2)The mathematical form of the law is unchanged; observers in different frames assign the same relationship among physical quantities. (3)The Galilean transformation.

21.3. 467 gm.

21.4. (1)0.489 MeV. (2)$v = 0.860c = 2.58 \times 10^{10}$ cm/sec.

21.5. (1)By 5×10^{-7}c, or 1.5×10^{4}cm/sec. (2)1.05×10^{11}eV. (3)2.20×10^{-3}sec.

21.6. (a)K.E. = 6 GeV = 9.61×10^{-3}erg; (b)p = 3.70×10^{-13} gm cm/sec (= 6.93 GeV/c); (c)v = 0.99c = 2.97×10^{10}cm/sec. Its effective mass is 1.17×10^{-23}gm, or 7.0 times its rest mass. (The answer 1.25×10^{-23}gm, or 7.5 times the rest mass should be considered correct; this results from using $mc^2 \cong 1$ GeV, but m = 1.673×10^{-24}gm.)

21.7. 1.05×10^{-22}gm cm/sec(= 1.96eV/c).

21.8. Fractional error = $\frac{1}{2}(v^2/c^2) = 3.60 \times 10^{-10}$.

21.9. $E/p = c^2/v$. For a massless particle, v = c and E/p = c.

21.10. The total mass of new particles may be as large as 1.07×10^{-24}gm, equivalent to 600 MeV. This limit is attainable in principle if two neutrinos of negligibly small energy are created, and if the massive particles have a total charge of -2 and zero kinetic energy.

21.11. (1)$E = \sqrt{p^2c^2 + m^2c^4}$. (2)$E \cong pc$ when mc^2 is much less than pc, or, equivalently, when E is much greater than mc^2.

21.12. (1)Expand the square root in Formula 21.3, so that the extra energy loss in the moving frame is $\frac{1}{2}\Delta E(v^2/c^2)$. Equate this to the change of kinetic energy of the block, $\frac{1}{2}\Delta mv^2$, to obtain $\Delta m \cong \Delta E/c^2$. (2)From Equation 21.8, the change of kinetic energy is $\frac{\Delta mc^2}{\sqrt{1-(v^2/c^2)}} - \Delta mc^2$. The extra energy loss in the moving frame is $\frac{\Delta E}{\sqrt{1-(v^2/c^2)}} - \Delta E$. Equate these two expressions to obtain $\Delta m = \Delta E/c^2$.

21.13. The answer should call attention to the fact that an infinite input of energy is required to bring a material particle up to the speed of light.

21.14. (1)To maintain the center-of-mass position at C in the lower part of Figure 21.4, $(m - \Delta m) \times (\frac{1}{2}d + x) = (m + \Delta m)\frac{1}{2}d$. Solve this to get $\Delta m = xm/(x + d)$. (2)If the recoil speed v is much less than the speed of light c, the distance x will be much less than the distance d. Then $x + d \cong d$. (3)Distances moved by object A and by photon are proportional to their speeds: $x/d = v/c$. Thus $\Delta m \cong mx/d = mv/c$. From momentum conservation, $mv = E_\gamma/c$, so $\Delta m = E_\gamma/c^2$.

21.16. Momentum conservation implies that the magnitudes p_1 and p_2 are equal: $p_1 = p_2 = mv/\sqrt{1 - (v^2/c^2)}$. The energy conservation equation is $p_1c + p_2c = 3p_1c = mc^2/\sqrt{1-(v^2/c^2)}$. Eliminate p_1 between these two equations to obtain $v = c/3$.

21.17. (1)Use $m_Kc^2 = 2\,m_\pi c^2/\sqrt{1-(v^2/c^2)}$. $v = c\sqrt{1-(2m_\pi/m_K)^2} = 0.828c = 2.48\times10^{10}$ cm/sec. (2)$v_1 = 2v/(1 + (v^2/c^2)) = 0.982c = 2.95\times10^{10}$ cm/sec.

21.18. $v = 1.67\times10^{-7}$ cm/sec. (Force $= 3.33\times10^{-5}$ dyne, $a = 3.33\times10^{-8}$ cm/sec^2.)

21.19. (1)1.07×10^{-12} gm cm/sec. (2)5.34×10^{-13} cm/sec. (3)K.E. $= 2.85\times10^{-25}$ erg $= 1.78\times10^{-22}$ GeV. (4)$E \cong mc^2 = 1.12\times10^{24}$ GeV.

21.20. (1) $p_x^2 + p_y^2 + p_z^2 - p_t^2 = p^2 - p_t^2 = (E/c)^2 - (E/c)^2 = 0$. (2) The space-time interval between two points on its path.

21.22. In the stationary frame, $E_T^2 - p_T^2c^2 = (Mc^2)^2 - 0 = M^2c^4$. In the moving frame, $E_T^2 - p_T^2c^2 = M^2c^4/(1-(v^2/c^2)) - M^2v^2c^2/(1-(v^2/c^2)) = M^2c^4$.

