Answers to Problems

K.1 (a) $31555872 \simeq 3.1556 \times 10^7$ seconds per year, (b) 9.46×10^{15} m

K.2 1233.5 m^3

K.3 (a) (i) 0.0001163, (ii) 6012.88, (b) The factors are reciprocal.

K.4 10 wavelengths

K.5 1000 kg/m^3

K.6 1070 kg/m^3

K.7 3×10^{-4} m, or 3/10 mm

K.8 10^9, one billion

K.9 25 m/s

K.10 $K \sim p^2/m$

K.11 $K \sim L^2/I$

K.12 (i) $P \sim \rho\, v^2$, (ii) $P \sim \rho\, g\, h$

K.13 $a = 4 = c$, $b = 2$, $d = 4$

K.14 See Chapter 47 for time and length. Mass, $m_P = \sqrt{\frac{\hbar\, c}{G}} \sim 2.18 \times 10^{-8}$ kg $\sim 20\,\mu$g.

K.15 10.44 m/s, (b) 37.58 km/h

K.16 (a) $F_{(a)}(t_f) - F_{(a)}(t_i) = a\,\Delta t$, evinces linearity, (b) $F_{(b)}(t_f) - F_{(b)}(t_i) = b\big(2\,t_i\,\Delta t + (\Delta t)^2\big)$, not linear, (c) $F_{(c)}(t_f) - F_{(c)}(t_i) = -\frac{c\,\Delta t}{t_i(t_i+\Delta t)}$, also not linear

K.17 (a) (all units m) (i) 7.5, (ii) -10, (iii) -10, (iv) 10, (v) -2.5, (vi) -2.5, (b) (all m/s) (i) 1.5, (ii) -2, (iii) -1, (iv) 2, (v) -0.1, (vi) -0.25

K.18 (a) 46 day, (b) (i) 25 km/day, (ii) $\frac{500}{23} = 21\,\frac{17}{23} \simeq 21.74$ km/day, (c) (i) 21.5 km/day, (ii) 11 km in the outbound direction of the path, (iii) $\frac{11}{46} \simeq 0.239$ km/day [outbound]

K.19 (a) (all in m) (i) 6, (ii) $7\frac{1}{3}$, (iii) $8\frac{2}{3}$, (iv) 10, (v) 0, (vi) 6, (b) (in m/min) (i) 2/3, (ii) $-3/4$, (iii) 0, (iv) -5, (v) -1, (vi) 3, (c) (m/min^2) (i) $-1\frac{2}{15}$, (ii) 1/3, (iii) 4, (iv) $-2\frac{5}{6}$

K.20 (a) (all in m) (i) 4, (ii) 10, (iii) 0, (iv) $1\frac{1}{3}$, (v) $2\frac{2}{3}$, (vi) 4, (b) (in m/s) (i) 3, (ii) -1, (iii) 0, (iv) -5, (v) $-\frac{3}{4}$, (vi) $\frac{2}{3}$, (c) (m/s^2) (i) -4, (ii) $2\frac{5}{6}$, (iii) $1\frac{5}{12}$, (iv) $-\frac{7}{18}$

K.21 (a) histogram graph, (b) 220 km, (c) (i) 44 kmh, (ii) 70 kmh, (iii) 50 kmh, (iv) 60 kmh, (v) $26\,\frac{2}{3}$ kmh, (vi) 20 kmh, (d) sketch

K.22 [Units are implicit.] (a) (i) 1, (ii) $\frac{3}{4}$, (iii) 1, (iv) $7\,\frac{3}{4}$, (b) (i) 0, (ii) $-\frac{1}{2}$, (iii) 2, (iv) $13\,\frac{1}{2}$, (c) (i) 0, (ii) 0, (iii) 6, (iv) 18, (d) (i) $-\frac{1}{4}$, (ii) 0, (iii) $\frac{9}{4}$, (iv) $\frac{1}{4}$, (v) $3\,\frac{1}{2}$, (vi) $\frac{27}{4} = 6\,\frac{3}{4}$, (e) (i) $-\frac{1}{2}$, (ii) 1, (iii) $\frac{9}{2} = 4\,\frac{1}{2}$, (iv) $\frac{5}{2} = 2\,\frac{1}{2}$, (v) 7, (vi) $\frac{23}{2} = 11\,\frac{1}{2}$, (f) (i) $\frac{7}{2} = 3\,\frac{1}{2}$, (ii) The velocity is assumed to be a continuous and differentiable function of time. The Mean Value Theorem ensures that there is a time t_{01}, with $0 < t_{01} < 1$, for which the instantaneous acceleration at t_{01} matches the average acceleration throughout the first second. In the same way, there is an instant t_{23}, $2 < t_{23} < 3$, when the instantaneous acceleration matches its average value in this one second interval. The times, t_{01} and t_{23}, are independent of one another, and so it is reasonable to expect that the time interval between them is $\simeq 2$ s. Therefore, a reasonable estimate of the average acceleration through this interval is obtained by taking $(v_{\mathrm{av},\,2\to 3} - v_{\mathrm{av},\,0\to 1})\big/(2.5 - 0.5)$.

K.23 (a) (in $\mathtt{m}$) (i) -7, (ii) 7, (iii) 45, (iv) 203, (b) (in $\mathtt{m/s}$) (i) 7, (ii) 19, (iii) 79, (iv) 35

K.24 (a) $v(t) = 6\,t^2 + 6\,t + 5$, (b) $a(t) = 12\,t + 6$

K.25 (a) (i-v) sketches, (b) (i-v) sketches

K.26 (a) (i) $v_- = \big(x_{-+} - x_{--}\big)/\Delta t$, (ii) $v_+ = \big(x_{++} - x_{+-}\big)/\Delta t$, (b) $a_{\rm av} = \big(x_{++} - x_{+-} - x_{-+} + x_{--}\big)/\big(\Delta t\,\Delta T\big)$, (c) $a_0 \simeq \big(x_+ - 2\,x_0 + x_-\big)/(\Delta t)^2$

K.27 (a) $a_{\rm av} = 9\,b$, (b) (i) $9\,b$, (ii) $9\,b$, (c) $9\,b$

K.28 (implicit units) (a) (i) 9.5, (ii) inner estimate = 21, outer estimate = 2125, (iii) 37.5, (b) 28, (c) (Std. method: narrow) 40, (Std. method: wide) 25, (hybrid method) 30

K.29 $x(2) = 6\frac{2}{3}\ \mathtt{m}$, $v(2) = 5\frac{1}{3}\ \mathtt{m/s}$, $a(2) = 3\ \mathtt{m/s^2}$

K.30 (a) (implicit units) (i-iv) all 0, (b) (i) $-3\,\pi$, (ii) $3\,\pi/2$, (iii) $-3\,\pi/5$, (iv) 0, (c) (i) $6\,\pi$, (ii) $-3\,\pi/2$, (iii) $6\,\pi/25$, (iv) 0

K.31 (a) $\mathtt{m}$, $\mathtt{s}^{-1}$, $\mathtt{s}^{-1}$, $\mathtt{rad}$, (b) $v(t) = -A\,e^{-\gamma\,t}\,\left(\gamma\,\cos(\omega\,t + \phi) + \omega\,\sin(\omega\,t+\phi)\right)$, $a(t) = A\,e^{-\gamma\,t}\,\left[\left(\gamma^2 - \omega^2\right)\,\cos(\omega\,t+\phi) + 2\,\gamma\,\omega\,\sin(\omega\,t+\phi)\right]$

K.32 (a) $\mathtt{m/s}$, $\mathtt{s}^{-4}$, $\mathtt{s}$, (b) $v(t) = V_0\,(1 + 4\,a\,t_0^2\,t^2 - 4\,a\,t^4)\,\exp\big(-a\,(t^2 - t_0^2)^2\big)$, $a(t) = 4\,V_0\,a\,t\,(3\,t_0^2 + (4\,a\,t_0^4 - 5)\,t^2 - 8\,a\,t_0^2\,t^4 + 4\,a\,t^6)\,\exp\big(-a\,(t^2-t_0^2)^2\big)$, (c) (i - iii) all 0, (d) (i - iii) all 0, (e) (i - iii) all 0

K.33 (a) (i) 1, (ii) -1, (iii) -1, (iv) 0, (v) 1 (all in $\mathtt{m/s}$), (b) (i) -0.5, (ii) -0.4, (iii) -0.125, (iv) 0 ($\mathtt{m/s^2}$), (c) (i) -0.5, (ii) 0, (iii) 0.5 ($\mathtt{m/s^2}$), (d) $t = 2, 8\ \mathtt{s}$

K.34 (a) ($\mathtt{m}$) (i) 15, (ii) 30, (iii) 30, (iv) 10, (b) $20\,\mathtt{m/s}$, (c) $15\,\mathtt{m/s}$

K.35 (a) $1700\,\mathtt{m}$, (b) $25\,\mathtt{m/s}$, (c) $5.67\,\mu\mathtt{s}$, validating the approximations that the light reached you “instantaneously”

K.36 (a) $510\,\mathtt{m}$, (b) $10\,\mathtt{m/s}$, (c) $1.7\,\mu\mathtt{s}$, effectively instantaneous

K.37 Answers will vary somewhat. (a) Measure, or otherwise determine, the area under the curve on the graph. (b) Read instantaneous velocities directly from the graph.
(c) Divide the value obtained for part (a) by the duration of the interval, t_f. Alternatively, find the constant velocity which bounds the same area as that found in part (a) through the same time interval. (d) Read $v_f = v(t_f)$, $v_0 = v(0)$, and t_f from the graph and form $a_{\rm av} = (v_f - v_0)/(t_f - 0)$. (e) The instantaneous acceleration at t is equal to the slope of the tangent to the velocity curve at that particular time.

K.38 $t = 7\,\mathtt{s}$

K.39 (a) (i) $\frac{1}{2}(7 \pm \sqrt{15})\ \mathtt{s}$, (ii) $\pm 2\,\sqrt{15}\ \mathtt{m/s}$, (b) (i) $3.5\,\mathtt{s}$, (ii) $7.5\,\mathtt{m}$

K.40 (a) (i) $6\,t - 12$, (ii) $3\,t^2 - 12\,t + 6$, (b) (i) -3, (ii) -6, (iii) -3, (iv) 6 (all in $\mathtt{m}$), (c) (i) Yes, (ii) $2 \pm \sqrt{2}\ \mathtt{s}$

K.41 (a) $v(t) = 4\,t - 1$, $x(t) = 2\,t^2 - t + 5$, (b) sketch

K.42 (positions in $\mathtt{cm}$, velocities in $\mathtt{cm/s}$) (a) (i) 4 , -5, (ii) 2, 3, (iii) 16, 11, (iv) 46, 19, (b) (i) 32, -15, (ii) 10, -7, (iii) 4, 1, (iv) 14, 9

K.43 (a) $v(t) = 4\,t^3 + 9\,t^2 + 2\,t$, $x(t) = t^4 + 3\,t^3 + t^2$, (b) $a(2) = 86$, $v(2) = 72$, $x(2) = 44$

K.44 (a) (i) 0, (ii) 6, (iii) 6, (iv) 10, (b) for $-1 < t < 2$, $v(t) = 3\,t^2 - t^3/2$, while for $2 < t < 4$, $v(t) = 24 - 8\,t$, (c) (i) 0, (ii) 8, (iii) 8, (iv) 0, (d) for $-1 < t < 2$, $a(t) = 6\,t - 3\,t^2/2$, while for $2 < t < 4$, $a(t) = -8$

K.45 (a) (i) $v(t) = 0$, $t < 0$, $v(t) = 2\,t - t^2/3$, $0 \le t \le 6$, $v(t) = 0$, $6 < t$, (ii) $x(t) = 0$, $t < 0$, $x(t) = t^2 - t^3/9$, $0 \le t \le 6$, $x(t) = 12$, (b) (i) $v(t) = 2$, $t < 0$, $v(t) = 2 + 2\,t - t^2/3$,

$0 \le t \le 6$, $v(t) = 2$, $6 < t$, (ii) $x(t) = 2\,t + 3$, $x(t) = 3 + 2\,t + t^2 - t^3/9$, $0 \le t \le 6$, $x(t) = 15 + 2\,t$

K.46 (a) (i) 20, (ii) 20, (iii) 20 (all m/s), (b) (i) 20, (ii) 25, (iii) 25 (m/s), (c) (i) 40, (ii) 60, (iii) 160 (all m), (d) (i) 40, (ii) 62.5, (iii) 187.5 (m), (e) sketches

K.47 (velocities in m/s, positions in m) (a) (i) $5\,t$, (ii) 30, (b) (i) $\frac{5}{2}\,t^2$, (ii) $90 + 30\,(t-6) = 30\,t - 90$, (c) sketches, (d) (i) $2\,t$, (ii) 30, (e) (i) t^2, (ii) $225 + 30\,(t-15) = 30\,t - 225$, (f) sketches

K.48 (a) 10, 5, (b) 20, 20, (c) 30, 45, (d) 40, 80, (e) 50, 125, (m/s, m), (f) histogram

K.49 (a) (i) $t \to 0$, all $\to 2$, (ii) $t \to 3$, all $\to 5$, (b) sketches, (c) $v_{s,\mathrm{av}} = 3$, $v_{l,\mathrm{av}} = 3.5$, $v_{r,\mathrm{av}} = 4$, (d) The particles travel different distances in the common time interval.

K.50 (a) (Position, velocity, acceleration values appear in this order at each instant (i-iv) with implicit units.) (i) $2\,X_0$, $-4\,X_0$, $2\,(8-\pi^2)\,X_0 \simeq -3.7392\,X_0$, (ii) 0, $-\pi\,X_0$, $2\,\pi\,X_0$, (iii) $-\frac{2}{3}\,X_0$, $\frac{4}{9}\,X_0$, $\frac{2}{3}\,(\pi^2 - 8/9) \simeq 5.9871$, (iv) 0, $\frac{\pi}{2}\,X_0$, $-\frac{\pi}{2}\,X_0$, (b) sketch

K.51 (a) Sketch, (b) (i) $-\frac{1}{4}\,e^{-t/20}$, (ii) $\frac{1}{80}\,e^{-t/20}$, (c) $20\,\ln(5) \simeq 32.19$ s

K.52 (a) sketch, (b) (i) $\left(\frac{5}{6}\,\pi\,\cos(\pi\,t/6) - \frac{1}{4}\,\sin(\pi\,t/6)\right) e^{-t/20}$, (ii) $\left[\left(\frac{1}{80} - \frac{5\,\pi^2}{36}\right)\sin(\pi\,t/6) - \frac{\pi}{12}\,\cos(\pi\,t/6)\right] e^{-t/20}$, (c) Estimate from the graph: $t_2 \simeq 16$ s

K.53 (a) $[\,X_0\,] = \mathtt{m}$, $[\,a\,] = \mathtt{s}$, (b) decreasing with time, (c) (i) $X_0\,\left[-\ln(3+\sqrt{10}) - \ln(-4+\sqrt{17})\right] \simeq 0.2763\,X_0$, (ii) $X_0\,\left[-\ln(6+\sqrt{37}) - \ln(-7+5\,\sqrt{2})\right] \simeq 0.1523\,X_0$, (d) The displacements in equal time intervals decrease with time.

K.54 (a) $[\,X_0\,] = \mathtt{m}$, $[\,a\,] = \mathtt{s}$, (b) increasing with time, (c) (i) $X_0\,\left[\sin^{-1}(1/3) - \sin^{-1}(1/4)\right] \simeq 0.08715\,X_0$, (ii) $X_0\,\left[\sin^{-1}(3/4) - \sin^{-1}(2/3)\right] \simeq 0.11833\,X_0$, (d) The displacements in equal time intervals increase with time.

K.55 (a) (i) $6\,(1 - e^{-t/3})$, (ii) $6\,t - 18\,(1 - e^{-t/3})$, (b) (i) $\to 6^-$, (ii) $\to 6\,t$

K.56 (a) (i) $\tau\,A\,(1 - e^{-t/\tau})$, (ii) (ii) $\tau\,A\,t - \tau^2\,A\,(1 - e^{-t/\tau})$, (b) (i) $\to \tau\,A$, (ii) $\to \tau\,A\,t$

K.57 (a) sketch, (b) (i) 0, 0, (ii) 2, 1, (iii) 4, 4, (iv) 0, 6, (v) -4, 4, (vi) -8, -2

K.58 For $t < 0$, $x(t) = 0$, $0 < t < 6$, $x(t) = t^2$, for $6 < t < 10$, $x(t) = \frac{5}{2}\,t^2 - 18\,t + 54$, for $10 < t$, $32\,t - 196$

K.59 0 for $t < 0$, $t^3/18$ for $0 < t < 6$, $102 - 42\,t + 11\,t^2/2 - t^3/6$ for $6 < t < 10$, $18\,t - 344/3$ for $t > 10$

K.60 $x(5) = 15$ m, $v(5) = 0$ m/s

K.61 $x(5) = 4\frac{2}{3}$ m, $v(5) = 1$ m/s

K.62 (a) (i) 0, (ii) 3/2, (iii) 2, (iv) 3, (b) (i) 0, (ii) 5/6, (iii) 8/3, (iv) 5

K.63 17.5 m

K.64 $(\sqrt{3}/2, 1/2)$

K.65 (a) 13 m/s, (b) $-\tan^{-1}(12/5) \simeq -67.38°$

K.66 (a) (16 , 2), (b) (8 , 8), (c) (56 , 0), (d) $33\,\overrightarrow{R} = (396\,,\,165)$, (e) (12 , −3), (f) (5 , 4)

K.67 (a) $65\,\cos(\pi/6) = 65\,\sqrt{3}/2$, (b) $5\,\sqrt{3}/2$

K.68 (a) (i) 56 [along z − axis], (ii) (0 , 0 , 56), (iii) 30 [⊙], (b) (i) −33, (ii) −33, (iii) 0

K.69 (a) (2 , 0 , 0), (b) (0 , −2 , 0), (c) 0, (d) (0 , 0 , 2)

K.70 The sum is zero, since each vector appears along with its additive inverse.