21.23. Bertram is older, by 8 years.

21.24. (1) The astronaut's clock is behind the earth-based clock, by a fraction $\frac{1}{2}(v^2/c^2) = 3.29\times10^{-10}$, or 1.78×10^{-6} sec. (2) No, since this difference amounts to about 0.01 sec per year.

21.26. (1) Most simply, use Equation 21.28; $(pc)^2 = E^2 - (mc^2)^2 = (7\text{ GeV})^2 - (1\text{ GeV})^2 = 48(\text{GeV})^2$, or $pc \cong 6.9$ GeV. (2) Each proton moves at speed v_1 relative to the center-of-momentum frame, and this frame moves at the same speed v_1 relative to the laboratory frame. The laboratory speed of one proton, v, is thus the relativistic sum of v_1 and v_1: $v = 2v_1/(1 + (v_1^2/c^2))$. For $E = 7\ mc^2$, $v = 0.99c$; then $v_1 = 0.87c$.

21.27. (1) $M_{total}c^2 = 3.94$ GeV; $M_{total} \cong 3.9m_p \cong 5\times10^{-24}$gm. (Use $E_{total} \cong 8\text{ GeV} = M_{total}c^2/\sqrt{1-(0.87)^2}$.) (2) Energy equivalent of the newly created mass is 1.9 GeV, less than the initial kinetic energy of 6 GeV. The difference, 4.1 GeV, appears as kinetic energy of the product particles.

21.29. (1) $E = mc^2$, $p_x = 0$. (2) $E' = mc^2/\sqrt{1-(v^2/c^2)}$, $p_x' = -mv/\sqrt{1-(v^2/c^2)}$.

21.30. Use $E' = (E \pm vp)/\sqrt{1-(v^2/c^2)}$. Set $p = E/c$, $E = hf$, and $E' = hf'$, to obtain $f' = f(1 \pm v/c)/\sqrt{1-(v^2/c^2)}$. The plus sign is appropriate when the velocity of the moving frame is directed toward the negative x-axis (opposite to the photon direction), the minus sign when the velocity of the moving frame is directed toward the positive x-axis (parallel to the photon direction).

21.31. (1) $v = 0.80c = 2.4 \times 10^{10}$ cm/sec. (2) Away from the earth. (3) 3,648 A, near the violet end of the visible spectrum.

CHAPTER TWENTY-TWO

22.1. $F = mv^2/r = m\omega^2 r$, directed radially outward.

22.2. (1) In the maneuver, the airplane must have acceleration g directed vertically downward. It cannot last very long. (2) The inertial force in the accelerated airplane is equal and opposite to the gravitational force.

22.3. (1) A large mass appears below the elevator and exerts a downward force on the occupants of the elevator. (2) An additional mass appears below the elevator for a time. (3) The additional mass is removed, and the first mass remains.

22.4. For example: Two bodies which experience the same force in a gravitational field would not experience the same inertial force in an accelerated frame of reference.

22.5. Relative to both rocket ships, the light follows a downward curving path.

22.6. He measures a frequency less than the frequency measured at the rear of the car. The situation is equivalent to the gravitational red shift (photons leaving a massive star).

22.7. Approximately, for mgh much less than mc^2, $E_2 = mc^2 + mgh = E_1 + mgh$. Thus $E_2 - E_1 = mgh$, $(E_2 - E_1)/E_1 = gh/c^2$.

22.8. (1) $\Delta p = Egh/c^3$. (2) $F = Eg/c^2$ (set $\Delta t = h/c$). (3) F(photon) $= 3.49 \times 10^{-30}$ dyne; F(electron) $= 8.93 \times 10^{-25}$ dyne. F(photon) is less than F(electron) by a factor of more than 10^5.

22.9. (1) $\Delta f/f = gh/c^2$. (2) Fraction 2.32×10^{-15}.

22.10. (1) Photon energy is proportional to photon frequency, vibrations per unit time. (2) Fractional change, 1.09×10^{-12}, or 3.44×10^{-5} sec in a year.

22.11. Rising from the earth, he must transmit on a slightly decreased frequency. Approaching Jupiter, he must increase his transmitting frequency, passing back through the original frequency. On the surface of Jupiter, he must transmit at a slightly higher frequency.

22.14. (1)d = 3.45×10^{-50}cm. (2)3.45×10^{-56}cm. (3)Both distances are extraordinarily small compared to any so far studied in the submicroscopic world. General relativity has not made itself felt in the world of particles.

CHAPTER TWENTY-THREE

23.2. (1)1.99×10^{34}. (2)30.0. (Typographical error in first printing of the book: 10^{11}cm instead of 10^{-11}cm. With the larger distance, the answer would be 3.00×10^{23}.)

23.3. For example: space, or time, or speed, or energy.

23.4. The mean life of such muons is 3.11×10^{-6} sec, and their mean distance of travel before decaying is 4.67×10^{4}cm. The two muons in question move 70.7% and 81.7% of this mean distance. Because of the role of probability in the decay, these measurements provide no evidence against the hypothesis that the particles are muons.

23.5. (1)It is very unlikely, because of the regularity. (2)(d) and/or (a).

23.6. (2)The negative of the slope is the rate of decay in nuclear disintegrations per unit time. (3)The probability of decay per unit time is the same for all nuclei, so that the observed rate of decay is (for a large sample) proportional to the number of radioactive nuclei present. (4)For example: population in certain biological samples, neutron density in early stage of nuclear explosion (or--a non-natural example--compound interest on savings).

23.7. Two half lives, or 11,400 years.

23.8. (1)By spontaneous decay, by collision with a proton or neutron, and in other ways. (2)In the beta decay of a neutron or a nucleus, in muon decay, in "pair creation" by a gamma ray, and in other ways.

23.9. (1) $\lambda = 1.45\text{x}10^{-7}$cm = 14.5A ($\lambda = h/\sqrt{3mkT}$).
(2) $\lambda = 1.45\text{x}10^{-8}$cm = 1.45A.

23.10. (a)$1.65\text{x}10^{-36}$cm; (b)$1.39\text{x}10^{-15}$cm. As the speed approaches zero, the wavelength becomes infinitely large, but in practice the wavelength is still extraordinarily small even for unimaginably low speeds.

23.11. The discussion should emphasize the fact that the neutron wavelength grows as the energy decreases.

23.12. (1)$v = h/\lambda m = 3.96\text{x}10^5$ cm/sec. This is, for a neutron, slow. (2)K.E. = $h^2/2m\lambda^2 = 1.31\text{x}10^{-13}$ erg = 0.082 eV. (3)K.E. = $2.41\text{x}10^{-10}$erg = 150 eV. (4)$E = hc/\lambda = 1.99\text{x}10^{-8}$ erg = $1.24\text{x}10^4$ eV = 12.4 KeV. The photon is in the X-ray region.

23.13. (1) $\lambda = h/p \cong hc/E = 6.20\text{x}10^{-15}$cm. This is roughly (a)one million times smaller than an atom and (b)one hundred times smaller than a nucleus. (2)For both particles, E is much greater than mc^2, so that $p \cong E/c$.

23.14. Use $[h] = ml^2t^{-1}$ and $[e^2] = ml^3t^{-2}$.

23.15. (1)(a)$2.42\text{x}10^{-10}$cm; (b)$1.32\text{x}10^{-13}$cm. (2)When $p = mc$, or $v = 0.707c = 2.12\text{x}10^{10}$cm/sec (relativity is important).

23.18. (1) $\lambda = h/mv = 7.27\text{x}10^{-8}$cm. (2)$\Delta x = \hbar/m\Delta v = 3.86\text{x}10^{-8}$cm. (3)X-rays.

23.19. $\Delta x = \hbar/\Delta p = 1.05\text{x}10^{-21}$cm. In practice, a determination within 10^{-5}cm would be extremely accurate, and a practical limit would be several atomic diameters, more than 10^{-8}cm, vastly greater than the limit of the uncertainty principle.

23.20. (a) $\Delta p = \hbar/\Delta x = 1.05\times10^{-19}$ gm cm/sec; (b) $\Delta v = 1.15\times10^{8}$ cm/sec. This is less than the speed of light by a factor of 260, or it is 0.38% of the speed of light. The remainder of the answer might paraphrase the discussion on p. 743.

23.21. Yes, it is possible. The uncertainty principle implies a velocity uncertainty of about 10^4 cm/sec, or 1 part in 10^4 of the velocity. Thus a measurement to 1 part in 10^3 is possible.

23.22. (1) Being confined, the proton must have finite wavelength, which implies non-zero momentum and energy. (2) $v_{min} \cong \hbar/mL \cong 6\times10^{-6}$ cm/sec. (Any answer of this order of magnitude is satisfactory.)

23.23. (a) Nearly 100%; (b) about 10%; (c) about 5%.

23.24. (1) A pattern with about 5 cycles of oscillation. (2) $\Delta x \cong 5\times10^{-9}$ cm; $\Delta p \cong 2\times10^{-19}$ gm cm/sec. (Approximate answers suffice. The technical definition of uncertainty in quantum mechanics actually makes Δx smaller than this number by a factor of 2π, and Δp larger by the same factor.)

23.25. (1) $L = 10\lambda = 10v/f = 1.13\times10^{4}$ cm. (2) $\lambda = 1.13\times10^{3}$ cm. (3) A fractional range of about 10%, or $\Delta\lambda \cong 10^{2}$ cm, or wavelengths from about 960 to 1,060 cm.