K.71 [Typo alert: This question is ill-formed in the first printing. The triangle inequality should (and in reprintings does) read $|\vec{A}+\vec{B}| \le |\vec{A}|+|\vec{B}|$.]
Expand the square of the LHS: $\big(\vec{A}+\vec{B}\big)\cdot\big(\vec{A}+\vec{B}\big) = \vec{A}\cdot\vec{A} + 2\,\vec{A}\cdot\vec{B} + \vec{B}\cdot\vec{B}$. Recognise that $\vec{A}\cdot\vec{B} \le |\vec{A}|\,|\vec{B}|$ according to the Cauchy–Schwarz identity [or the defining properties of `cosine`]. Thus, the square of the LHS is less than the square of the RHS, and the triangle inequality holds for all pairs of vectors.

K.72 Both vectors have magnitude 100.

K.73 (a) sketch, (b) $|\vec{A}| = \sqrt{26} \simeq 5.10$, $\theta_A = 0.1974\,\texttt{rad}$, $\theta_A = 11.31°$, $|\vec{B}| = 2\sqrt{5} \simeq 4.48$, $\theta_B = -0.4636\,\texttt{rad}$, $\theta_B = -26.57°$, $|\vec{C}| = 3\sqrt{2} \simeq 4.23$, $\theta_C = 0.7854\,\texttt{rad}$, $\theta_C = 45°$, $|\vec{D}| = 2\sqrt{5} \simeq 4.48$, $\theta_D = -1.107\,\texttt{rad}$, $\theta_D = -63.44°$, $|\vec{E}| = \sqrt{26} \simeq 5.10$, $\theta_E = 1.373\,\texttt{rad}$, $\theta_E = 78.68°$, (c) (i) $\vec{F} = (15\,,\,3)$, (ii) $|\vec{F}| = 3\sqrt{26} \simeq 15.3$, $\theta_F = 0.1974\ \texttt{rad} = 11.31°$,
(d) (i) $\vec{G} = (3\,,\,55)$, (ii) $|\vec{G}| = \sqrt{3034} \simeq 55.1$, $\theta_G = 1.5163\ \texttt{rad} = 86.88°$

K.74 (all lengths in `cm`) (a) sketch, (b) $\vec{V}_1 = (3\sqrt{3}\,,\,3)$, $\vec{V}_2 = (0\,,\,6)$, $\vec{V}_3 = (-3\sqrt{3}\,,\,3)$, $\vec{V}_4 = (-3\sqrt{3}\,,\,-3)$, $\vec{V}_5 = (3\,,\,-3\sqrt{3})$, $\vec{V}_6 = (3\sqrt{3}\,,\,-3)$, (c) (i) $(3\,,\,6-3\sqrt{3}) \simeq (3\,,\,0.804)$, (ii) 3.106, $\theta \simeq 0.2618\,\texttt{rad} = 15°$, (d) $\vec{V}_5 \to (0\,,\,-6)$

K.75 Southeast

K.76 $\frac{5}{6}$ `km/h` [north]

K.77 1/3 `floor/h` [upward]

K.78 $\vec{0}$

K.79 (a) 13/12 `mile`, (b) $\sqrt{97}/12 \simeq 0.82$ `mile`

K.80 (a) $40\,(1+\sqrt{2}) \simeq 96.57\,\texttt{km}$, (b) 40 `km` west, 80 `km` north, or $40\sqrt{5}$ `km` at 26.57° west of north, (c) $10\,(1+\sqrt{2}) \simeq 24.14\,\texttt{km/h}$, (d) 10 `km/h` west, 20 `km/h` north, or $10\sqrt{5}$ `km/h` at 26.57° west of north

K.81 (a) 115 `km`, (b) $(-45\,,\,100)$ `km` or $5\sqrt{481}$ `km` at 24.23° west of north, (c) 23 `km/h`, (d) $(-9\,,\,20)$ `km/h` or $\sqrt{481} \simeq 21.93$ `km/h` at 24.23° west of north

K.82 (a) 100 `km`, (b) $(42.3\,,\,82.3)$ `km` $= 92.6$ `km` [at 27.23° east of north], (c) 25 `km/h`, (d) $(10.6\,,\,20.6)$ `km/h` $= 23.2$`km/h` [at 27.23° east of north]

K.83 (a) $(5+t\,,\,10-2\,t)$, (b-c) sketches, (d) no, (e) at $y = -480\,\texttt{m}$, when $t = 245\,\texttt{s}$

K.84 (a) $\sqrt{29}$ `m/s`, (b) $(4\,,\,-6\,,\,8)$ `m`, (c) $(5\,,\,-7.5\,,\,10)$ `m`

K.85 (a) 18 $\texttt{cm/s}^2$, (b) (i) $(12\,,\,-12\,,\,6)$ `cm/s`, (ii) $(6\,,\,18\,,\,20)$ `cm`, (c) $(24\,,\,0\,,\,29)$ `cm`

K.86 (a) (i) $\frac{17}{39}$ `km/min`, (ii) 13 `km` at 22.62° north of east, (iii) $\frac{1}{3}$ `km/min` at 22.62° north of east; (b) (i) 4 `km/h`, (ii) 2 `km` west, (iii) 4 `km/h` west, (c) (i) 1 `km/h`, (ii) 1 `km` south,
(iii) 0.2 `km/h` south, (d) (i) 1 `km/min` (ii) 5 `km` at 36.87° west of north, (iii) 1 `km/min` at 36.87° west of north

K.87 (a) (i) 0.2 `km/min` $= 3\frac{1}{3}$ `m/s`, (ii) 5 `km` at 36.87° north of east, (iii) $\frac{1}{7}$ `km/min` at 36.87° north of east or 2.38 `m/s` at 36.87° north of east, (b) (i) 2 `km/min` or $33\frac{1}{3}$ `m/s`, (ii) 2 `km` due east, (iii) 2 `km/min` east or $33\frac{1}{3}$ `m/s` east, (c) (i) 2.5 `km/h` $= 0.694$ `m/s`, (ii) 1 `km` south,
(iii) 0.25 `km/h` south

K.88 (a) (i) 7 `km`, (ii) 5 `km`, (iii) 36.87° east of north, (b) (i) $\frac{1}{5}$ `km/h`, (ii) $\frac{1}{7}$ `km/h` at 36.87° east of north, (c) (i) $\frac{12}{17}$ `km/h`, (ii) $\frac{12}{17}$ `km/h` at 36.87° south of east, (d) (i) 13 `km` at 14.25° south of east, (ii) 19/52 `km/h`, (iii) $\frac{1}{4}$ `km/h` at 14.25° south of east

K.89 (a) (i) $(0\,,\,0)$, (ii) $(32\,,\,2)$, (iii) $(12\,,\,0)$, (b) (i) $(0\,,\,0)$, (ii) $(48\,,\,2)$, (iii) $(92\,,\,4)$

K.90 (a) (i) $(0\,,\,4\,t)$, (ii) $(0\,,\,16)$, (iii) $(0\,,\,2\,t^2)$, (iv) $(0\,,\,32)$,
(b) (i) $(3\,(t-4)\,,\,16-4\,(t-4)) = (3\,t-12\,,\,32-4\,t)$, (ii) $(12\,,\,0)$,
(iii) $(\frac{3}{2}\,(t-4)^2\,,\,32+16\,(t-4)-2\,(t-4)^2) = (\frac{3}{2}\,t^2-12\,t+24\,,\,-2\,t^2+32\,t-64)$,
(iv) $(24\,,\,64)$, (c) (i) $(12\,,\,0)$, (ii) $(12\,,\,0)$, (iii) $(24+12\,(t-8)\,,\,64) = (12\,t-72\,,\,64)$

K.91 (a) sketches, (b) (i) $(12\,t\,,\,-5\,t)$, (ii) sketches, (c) (i) $(6\,t^2\,,\,-\frac{5}{2}\,t^2)$, (ii-iii) sketches, (d) inertial motion in the direction $\frac{1}{13}(12\,,\,-5)$

K.92 (a) (i) $(4\,,\,2)$, (ii) $(4\,,\,2)$, (b) (i) $(8\,,\,0)$, (ii) $(16\,,\,4)$,
(c) (i) $(8\,,\,0)$, (ii) $(16+8(t-4)\,,\,4) = (8\,t-16\,,\,4)$

K.93 $\vec{v} = (t-1\,,\,2+\frac{t}{2})$, $\vec{r} = (1-t+\frac{1}{2}\,t^2\,,\,-3+2\,t+\frac{1}{4}\,t^2)$

K.94 (a) (i) $\frac{121\sqrt{3}}{20} \simeq 10.48\,\mathtt{m}$, (ii) $10.48\,\mathtt{m}$, (b) $\frac{11}{40}\left(11\sqrt{3} \pm \sqrt{203}\right) \simeq 1.32\,\mathtt{m}$ and $9.16\,\mathtt{m}$

K.95 (a) (i) $v_x = \frac{15\sqrt{3}}{2}$, $v_y = \frac{15}{2} - 10\,t$, $r_x = \frac{15\sqrt{3}}{2}\,t$, $r_y = \frac{15}{2}\,t - 5\,t^2$, (ii) $1.5\,\mathtt{s}$, (iii) $\frac{45\sqrt{3}}{4} \simeq 19.48\,\mathtt{m}$, (b) (i) $v_x = \frac{15}{2}$, $v_y = \frac{15\sqrt{3}}{2} - 10\,t$, $r_x = \frac{15}{2}\,t$, $r_y = \frac{15\sqrt{3}}{2}\,t - 5\,t^2$, (ii) $\frac{3\sqrt{3}}{2} \simeq 2.6\,\mathtt{s}$, (iii) $\frac{45\sqrt{3}}{4} \simeq 19.48\,\mathtt{m}$, (c) (i) $v_x = \frac{25}{2}$, $v_y = \frac{25\sqrt{3}}{2} - 10\,t$, $r_x = \frac{25}{2}\,t$, $r_y = \frac{25\sqrt{3}}{2}\,t - 5\,t^2$, (ii) $\frac{5\sqrt{3}}{2} \simeq 4.33\,\mathtt{s}$, (iii) $\frac{125\sqrt{3}}{4} \simeq 54.12\,\mathtt{m}$

K.96 $\theta_{\max} = \pi/4\ \mathtt{rad}$

K.97 $\frac{v_0^2}{g}\,\sin(\theta_0)\,\cos(\theta_0)\,\left(1 + \sqrt{1 + 2\,g\,H/\big(v_0^2\,\sin^2(\theta_0)\big)}\,\right)$

K.98 (a) $\sqrt{2}\ \mathtt{s}$, (b) $3\sqrt{2}\ \mathtt{m}$, (c) $(3\,,\,-10\sqrt{2}) = \sqrt{209}\ \mathtt{m/s}$ at $\tan^{-1}(10\sqrt{2}/3) \simeq 78^\circ$ from horizontal, or 12° from vertical

K.99 (a) $240\,\mathtt{m}$, (b) $\theta = \sin^{-1}\left(\frac{3}{\sqrt{22}}\right) = \tan^{-1}\left(\frac{3}{\sqrt{13}}\right) \simeq 0.694\ \mathtt{rad} \simeq 39.76^\circ$

K.100 (a) $50\,\mathtt{m/s}$, (b) $(50\,,\,150)\ \mathtt{m/s}$, (c) nope

K.101 $1+\sqrt{2} \simeq 2.414\ \mathtt{s}$ and $\big(10\,(1+\sqrt{2})\,,\,-5\big) \simeq \big(24.14\,,\,-5\big)\,\mathtt{m}$ WRT launch point

K.102 (a) $160\,\mathtt{m}$, (b) $160.9\ \mathtt{m}$, (c) $22.38\ \mathtt{m}$, (d) $0.9\ \mathtt{m}$. Have the defending archers fire from the roof to gain increased range until the attackers are well within $160\,\mathtt{m}$ from the tower.

K.103 (a) $(40\,\cos(\theta_0)\,t\,,\,20+40\,\sin(\theta_0)\,t-5\,t^2)$,
(b) Range $= 160\,\cos(\theta_0)\left(\sin(\theta_0) + \sqrt{\sin^2(\theta_0)+1/4}\right)$, (c) $\tan^{-1}\big(2/\sqrt{5}\big) \simeq 41.8^\circ$,
(d) Max. Range $\simeq 178.9\,\mathtt{m}$, a significant increase

K.104 (a) $4\,\sin(15) \simeq 1.035\ \mathtt{s}$, (b) $15\ \mathtt{m}$ from scrimmage, 20 from QB, (c) $25\ \mathtt{m}$, (d) 53.13° from forward, (e) $8.24\ \mathtt{m/s}$

K.105 (a) Max. height $\simeq 1.225\,\mathtt{m}$, Range $\simeq 4.9\,\mathtt{m}$, (b) $255.65\ \mathtt{m}$

K.106 (a) $8\,\mathtt{s}$, (b) (i) $320\,\mathtt{m}$, (ii) 45° below horizontal, (c) (i) $(-80\,,\,160)\ \mathtt{m/s^2}$,
(ii) $178.9\ \mathtt{m/s^2}$, $\tan^{-1}(2) \simeq 63.4^\circ$ backward and up above horizontal

K.107 (a) $v_0 = 11\ \mathtt{m/s}$, $\theta_0 = \tan^{-1}\big(2\sqrt{30}\big) \simeq 1.48\ \mathtt{rad} \simeq 84.78^\circ$, $D_0 \simeq 1.095\ \mathtt{m}$,
(b) $a_{\mathrm{av}} \simeq 30.25\ \mathtt{m/s^2} \sim 3\,g$

K.108 (a) $700\,\mathtt{m/s}$, $\sim 99\,\mathtt{s}$, (b) $30625\,\mathtt{m/s^2}$, lethal acceleration

K.109 The range constraint fixes the angle to be nearly 22° or 68°. Of these, only 68° enables the balloon to pass over the fence. Therefore, fire at 68° elevation above horizontal.

K.110 (a) (i) $\frac{1000\,\pi}{3} \simeq 1047.2\ \mathtt{m}$, (ii) $\frac{25\,\pi}{9}\ \mathtt{m/s}$, (iii) $(-500\sqrt{3}, 0)\ \mathtt{m}$, (iv) $(-\frac{25\sqrt{3}}{6}, 0)$,
(b) (i) $\frac{1000\,\pi}{3}\ \mathtt{m}$, (ii) $\frac{50\,\pi}{27}\ \mathtt{m/s}$, (iii) $(250\sqrt{3}, -750)\ \mathtt{m}$, (iv) $(\frac{25\sqrt{3}}{18}, -\frac{25}{6})\ \mathtt{m/s}$,
(c) (i) $1000\,\pi\ \mathtt{m}$, (ii) $125\,\pi\ \mathtt{m/min} = 2\,\frac{1}{12}\,\pi\ \mathtt{m/s}$, (iii) $(0, 0)\ \mathtt{m}$, (iv) $(0, 0)\ \mathtt{m/s}$

K.111 (a) $30/\pi$, (b) $\pi/30$

K.112 $a_c \simeq 5.93 \times 10^{-3}\ \mathtt{m/s}$, the direction is changing

K.113 (a) $\frac{4\pi^2}{25}\ \mathtt{m/s}^2$, (b) $\frac{\pi^2}{5}\ \mathtt{m/s}^2$

K.114 (a) $\frac{4\pi^2 R_i}{\tau^2}$, (b) $\frac{4\pi^2 R_o}{\tau^2}$

K.115 (a) $52\,\mathtt{rad/s}$, (b) $11.3\,\mathtt{rad/s}$

K.116 (a) $40\,\pi/3 \simeq 41.89\,\mathtt{rad/s}$, (b) (i) $4\,\pi/5 \simeq 2.51\,\mathtt{m/s}$, (ii) $2\,\pi/5 \simeq 1.26\,\mathtt{m/s}$, (c) (i) Feels a pseudoforce deflecting him to the left, (ii) same as (i)

K.117 (a) (i) $10\,\mathtt{m/s}$, (ii) $10\,\mathtt{m}$, (iii) $2\,\mathtt{s}$, (b) (i) $15\,\pi \simeq 47.12\,\mathtt{m}$, (ii) $7\frac{1}{2}\ \mathtt{s}$, (iii) $\frac{4\pi^2}{15} \simeq 2.63\,\mathtt{m/s}^2$, (iv) inward, toward the centre

K.118 (a) $\vec{v} = \omega\, R\big(-\sin(\omega\, t)\,,\, \cos(\omega\, t)\big)$, (b) $\vec{a} = -\omega^2\, R\big(\cos(\omega\, t)\,,\, \sin(\omega\, t)\big)$

K.119 (a) (i-ii) $\frac{d\vec{r}}{dt} = (3, 4)$, (iii) $\vec{r}(0) = \vec{0}$, (b) (i) $(r\,,\,\theta) = (5\,t\,,\, 53.13°)$ (ii-iii) $\vec{v} = (5\,,\,0)$

K.120 [Typo alert: A factor of a_0 is missing in the polar expression of $\vec{r}$ in part (b).]
(a) (i) use $\frac{dy}{dx} = \frac{\frac{dy}{dt}}{\frac{dx}{dt}}$ to show that $\frac{dy}{dx}$ is constant, (ii) $\left|\frac{d\vec{r}}{dt}\right| = a_0$, (iii) $\vec{r}(0) = \vec{0}$,
(b) (i) $\tan\big(\theta(t)\big) = \gamma$, and $r^2(t) = x^2(t) + y^2(t) = a_0^2$, (ii) In Cartesian parameterisation: $\vec{v} = \left(\frac{a_0}{\sqrt{1+\gamma^2}}\,,\, \frac{a_0\,\gamma}{\sqrt{1+\gamma^2}}\right)$ and $\vec{a} = (0\,,\,0)$. In the polar parameterisation: $\vec{v} = (a_0\,,\,0)$ and $\vec{a} = (0\,,\,0)$. (iii) The acceleration of the particle is zero, irrespective of the use of Cartesian of polar parameterisation.

K.121 (a) $r(t) = t\,\sqrt{1+t^2}$, $\theta(t) = \tan^{-1}(t)$, (b) Cartesian $\vec{v} = (1\,,\,2\,t)$, polar $\vec{v} = \left(\frac{1+2\,t^2}{\sqrt{1+t^2}}\,,\, \frac{t}{\sqrt{1+t^2}}\right)$, (c) Cartesian $\vec{a} = (0\,,\,2)$, polar $\vec{a} = \left(\frac{2\,t}{\sqrt{1+t^2}}\,,\, \frac{2}{\sqrt{1+t^2}}\right)$

K.122 (a) $r(t) = V_0\,t\sqrt{1+\left(\frac{A_0\,t}{2\,V_0}\right)^2}$, $\theta(t) = \tan^{-1}(\frac{A_0\,t}{2\,V_0})$,

(b) Cartesian $\vec{v} = (V_0\,,\,A_0\,t)$, polar $\vec{v} = \left(V_0\,\frac{1+2\left(\frac{A_0\,t}{2\,V_0}\right)^2}{\sqrt{1+\left(\frac{A_0\,t}{2\,V_0}\right)^2}}\,,\, V_0\,\frac{\frac{A_0\,t}{2\,V_0}}{\sqrt{1+\left(\frac{A_0\,t}{2\,V_0}\right)^2}}\right)$,

(c) Cartesian $\vec{a} = (0\,,\,A_0)$, polar $\vec{a} = \left(A_0\,\frac{\frac{A_0\,t}{2\,V_0}}{\sqrt{1+\left(\frac{A_0\,t}{2\,V_0}\right)^2}}\,,\, A_0\,\frac{1}{\sqrt{1+\left(\frac{A_0\,t}{2\,V_0}\right)^2}}\right)$

K.123 (a) $r(t) = \sqrt{1+t^2}$, $\theta(t) = \tan^{-1}(t)$, (b) Cartesian $\vec{v} = (0\,,\,1)$, polar $\vec{v} = \left(\frac{t}{\sqrt{1+t^2}}\,,\, \frac{1}{\sqrt{1+t^2}}\right)$, (c) Cartesian $\vec{a} = (0\,,\,0)$, polar $\vec{a} = (0\,,\,0)$

K.124 (a) $r(t) = \sqrt{X_0^2 + V_0^2\,t^2}$, $\theta(t) = \tan^{-1}(\frac{V_0\,t}{X_0})$, (b) Cartesian $\vec{v} = (0\,,\,V_0)$, polar $\vec{v} = \left(\frac{V_0^2\,t}{\sqrt{X_0^2+V_0^2\,t^2}}\,,\, \frac{X_0\,V_0}{\sqrt{X_0^2+V_0^2\,t^2}}\right)$, (c) Cartesian $\vec{a} = (0\,,\,0)$, polar $\vec{a} = (0\,,\,0)$

K.125 $\vec{v} = \big(\frac{R}{t}\,,\,\omega\,R\,\ln(\gamma\,t)\big)$, $\vec{a} = \big(-\frac{R}{t^2} - \omega^2\,R\,\ln(\gamma\,t)\,,\, \frac{2\,\omega\,R}{t}\big)$

D.1 (a) sketch, (b) $10\,\mathtt{s}$, (c) $250\,\mathtt{m}$ [behind]

D.2 $27\,\mathtt{m/s}$

D.3 $(v_{\rm T}\,,\,v_{\rm C})$ (a) (i) 15, −35, (ii) 5, −45, (b) (i) 20, −30, (ii) 0, −50, (c) (i) 25, −25, (ii) −5, −55

D.4 (fwd , sdwys) (a) $\vec{v}_{\rm T} = (10\,,5)$, $\vec{v}_{\rm C} = (-40\,,\,5)$, (b) $\vec{v}_{\rm T} = (10\,,\,-15)$, $\vec{v}_{\rm C} = (-40\,,\,-15)$

D.5 (a) (i) $(-12.5\,,\,0)$, (ii) $(-8\,,\,6)$, (b) (i) $(12.5\,,\,0)$, (ii) $(4.5\,,\,6)$, (c) (i) $(8\,,\,-6)$, (ii) $(-4.5\,,\,-6)$, (d) sketches

D.7 (a) (i) $-g = -10\,\mathtt{m/s}^2$, (ii) $v_A(t_A) = -g\,t_A = -10\,t_A$, $y_A(t_A) = 3080 - (g/2)\,t_A^2 = 3080 - 5\,t_A^2$, (b) (i) $-g$, (ii) $v_B(t_B) = -10\,t_B$, $y_B(t_B) = 3000 - 5\,t_B^2$, (c) (i) $t_A = 4\,\mathtt{s}$, when $t_B = 0$, (ii) $v_A(4) = -40\,\mathtt{m/s}$, (d) $v_B(t_A) = 40 - 10\,t_A$, $y_B = 2920 + 40\,t_A - 5\,t_A^2$, provided that $t_A \geq 4$, (e) (i) and (ii) $v_b(t_B) = -20 - 10\,t_B = 20 - 10\,t_A$, $y_b(t_B) = 3000 - 20\,t_B - 5\,t_B^2 = 3000 - 20\,t_A - 5\,t_A^2$, for $t_A \geq 4$, (f) (i) sketch, (ii) inertial behaviour is exhibited in freely falling frames

D.8 125 $\mathtt{N}$

D.9 500 $\mathtt{N}$

D.10 (a) Team Left, (b) 0.2 $\mathtt{m/s}^2$, (c) $2\sqrt{10}\,\mathtt{s}$, (d) $\frac{2\sqrt{10}}{5}$

D.11 (a) (i) $1\,\mathtt{m/s}^2\,[\downarrow]$, (ii) $5\,\mathtt{s}$ (moving downward), (b) (i) $2\,\mathtt{m/s}^2\,[\uparrow]$, (ii) $2.5\,\mathtt{s}$ (upward)

D.12 (a) sketch, (b) $2\,\mathtt{m/s}^2$, (c) (i) $2\,\mathtt{s}$, (ii) $-4\,\mathtt{m}$

D.13 (a) $(48\,,\,-20) = 52\ \mathtt{m/s}\,[-22.62^\circ$ WRT x-axis$]$, (b) $(96\,,\,-40) = 104\ \mathtt{m}\,[22.62^\circ$ below x-axis$]$

D.14 (a) (i) $(0\,,\,-10)$, (ii) $(0\,,\,2)$, (iii) $(0\,,\,0)$, (b) (i) $(5\sqrt{3}\,,\,5 - 10\,t)$, (ii) $(5\sqrt{3}\,,\,-5 + 2\,(t-1)) = (5\sqrt{3}\,,\,2\,t - 7)$, (iii) $(5\sqrt{3}\,,\,5)$, (c) (i) $(5\sqrt{3}\,t\,,\,5\,t\,(1-t))$, (ii) $(5\sqrt{3}\,t\,,\,(t-1)(t-6))$, (iii) $(5\sqrt{3}\,t\,,\,5\,t - 30)$

D.15 (a) sketch, (b) $100\,\mathtt{N}$, (c) $20\ \mathtt{N}\,[\rightarrow]$, (d) $2\ \mathtt{m/s}^2\ [\rightarrow]$, (e) $2\,\mathtt{s}$, (f) $2\,\mathtt{m/s}\ [\rightarrow]$

D.16 (a) sketch, (b) $40\ \mathtt{N}\,[\rightarrow] = (40\,,\,0)\ \mathtt{N}$, (c) $4\ \mathtt{m/s}^2\ [\rightarrow]$, (d) (i) $14\ \mathtt{m/s}\,[\rightarrow]$, (ii) $24\ \mathtt{m}\,[\rightarrow] = (24\,,\,0)\ \mathtt{m}$

D.17 (a) sketch, (b) $(0\,,\,2)\ \mathtt{m/s}^2$, (c) kinematical verification, (d) (i) $(3\,,\,4)\ \mathtt{m/s}$, (ii) $5\,\mathtt{m/s}$

D.18 (a) (i) $(\frac{3}{32}\,t^2\,,\,\frac{5}{64}\,t^{3/2})$, (ii) $(1 + \frac{1}{32}\,t^3\,,\,2 + \frac{1}{32}\,t^{5/2})$, (iii) $(3/2\,,\,5/8)\ \mathtt{m/s}$, (iv) $(3\,,\,3)\ \mathtt{m}$, (b) (i) $(\frac{3}{2} + \frac{3}{4}\,(t-4)\,,\,\frac{5}{8} + \frac{15}{64}\,(t-4)) = (\frac{3}{4}\,t - \frac{3}{2}\,,\,\frac{15}{64}\,t - \frac{5}{16})$, (ii) $(\frac{3}{8}\,t^2 - \frac{3}{2}\,t + 3\,,\,\frac{15}{128}\,t^2 - \frac{5}{16}\,t + \frac{19}{8})$, (iii) $(9/2, 25/16)\ \mathtt{m/s}$, (iv) $(15, 7\,\frac{3}{8})\ \mathtt{m}$, (c) (i) $(9/2, 25/16)$, (ii) $(\frac{9}{2}\,t - 21\,,\,\frac{25}{16}\,t - 5\,\frac{1}{8})$, (iii) $(9/2, 25/16)$, (iv) $(33\,,\,13\,\frac{5}{8})$

D.19 (a) (i) $(2\,,\,-1)$, (ii) $(0\,,\,-3/2)$, (b) (i) $(0\,,\,1)$, (ii) $(1\,,\,-3/2)$, (c) (i) $(0\,,\,1)$, (ii) $(1\,,\,1/2)$

D.20 (a) (all in $\mathtt{N}$) (i) $(6\,,\,9\,,\,0)$, (ii) $(-6\,,\,-6\,,\,0)$, (iii) $\vec{0}$, (b) $(\mathtt{m/s}^2)$ (i) $(2\,,\,3\,,\,0)$, (ii) $(-2\,,\,-2\,,\,0)$, (iii) $\vec{0}$, (c) $(\mathtt{m/s})$ (i) $\vec{0}$, (ii) $(10\,,\,15\,,\,0)$, (iii) $(0\,,\,5\,,\,0)$, (iv) $(0\,,\,5\,,\,0)$, (d) $(\mathtt{m})$ (i) $(1\,,\,1\,,\,0)$, (ii) $(26\,,\,75/2\,,\,0)$, (iii) $(51\,,\,177/2\,,\,0)$, (iv) $(51\,,\,227/2\,,\,0)$

D.21 $\vec{r} = (28.5\,,\,-6.5)$, $\vec{v} = \vec{0}$

D.22 (a) $\frac{F_0}{M}\,\sin(2\,\pi\,t)$, (b) $-\frac{F_0}{2\,\pi\,M}\,\cos(2\,\pi\,t)$, (c) $-\frac{F_0}{4\,\pi^2\,M}\,\sin(2\,\pi\,t)$

D.23 (a) $\frac{F_0}{M}\,(1 - e^{-\gamma t})$, (b) $\frac{F_0}{M}\left(1 - \frac{1}{\gamma}\big(1 - e^{-\gamma t}\big)\right)$, (c) $\frac{F_0}{2\,M}\left(t^2 - \frac{2}{\gamma}\,t - \frac{1}{\gamma^2}\big(1 - e^{-\gamma t}\big)\right)$

D.24 (a) $(\frac{1}{4}\,t^2\,,\,\frac{1}{6}\,t^2)$, (b) $(3 + 2\,t - \frac{1}{12}\,t^2\,,\,t)$, (c) Although the trajectories intersect, the particles do not collide, as they reach the crossing point at different times.

D.25 (a) $\frac{m_1}{m_1+m_2}$, (b) $\frac{m_1\,\cos(\theta)}{m_1+m_2}$

D.26 (a) $\sqrt{v_0^2 + \frac{2\,F_{(a)}\,D}{m_1+m_2}}$, (b) $\sqrt{v_0^2 + \frac{2\,F_{(b)}\,\cos(\theta)\,D}{m_1+m_2}}$

D.27 $\frac{M\,g}{2\,\sin(\theta)}$

D.28 Approximately $7200\,\mathtt{N}$

D.29 (a) Rope 1, since $\frac{T_1}{T_3} = \cos(60°)$ and $\frac{T_2}{T_3} = \cos(30°)$, (b) Rope 3

D.30 (a) $a = \frac{20}{3}\ \mathtt{m/s}^2$, $T = \frac{40}{3}\ \mathtt{N}$, (b) $a = \frac{10}{3}\ \mathtt{m/s}^2$, $T = \frac{40}{3}\ \mathtt{N}$

D.31 (a) $a = \frac{m_2}{m_1+m_2}\, g$, $T = \frac{m_1\, m_2}{m_1+m_2}\, g$, (b) switch the labels in (a)

D.32 $a = g/2$, $T = M\, g/2$

D.33 (a) sketches, (b) $a = \frac{1}{3}\, g$, $T_1 = \frac{1}{3}\, M\, g$, $T_2 = \frac{2}{3}\, M\, g$

D.34 $\sqrt{2\, g\, H/3}$

D.35 (a) (i) sketches, (ii) Block 1: weight, normal, tension (right), Block 2: weight, tensions (up and down), Block 3: weight, tension (up), (iii) $M\, a_{1x} = T_1$, $M\, a_{1y} = N_1 - M\, g = 0$, $M\, a_{2x} = M\, g - T_1 + T_2$, $M\, a_{3x} = M\, g - T_2$, (b) (i) $a = \frac{2}{3}\, g$, (ii) $T_1 = \frac{2}{3}\, M\, g$, $T_2 = \frac{1}{3}\, M\, g$

D.36 $\sqrt{4\, g\, H/3}$

D.37 (a) sketches, (b) $a = g/2$, (c) $T_1 = M\, g/2$, $T_2 = M\, g$, $T_3 = M\, g/2$

D.38 $\sqrt{g\, H}$

D.39 (a) sketches, (b) (i) 0, (ii) $M\, g$, (iii) $y_L(t) = v_0\, t$, $y_R(t) = -v_0\, t$, (iv) speed v_0, direction is either up or down, (c) (i) $\frac{m}{M}\, g$, (ii) $\left(1 - \frac{m^2}{M^2}\right) M\, g$, (iii) $y_L(t) = v_0\, t + \frac{m}{2\, M}\, g\, t^2$, $y_R(t) = -y_L(t)$, (iv) $\sqrt{v_0^2 + 2\, \frac{m}{M}\, g\, H}$

D.40 (X) $1.678\,\mathtt{s}$, (Y) $1.872\,\mathtt{s}$, (Z) $1.668\,\mathtt{s}$

D.41 $5\sqrt{2}\ \mathtt{m/s}$

D.42 (a) $9\sqrt{2}/5\ \mathtt{m}$, (b) $6\,\mathtt{m/s}$

D.43 (a) $M\, g/2$, (b) $M\, g\, \tan(\theta)$, (c) $\frac{\sin(\theta)}{\cos(2\,\theta)}\, M\, g$, (d) $T_d \to \infty$

D.44 (letting up the incline be the positive direction) (a) (i) $\frac{F_A}{M} - g\, \sin(\theta)$, (ii) $M\, g\, \sin(\theta)$, (iii) $2 - 10\, \sin(20°) \simeq -1.42$, (iv) $8 - 10\, \sin(20°) \simeq 4.58$, (b) (i) $\frac{F_A\, \cos(\theta)}{M} - g\, \sin(\theta)$, (ii) $M\, g\, \tan(\theta)$, (iii) $2\, \cos(20°) - 10\, \sin(20°) \simeq -1.54$, (iv) $8\, \cos(20°) - 10\, \sin(20°) \simeq 4.10$, (c) same as (b)

D.45 $a = \frac{F_{\mathrm{A}}}{M_1+M_2+M_3}$, $C_{12} = \frac{(M_2+M_3)}{M_1+M_2+M_3}\, F_{\mathrm{A}}$, $C_{23} = \frac{M_3}{M_1+M_2+M_3}\, F_{\mathrm{A}}$

D.46 $F_{\mathrm{A},0} = (m_1 + m_2)\, g\, \sin(\theta)$, $C_0 = m_2\, g\, \sin(\theta)$

D.47 $F_{\mathrm{A},0} = (m_1 + m_2)\, g\, \tan(\theta)$, $C_0 = m_2\, g\, \sin(\theta)$

D.48 $a = \frac{1+\sin(\pi/12)}{2}\, g \simeq 6.3\ \mathtt{m/s}^2$, $T = \frac{1-\sin(\pi/12)}{2}\, m\, g \simeq 92.65\ \mathtt{N}$

D.49 $a = \frac{1}{2}\, (1 + \sin(\theta))\, g$, $T = \frac{1}{2}\, (1 - \sin(\theta))\, m\, g$

D.50 $\sqrt{15\big(1 + \sin(\pi/12)\big)}$

D.51 (a) $(\sqrt{3} - 1)\, \frac{g}{4} \simeq 1.83\ \mathtt{m/s}^2$, (b) $\frac{4}{5}\, (\sqrt{3} + 1) \simeq 2.53\,\mathtt{s}$

D.52 (a) sketches, (b) $M_1\, a = T - M_1\, g$, $M_2\, a = M_2\, g\, \sin(\theta) - C$, $M_3\, a = M_3\, g\, \sin(\theta) + C$, $[N_2 = M_2\, g\, \cos(\theta)$, $N_3 = M_3\, g\, \cos(\theta)]$, (c) $a = \frac{(M_2+M_3)\, \sin(\theta) - M_1}{M_1+M_2+M_3}\, g = -4 = 4\,\mathtt{m/s}^2$ [up incline]

D.53 (a) (i) $25\,\mathtt{N}$, (ii) $\frac{16}{9}\ \mathtt{N}$, (b) (i) $1\,\mathtt{m/s}$, (ii) $\frac{8\,\pi}{5}\ \mathtt{s}$

D.54 (a) (i) $5/3\ \mathtt{m/s}^2$, (ii) $5/9\ \mathtt{m}$, (b) (i) $5/3\ \mathtt{m/s}^2$, (ii) $10/9\ \mathtt{m}$, (c) same accelerations occur in (a) and (b), the spring force ensures that each block accelerates at the same rate.