23.26. (1) $e^2/\hbar c = 7.30\times10^{-3}$. Use $[e^2] = ml^3t^{-2}$, $[\hbar] = ml^2t^{-1}$, $[c] = lt^{-1}$. (2) It would not change.

23.28. (1) For example: angular momentum, energies of atoms. (2) For example: position, momentum.

CHAPTER TWENTY-FOUR

24.1. It has finite energy despite no mass; its speed is independent of its energy; it obeys neither the equation K.E. = $\frac{1}{2}mv^2$ nor the equation $p = mv$; it cannot be accelerated.

24.2. (a)The number of photoelectrons is doubled, with no change in their energy; (b)the energy of the photoelectrons plus the work function is doubled. The effects support the proportionality of photon energy to photon frequency, and the proportionality of total energy to the number of photons.

24.3. (1)$v_{wave} = E/p$. (2)Use $E = mc^2/\sqrt{1 - (v^2/c^2)}$ and $p = mv/\sqrt{1 - (v^2/c^2)}$ to obtain $v_{wave} = c^2/v = c(c/v)$, a quantity greater than c if v is less than c.

24.4. For example: the relation of discrete energy states in atoms to characteristic line spectra, the observation of electron-positron pair creation by gamma rays, the Compton effect (photon-electron scattering).

24.5. For example: A photograph of an interference pattern made in light so weak that only one photon at a time passes through the apparatus.

24.6. Its wavelength is less in air than in vacuum, by about 1.8A.

24.7. (2)The main conclusions would be that atoms possess discrete energy states, and that photons are emitted in transitions between these states.

24.8. (1)$\frac{1}{\lambda} = \mathcal{R}(1 - \frac{1}{m^2})$, with $\mathcal{R} = 1.097\text{x}10^5 \text{cm}^{-1}$, and m an integer greater than 1. (2)The Lyman series. (3)$(1/\lambda_\infty) = \mathcal{R} = 1.097\text{x}10^5 \text{cm}^{-1}$; $\lambda_\infty = 9.12\text{x}10^{-6}$cm = 912 A. This lies in the ultraviolet.

24.9. (1)The term proportional to $1/m^2$ arises from the energies of single electron states far removed from the inner electrons, where the electric field is nearly the same as in the hydrogen atom. (2)Set $m = \infty$; $E = hc/\lambda_\infty = 0.378\ hc\mathcal{R} = 5.14$eV.

24.10. It is large relative to the charge-to-mass ratio of protons and of all normal ions.

24.11. At 30,000 volts, K.E. = 30 KeV, still considerably less than mc^2 = 511 KeV, so that relativity was not important (within the limits of his accuracy at that time).

24.12. Since $F \sim q$ (q = charge), and F = ma, $a \sim q/m$.

24.13. From Equation 17.56, $v = \sqrt{2eV/m}$; or, including Equation 17.58, $v = 2Vc/\mathcal{B}r$.

24.14. (1) $m = 1.47\times10^{-12}$ gm. (2) $D = 1.67\times10^{-4}$ cm. Yes, this is reasonable.

24.15. It is the only hydrogen series in the visible region.

24.17. He assumed that states of large n correspond to great separation of electron and proton, and he adopted the usual choice of zero energy at infinite separation.

24.18. (1)(a) $\alpha = e^2/\hbar c$; (b) $\alpha = 7.30\times10^{-3}$. (3) Because α is much smaller than 1, the binding energies (and also the kinetic energies) of the electron are much less than mc^2, and the electron motion is, to a good approximation, non-relativistic.

24.19. 13.6 eV. A photon of this energy is in the ultraviolet.

24.20. An equation of force is $\frac{mv^2}{r} = \frac{e^2}{r^2}$. This gives $K.E. = \frac{1}{2}mv^2 = \frac{1}{2}e^2/r$. The potential energy is $P.E. = -e^2/r = -2\ K.E.$ The binding energy is the negative of the total energy: $W = -E = -(K.E. + P.E.) = +K.E.$

24.21. Use $v = 2\pi r f_e$, so that $W = K.E. = \frac{1}{2}m(2\pi r f_e)^2$. Solve this for f_e, and eliminate r with the help of the equation, $W = e^2/2r$. Equation 24.28 is the result.

24.22. (1) Use $[e^2] = ml^3t^{-2}$, $[h] = ml^2t^{-1}$, $[c] = lt^{-1}$. (2) This is the wavelength of the series limit of the Lyman series, corresponding to an electron transition from very great distance to the ground state of the hydrogen atom. (3) $(1/\mathcal{R}a) = 4\pi\hbar c/e^2 = 4\pi/\alpha$.