D.55 0.0225

D.56 For small forces, the stack of blocks accelerates at a rate of $F_A/(14\,M)$. When the applied force reaches $14\,\mu_S\,M\,g$, then the static frictional force attains its maximum value at both interfaces. For greater applied forces, the tower falls apart. Effects not modelled here (drag, for instance) will determine which block slips first.

D.57 (a) $a = 37/6$, $T = 46/3$, (b) $a = 7/3$, $T = 46/3$, (note accelerations are reduced, tension is increased *vis-à-vis* D.30)

D.58 $a = (1-\mu_K)\,g/2 = 17/4\ \mathtt{m/s}^2$, $T = (1+\mu_K)\,M\,g/2 = \frac{23}{40}\,M\,g$

D.59 (a) (i) $(1-\mu_K)\,g/3$, (ii) $T_1 = (1+2\,\mu_K)\,M\,g/3$, $T_2 = (2+\mu_K)\,M\,g/3$, (b) (i) $(1-2\,\mu_K)\,g/3$, (ii) $T_1 = (1+\mu_K)\,M\,g/3$, $T_2 = 2\,(1+\mu_K)\,M\,g/3$, (c) (i) $(1-\mu_{Kl}-\mu_{Kr})\,g/3$, (ii) $T_1 = (1+2\,\mu_{Kl}-\mu_{Kr})\,M\,g/3$, $T_2 = (2+\mu_{Kl}+\mu_{Kr})\,M\,g/3$

D.60 $\sqrt{2\,(1-\mu_K)\,g\,D/3}$

D.61 (a) $(2-\mu_K)\,g/3$, (b) $T_1 = 2\,(1+\mu_K)\,M\,g/3$, $T_2 = (1+\mu_K)\,M\,g/3$

D.62 (a) (i) $(2-\mu_K)\,g/4$, (ii) $T_1 = (2+3\,\mu_K)\,M\,g/4$, $T_2 = (2+\mu_K)\,M\,g/2$, $T_3 = (2+\mu_K)\,M\,g/4$, (b) (i) $(1-\mu_K)\,g/2$, (ii) $T_1 = (1+\mu_K)\,M\,g/2$, $T_2 = (1+\mu_K)\,M\,g$, $T_3 = (1+\mu_K)\,M\,g/2$, (c) (i) $(2-\mu_{Kl}-\mu_{Kr})\,g/4$, (ii) $T_1 = (2+3\,\mu_{Kl}-\mu_{Kr})\,M\,g/4$, $T_2 = (2+\mu_{Kl}+\mu_{Kr})\,M\,g/2$, $T_3 = (2+\mu_{Kl}+\mu_{Kr})\,M\,g/4$

D.63 $\sqrt{(2-\mu_K)\,g\,D/2}$

D.64 $a \simeq 5.544\ \mathtt{m/s}^2$, $T \simeq 111.4\ \mathtt{N}$

D.65 $a \simeq 5.544\ \mathtt{m/s}^2$, $T \simeq 4.456\,M$

D.66 (a) sketches, (b) (i) $\frac{F_A}{M+m}$, (ii) $\frac{M}{M+m}\,\frac{F_A}{k}$, (c) (i) $\frac{F_A}{M+m} - \mu_K\,g$, (ii) $\frac{M}{M+m}\,\frac{F_A}{k}$

D.67 (a) sketch, (b) $2\,\mathtt{m/s}^2$, (c) $(0\,,\,-9)\ \mathtt{m}$

D.68 (a) Sketch, (b) $2\,\mathtt{m/s}^2$ [bkwd] $= \frac{2}{\sqrt{5}}(-2\,\hat{\imath} - \hat{\jmath})\ \mathtt{m/s}$, (c) (i) $2\,\mathtt{s}$, (ii) $4\,\mathtt{m}$ [fwd] $= \frac{4}{\sqrt{5}}(2\,\hat{\imath} + \hat{\jmath})$

D.69 (a) sketches, (b) sketch, (c) (i) $5\,e^{-t/3}$, (ii) $20 - 15\,e^{-t/3}$, (iii) $20\,t - 45\big(1-e^{-t/3}\big)$, (d) $a(t) \to 0$, $v(t) \to 20\,\mathtt{m/s}$, $x(t) \to 20\,t - 45\ \mathtt{m}$

D.70 (a) $m = M(\sin(\theta) + \mu_S\cos(\theta))$, (b) $m = M(\sin(\theta) - \mu_S\cos(\theta))$, m is assuredly positive because the inclination angle is assumed to be greater than the angle of repose

D.71 (a) $F_{S,max}$ is greater than the component of the block's weight acting down the incline, (b) (i) 257 N, (ii) 219 N, (c) 200.7 N exerted at the angle of repose, $\tan^{-1}(0.8) \simeq 38.66°$, above the inclined plane

D.72 (a) $a = 17/3$, $T = 52/3$, (b) $a = 4/3$, $T = 52/3$

D.73 (a) $a = \frac{M_2 - \mu\,M_1}{M_1+M_2}\,g$, $T = (1+\mu)\,\frac{M_1\,M_2}{M_1+M_2}\,g$, (b) $a = \frac{M_1-\mu\,M_2}{M_1+M_2}\,g$, T is unchanged

D.74 (a) $a = \frac{1}{2}\,(1-\mu_K)\,g$, $T = \frac{1}{2}(1+\mu_K)\,M\,g$, (b) $4\,\mathtt{m/s}$

D.75 (a) $a = \frac{1}{2}\,(1+\mu_K)\,g$, $T = \frac{1}{2}(1-\mu_K)\,M\,g$ (b) $2\,\mathtt{m/s}$

D.76 $a = \frac{F_A}{2\,M} - \mu_K\,g$, $T = \frac{F_A}{2}$

D.77 $v_f^2 = v_0^2 + 2\,\left(\frac{F_A}{2\,M} - \mu_K\,g\right)\,D$

D.78 (a) $\mu_S\,M\,g$, (b) $\mu_K\,M\,g$, (c) (i) $\tan^{-1}(\mu_S)$, (ii) $\tan^{-1}(\mu_K)$

D.79 (a) $\frac{23}{6}$ $\mathtt{m/s}^2$, (b) the rod is compressed

D.80 [Typo alert: The parameter value $M = 5\,\mathtt{kg}$ was omitted in the first printing.] (Choosing up the incline to be positive) (a) $\frac{F_{\rm A}}{M} - \big(\sin(\theta) + \mu_{\rm K} \cos(\theta)\big)\, g$, (b) $\big(\sin(\theta) + \mu_{\rm K} \cos(\theta)\big)\, M\, g$, (c) (i) -3.3, (ii) 2.7

D.81 $0\,\mathtt{m/s}$

D.82 $F_{\rm A,0} = (m_1 + m_2)\, g\, \sin(\theta) + (\mu_{\rm K1}\, m_1 + \mu_{\rm K2}\, m_2)\, g\, \cos(\theta)$, $C_0 = m_2\, g\, [\sin(\theta) + \mu_{\rm K2} \cos(\theta)]$

D.83 $F_{\rm A,0} = \big[(m_1 + m_2)\, g\, \sin(\theta) + (\mu_{\rm K1}\, m_1 + \mu_{\rm K2}\, m_2)\, g\, \cos(\theta)\big] / \big(\cos(\theta) - \mu_{\rm K} \sin(\theta)\big)$, $C_0 = m_2\, g\, [\sin(\theta) + \mu_{\rm K2} \cos(\theta)]$

D.84 (implicit units, rightward is positive) (a) (i) $-5/6$, (ii) $2/9$, (b) (i) $-25/6$, (ii) $7/9$, (c) (i) $-1/3$, (ii) $8/9$, (d) (i) $-11/3$, (ii) $13/9$, (e) (i) $-4/3$, (ii) $5/9$, (f) (i) $-14/3$, (ii) $10/9$

D.85 (a) $1.085\,\mathtt{m/s}$, (b) $3.915\,\mathtt{m/s}$

D.86 (a) $\frac{5\sqrt{2}}{6}\,(46 - 20\sqrt{3}) \simeq 13.4\,\mathtt{N}$, (b) $230\sqrt{2} \simeq 325.3\,\mathtt{N}$

D.87 (a) $\frac{5\sqrt{2}}{6}\,\big(250\, \sin(15°) + 50\, \cos(15°) - 20\sqrt{3} - 4\big) \simeq 87.6\,\mathtt{N}$, (b) $\big(250\, \cos(15°) - 20\big)\sqrt{2} \simeq 313.2\,\mathtt{N}$

D.88 Distance $= \sqrt{L/g}\, V_0$

D.89 (a) sketches, (b) $a = \frac{m_1 - m_2}{m_1 + m_2}\, g$, (c) $t = \sqrt{\frac{2\,h}{g}\, \frac{m_1 + m_2}{m_1 - m_2}}$, (d) $v_h = \sqrt{2\, \frac{m_1 - m_2}{m_1 + m_2}\, g\, h}$

D.90 ratio $= 8/3$

D.91 $g \simeq 10\,\mathtt{m/s}^2$

D.92 (a) sketches, (b) $M_2\, v^2/R$, (c) $T = M_1\, g$, (d) $v = \sqrt{\frac{M_1}{M_2}\, g\, R}$, (e) M_1 drops while M_2 spirals inward

D.93 (a) sketch, (b) $v_{\max} = \sqrt{\frac{\mu_{\rm S} \cos(\theta) - \sin(\theta)}{\mu_{\rm S} \sin(\theta) + \cos(\theta)}\, g\, R}$, (c) (i) $\sqrt{\mu_{\rm S}\, g\, R}$, (ii) as expected, (iii) maximum safe speed is reduced

D.94 (a) $x(t) = 4\,t + t^2$, $x_S(t) = 2\,t + t^2$, $x_F(t) = 6\,t + t^2$, (b) $\tilde{x}(t) = 0$, $\tilde{x}_S(t) = -2\,t$, $\tilde{x}_F(t) = 2\,t$, (c) Motion of freely falling objects appears inertial. [Einstein's insight.]

D.95 $v_{\rm T} = 2\,\mathtt{m/s}$

D.96 (a) $M\, a = -k\, x - b\, v$, (b) (i) $v(t) = -A\, e^{-\gamma\, t}\, [\gamma\, \cos(\omega\, t) + \omega\, \sin(\omega\, t)]$, $a(t) = A\, e^{-\gamma\, t}\, \big[(\gamma^2 - \omega^2)\, \cos(\omega\, t) + 2\, \gamma\, \omega\, \sin(\omega\, t)\big]$, (ii) `sine` $2\, M\, \gamma\, \omega = b\, \omega$, `cosine` $M\, (\gamma^2 - \omega^2) = -k + b\, \gamma$, (iii) $\gamma = \frac{b}{2\,M}$, $\omega^2 = \frac{k}{M} - \frac{b^2}{4\,M^2}$, (iv) $x(t) = A\, e^{-\frac{b\,t}{2\,M}}\, \cos\left(\sqrt{\frac{k}{M} - \frac{b^2}{4\,M^2}}\; t\right)$

E.1 (all in $\mathtt{J}$) (a) 15, (b) 0, (c) 12, (d) 6

E.2 (all in $\mathtt{J}$) (a) 6, (b) 8, (c) -13, (d) 50

E.3 (all in $\mathtt{J}$) (a) 18, (b) 144, (c) 1008, (d) 1350

E.4 (a) $40\,\mathtt{N}$ [$\rightarrow$], (b) $960\,\mathtt{J}$, (c) These forces cancel everywhere along the path. Alternatively, the block does not displace in the directions along which these forces act. (d) (in $\mathtt{J}$) 240, 0, 720, 960, (e) $14\,\mathtt{m/s}$

E.5 (a) $25\,\mathtt{N}$ [bkwds], (b) $25\,\mathtt{N}$ [fwds], (c) $-125\,\mathtt{J}$, (d) $125\,\mathtt{J}$, (e) net work is zero; no net gain in kinetic energy, (f) $P_f = -75\,\mathtt{W}$, $P_A = 75\,\mathtt{W}$, $P_{\rm net} = 0$, net power is zero at all times; the block moves with constant speed

E.6 See the answers for the next three problems.

E.7 (all in $\mathtt{J}$) (a) 40, (b) 40, (c) 40, (d) a constant force is conservative

E.8 (all in $\mathtt{J}$) (a) -72, (b) -72, (c) $-8\sqrt{41}$, (d) work done by kinetic friction is proportional to arc length

E.9 (all in $\mathtt{J}$) (a) 125, (b) 175, (c) 135, (d) non-conservative force

E.10 (a) sketch, (b) $(25\sqrt{3} - 15\,,\,0) \simeq (28.3\,,\,0)\ \mathtt{N}$,
(c) ($\mathtt{J}$) (i) 0, (ii) 0, (iii) $250\sqrt{3}$, (iv) -150, (d) $50\,(5\sqrt{3} - 3) \simeq 283\,\mathtt{J}$

E.11 The latter is three times the former.

E.12 (a) (i) $250\,\mathtt{MJ}$, (ii) $0\,\mathtt{J}$, (iii) $-250\,\mathtt{MJ}$, (iv) $1.25\,\mathtt{MN}$, (v) $6.25\,\mathtt{m/s}^2$ [bkwds],
(b) (i) $\mathrm{a} = \frac{1}{2\,\Delta x}\,(v_f^2 - v_i^2) = -6.25\,\mathtt{m/s}^2$, (ii) $F_{\mathrm{S}} = M\,\mathrm{a} = -1.25 \times 10^6\ \mathtt{N}$

E.13 (a) (i) Block 1: $(F_{(\mathrm{a})} - T)\,D$, Block 2: $T\,D$, (ii) $F_{(\mathrm{a})}\,D$, (iii) $v_f^2 = v_0^2 + 2\,\frac{F_{(\mathrm{a})}}{m_1+m_2}\,D$,
(b) (i) Block 1: $(F_{(\mathrm{b})}\,\cos(\theta) - T)\,D$, Block 2: $T\,D$, (ii) $F_{(\mathrm{b})}\,\cos(\theta)\,D$,
(iii) $v_f^2 = v_0^2 + 2\,\frac{F_{(\mathrm{b})}\,\cos(\theta)}{m_1+m_2}\,D$

E.14 (a) $(0\,,\,5)\ \mathtt{N}$, (b) (i) parabolic trajectory (not unlike projectile motion), (ii) $(6\,,\,4)\ \mathtt{m}$,
(c) (i) constant forces are conservative, (ii) $W[\vec{F}_1] = 92\,\mathtt{J}$, $W[\vec{F}_2] = -12\,\mathtt{J}$, $W[\vec{F}_3] = -48\,\mathtt{J}$,
$W[\vec{F}_4] = -12\,\mathtt{J}$, (d) $W[\,\mathrm{net}\,] = 20\,\mathtt{J}$, (e) (i) $K_i = \frac{45}{4}\ \mathtt{J}$, (ii) $K_f = \frac{125}{4}\ \mathtt{J}$, (iii) $5\,\mathtt{m/s}$

E.15 $4\,\mathtt{m/s}$

E.16 $4\,\mathtt{m/s}$

E.17 $v_f^2 = 2\,\frac{m_2}{m_1+m_2}\,g\,D$

E.18 $\sqrt{2\,g\,H/3}$

E.19 $\sqrt{4\,g\,H/3}$

E.20 $\sqrt{g\,H}$

E.21 [Typo alert: The parameter value $D = 3\,\mathtt{m}$ was omitted in the first printing.]
(a) (i) $\big(F_{\mathrm{A}} - M\,g\,\sin(\theta)\big)\,D$, (ii) $-21.3\,\mathtt{J}$, (iii) $68.7\,\mathtt{J}$, (b) (i) $\big(F_{\mathrm{A}}\,\cos(\theta) - M\,g\,\sin(\theta)\big)\,D$,
(ii) $-23.1\,\mathtt{J}$, (iii) $61.5\,\mathtt{J}$, (c) same as in (b)