24.23. (1) Gases emitting radiation on earth are not sufficiently dilute to allow an atom of diameter 2,500 A to exist undisturbed for a sufficiently long time to radiate. (2)(a) $v = \alpha c/n = 4.38\times10^6$ cm/sec; (b) $D = 2an^2 = 2{,}650$ A $= 2.65\times10^{-5}$ cm; (c) $f_e = v/\pi D = 5.26\times10^{10}\ \text{sec}^{-1}$. (3) $f_r \cong 2c\mathcal{R}/n^3 = 5.26\times10^{10}\ \text{sec}^{-1}$. This radiation is in the microwave region ($\lambda = 0.57$ cm).

24.24. (1) $r = h^2/16me^2 = 1.31\times10^{-8}$ cm.

24.25. (1) $n = 4$. (2) K.E. = 5.25×10^{-5} erg = 32.8 MeV.

24.27. (2) The relative probabilities are (a) 0, (b) 1, and (c) 0.5.

24.28. (1) $d = 4.34\times10^{-8}$ cm. (2) Two in the first state ($n = 1$), two in the second ($n = 2$), and one in the third ($n = 3$). (3) 38 eV (or 6.09×10^{-11} erg). The first three states are at 2 eV, 8 eV, and 18 eV.

24.30. (1) Use $E = pc$, so $E = (hc/2d)n$. (2) $E = 9.94\times10^{-5}$ erg = 62.1 MeV, much greater than the electron's rest energy of 0.511 MeV.

24.32. The orientation with $m = -1$ has the least energy; the orientation with $m = +1$ has the greatest energy.

24.33.

n	ℓ	m_ℓ	m_s
3	0	0	$-\frac{1}{2}$
			$+\frac{1}{2}$
	1	-1	$-\frac{1}{2}$
			$+\frac{1}{2}$
		0	$-\frac{1}{2}$
			$+\frac{1}{2}$
		+1	$-\frac{1}{2}$
			$+\frac{1}{2}$
	2	-2	$-\frac{1}{2}$
			$+\frac{1}{2}$
		-1	$-\frac{1}{2}$
			$+\frac{1}{2}$
		0	$-\frac{1}{2}$
			$+\frac{1}{2}$
		+1	$-\frac{1}{2}$
			$+\frac{1}{2}$
		+2	$-\frac{1}{2}$
			$+\frac{1}{2}$

24.34.

n	ℓ	j	m
3	0	½	-½
			+½
	1	½	-½
			+½
		3/2	-3/2
			-½
			+½
			+3/2
	2	3/2	-3/2
			-½
			+½
			+3/2
		5/2	-5/2
			-3/2
			-½
			+½
			+3/2
			+5/2

24.35. (1) For $\ell = 0$, $j = ½$, 2 states; for $\ell = 1$, $j = ½$, 2 states; for $\ell = 1$, $j = 3/2$, 4 states. Total, 8 states. The individual quantum numbers are those of Table 24.3 for n = 2. (2) The states with $j = ½$ are split into doublets; the state with $j = 3/2$ is split into a quartet.

24.36. Let Z = atomic number (= 11 in this example). The product of nuclear charge and electron charge, equal to $-e^2$ for hydrogen, is equal to $-Ze^2$ for the heavier element. Throughout the Bohr atom theory, replace e^2 by Ze^2. Then (a) the generalization of Equation 24.41 shows that $a \sim 1/Z$, and (b) the generalization of Equation 24.34 shows that $W \sim Z^2$.

24.37. (1) $n = 2$, $\ell = 0$ in lowest state; $n = 2$, $\ell = 1$ in first excited state. (2) $n = 3$, $\ell = 0$; and $n = 3$, $\ell = 1$.

24.38. (1) $n = 1$, $\ell = 0$ (2 electrons); $n = 2$, $\ell = 0$ and 1 (8 electrons); $n = 3$, $\ell = 0$, 1, and 2 (18 electrons); and $n = 4$, $\ell = 0$ and 1 (8 electrons). (2) The 36 electrons fill the first four shells (Figure 24.24), and more than average energy is required to excite an electron to an unoccupied state of motion.

24.39. (a)The atomic shells would be occupied by half as many electrons as in the real world; (b)the atomic shells would be occupied by twice as many electrons as in the real world; (c)there would be no atomic shell structure, no periodic properties, and a wholly different kind of chemistry.

24.40. In hydrogen, the K-shell electron speed is approximately (1/137) c = 2.19×10^8 cm/sec; relativity is of little importance. In uranium, the K-shell electron speed is roughly (92/137)c $\cong 2\times10^{10}$ cm/sec; relativity is important.

24.41. Aluminum, Z = 13. (The K_α photon in hydrogen has energy 10.2 eV. The energy 1.49 KeV is 146 times as great.)

24.42. The discussion should focus on the central position of carbon in the second period. Silicon occupies the corresponding position in the third period.

24.43. (1)In OH, hydrogen shares its electron with oxygen, leaving one unoccupied state of motion in the outer shell of oxygen. Its common compounds include HOH, or H_2O (and NaOH, $Ca(OH)_2$, etc). (2)The valence of NH_4 = -3 + 4 = +1; or, better, explain in more physical terms.