E.22 (a) (i) $\big[F_{\mathrm{A}} - M\,g\,\big(\sin(\theta) + \mu_{\mathrm{K}}\,\cos(\theta)\big)\big]\,D$, (ii) $-49.5\,\mathtt{J}$, (iii) $40.5\,\mathtt{J}$,
(b) (i) $\big[F_{\mathrm{A}}\,\big(\cos(\theta) - \mu_{\mathrm{K}}\,\sin(\theta)\big) - M\,g\,\big(\sin(\theta) + \mu_{\mathrm{K}}\,\cos(\theta)\big)\big]\,D$, (ii) $-53.4\,\mathtt{J}$, (iii) $25.1\,\mathtt{J}$,
(c) (i) $\big[F_{\mathrm{A}}\,\big(\cos(\theta) + \mu_{\mathrm{K}}\,\sin(\theta)\big) - M\,g\,\big(\sin(\theta) + \mu_{\mathrm{K}}\,\cos(\theta)\big)\big]\,D$, (ii) $-49.2\,\mathtt{J}$, (iii) $41.5\,\mathtt{J}$

E.23 (a) $-M\,g\,(y_f - y_i)$, (b) $+M\,g\,(y_f - y_i)$, (c) unchanged

E.24 $5\sqrt{2}\ \mathtt{m/s}$

E.25 (a) $9\sqrt{2}/5\ \mathtt{m}$, (b) $6\,\mathtt{m/s}$

E.26 $(0\,,\,-9)\ \mathtt{m}$

E.27 $4\,\mathtt{m}\,[\,\mathrm{fwd}\,] = \frac{4}{\sqrt{5}}(2\,\hat{\imath} + \hat{\jmath})$

E.28 $\frac{9}{8}\ \mathtt{J}$

E.29 (a) $F_{\mathrm{S}} = -k\,(x - x_0)$, (b) $U_{\mathrm{S}} = \frac{1}{2}\,k\,(x - x_0)^2$

E.30 (a) $M\,g\,\sin(\theta)/k$ [down the incline], (b) $2\,M\,g\,\sin(\theta)/k$, or twice as far as x_0

E.31 (a) $\sqrt{6}\ \mathtt{m/s}$, (b) no, (c) yes

E.32 $2\sqrt{3} \simeq 3.464\ \mathtt{m}$

E.33 $0.375\,\mathtt{m}$

E.34 $\sqrt{15\big(1+\sin(\pi/12)\big)}$

E.35 (a) (i) no, (ii) barely succeeds, (iii) easily, (b) (i) no, (ii) barely fails, (iii) no problem

E.36 (a) (i) $\frac{1}{2}\,M_L\,v_0^2$, (ii) $\frac{1}{2}\,M_R\,v_0^2$, (iii) $\frac{1}{2}\,(M_L+M_R)\,v_0^2$, (b) (i - ii) values are arbitrary, (iii) the sum of (i) and (ii), (c) (i) $M_L\,g\,H$, (ii) $-M_R\,g\,H$, (iii) $(M_L-M_R)\,g\,H$, (d) $\Delta K=(M_R-M_L)\,g\,H$, $v_f^2=v_0^2+2\,\frac{M_R-M_L}{M_R+M_L}\,g\,H$

E.37 (a) (energies in $\mathtt{J}$) (i) 0, (ii) 0, (b) (i) $\frac{1}{2}\,m_1\,v^2$, (ii) $\frac{1}{2}\,m_2\,v^2$, (c) $-(m_1-m_2)\,g\,h$, (d) $v^2=2\,\frac{m_1-m_2}{m_1+m_2}\,g\,h$

E.38 (a) sketch, (b) (i) $20\,\mathtt{J}$, (ii) $0\,\mathtt{J}$, (c) $20\,\mathtt{J}$, (d) (i) $20\,\mathtt{J}$, (ii) $2\,\mathtt{m/s}$, (e) (i) $10\,\mathtt{W}$, (ii) $[\Delta t=4\,\mathtt{s}]$, $5\,\mathtt{W}$

E.39 (a) $(\Delta x)^2=2\,M\,g\,L_1\,\sin(\theta)/k$, (b) $(\Delta x)^2=2\,M\,g\big[L_1\big(\sin(\theta)-\mu_{\mathrm{K}}\cos(\theta)\big)-\mu_{\mathrm{K}}\,L_2\big]/k$, (c) Δx is the solution to: $0=\frac{1}{2}\,k\,(\Delta x)^2+\mu_{\mathrm{K}}\,M\,g\,(\Delta x)+M\,g\big[\mu_{\mathrm{K}}\,L_2+\big(\mu_{\mathrm{K}}\cos(\theta)-\sin(\theta)\big)\,L_1\big]$

E.40 (a) (i) $6\,\mathtt{m/s}$, (ii) $12\,\mathtt{W}$, (b) (i) $10\,\mathtt{m/s}$, (ii) $12\,\mathtt{W}$

E.41 (a) (positions in $\mathtt{m}$, velocities in $\mathtt{m/s}$) $v(1)=5$, $v(3)=15$, $v(5)=25$, $r(1)=5/2$, $r(3)=45/2$, $r(5)=125/2$, (b) (work in $\mathtt{J}$) $W_{01}=75/2$, $W_{03}=675/2$, $W_{05}=1875/2$, (c) (power in $\mathtt{W}$) $P_1=75$, $P_3=225$, $P_5=375$, (d) $P(t)=75\,t$, integrated this becomes $\frac{75}{2}\,t^2$, (integrated power, energy, in $\mathtt{J}$) 75/2, 675/2, 1875/2, The mechanical work is equal to the integrated power.

E.42 (a) (i) $P_{\mathrm{av},W}=0\,\mathtt{W}$, (ii) $P_{\mathrm{av},N}=0\,\mathtt{W}$, (iii) $P_{\mathrm{av},A}=\frac{125\sqrt{3}}{2}\,\mathtt{W}$, (iv) $P_{\mathrm{av},f}=-37\,\frac{1}{2}\,\mathtt{W}$, (b) $P_{\mathrm{av,net}}=\frac{25}{2}\,\big(5\sqrt{3}-3\big)\,\mathtt{W}$, (c) The particle velocity is changing.

E.43 (a) $-\frac{M\,g}{2\,L}\,a^2$, (b) $\frac{1}{2}\,M\,V_0^2$, (c) $a=\sqrt{L/g}\,V_0$

E.44 (a) (i) $-b_1\,v\,D$, (ii) $-b_2\,v^2\,D$, (iii) $-b_1\,v\,(1-\xi\,v)\,D$, (b) (i) 5/3, (ii) 25/9, (iii) $\frac{5\,(1-150\,\xi)}{3\,(1-90\,\xi)}$, (c) (i) 5/3, (ii) 25/9

E.45 (a) sketches, (b) $a=5\,\mathtt{m/s^2}$, $v(2)=10\,\mathtt{m/s}$, (c) $0\,\mathtt{J}$, (d) (i) $\Delta U_{g1}=0\,\mathtt{J}$, $\Delta U_{g2}=-400\,\mathtt{J}$, (ii) $-100\,\mathtt{J}$, (e) $K_f=300\,\mathtt{J}$, $v_2=10\,\mathtt{m/s}$

E.46 (a) $3000\,\mathtt{J}$, (b) (i) $3000\,\mathtt{J}$, $-3000\,\mathtt{J}$, (ii) $-3000\,\mathtt{J}$, (c) (i) $0\,\mathtt{J}$, (ii) $0\,\mathtt{m/s}$

E.47 (a) sketch, (b) $W[\,\vec{N}\,]=0\,\mathtt{J}$, $W[\,\vec{W}\,]=\frac{25\sqrt{3}}{3}\,\mathtt{J}$, $W[\,\vec{f}_{\mathrm{K}}\,]=-\frac{5}{6}\,\mathtt{J}$, (c) (i) $-\frac{25\sqrt{3}}{3}\,\mathtt{J}$, (ii) $\frac{5}{6}\,(10\sqrt{3}-1)\,\mathtt{J}$, (d) (i) $W[\,\vec{f}_{\mathrm{K}}(x)\,]=-\frac{5}{3}\,\mathtt{J}$, (ii) $\frac{5}{3}\,(5\sqrt{3}-1)\,\mathtt{J}$

E.48 Setting net power input to zero, fixes $v_{\mathrm{T}}=2\,\mathtt{m/s}$

E.49 (a) (i) $\sqrt{\frac{M}{k}}\,v_i$, (ii) v_i, (b) (i) $\frac{\mu\,M\,g}{k}\left[\sqrt{1+\frac{k}{\mu\,M\,g}\left(\frac{v_i^2}{\mu\,g}-D\right)}-1\right]$ (the solution of $0=x_f^2+2\frac{\mu\,M\,g}{k}-\left(\frac{m}{k}\,v_i^2-2\,\frac{\mu\,M\,g}{k}\,D\right)$), (ii) [Assuming that it returns (with positive kinetic energy)] $v_f^2=v_i^2-4\,\mu\,g(D+x_f)$

E.50 (a) (i) $3\sqrt{\frac{2}{5}}\,\mathtt{m}$, (ii) $3\,\mathtt{m/s}$, (b) (i) $1\,\frac{3}{5}\,\mathtt{m}$, (ii) $\sqrt{\frac{19}{5}}\,\mathtt{m/s}$

E.51 (implicit units) (a) (i) 10, 10, (ii) 0, (iii) 500, (iv) 500, (b) (i) 15, 20, (ii) 125, (iii) 1000, (iv) 1125, (c) (i) 0, −10, (ii) 500, (iii) −500, (iv) 0, (d) (i) −5, −20, (ii) 1125, (iii) −1000, (iv) 125, (e) (i) 5, 0, (ii) 125, (iii) 0, (iv) 125, (f) Work–Energy Theorem satisfied, (g) sketch

E.52 (a) $\sqrt{\frac{2}{m}}\,dt = \sqrt{\frac{2}{k}}\,\frac{dx}{\sqrt{A^2-x^2}}$, (b) $\omega\,dt = \frac{du}{\sqrt{(1-u^2}}$, (c) $\omega\,(t-0) = \theta - \theta_0$, (d) $\theta(t) = \theta_0 + \omega\,t \implies x(t) = A\,\sin(\omega\,t + \theta_0)$, SHO trajectory

E.53 (a) $\{-\sqrt{k/\kappa}, 0, \sqrt{k/\kappa}\}$, (b) $U(x) = -\frac{1}{4}\,\kappa\,x^4 + \frac{1}{2}\,k\,x^2$, (c) sketch, (d) unstable, stable, unstable

E.54 (a) $\{-\frac{1}{\sqrt{2}}, 0, \frac{1}{\sqrt{2}}\}$, (b) $U(x) = -x^4 + x^2$, (c) sketch, (d) unstable, stable, unstable

E.55 (a) $-\frac{2\,x}{x^4 - 2\,x^2 + 2}$, (b) sketch, (c) $x = 0$ stable, $x \to \pm\infty$ neutral

M.1 (a) $M\,(a\,,\,-2\,b\,,\,-c)$, (b) $\frac{M}{5}\,(a\,,\,-2\,b\,,\,-c)$

M.2 (a) $20\,\texttt{N}{\cdot}\texttt{s}\ [\,\hat{\imath}\,]$, other impulses cancel, (b) (i) $\vec{0}$, (ii) $20\,\texttt{N}{\cdot}\texttt{s}\ [\,\hat{\imath}\,]$, (iii) $2\,\texttt{m/s}\ [\,\hat{\imath}\,]$

M.3 (a) $-8\,\texttt{N}{\cdot}\texttt{s}\ [\,\hat{\imath}\,]$, weight and normal force impulses cancel, (b) (i) $\vec{0}$, (ii) $-8\,\texttt{N}{\cdot}\texttt{s}\ [\,\hat{\imath}\,]$, (iii) $4\,\texttt{m/s}\ [\,-\hat{\imath}\,]$

M.4 (a) (impulses in $\texttt{N}{\cdot}\texttt{s}$), (i) $(0\,,\,-5.1)$, (ii) $(-6.8\,,\,0)$, (iii) $(-6.8\,,\,-5.1)$, (b) (forces in $\texttt{N}$) (i) $(0\,,\,-637.5)$, (ii) $(-850\,,\,0)$, (iii) $(-850\,,\,-637.5)$, magnitude $= 1062.5$

M.5 (a) $\vec{F}_{\text{NET}} = (40\,,\,0)\ \texttt{N}$, (b) $\vec{I}_{if}[\,\vec{F}_{\text{NET}}\,] = (160\,,\,0)\ \texttt{N}{\cdot}\texttt{s}$, (c) The forces cancel, hence so too do their respective impulses. (d) $\vec{I}_{if}[\,\vec{F}_1\,] = (40\,,\,0)$, $\vec{I}_{if}[\,\vec{F}_2\,] = (0\,,\,-160)$, $\vec{I}_{if}[\,\vec{F}_3\,] = (120\,,\,160)$, $\vec{I}_{if}[\,\text{net}\,] = (160\,,\,0)$ (all in $\texttt{N}{\cdot}\texttt{s}$), (e) $\vec{v}_f = (14\,,\,0)\ \texttt{m/s}\ [\rightarrow]$

M.6 (a) (i) $\vec{I}_1 = (F_{(a)} - T)\,t\ [\ \rightarrow\ ]$, $\vec{I}_2 = T\,t\ [\ \rightarrow\ ]$, (ii) $\vec{I}_{\text{net}} = F_{(a)}\,t\ [\ \rightarrow\ ] = \Delta\vec{P} = (m_1 + m_2)\Delta\vec{v}$, (iii) $v_f = v_0 + \frac{F_{(a)}}{m_1+m_2}\,t$, (b) (i) $\vec{I}_1 = (F_{(b)}\,\cos(\theta) - T)\,t\ [\ \rightarrow\ ]$, $\vec{I}_2 = T\,t\ [\ \rightarrow\ ]$, (ii) $\vec{I}_{\text{net}} = F_{(b)}\,\cos(\theta)\,t\ [\ \rightarrow\ ] = \Delta\vec{P} = (m_1 + m_2)\Delta\vec{v}$, (iii) $v_f = v_0 + \frac{F_{(b)}\,\cos(\theta)}{m_1+m_2}\,t$

M.7 (a) (i) $(0\,,\,5)\ \texttt{N}$, (ii) evidently constant, (all impulses and momenta in $\texttt{N}{\cdot}\texttt{s}$) (b) $\vec{I}[\,\text{net}\,] = (0\,,\,10)$, (c) (i) $\vec{I}[\,\vec{F}_1\,] = (24\,,\,10)$, $\vec{I}[\,\vec{F}_2\,] = (-8\,,\,6)$, $\vec{I}[\,\vec{F}_3\,] = (-16\,,\,0)$, $\vec{I}[\,\vec{F}_4\,] = (0\,,\,-6)$, (ii) $\vec{I}[\,\text{net}\,] = (0\,,\,10)$, (d) $(\frac{15}{2}\,,\,0)$, (e) (i) $(\frac{15}{2}\,,\,10)$, (ii) $\vec{v}_f = (3\,,\,4)\ \texttt{m/s}$, (iii) $v_f = 5\ \texttt{m/s}$

M.8 (a) (i) $(25\sqrt{3} - 15\,,\,0) \simeq (28.3\,,\,0)\ \texttt{N}$, (ii) yes, the net force is constant, (b) $(100\sqrt{3} - 60\,,\,0) \simeq (113.2\,,\,0)\ \texttt{N}{\cdot}\texttt{s}$, (c) (i) $\vec{I}_W = (0\,,\,-1600)\ \texttt{N}{\cdot}\texttt{s}$, $\vec{I}_N = (0\,,\,1500)\ \texttt{N}{\cdot}\texttt{s}$, $\vec{I}_A = (100\sqrt{3}\,,\,100)\ \texttt{N}{\cdot}\texttt{s}$, $\vec{I}_f = (-60\,,\,0)\ \texttt{N}{\cdot}\texttt{s}$, (ii) $\vec{I}_{\text{net}} = (100\sqrt{3} - 60\,,\,0)\ \texttt{N}{\cdot}\texttt{s}$, net impulse equals impulse provided by the net force, (d) $\Delta\vec{p} = (100\sqrt{3} - 60\,,\,0)\ \texttt{N}{\cdot}\texttt{s}$

M.9 (a) sketches, (b) (i) $\frac{d\vec{p}_1}{dt} = T_1\ [\ \rightarrow\ ]$, $\frac{d\vec{p}_2}{dt} = (T_2 - T_1)\,[\ \rightarrow\ ]$, $\frac{d\vec{p}_3}{dt} = (M\,g - T_2)\,[\ \downarrow\ ]$, $\frac{d\vec{p}_{\mathbb{P}}}{dt} = (\mathbb{P}_x - T_2)\,[\ \rightarrow\ ] + (T_2 - \mathbb{P}_y)\,[\ \downarrow\ ]$, (ii) $\frac{d\vec{P}_{\text{Total}}}{dt} = \mathbb{P}_x\,[\ \rightarrow\ ] + (M\,g - \mathbb{P}_y)\,[\ \downarrow\ ]$, (c) (i) $\Delta\vec{p}_1 = \frac{1}{3}\,M\,g\,\Delta t\ [\ \rightarrow\ ]$, $\Delta\vec{p}_2 = \frac{1}{3}\,M\,g\,\Delta t\ [\ \rightarrow\ ]$, $\Delta\vec{p}_3 = \frac{1}{3}\,M\,g\,\Delta t\ [\ \downarrow\ ]$, $\Delta\vec{p}_{\mathbb{P}} = \vec{0}$, (ii) $\Delta\vec{P}_{\text{Total}} = \frac{2}{3}\,M\,g\,\Delta t\ [\ \rightarrow\ ] + \frac{1}{3}\,M\,g\,\Delta t\ [\ \downarrow\ ]$, (d) constant $\frac{d\vec{P}_{\text{Total}}}{dt}$ equals $\frac{\Delta\vec{P}_{\text{Total}}}{\Delta t}$, implies $\vec{\mathbb{P}} = \frac{2}{3}\,M\,g\ [\ \rightarrow\ ] + \frac{2}{3}\,M\,g\ [\ \uparrow\ ]$