24.44. (1)L = Mvd. (2)For the pair of nuclei, K.E. = Mv^2. In this formula, set v = L/Md, and set L = $\ell\hbar$. (3)K.E. = 4.75×10^{-14} erg = 0.0297 eV. This is roughly 10^2 times less than a typical energy of electronic motion in the hydrogen atom.

24.45. The answer should focus on the decreased rate of chemical reaction, decreased metabolism, etc.

CHAPTER TWENTY-FIVE

25.1. Primarily to the nucleus: (a), (f), (g). To its electronic structure: (b), (c), (d), (e).

25.2. (1) $\rho = 3/[4\pi(1.2 \text{ fermi})^3]$ = 0.138 nucleons/(fermi)^3.

25.3. (1) $v = 1.96\times10^5$ cm/sec. (2) $\lambda = 2.02\times10^{-8}$ cm = 2.02 A, comparable to the size of an atom, very much larger than a nucleus. (3) K.E. = 8.18×10^6 eV = 8.18 MeV.

25.4. (1) Discussion should focus on (a) the great strength, and (b) the short range of the nuclear force. (2) Removal of a neutron or proton from the nucleus, which changes the isotope and possibly the element.

25.5. (1) No, not in practice, because binding energy changes atomic masses by such a tiny fraction--e.g. 13 parts in one billion for hydrogen. (2) For example: Measurement of the energy required to separate the system into its components (feasible for light atoms and light nuclei).

25.6. The discussion should focus on the uncertainty principle and the zero-point energy of a confined particle.

25.7. (1) Krypton 89 contains more neutrons than does yttrium 89, and neutrons are more massive than protons. (2) In stable yttruim 89, the exclusion principle, which favors equal proton and neutron number, and the proton electrical repulsion, which favors lesser proton number, are in balance. In unstable krypton 89, these opposing influences are out of balance. Because of the exclusion principle, the excessive number of neutrons in krypton 89 must fill higher-energy states of motion, which adds extra mass.

25.8. (1) Neutrons are more massive than protons. (2) There is a greater energy associated with proton electrical repulsion in carbon 11 than in boron 11.

25.9. (1) $2^{20} \cong 1.05\times10^6$. (2)(d) Very unlikely. The time in question is more than 60 half lives. The original 10^{12} should decrease to 10^6 in 20 half lives, and to no more than a few after 40 half lives. None of these few is likely to survive another 20 half-lives.

25.10. $\Delta E = \hbar/\Delta t = 4.11\times10^{-7}$ eV. $\Delta E/E = 4.03\times10^{-8}$, a very small fractional uncertainty.

25.11. $\Delta E = \hbar/\Delta t \cong 0.66$ MeV ($\cong 1.05 \times 10^{-6}$ erg). Yes, this would influence the experiment, since this energy uncertainty corresponds to a mass uncertainty $\Delta m = \Delta E/c^2 = 1.17 \times 10^{-27}$ gm, which is greater than the desired accuracy.

25.12. (1) $\Delta t = \hbar/\Delta E \cong \hbar/mc^2$. Set $d = c\Delta t$ to obtain $d \cong \hbar/mc$. (2) $d = 1.4 \times 10^{-13}$ cm = 1.4 fermis.

25.13. (1) For example: By a gamma ray, by an incident proton, by collision with any other particle or nucleus. (2) 2.23×10^6 eV = 2.23 MeV.

25.14. (1) Shell structure and the exclusion principle are the main reasons. (2) For the alpha particle, both neutrons and protons fill the first shell.

25.15. 40. ($n = 3$, $\ell = 1$; and $n = 4$, $\ell = 3$).

25.16. (1)(a) 710 MeV/cm; (b) 940 MeV/cm; (c) 1,350 MeV/cm; (d) 2,500 MeV/cm. (2) 167,000. (3) In the direction of motion, the track becomes heavier because of the increasing rate of energy loss.

25.17. (1) In beta decay, a nucleus loses a neutron and gains a proton (e^- emission, arrow left and upward) or loses a proton and gains a neutron (e^+ emission, arrow right and downward). (2) No arrow; neither Z nor N changes.

25.18. (1) In the nucleus, a proton is transformed to a neutron; a neutrino is emitted; an electron is annihilated instead of created. (2) Their states of motion are re-arranged, but their number is unchanged.

25.19. (a) ${}_{27}Co^{56} \rightarrow {}_{26}Fe^{56} + e^+ + \nu_e$;
(b) ${}_{27}Co^{60} \rightarrow e^- + \bar{\nu}_e + {}_{28}Ni^{60}$;
(c) ${}_{84}Po^{212} \rightarrow {}_{82}Pb^{208} + \alpha$.