M.10 (a) sketches, (b) (i) $\frac{d\vec{p}_1}{dt} = T_1\ [\ \rightarrow\ ]$, $\frac{d\vec{p}_2}{dt} = (M\,g + T_2 - T_1)\,[\ \downarrow\ ]$, $\frac{d\vec{p}_3}{dt} = (M\,g - T_2)\,[\ \downarrow\ ]$, $\frac{d\vec{p}_{\mathbb{P}}}{dt} = (\mathbb{P}_x - T_1)\,[\ \rightarrow\ ] + (T_1 - \mathbb{P}_y)\,[\ \downarrow\ ]$, (ii) $\frac{d\vec{P}_{\text{Total}}}{dt} = \mathbb{P}_x\,[\ \rightarrow\ ] + (2\,M\,g - \mathbb{P}_y)\,[\ \downarrow\ ]$, (c) (i) $\Delta\vec{p}_1 = \frac{2}{3}\,M\,g\,\Delta t\ [\ \rightarrow\ ]$, $\Delta\vec{p}_2 = \frac{2}{3}\,M\,g\,\Delta t\ [\ \downarrow\ ]$, $\Delta\vec{p}_3 = \frac{2}{3}\,M\,g\,\Delta t\ [\ \downarrow\ ]$, $\Delta\vec{p}_{\mathbb{P}} = \vec{0}$, (ii) $\Delta\vec{P}_{\text{Total}} = \frac{2}{3}\,M\,g\,\Delta t\ [\ \rightarrow\ ] + \frac{4}{3}\,M\,g\,\Delta t\ [\ \downarrow\ ]$, (d) constant $\frac{d\vec{P}_{\text{Total}}}{dt}$ equals $\frac{\Delta\vec{P}_{\text{Total}}}{\Delta t}$, implies $\vec{\mathbb{P}} = \frac{2}{3}\,M\,g\ [\ \rightarrow\ ] + \frac{2}{3}\,M\,g\ [\ \uparrow\ ]$

M.11 (a) sketches, (b) (i) $\frac{d\vec{p}_1}{dt} = T_1\ [\ \rightarrow\ ]$, $\frac{d\vec{p}_2}{dt} = (T_2 - T_1)\,[\ \rightarrow\ ]$, $\frac{d\vec{p}_3}{dt} = (M\,g + T_3 - T_2)\,[\ \downarrow\ ]$, $\frac{d\vec{p}_4}{dt} = (M\,g - T_3)\,[\ \downarrow\ ]$, $\frac{d\vec{p}_{\mathbb{P}}}{dt} = (\mathbb{P}_x - T_2)\,[\ \rightarrow\ ] + (T_2 - \mathbb{P}_y)\,[\ \downarrow\ ]$, (ii) $\frac{d\vec{P}_{\text{Total}}}{dt} = \mathbb{P}_x\,[\ \rightarrow\ ] + (2\,M\,g - \mathbb{P}_y)\,[\ \downarrow\ ]$, (c) (i) $\Delta\vec{p}_1 = \frac{1}{2}\,M\,g\,\Delta t\ [\ \rightarrow\ ]$,

$\Delta\vec{p}_2 = \frac{1}{2}\,M\,g\,\Delta t\ [\ \rightarrow\ ]$, $\Delta\vec{p}_3 = \frac{1}{2}\,M\,g\,\Delta t\ [\ \downarrow\ ]$, $\Delta\vec{p}_4 = \frac{1}{2}\,M\,g\,\Delta t\ [\ \downarrow\ ]$, $\Delta\vec{p}_{\mathbb{P}} = \vec{0}$, (ii) $\Delta\vec{P}_{\rm Total} = M\,g\,\Delta t\ [\ \rightarrow\ ] + M\,g\,\Delta t\ [\ \downarrow\ ]$, (d) constant $\frac{d\vec{P}_{\rm Total}}{dt}$ equals $\frac{\Delta\vec{P}_{\rm Total}}{\Delta t}$, implies $\vec{\mathbb{P}} = M\,g\ [\ \rightarrow\ ] + M\,g\ [\ \uparrow\ ]$

M.12 (a) $1.5\,\mathtt{N}$, (b) $3\,\mathtt{N}$, (c) $2\,\mathtt{N}$

M.13 (a) 1, (b) $1+\frac{2}{\pi}$, (c) $1+\frac{2}{3\,\pi}$, (d) $1-\frac{\cos(\omega\,t_f)-\cos(\omega\,t_i)}{\omega\,(t_f-t_i)}$

M.14 (a) 1, (b) $1+\frac{2}{\pi}$, (c) $1+\frac{2}{3\,\pi}$, (d) $1-2\,\frac{\cos(\pi\,t_f/2)-\cos(\pi\,t_i/2)}{\pi\,(t_f-t_i)}$

M.15 (a) $\frac{F_0}{\gamma^2}\left(1-\frac{2}{\gamma\,T_f}+(1+\frac{2}{\gamma\,T_f})\ \exp(-\gamma\,T_f)\right)$, [Letting $\tau = T_f/2$ for (b) and (c).] (b) $\frac{F_0}{\gamma^2}\left(2-\frac{2}{\gamma\,\tau}+(\frac{2}{\gamma\,\tau}-\gamma\,\tau)\ \exp(-\gamma\,\tau)\right)$, (c) $\frac{F_0}{\gamma^2}\,e^{-\gamma\,\tau}\left(-\frac{2}{\gamma\,\tau}+\gamma\,\tau+2(1+\frac{1}{\gamma\,\tau})\ \exp(-\gamma\,\tau)\right)$, (d) a complicated expression

M.16 (a) $24\,e^{-2} \simeq 3.2482$, (b) $12\,e^{-1} \simeq 4.4146$, (c) $18\,e^{-3/2} \simeq 4.0163$

M.17 $\tilde{t} = t - T_i$, $F(\tilde{t}) = \tilde{t}\,(T_i + T_f - \tilde{t})\,F_0\,\exp(-\gamma\,T_i)\,\exp(-\gamma\,\tilde{t})$

M.18 (units are implicit) (a) (i) 10, 10, (ii) 0, (iii) 100, (iv) 100, (b) (i) 15, 20, (ii) 50, (iii) 100, (iv) 150, (c) (i) 0, -10, (ii) -100, (iii) 100, (iv) 0, (d) (i) -5, -20, (ii) -150, (iii) 100, (iv) -50, (e) (i) 5, 0, (ii) -50, (iii) 100, (iv) 50, (f) Impulse–Momentum Theorem satisfied, (g) sketch

M.19 (a) $10\,\mathtt{MN{\cdot}s}$ [fwd], (b) $0\,\mathtt{N{\cdot}s}$, (c) $10\,\mathtt{MN{\cdot}s}$ [bkwd], (d) $1.25\,\mathtt{MN}$, (e) $6.25\,\mathtt{m/s}^2$

M.20 The centre of mass of the Earth-Sun system is approximately $4.5\times10^5\ \mathtt{m}$ from the centre of the Sun. This is very much below the solar surface, *i.e.,* deep in the interior of the Sun.

M.21 rower 2 is closest

M.22 (a) $M_{\rm Total} = L\,(\lambda_l+\lambda_r) = (2\,L)\,[\frac{1}{2}\,(\lambda_l+\lambda_r)]$, *i.e.,* the total length multiplied by the average density, (b) $\frac{1}{2}\,\frac{\lambda_r-\lambda_l}{\lambda_r+\lambda_l}\,L$

M.23 (a) $\frac{1}{3}\,\lambda_0\,L^3$, (b) $\frac{3}{4}\,L$, (c) This might be a narrow homogeneous cone or pyramid.

M.24 (a) $9\,\mathtt{kg}$, (b) $2\,\mathtt{m}$

M.25 (a) $\frac{3}{4}\,\lambda_0\,L$, (b) $\frac{2}{5}\,\lambda_0\,L$

M.26 (a) Xavier must sit $\frac{4}{3}\ \mathtt{m}$ from the fulcrum, (b) Zoe must sit $1\,\mathtt{m}$ from the fulcrum

M.27 halfway across and one third of the way across the rectangle

M.28 (a) $900\,\mathtt{g}$, (b) $\overrightarrow{R}_{\rm CofM} = (4\,,1)\ \mathtt{m}$ (WRT an origin at the leftmost tip of the triangle)

M.29 (a) Use calculus to obtain the CofM position, (b) the centre of the enclosed square

M.30 (a) $1-\frac{2}{3\,\pi} \simeq 0.7878\,\mathtt{kg}$, (b) $(1\,,\ \frac{1}{12}\ \frac{19\,\pi-24}{3\,\pi+2}) \simeq (1\,,\ 0.40)\ \mathtt{m}$

M.31 (a) $\sigma_0\ \left(A-\frac{2}{\pi}\,B\right)\ L$, (b) $\left(\frac{L}{2}\,,\ \frac{2\,A^2-\frac{8}{\pi}\,A\,B+B^2}{4\,(A-\frac{2}{\pi}\,B)}\right)$

M.32 (a) $(1+\frac{2}{3\,\pi}) \simeq 1.2122\,\mathtt{kg}$, (b) $\left(\frac{3\,\pi^2+4\,\pi-8}{\pi(3\,\pi+2)}\,,\ \frac{1}{12}\ \frac{19\,\pi+24}{3\,\pi+2}\right) \simeq (0.95214\,,\ 0.61045)\ \mathtt{m}$

M.33 (a) $\sigma_0\,(A+\frac{2}{\pi}\,B)\,L$, (b) $\left(\frac{L}{2}\ \frac{A\,\pi^2+4\,\pi\,B-8\,B}{\pi\,(\pi\,A+2\,B)}\,,\ \frac{1}{4}\ \frac{2\,\pi\,A^2+8\,A\,B+\pi\,B^2}{\pi\,A+2\,B}\right)$

M.34 At three tiles, the CofM lies on the edge (the verge of toppling). The fourth tile will always collapse the pile.

M.35 (a) $\pi\,R^2\,\sigma$, (b) the geometrical centre of the pizza

M.36 (a) $\sigma_0\,\theta_0\,R^2$, (b) $\frac{\Theta}{2\,\pi}\,M_T = \frac{\theta}{\pi}\,M_T$, (c) $\frac{2}{3}\,\sigma_0\,\sin(\theta_0)\,R^3$, (d) $\frac{2\,\sin(\theta_0)}{3\,\theta_0}\,R$, (e) (i) $\frac{2}{3}\,R$, (ii) $\frac{4\,R}{3\,\pi}$, (iii) 0

M.37 (a) 5.27×10^{18} kg, (b) at the centre of the Earth

M.38 (a) $T_l = M\,g$, $T_u = (M+m)\,g$, (b) $T(y) = (M+\lambda_0\,y)\,g$

M.39 (a) $a = \frac{F_A}{M_1+M_2+m}$, $T_l = \frac{M_2}{M_1+M_2+m}\,F_A$, $T_r = \frac{M_2+m}{M_1+M_2+m}\,F_A$, (b) $a = \frac{F_A}{M_1+M_2+m}$, $T_l\,\cos(\theta) = \frac{M_2}{M_1+M_2+m}\,F_A$, $T_r\,\cos(\theta) = \frac{M_2+m}{M_1+M_2+m}\,F_A$, and $m\,g = (T_l+T_r)\,\sin(\theta)$ … Solving: $T_r = \left[\left(\frac{M_2+m}{M_1+M_2+m}\,F_A\right)^2 + \left(\frac{M_2+m}{2\,M_2+m}\,m\,g\right)^2\right]^{1/2}$, $T_l = \frac{M_2}{M_2+m}\,T_r$, $\tan(\theta) = \frac{M_1+M_2+m}{2\,M_2+m}\,\frac{m\,g}{F_A}$

M.40 (a) The boat moves away from the dock in such a manner as to preserve the location of the CofM of the PK–boat system. (b) The boat returns to its original position when PK returns to his. (c) The boat, along with PK, recoils and moves alongside the dock.

M.41 1 cm/s

M.42 The boat will eventually come to rest 1.25 m from its original position.

M.43 (a) $\Delta M\,v_e$ [bkwds], (b) $\Delta v_r = \frac{\Delta M}{M}\,v_e$ [fwd], (c) $dv_r = -v_e\,\frac{dM}{M}$, (d) $v_f - v_i = v_e\,\ln\left(\frac{M_i}{M_f}\right)$, (e) $v_f = 3\,v_e$ is greater than the speed with which the fuel is ejected!

M.44 (a) 1 m, (b) (i) a, (ii) $a\,t$, (iii) $1+\frac{1}{2}\,a\,t^2$, (c) (i) $a/3$, (ii) $\frac{1}{3}\,a\,t$, (iii) $1+\frac{1}{6}\,a\,t^2$

M.45 (a) 3 m, (b) (i) 0 m/s^2, (ii) $\frac{7}{5}$ m/s, (iii) $3+\frac{7}{5}\,t$ m, (c) (i) $x_A = -10-6\,t$, $x_B = 5+2\,t$, $x_C = 7+4\,t$, (ii) $3+\frac{7}{5}\,t$, (iii) perfect agreement

M.46 (a) $(-5\,,\,-12)$ kg·m/s, (b) $\frac{1}{7}\,(-5\,,\,-12)$ m/s

M.47 (a) (i) $\vec{a}_L = \vec{0} = \vec{a}_R$, (ii) $\vec{v}_L = 2$ m/s $[\uparrow]$, $\vec{v}_R = 2$ m/s $[\downarrow]$, (iii) [setting $y_{L,R} = 0$ at the common initial height] $y_L = 2\,t\ [\uparrow]$, $y_R = 2\,t\ [\downarrow]$, (b) (i) $\vec{0}$, (ii) $\vec{0}$, (iii) [same convention as in (a)] $\vec{0}$, The CofM of this system remains at rest [viewed in the rest-frame of the pulley]

M.48 (a) (i) $\vec{a}_L = \frac{g}{3}\ [\uparrow]$, $\vec{a}_R = \frac{g}{3}\ [\downarrow]$, (ii) $\vec{v}_L = 2+\frac{g}{3}\,t\ [\uparrow]$, $\vec{v}_R = 2+\frac{g}{3}\,t\ [\downarrow]$, (iii) [setting $y_{0(L,R)} = 0$] $y_L = 2\,t+\frac{g}{6}\,t^2\ [\uparrow]$, $y_R = 2\,t+\frac{g}{6}\,t^2\ [\downarrow]$ (b) (i) $\frac{g}{9}\ [\downarrow]$, (ii) $\frac{2}{3}+\frac{g}{9}\,t\ [\downarrow]$, (iii) [setting $Y_{\mathrm{CofM},0} = 0$], $\frac{2}{3}\,t+\frac{g}{18}\,t^2\ [\downarrow]$, The CofM motion is consistent with that of the blocks.