25.20. (1) The binding energy of the alpha particle means that its mass per nucleon is less than the mass of either a proton or a neutron. Alpha emission is energetically favored because of this binding energy. (2) Shorter than alpha decay because there is no Coulomb barrier; shorter than beta decay because it involves the strong interaction instead of the weak interaction.

25.21. (1) Among the product isotopes, Pb 210 will be most populous; next Po 210 and Pb 206. (2) Pb 206. (3) Seven elements: radium and all of its products.

25.22. About 4 atoms of U238 to 1 atom of U235. (Six half lives of U235, almost one half life of U238.)

25.23. (1)(2) The student should determine a half life of 54 to 64 minutes and should estimate an uncertainty of ± 2 min to ± 5 min. (The accepted value of the half life of Bi 212 is 60.6 min.) (3) The approximately exponential decay, and the fluctuations of individual measurements away from the smooth curve. [Note: These were actual classroom data.]

25.24. For the given conditions, 1 roentgen = 0.81 rad.

25.25. 4.89×10^4 disintegrations per second.

25.26. (1) ${}_{92}U^{233}$. (2) More easily fissionable (both are odd isotopes, and Z^2/A is greater for U233).

25.27. $E = 8.21 \times 10^{20}$ ergs $= 1.96 \times 10^{13}$ calories. This can heat 3.92×10^8 kg of water by 50°C. The mass of heated water exceeds by a factor of nearly one billion the mass of fissioning uranium.

25.28. (1) 1.02 kg. (2) 435 kg.

25.29. (1) Its protons recoil when struck by neutrons, and the neutron energy is thereby decreased. (2) Deuterons capture neutrons less readily than do protons.

25.30. (1) It decreases. The number of plutonium nuclei in an imaginary cylinder through the sphere increases, despite the lesser diameter. Or, perhaps better, a line drawn through the sphere has a greater chance to intersect a nucleus if the sphere is compressed. (2) Decreased neutron loss can make a subcritical mass go critical (analogous to removal of control rods from a reactor).

25.31. Alpha particle and neutron separate with equal magnitude of momentum. Write K.E.(α) $= p^2/2m_\alpha$, K.E.(n) $= p^2/2m_n$. Energies are inversely proportional to mass for equal momentum. Thus the neutron gets 80% of the energy, the alpha particle 20% of the energy, since $m_\alpha \cong 4m_n$.

25.32. (1) Use $p = h/\lambda$, so $E = p^2/2m = h^2/2m\lambda^2$, and

$$\frac{E_n}{E_e} = \frac{m_e \lambda_e^2}{m_n \lambda_n^2}.$$

(2) $E_n/E_e = 8.7\times10^5$.

CHAPTER TWENTY-SIX

26.1. Electromagnetic and gravitational.

26.3.

	Strong	Electro-magnetic	Weak	Gravitational
(a) neutron	yes	yes	yes	yes
(b) pion	yes	yes	yes	yes
(c) neutrino	no	no	yes	yes
(d) electron	no	yes	yes	yes

The more massive particles experience more interactions.

26.4. Size is inversely proportional to mass; thus the Bohr radius of the muon atom is 2.56×10^{-11} cm, and of the pion atom 1.94×10^{-11} cm. Energies and spectral frequencies are proportional to mass; the characteristic spectra are in the X-ray region. The negative muon cascades to its ground state and then decays. The negative pion cascades to a low state and is captured (a strong interaction) by the proton.

26.5. (1) The factor 17,000 is approximately $Z(m_\mu/m_e) = 82\times206.8$ (refer to Formula 24.41). (2) 3.12×10^{-13} cm = 3.12 fermis. (3) $R = 7.1\times10^{-13}$ cm = 7.1 fermis, more than twice the muon Bohr radius. (4)(a) It raises the energy of the muon (less binding). (b) It enlarges the orbit of the muon.

26.6. Into the page.

26.7. For example:

$$p + p \rightarrow p + \Sigma^+$$
$$p + n \rightarrow p + \Lambda^0$$
$$\pi^- + p \rightarrow K^0 + n$$

and many others.

26.8. (1) $\tau \cong \hbar/\Delta E = \hbar/(\Delta mc^2) = 8.6\text{x}10^{-23}$ sec.
(2) $2.57\text{x}10^{-12}$ cm multiplied by the time dilation factor, $1/\sqrt{1-(v^2/c^2)}$, for speeds near the speed of light.

26.9. (1)Strangeness changes, from -3 to -2. (2)-2 (strangeness is conserved).

26.10. Because of time dilation, pions of extremely great energy can pass vertically through the atmosphere and into the earth before they decay. Pions travelling more nearly horizontally have a much greater path length in air and are more likely to decay before striking the earth.

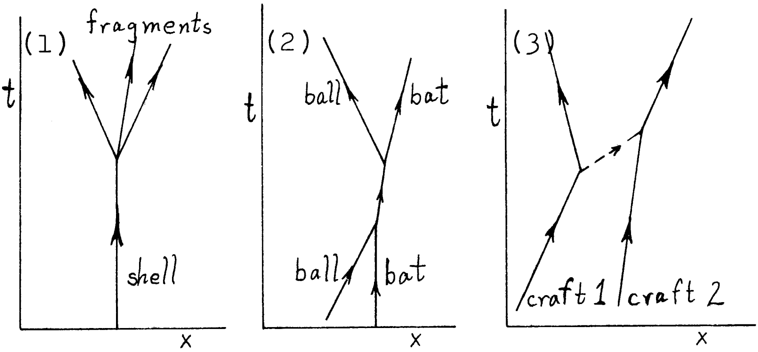
26.11.
$$\nu_e + {}_{17}Cl^{37} \longrightarrow {}_{18}A^{37} + e^-.$$
The conservation laws of charge and of electron-family number play particularly important roles. (Other conservation laws—of energy, momentum, angular momentum, and baryon number—are also obeyed.)

26.12. Fusion of protons to produce alpha particles (or any other heavier nuclei) involves the transformation of some protons to neutrons. For charge conservation, positrons must be created or electrons annihilated. Then, for electron-family number conservation, neutrinos must be created. (The alternative, annihilation of antineutrinos, is very unlikely.)

26.13. (1)The sun would be brighter than the stars. Illumination would be from above in the day and from below (through the planet) at night. The sun would appear small because its neutrinos emanate from a hot core.

CHAPTER TWENTY-SEVEN

27.1.



Neutron decay is similar. | Pion-proton scattering is similar. | Proton-proton scattering is similar.

27.2. The discussion could be built on diagrams such as those of Figures 27.5 to 27.7.

27.3. (2)Baryon conservation is illustrated in Figures 27.2 (c) and (e), 27.9, 27.15, and 27.16. Electron-family number conservation is illustrated in Figures 27.2 (c) and (d), 27.3, 27.4, 27.5, 27.6, 27.7, and 27.16. Muon-family number conservation is illustrated in Figure 27.2 (b). Many of the diagrams are drawn to indicate momentum conservation.

27.4. (1)A negative pion strikes a stationary proton. From the collision emerge a neutron and a neutral pion.

$$\pi^- + p \rightarrow n + \pi^0.$$

(This is sometimes called charge-exchange scattering.) (2)$\pi^+ + \bar{p} \rightarrow \bar{n} + \pi^0$, a process initiated by the collision of a positive pion and an antiproton. It is possible but very unlikely in practice. (3)$\pi^0 + n \rightarrow p + \pi^-$. This process is possible, and is also likely, since a neutral pion can strike a neutron within a nucleus. (However, the interaction of a free neutron and a neutral pion is unlikely.)

27.5. The TCP theorem implies that the reaction $\pi^0 + \bar{n} \rightarrow \bar{p} + \pi^+$, with spins reversed (as well as before and after interchanged, and particles and antiparticles interchanged), is possible in principle.

27.6. (1)For example: orbital motion of astronauts, the nearly elastic collision of cars on an air track, the compression of gas in a cylinder with negligible heat loss. (2)Any processes involving friction or increasing disorder.

27.7. (a)Any symmetrical object such as a rubber ball or a plastic rectangle, and some asymmetrical objects such as gloves or scissors which are deliberately made both left-handed and right-handed. (b)A printed page, most houses and buildings, etc. Mirror images of these are possible in principle.

27.8. (2)For example, a trajectory which spirals always toward one pole, a bedspring pattern.

27.9. (1)$\bar{n} \rightarrow \bar{p} + e^{+} + \nu_e$. (2)The same as the neutron lifetime given in Table 2.1. (This is 1010 sec in the first printing, 935 sec in the second printing, and may change in later printings as the best experimental result changes.)

27.10. (1)A muon's antineutrino, $\bar{\nu}_\mu$. (2)Yes. The muon is right-handed, its spin directed parallel to its momentum. (3)An antineutrino is created, and this particle is involved only in weak interaction processes (overlooking gravity, which may be neglected).

27.11. (1)$\nu_{eR} + \bar{p} \rightarrow \bar{n} + e_R^{-}$. (2)It is not possible in principle, because neutrinos (according to present evidence) are left-handed only. (3)It is not possible in practice.

27.12. (a)½, because it is a charge doublet; (b)0, because it is a charge singlet.

27.13. The pairs differ in isotopic spin orientation. Strong interactions conserve isotopic spin. Electromagnetic interactions do not.

27.14. (1) $t \cong \hbar/(2mc^2) = 6.44\times10^{-22}$sec. (2)$d \cong c\Delta t = 1.93\times10^{-11}$cm. This distance is much larger than a nucleus and much smaller than an atom.

CHAPTER TWENTY-EIGHT

28.1. (1), (3), and (4) are quantitative statements.

The remaining exercises in this chapter have no single simple answers.

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