M.49 (a) $(2.7\,,\,2)$, (b) $(3\,,\,3)$, (c) $(0\,,\,-3/5)$

M.50 (a) Sketch, (b) (i) $(6\,,\,2.8)$, (c) (i) $(-0.8\,,\,1.2)$, (d) (i) $(0.2\,,\,0.2)$, (ii) net force is non-zero

M.51 (a) (i) $\vec{0}$, (ii) $\vec{R}_{\mathrm{CofM}} = \vec{0}$, (b) (i) $\vec{v}_A = (4\,,\,0)$, $\vec{v}_B = (0\,,\,2)$, $\vec{v}_C = (-2\,,\,-1)$, $\vec{v}_D = (0\,,\,0)$, (ii) $\vec{V}_{\mathrm{CofM}} = \vec{0}$, (c) (i) $\vec{p}_A = (4\,M\,,\,0)$, $\vec{p}_B = (0\,,\,2\,M)$, $\vec{p}_C = (-4\,M\,,\,-2\,M)$, $\vec{p}_D = (0\,,\,0)$, (ii) $\vec{P}_{\mathrm{Total}} = \vec{0}$, (d) (i) $\vec{a} = \vec{0}$ for all four blocks, (ii) $\vec{A}_{\mathrm{CofM}} = \vec{0}$, (e) $\vec{R}_{\mathrm{CofM}} = \vec{0}\ \forall\ t$, the CofM is at rest in this IRF

M.52 (a) (i) $\vec{0}$, (ii) $\vec{R}_{\mathrm{CofM}} = \vec{0}$, (b) (i) $\vec{v}_A = (4+2\,t\,,\,4\,t)$, $\vec{v}_B = (-2\,t\,,\,2-4\,t)$, $\vec{v}_C = (-2+8\,t\,,\,-1+4\,t)$, $\vec{v}_D = (-4\,t\,,\,-2\,t)$, (ii) $\vec{V}_{\mathrm{CofM}} = \vec{0}$, (c) (i) $\vec{p}_A = M\,(4+2\,t\,,\,4\,t)$, $\vec{p}_B = M\,(-2\,t\,,\,2-4\,t)$, $\vec{p}_C = M\,(-4+16\,t\,,\,-2+8\,t)$, $\vec{p}_D = M\,(-16\,t\,,\,-8\,t)$, (ii) $\vec{P}_{\mathrm{Total}} = \vec{0}$, (d) (i) $\vec{a}_A = (2\,,\,4)$ $\vec{a}_B = (-2\,,\,-4)$ $\vec{a}_C = (8\,,\,4)$ $\vec{a}_D = (-4\,,\,-2)$ (ii) $\vec{A}_{\mathrm{CofM}} = \vec{0}$,
(e) $\vec{R}_{\mathrm{CofM}} = \vec{0}\ \forall\ t$, the CofM is at rest in this IRF

M.53 (all in m/s) (a) $\frac{4}{15}\,(4\,,\,7)$, (b) $\frac{4}{15}\,(-26\,,\,7)$, (c) $\frac{4}{15}\,(\frac{167}{8}\,,\,7)$, (d) $\frac{4}{15}\,(4\,,\,-\frac{31}{2})$

M.54 final speeds: incident particle $v/3$, struck particle $4\,v/3$

M.55 $v_{5,f} = -1.5$, $v_{4,f} = 1.2$

M.56 (a) $v_1 = -8$, $v_2 = +10$ (Each player is "reflected" [moves backwards at his pre-collision speed] by the elastic collision.), (b) (i) $I_{12} = -1600\,\mathtt{N{\cdot}s}$, $I_{21} = +1600\,\mathtt{N{\cdot}s}$, (ii) $I_{\text{net}} = 0$

M.57 (a) (i) $\frac{3}{2}$ $\mathtt{kg{\cdot}m/s}$ $[\rightarrow]$, (ii) $\vec{0}$, (iii) $\frac{3}{2}$ $\mathtt{kg{\cdot}m/s}$ $[\rightarrow]$, (b) $\frac{3}{2}$ $\mathtt{m/s}$ $[\rightarrow]$, (c) (i) $\frac{3}{2}$ $\mathtt{kg{\cdot}m/s}$ $[\rightarrow]$, (ii) $\frac{3}{2}$ $\mathtt{m/s}$ $[\rightarrow]$, (d) (i) $\vec{0}$, (ii) $3\,\mathtt{m/s}$ $[\rightarrow]$, (e) (i) $\frac{3}{2}$ $\mathtt{kg{\cdot}m/s}$ $[\rightarrow]$, (ii) $\frac{3}{2}$ $\mathtt{kg{\cdot}m/s}$ $[\leftarrow]$, (iii) $\vec{0}$, (f) $15\,\mathtt{N}$ $[\rightarrow]$, (g) (i) $\frac{9}{4}$ $\mathtt{J}$, (ii) $\frac{9}{4}$ $\mathtt{J}$

M.58 (a) (i) $\vec{P}_{\text{Total}} = M\,v$ $[\rightarrow]$, $K_i = \frac{1}{2}\,M\,v^2$, (ii) $\vec{v}_{M,f} = \frac{3}{5}\,v$ $[\leftarrow]$, $\vec{v}_{4M,f} = \frac{2}{5}\,v$ $[\rightarrow]$, (iii) $\vec{P}_{\text{Total}} = M\,v$ $[\rightarrow]$, $K_f = \frac{1}{2}\,M\,v^2$, (b) (i) $\vec{P}_{\text{Total}} = 4\,M\,v$ $[\leftarrow]$, $K_i = 2\,M\,v^2$, (ii) $\vec{v}_{4M,f} = \frac{3}{5}\,v$ $[\leftarrow]$, $\vec{v}_{M,f} = \frac{8}{5}\,v$ $[\leftarrow]$, (iii) $\vec{P}_{\text{Total}} = 4\,M\,v$ $[\leftarrow]$, $K_f = 2\,M\,v^2$, (c) This might be the same collision, viewed by different observers at rest with the respective train cars.

M.59 (a) (i) $M\,v$ $[\rightarrow]$, (ii) $\frac{1}{2}\,M\,v^2$, (b) $\vec{v}_M = \frac{4}{5}\,v$ $[\leftarrow]$, $\vec{v}_{9M} = \frac{1}{5}\,v$ $[\rightarrow]$, (c) (i) $M\,v$ $[\rightarrow]$, (ii) $\frac{1}{2}\,M\,v^2$

M.60 (a) (i) $9\,M\,v$ $[\leftarrow]$, (ii) $\frac{9}{2}\,M\,v^2$, (b) $\vec{v}_M = \frac{9}{5}\,v$ $[\leftarrow]$, $\vec{v}_{9M} = \frac{4}{5}\,v$ $[\leftarrow]$, (c) (i) $9\,M\,v$ $[\leftarrow]$, (ii) $\frac{9}{2}\,M\,v^2$

M.61 (a) $v_1 = 2\,v\,\cos(\theta)$, $v_2 = v\,\sin(\theta)$, (b) this collision is inelastic; surprisingly, there is more kinetic energy in the final state than in the initial state

M.62 fraction of the neutron's energy lost, $\frac{48}{169}$, $n = 10 \geq \frac{\ln(25)}{2\,\ln(13/11)}$ is the minimum number of these collisions needed

M.63 $2.5\,\mathtt{m/s}$ $[\rightarrow]$

M.64 (a) 0, (Both players are stopped by this inelastic collision.), (b) (i) $I_{12} = -800\,\mathtt{N{\cdot}s}$, $I_{21} = +800\,\mathtt{N{\cdot}s}$, (ii) $I_{\text{net}} = 0$

M.65 (a) $\vec{P}_{A,0} = \frac{3}{2}$ $\mathtt{kg{\cdot}m/s}$ $[\rightarrow]$, $\vec{P}_{B,0} = \vec{0}$, $\vec{P}_{\text{Total},0} = \frac{3}{2}$ $\mathtt{kg{\cdot}m/s}$ $[\rightarrow]$, (b) $\frac{3}{2}$ $\mathtt{m/s}$ $[\rightarrow]$, (c) $\frac{3}{2}$ $\mathtt{kg{\cdot}m/s}$ $[\rightarrow]$, (d) $\frac{3}{2}$ $\mathtt{m/s}$ $[\rightarrow]$, (e) (i) $\frac{3}{4}$ $\mathtt{kg{\cdot}m/s}$ $[\rightarrow]$, (ii) $\frac{3}{4}$ $\mathtt{kg{\cdot}m/s}$ $[\leftarrow]$, the impulses are symmetric; the force mediating the collision is internal to the system, (f) $7.5\,\mathtt{N}$ $[\rightarrow]$, (g) (i) $\frac{9}{4}$ $\mathtt{J}$, (ii) $\frac{9}{8}$ $\mathtt{J}$, kinetic energy was lost

M.66 (a) (i) $M\,v$ $[\rightarrow]$, (ii) $\frac{1}{2}\,M\,v^2$, (b) (i) $M\,v$ $[\rightarrow]$, (ii) $\frac{1}{10}\,M\,v^2 = \frac{1}{5}\,K_i$, (c) (i) $\vec{0}$, (ii) $-\frac{2}{5}\,M\,v^2$

M.67 (a) (i) $4\,M\,v$ $[\leftarrow]$, (ii) $2\,M\,v^2$, (b) (i) $4\,M\,v$ $[\leftarrow]$, (ii) $\frac{8}{5}\,M\,v^2 = \frac{4}{5}\,K_i$, (c) (i) $\vec{0}$, (ii) $-\frac{2}{5}\,M\,v^2$

M.68 This might be the same event viewed by different observers riding with each of the colliding train cars.

M.69 (a) (i) $M\,v$ $[\rightarrow]$, (ii) $\frac{1}{2}\,M\,v^2$, (b) (i) $M\,v$ $[\rightarrow]$, (ii) $\frac{1}{20}\,M\,v^2 = \frac{1}{10}\,K_i$, (c) $-\frac{9}{20}\,M\,v^2$

M.70 (a) (i) $9\,M\,v$ $[\leftarrow]$, (ii) $\frac{9}{2}\,M\,v^2$, (b) (i) $9\,M\,v$ $[\leftarrow]$, (ii) $\frac{81}{20}\,M\,v^2 = \frac{9}{10}\,K_i$, (c) $-\frac{9}{20}\,M\,v^2$

M.71 (a) $12\,\mathtt{m/s}$, (b) $16:5$

M.72 (implicit units, $A[B]$ moves left[right]) (a) (i) $v_A = -\sqrt{3}$, $v_B = 1/\sqrt{3}$, (ii) $\Delta p_A = -\sqrt{3}/2$, $\Delta p_B = +\sqrt{3}/2$, (iii) $\Delta K_A = 3/4$, $\Delta K_B = 1/4$, (iv) $\Delta p_{\text{net}} = 0$, $\Delta K_{\text{net}} = 1$, (initial spring potential energy, $U_s = 1$), (b) (i) $v_A = V - \sqrt{3}$, $v_B = V + 1/\sqrt{3}$, (with the assumption that $V > \sqrt{3}$), (ii) $\Delta p_A = -\sqrt{3}/2$, $\Delta p_B = +\sqrt{3}/2$, (iii) $\Delta K_A = \frac{1}{4}\,(3 - 2\,\sqrt{3}\,V)$, $\Delta K_B = \frac{1}{4}\,(1 + 2\,\sqrt{3}\,V)$, (iv) $\Delta p_{\text{net}} = 0$, $\Delta K_{\text{net}} = 1$

M.73 M absorbs $\frac{5}{6}$ of the energy, $5\,M$ takes $\frac{1}{6}$

M.74 (a) v [$\rightarrow$], (b) $4\,M\,v$ [$\leftarrow$], (c) $400\,M\,v$ [$\leftarrow$], (d) $v/3$ [$\leftarrow$], (e) (i) $\vec{v}_g = \frac{5}{3}\,v$ [$\leftarrow$], $\vec{v}_r = \frac{v}{3}$ [$\rightarrow$], (ii) $v/3$ [$\leftarrow$], (f) zero, the collision is assumed to be elastic, (g) (i - ii) $\vec{v}_g = \vec{v}_r = \frac{v}{3}$ [$\leftarrow$], (h) $-\frac{4}{3}\,M\,v^2$

M.75 $\frac{25}{9}\,H$

M.76 $v_\alpha = \sqrt{\frac{2\,K}{M_\alpha\left(1+\frac{M_\alpha}{M_{\text{Pb}}}\right)}} \simeq 1.6\times 10^7$ m/s [roughly 5.3 % the speed of light], $v_{\text{Pb}} = \frac{M_\alpha}{M_{\text{Pb}}}\,v_\alpha \simeq 3.1\times 10^5$ m/s

M.77 (a) setting the origin at the launch point, $x(t) = 15\,t$, $y(t) = 15\,t - 5\,t^2$, (b) [max height, $\frac{45}{4}$ m, occurs at $t = \frac{3}{2}$ s, and $x(\frac{3}{2}) = \frac{45}{2}$ m], setting $\tilde{t} = t - 3/2$, $\{x_f(\tilde{t}) = \frac{45}{2} + 20\,\tilde{t}\,,\, y_f(\tilde{t}) = \frac{45}{4} - 5\,\tilde{t}^2\}$, $\{x_b(\tilde{t}) = \frac{45}{2} + 10\,\tilde{t}\,,\, y_b(\tilde{t}) = \frac{45}{4} - 5\,\tilde{t}^2\}$, $\{x_u(\tilde{t}) = \frac{45}{2} + 15\,\tilde{t}\,,\, y_u(\tilde{t}) = \frac{45}{4} + 5\,\tilde{t} - 5\,\tilde{t}^2\}$, $\{x_d(\tilde{t}) = \frac{45}{2} + 15\,\tilde{t}\,,\, y_d(\tilde{t}) = \frac{45}{4} - 5\,\tilde{t} - 5\,\tilde{t}^2\}$, (c) $\tilde{t}_{R,f} = \frac{3}{2}$, $\tilde{t}_{R,b} = \frac{3}{2}$, $\tilde{t}_{R,u} = (1+\sqrt{10})/2 \simeq 2.08$ s, $\tilde{t}_{R,d} = (-1+\sqrt{10})/2 \simeq 1.08$ s, (d) (i) along the parabolic path taken by the firework until it explodes and then along the parabola it would have taken had it not exploded, (ii) the CofM deviates from the parabola once the downwardly directed piece strikes, since it is no longer moving forward and down, (iii) the CofM is at rest [nearer the launch point than the naive range calculation would suggest]

M.78 (a) $\vec{R}_{\text{CofM}} = (-3\,,\,-4)$, $\vec{V}_{\text{CofM}} = (3\sqrt{3}\,,\,-1)$, (b) $\vec{r}_A = (0\,,\,16+4\,t)$, $\vec{r}_B = (0\,,\,-8-2\,t)$

R.1 (a) (i) $0°/\text{s}^2$, (ii) $5°/\text{s}$, (iii) $45°$, (b) (i) (i) $0°/\text{s}^2$, (ii) $5°/\text{s}$, (iii) $60°$, (c) 72 s

R.2 (a) (i) $-2°/\text{s}^2$, (ii) $-1°/\text{s}$, (iii) $36°$, (b) (i) $-2°/\text{s}^2$, (ii) $-7°/\text{s}$, (iii) $24°$, (c) (i) $\frac{5}{2}$ s, (ii) $36.25°$

R.3 (a) (i) -5 rad/s, (ii) 7.5 rad, (b) (i) -20 rad/s, (ii) -30 rad

R.4 (a) (in rad/s) (i) 1/4, (ii) 3/4, (iii) 1, (b) (in rad) (i) 1/8, (ii) 9/8, (iii) 3

R.5 (in m/s^2) (a) (i) 3/4, (ii) 3/4, (iii) 0, (b) (i) 3/16, (ii) 27/16, (iii) 3, (c) (i) $\frac{3}{16}\sqrt{17}$, (ii) $\frac{3}{16}\sqrt{97}$, (iii) 3

R.6 Alex and Bobby have equal bulk kinetic energies. Bobby has more internal, or relative, kinetic energy.

R.7 (a) (i) $4\,a\,t^3$, (ii) $12\,a\,t^2$, (b) $12\,a\,I\,t^2$, positive, anti-clockwise if $a > 0$, negative, clockwise for $a < 0$, (c) (i) $8\,I\,a^2\,t^6$, (ii) $P = \tau\cdot\omega = 48\,I\,a^2\,t^5 = \frac{dK}{dt}$

R.8 (a) (in kg·m^2) (i) 56250, (ii) 225, (iii) 400, (iv) 2500, (b) 62500 kg·m^2, (c) (i) $\frac{1}{40}$ rad/s^2, (ii) 1562.5 N·m, (iii) (assuming $\alpha = \alpha_{\text{av}}$) 5 rad, (iv) 7812.5 J, (d) (in J) (i) 7031.25, (ii) 28.125, (iii) 50, (iv) 312.5, (e) 7812.5 J

R.9 (a) $\frac{1}{2}\,M\,R^2 + 12\,m_h\,(r_i^2 + r_o^2)$, (b) $\frac{1}{2}\,M\,(R_i^2 + R_o^2) + 12\,m_h\,(r_i^2 + r_o^2)$, The annular disk has a larger moment of inertia than does the solid disk, as more of the mass is distributed farther from the axis.

R.10 $I_B = I_A + M\,(d_B^2 - d_A^2)$

R.11 $I_B = I_A$, nicely symmetric

R.12 (a) $(0\,,\,\frac{M_2}{M_1+M_2}\,,\,0)$, (b) (i) $\frac{M_1\,M_2}{M_1+M_2}$, (ii) M_2, (c) (i) $\frac{M_1\,M_2}{M_1+M_2}$, (ii) M_2, (d) trivially (i) 0, (ii) 0, (e) (i) smallest y-axis (trivial), smallest non-trivial, axes through CofM, (ii) axes through M_1

R.13 (a) $\sigma_0\,\pi\,R^2$, (b) (i) $\frac{1}{2}\,M\,R^2$, (ii) $\frac{1}{4}\,M\,R^2$, (c) (i) $\sigma_0\int_0^R dr\int_0^{2\pi} d\theta\; r\,(R - r\,\cos(\theta))^2$ (ii) $\sigma_0\int_0^R dr\int_0^{2\pi} d\theta\; r\,(R^2 - 2\,R\,r\,\cos(\theta) + r^2)$

R.14 (a) $M_T = \sigma_0\,\theta_0\,R^2$, (b) $\frac{1}{2}\,M_T\,R^2$, (just like a thin disk of the same total mass)

R.15 (a) $\frac{1}{2}\,M_T\,R^2\left[1-\frac{8}{9}\,\frac{\sin^2(\theta_0)}{\theta_0^2}\right]$, (b) $\frac{3}{2}\,M_T\,R^2\left[1-\frac{8}{9}\,\frac{\sin(\theta_0)}{\theta_0}\right]$

R.16 (a) $\frac{4}{3}\,\lambda_0\,L$, (b) $\frac{9}{16}\,L$, (c) (i) $\frac{2}{5}\,M\,L^2$, (ii) $\frac{11}{40}\,M\,L^2$, (iii) $\frac{107}{1280}\,M\,L^2$, (d) $\frac{107}{1280}+(\frac{9}{16})^2=\frac{2}{5}$ and $\frac{107}{1280}+(\frac{7}{16})^2=\frac{11}{40}$

R.17 (a) $400\,\mathtt{N}$, (b) infinite force

R.18 (a) $5\,\mathtt{m/s}^2$, (b) $T_1 = 10\,\mathtt{N}$, $T_2 = 20\,\mathtt{N}$, (c) $2\,\sqrt{3}\,\mathtt{m/s}$

R.19 (a) (i-iii) 0, (b) (i) $\frac{1}{2}\,m_1\,v^2$, (ii) $\frac{1}{2}\,m_2\,v^2$, (iii) $\frac{1}{2}\,I\,\omega^2 = \frac{1}{4}\,M\,v^2$, (c) $-(m_1-m_2)\,g\,h$, (d) $v^2 = \frac{2\,(m_1-m_2)\,g\,h}{m_1+m_2+\frac{1}{4}\,M}$

R.20 (a) (i) $\omega_i = \frac{v_i}{2\,l}$, (ii) $2\,M\,v_i\,l\;[\odot]$, (b) (i) $4\,M\,v_i\,l\;[\odot]$, (ii) $K_i = M\,v_i^2$, (c) (i) $\vec{0}$, (ii) $\Delta\vec{L} = \vec{0}$, (iii) positive work was done by the skaters pulling inward on the rope, (d) (i) $4\,\omega_i$, (ii) $2\,v_i$, (e) (i) $4\,M\,v_i^2 = 4\,K_i$, (ii) $3\,K_i$, (iii) $\frac{3\,K_i}{T}$

R.21 (a) (i) $\omega_{1,i} = \omega_{2,i}$, because $\frac{r_1}{r_2} = \frac{1-\frac{m}{M}}{1+\frac{m}{M}}$ and $\frac{v_1}{v_2} = \frac{1-\frac{m}{M}}{1+\frac{m}{M}}$, (ii) $\vec{L}_1 = M_1\,r_1\,v_1\;[\odot]$, $\vec{L}_2 = M_2\,r_2\,v_2\;[\odot]$, (b) $\vec{L}_{\text{Total}} = \frac{2}{1+\frac{m}{M}}\,\vec{L}_2$, $K_{\text{Total}} = \frac{2}{1+\frac{m}{M}}\,K_2$, (c) (i) $\vec{0}$, (ii) $\Delta\vec{L} = \vec{0}$, (iii) work done by the skaters pulling on the rope was positive, (d) (i) $\omega_f = 4\,\omega_i$, (ii) $v_{1,f} = 2\,v_{1,i}$, $v_{2,f} = 2\,v_{2,i}$, (e) (i) $K_{1,f} = 4\,K_{1,i}$, $K_{2,f} = 4\,K_{2,i}$, $K_f = 4\,K_i$, (ii) $3\,K_i$, (iii) $\frac{3\,K_i}{T}$

R.22 (a) (i) $2\,M\,L^2$, (ii) $\vec{L}_{(\text{a})} = 2\,M\,v\,L\;[\hat{k}]$, (b) (i) $\frac{5}{2}\,M\,L^2$, (ii) $\vec{L}_{(\text{b})} = \frac{5}{2}\,M\,v\,L\;[\hat{k}]$, (c) (i) equal, (ii) equal, there exists sufficient symmetry in both cases

R.23 (a) (i) $2\,M\,L^2$, (ii) $\vec{L}_1 = M\,v\;[\hat{\imath}] + M\,v\,L\;[\hat{k}]$, $\vec{L}_2 = -M\,v\;[\hat{\imath}] + M\,v\,L\;[\hat{k}]$, $\vec{L}_{(\text{a})} = 2\,M\,v\,L\;[\hat{k}]$, (b) (i) $\frac{5}{2}\,M\,L^2$, (ii) $\vec{L}_1 = \frac{1}{2}\,M\,v\;[\hat{\imath}]+\frac{1}{4}M\,v\,L\;[\hat{k}]$, $\vec{L}_2 = -\frac{3}{2}\,M\,v\;[\hat{\imath}]+\frac{9}{4}M\,v\,L\;[\hat{k}]$, $\vec{L}_{(\text{b})} = -M\,v\;[\hat{\imath}] + \frac{5}{2}\,M\,v\,L\;[\hat{k}]$, (c) (i) equal, (ii) not equal, insufficiently symmetric

R.24 (a) (i) $\vec{L}_{\text{L}} = M\,v_0\,R\;[\otimes]$, $\vec{L}_{\text{R}} = M\,v_0\,R\;[\otimes]$, (ii) $\vec{L}_{\mathbb{P}} = I_{\mathbb{P}}\,\omega_0\;[\otimes] = \frac{I_{\mathbb{P}}}{R}\,v_0\;[\otimes]$, (b) $\vec{L}_{\text{Total}} = (2\,M + \frac{I_{\mathbb{P}}}{R^2})\,v_0\,R$, (c) sketches, (d) $\vec{0}$, (e) $\vec{L}_{\text{Total}}$ is constant, the system does not accelerate

R.25 (a) (i) $\vec{L}_{\text{L}} = M_L\,v_0\,R\;[\otimes]$, $\vec{L}_{\text{R}} = M_R\,v_0\,R\;[\otimes]$, (ii) $\vec{L}_{\mathbb{P}} = I_{\mathbb{P}}\,\omega_0\;[\otimes] = \frac{I_{\mathbb{P}}}{R}\,v_0\;[\otimes]$, (b) $\vec{L}_{\text{Total}} = (M_L + M_R + \frac{I_{\mathbb{P}}}{R^2})\,v_0\,R$, (c) sketches, (d) $(M_R - M_L)\,g\,R\;[\otimes]$ (e) (i) $\frac{d}{dt}\vec{L}_{\text{Total}} = (M_L + M_R + \frac{I_{\mathbb{P}}}{R^2})\,a\,R$, (ii) $a = \frac{(M_R-M_L)\,g}{M_L+M_R+\frac{I_{\mathbb{P}}}{R^2}}$

R.26 (a) sketches, (b) (i) 0, (ii) $T_L = T_R = M\,g$, (iii) $y_L = y_{L0} + v_0\,t$, $y_R = y_{R0} - v_0\,t$, (iv) $\vec{v}_L = v_0\;[\uparrow]$, $\vec{v}_R = v_0\;[\downarrow]$, (c) (i) $\frac{2\,m}{2\,M+\frac{I_{\mathbb{P}}}{R^2}}\,g$, (ii) $T_L = (M-m)\,g\left[1+\frac{2\,m}{2\,M+\frac{I_{\mathbb{P}}}{R^2}}\right]$, $T_R = (M+m)\,g\left[1-\frac{2\,m}{2\,M+\frac{I_{\mathbb{P}}}{R^2}}\right]$, (iii) $y_L = y_{L0}+v_0\,t+\frac{m\,g}{2\,M+\frac{I_{\mathbb{P}}}{R^2}}\,t^2$, $y_R = y_{R0}-v_0\,t-\frac{m\,g}{2\,M+\frac{I_{\mathbb{P}}}{R^2}}\,t^2$, (iv) $\vec{v}_L^2 = v_0^2 + \frac{4\,m\,g\,H}{2\,M+\frac{I_{\mathbb{P}}}{R^2}}$, $\vec{v}_R = -\vec{v}_L$

R.27 (a) $K_{L0} = \frac{1}{2}\,M_L\,v_0^2$, $K_{R0} = \frac{1}{2}\,M_R\,v_0^2$, $K_{\mathbb{P}0} = \frac{1}{2}\,\frac{I_{\mathbb{P}}}{R^2}\,v_0^2$, $K_0 = \frac{1}{2}(M_L + M_R + \frac{I_{\mathbb{P}}}{R^2})\,v_0^2$, (b) (i) $U_{gL,0}$, (ii) $U_{gR,0}$, (iii) $U_{gL,0}+U_{gR,0}$, WLOG these can be set to zero, (c) (i) $\Delta U_{gL} = +M_L\,g\,H$, (ii) $\Delta U_{gR} = -M_R\,g\,H$, (iii) $-(M_R-M_L)\,g\,H$, (d) $\Delta K = -\Delta U_{gLR}$, $v^2 = v_0^2 + \frac{2\,(M_R-M_L)\,g\,H}{M_L+M_R+\frac{I_{\mathbb{P}}}{R^2}}$

R.28 (a) (i) $\frac{18}{7}\,\mathtt{m/s}^2$, (ii) $\vec{v}_L = 2+\frac{18}{7}\,t\;[\uparrow]$, $\vec{v}_R = 2+\frac{18}{7}\,t\;[\downarrow]$, (iii) $\vec{y}_L = y_{L0}+2\,t+\frac{9}{7}\,t^2\;[\uparrow]$, $\vec{y}_R = y_{R0} - 2\,t - \frac{9}{7}\,t^2\;[\uparrow]$, (b) (the pulley is not part of the two-block system) (i) $\frac{6}{7}\,\mathtt{m/s}^2\;[\downarrow]$, (ii) $(\frac{2}{3} + \frac{6}{7}\,t)\,\mathtt{m/s}\;[\downarrow]$, (iii) $[\frac{M_R\,y_{R0}+M_L\,y_{L0}}{M_R+M_L} + \frac{2}{3}\,t + \frac{3}{7}\,t^2]\;\mathtt{m}\;[\downarrow]$

R.29 $K_{\text{rot}} = \frac{1}{2}\,K_{\text{trans}}$

R.30 (a) (i) $\sqrt{g\,L\,\sin(\theta)}$, (ii) $\sqrt{\frac{4}{3}\,g\,L\,\sin(\theta)}$, (b) the slab

R.31 (a) (i) $\sqrt{2\,g\,P}$, (ii) yes, (b) (i) $\sqrt{\frac{8}{5}\,g\,P}$, (ii) yes, (c) (i) $\sqrt{\frac{10}{7}\,g\,P}$, (ii) yes, (d) (i) $\sqrt{(2\,g - \frac{F_{\text{R}}\,\pi}{M})\,P}$, (ii) no

R.32 (a) $(0\,,\,0\,,\,M)$ $\mathtt{kg{\cdot}m^2/s}$, (b) $\vec{0}$. No net torque acts on the particle; its motion is inertial.

R.33 (a) $(0\,,\,0\,,\,M\,X_0\,V_0)$, (b) $\vec{0}$. No net torque acts on the particle; its motion is inertial.

S.1 (a) $\frac{M_2\,g}{k}$, (b) $x_- = (M_2 - \mu_{\text{S}}\,M_1)\,\frac{g}{k}$, $x_+ = (M_2 + \mu_{\text{S}}\,M_1)\,\frac{g}{k}$

S.2 $500\,\mathtt{N}$; $0.4\,\mathtt{m}$ from the left rope, $0.6\,\mathtt{m}$ from the right

S.3 $\frac{5}{3}\,\mathtt{m}$ from the fulcrum

S.4 $2500\,\mathtt{N}$, $0\,\mathtt{N}$

S.5 (a) The vertical (components of the) forces provided by the hinges sum to equal the weight of the door *i.e.,* $M\,g$. The horizontal components are of equal magnitude, $M\,g\,\frac{W}{2\,H}$, and opposite direction, away from/toward the door at the top/bottom.

S.6 $M\,g\,\cot(\theta) = \frac{M\,g}{\tan(\theta)}$

S.7 $T = 875\,\mathtt{N}$, $\vec{F_{\text{P}}} = (700\,,\,775)\,\mathtt{N}$

S.8 (a) $F_{\text{S}} = 2\,\sqrt{2}\,M\,g$, $\vec{F_{\text{P}}} = \sqrt{5}\,M\,g\,\big(\frac{2}{\sqrt{5}}\,,\,-\frac{1}{\sqrt{5}}\big)$, (b) $F_{\text{S}} = \sqrt{2}\,(2\,M + M_b)\,g$, $\vec{F_{\text{P}}} = \big((2\,M + M_b)\,g\,,\,-M\,g\big)$

S.9 (a) sketch, (b) (i) $1500\,\mathtt{N}$, (ii) $424\,\frac{53}{76}\,\mathtt{N}$, (c) $\frac{265}{936} \simeq 0.283$

S.10 $F_{\text{S}} = 375\,\mathtt{N}$, $\mu_{\text{S}} \geq \frac{15}{28} \simeq 0.536$

S.11 yes

S.12 (a) $\frac{100}{\sqrt{3}}\,\mathtt{N}\,[\rightarrow]$, (b) $100\,\sqrt{3}\,\mathtt{N}\,[\rightarrow]$, (c) $\frac{700}{\sqrt{3}}\,\mathtt{N}\,[\rightarrow]$

S.13 (a) stable, (b) not stable, (c) one pawn standing on the ladder's base makes the system barely stable

S.14 (a) $\frac{\phi\,H}{2\,\cos(\theta)}$, (b) (i) $\phi = \phi_g + (\phi_t - \phi_g)\,\frac{y}{H}$, (ii) $\frac{(\phi_g + 2\,\phi_t)\,H}{6\,\cos(\theta)}$

S.15 the required forces are identical

S.16 (a) $225\,\mathtt{N}$, (b) greater force is required in this case

S.17 $137.5\,\mathtt{N}$

S.18 $\frac{5500\,\sqrt{11}}{3} \simeq 6080\,\mathtt{N}$

G.1 (a) (i) $625\,G$, (ii) $\frac{625\,G}{6}$, (iii) $\frac{3}{8}\,625\,G$, (b) (i) $\frac{13}{24}\,625\,G\,[\rightarrow]$, (ii) $\frac{5}{8}\,625\,G\,[\leftarrow]$, (iii) $\frac{7}{6}\,625\,G\,[\leftarrow]$

G.2 (l) $\frac{4}{3}\,\frac{G\,M}{X^2}\,[\rightarrow]$, (m) $2\,\frac{G\,M}{X^2}\,[\rightarrow]$, (r) $3\,\frac{1}{9}\,\frac{G\,M}{X^2}\,[\leftarrow]$

G.3 (a) $9.83\,\mathtt{m/s^2}$ [toward Gaia], (b) $835.6\,\mathtt{N}$, this is PK's weight on Earth.

G.4 doubled

G.5 (a) (i) $-2\,(625\,G)$, (ii) $-625\,G$, (iii) $-\frac{3}{2}\,625\,G$, (b) $-\frac{9}{2}\,625\,G$

G.6 (a) (i) $\frac{1}{2}$, (ii) 0 or 1, (b) (i) 0 or 1, (ii) $\frac{1}{2}$

G.8 (l) $-2\,\frac{G\,M}{X}$, (m) $-4\,\frac{G\,M}{X}$, (r) $-\frac{10}{3}\,\frac{G\,M}{X}$

G.9 (a) $\frac{2\,G\,M}{r^2}$ [inward], (b) $\frac{G\,M}{r^2}$ [inward], (c) $\vec{0}$

G.10 (a) $-\frac{2\,G\,M}{r}$, (b) $-\frac{G\,M}{r} - \frac{G\,M}{2\,R}$, (c) $-\frac{3\,M}{2\,R}$

G.11 (a) $\frac{G\,(M_i+M_o)}{r^2}$, (b) $\frac{G\,M_i}{r^2}$, (c) 0, (d) $V_{(\mathrm{a})} = -\frac{G\,(M_i+M_o)}{r}$, $V_{(\mathrm{b})} = -\frac{G\,M_i}{r} - \frac{G\,M_o}{R_o}$, $V_{(\mathrm{c})} = -G\left(\frac{M_i}{R_i} + \frac{M_o}{R_o}\right)$

G.12 (a) $9.83\,\mathtt{m/s}^2$, (b) $9.84\,\mathtt{m/s}^2$, (c) (i) $\frac{G\,M_c}{r^2}$, (ii) $\frac{G\,(M_c+M_s}{r^2} = \frac{G\,M_\oplus}{r^2}$, (d) density profile

G.13 (a) (i) $\frac{G\,M_m}{(R-r)^2}$, (ii) $\frac{G\,M_m}{(R+r)^2}$, (b) $G\,M_m\left[\frac{1}{(R-r)^2} - \frac{1}{(R+r)^2}\right]$, (c) $g_m(h) \simeq \frac{G\,M_m}{R^2}\left(1 - \frac{2\,h}{R} + \ldots\right)$, (d) $\Delta g \simeq \frac{4\,G\,M_m\,r}{R^3}$, (e) the approx. is valid when $h/R \ll 1$

G.14 (a) no change, (b) doubled, (c) doubled

G.15 the current estimate would be revised down

G.16 (a) (i) $v^2 = G\,m\left[\frac{1}{2\,\rho} - \frac{1}{R}\right]$, (ii) same speeds, kinetic energy is conserved, (iii) 0, (iv) $G\,m^2\left[\frac{1}{2\,\rho} - \frac{1}{R}\right]$, (b) (i) $v^2 = \frac{G\,m}{2\,R}$, (ii) $\pi\sqrt{\frac{2\,R^3}{G\,m}}$

G.17 (a) $\sqrt{\frac{2\,G\,M_\odot}{R_\odot}} \simeq \frac{1.6293\times10^7}{\sqrt{R_\odot}}$, (b) approx. $2950\,\mathtt{m}$ or $3\,\mathtt{km}$

G.18 (a) $35.9\times10^6\ \mathtt{m} = 35.9\times10^3\ \mathtt{km}$ above the observer on the surface of the Earth, (b) $4.225\times10^7\ \mathtt{m}$ is approximately 11% of the distance to the centre of the Moon.

G.19 (a) $0.885\times10^8\ \mathtt{m}$, (b) this is a significant fraction, 18.1% of the Earth–Moon distance, and it is likely that [with its proportionally large mass] the Earth's presence will disrupt the motion of the satellite.

G.20 (a) $2.52\times10^{10}\ \mathtt{m}$, (b) this distance places the solarstationary satellite well outside the body of the Sun, and deep inside Mercury's orbit

G.21 (a) $7.7\,\mathtt{km/s}$, (b) $5505\,\mathtt{s} \simeq 91.75\,\mathtt{min} \simeq 1.53\,\mathtt{h}$

G.22 0.0167