# Answers to Odd Problems in Intermediate Dynamics

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January 13, 2009

## Chapter 1

1.1 75.17 cm/sec at 3.81° above the horizontal
1.3 (a) $1.44 ft/\sec^2$, (b) 102.3 mph.
1.5 $v = \frac{k}{b^2}\left[1 - e^{-bt}(bt+1)\right], x = x_0 + \frac{k}{b^2}\left[e^{-bt}\left(t + \frac{2}{b}\right) + t - \frac{2}{b}\right]$
1.7 $t = 0.1$ sec.
1.11 5609 m.
1.13 15.7 m
1.15 0.21
1.19 (a) $(\frac{4a}{3\pi}, \frac{4b}{3\pi})$. (b) $x_{cm} = 0, y_{cm} = \frac{4}{3\pi}\frac{b^3 - a^3}{b^2 - a^2}$, (c) $(16.77, 8)$.
1.21 $R_{cm} = (\frac{3}{8}R, \frac{3}{8}R, \frac{3}{8}R)$.
1.23 $\frac{3\sqrt{2}}{16}a$.
1.25 21.37°
1.27 $5mg$.
1.29 (a) 1.7 mph (b) 2.4 mph.
1.31 3520 watt.
1.33 4.3 m/s.
1.35 $v_i/v_f = 0.89$; the streetcars will run about 10 percent faster.

## Chapter 2

2.1 6 m/s.
2.3 (a) $v = \frac{v_0}{1+kv_0t}, x = x_0 + \frac{1}{k}\left[\ln(1 + kv_0t)\right]$ (b) As $t \to \infty$, $v \to 0$.
2.5 $v = \sqrt{v_{0x}^2 + v_{0y}^2} = [(g^2x^2/2yg) + (2yg)]^{1/2}$,
$\theta = \tan^{-1}(v_{0y}/v_{0x}) = \tan^{-1}(2y/x)$.
2.7 455 km.
2.9 (a)$\tau = 2\pi\sqrt{\frac{r}{a}}$ (b) $a = 9.81$ m/s, $v = 7.91 \times 10^3$ m/s, $\tau = 84.4$ min.
2.11 $\Delta\tau/\tau = \frac{3}{2}\left(\Delta r/r\right)$.
2.19 $\mathbf{v} = 4\sin\theta\hat{\mathbf{r}} + (4 - 4\cos\theta)\hat{\boldsymbol{\theta}}$, $\mathbf{a} = (32\cos\theta - 16)\hat{\mathbf{r}} + 32\sin\theta\hat{\boldsymbol{\theta}}$.

2.21 $\hat{\mathbf{r}}(\dddot{r} - 3\dot{r}\dot{\theta}^2 - 3r\dot{\theta}\ddot{\theta}) + \hat{\boldsymbol{\theta}}(r\dddot{\theta} + 3\dot{r}\ddot{\theta} + 3\ddot{r}\dot{\theta} - r\dot{\theta}^3)$.
2.25 0.996 m/s.
2.27 $2 + \frac{1}{\rho}z\cos\phi + \frac{1}{2}\sqrt{\frac{\rho}{z}}$.
2.29 $x = a\cos\omega(t-\tau_1)\cos\Omega(t-\tau_2)$,
$y = -a\cos\omega(t-\tau_1)\sin\Omega(t-\tau_2)$,
$z = a\sin\omega(t-\tau_1)$.
2.31 $r^2 = \rho^2 + z^2, \theta = \tan^{-1}\frac{\rho}{z}, \phi = \phi; \rho = r\sin\theta, \phi = \phi, z = r\cos\theta$.
2.33 (a) An inward spiral. (b)$\sqrt{b^2 + (akt - bkt^2)^2}$.

## Chapter 3

3.1 $-\omega A\sin\omega t, -\omega^2 A\cos\omega t$.
3.3 $8 \times 10^4$ N.
3.5 $\frac{M_2}{M_1}, \frac{M_2}{M_1}$.
3.7 (a)$a = -g\frac{m_1-m_2}{m_1+m_2}, T = 2\frac{m_1m_2}{m_1+m_2}g$ (b) $g(m_1-m_2)/(m_1+m_2-I/R^2)$.
3.11 $T/T_0 = (7\times10^6)^{0.001/2} = 1.0079$. Periods differ by about 0.8%; could be detetected easily.
3.13 (a) (1)Book/Earth (gravitational); Book/Table (electrostatic); Table/Surface (electrostatic); Table/Earth(gravitational) (2)Rocket/Earth (gravitational); Rocket/Plume (molecular collisions - fundamentally electrostatic), Plume/Atmosphere (molecular collisions) (3) Donkey/Road (friction); Donkey/Cart (mechanical). (b) Unbalanced force on inner wall opposite to nozzle. (c) Road on donkey's hooves.
3.15 $5L/6, 5L/6$.
3.17 (a)$v = \frac{F}{m_0}\frac{t}{1-(\kappa t/m_0)}$, $x = \frac{Fm_0}{\kappa^2}\left[-\frac{\kappa}{m_0}t - \ln(1-\frac{\kappa}{m_0}t)\right]$,
(b)$\frac{1}{2}\frac{F}{m_0}t^2 + \cdots$
3.19 $T_{bot} = 2156$ N;$T_{mid} = 2207$ N;$T_{top} = 2259$ N;
Equation: $T(x) = g(220+7x)$.
3.21 358 m/s.
3.25 32.67 m/s, 77.33 m.
3.27 $v(t) = -\frac{1}{b}\ln\left(e^{-bv_0} + \frac{A}{bm}t\right)$
3.29 $v(t) = \sqrt{mg/b}\tanh\sqrt{gb/m}t$,
$x(t) = \frac{m}{b}\log\cosh\sqrt{gb/m}t = \frac{m}{b}\log\frac{e^{\sqrt{gb/m}t}+e^{-\sqrt{gb/m}t}}{2}$.
3.31 (a) $v_T = \sqrt{mg/D}$,
(b) $h = (m/2D)\ln\left[\left(v_0^2 + v_T^2\right)/v_T^2\right]$,
(c) $v_g = v_Tv_0/\sqrt{v_0^2+v_T^2}$.
3.33 (a) 21.8 m$^2$, (b) 0.35 s.
3.35 (a) 55.87 m/s.
(b) $v = v_T\sqrt{1-\exp(-2gx/v_T^2)}$.
(c) 38.2 m/s.
3.37 $y = \frac{mg}{b}\left(t + \frac{m}{b}\left(e^{-bt/m} - 1\right)\right)$.
3.39 (a) 90 m/s, (b) 14.7 s.
3.41 1.67 m/s.
3.43 $\sqrt{x_0^3\pi^2/8GM}$.

3.45 (a)$x(t) = \frac{D}{2} e^{\sqrt{\beta} t} + \left( \frac{C^2}{2D} \right) e^{-\sqrt{\beta} t}$.

(b)$v_0 = -\sqrt{\frac{k}{m}} x_0$.

3.47 $1.26 X 10^3$ s $\simeq$ 42 min.

Chapter 4

4.1 $L = \frac{1}{2} m a^2 \dot{\theta}^2 + \frac{1}{2} m a^2 \dot{\phi}^2 \sin^2\theta - mga\cos\theta$.

4.3 $L = \frac{1}{2} m \dot{z}^2 - \frac{3}{2} k z^2 - 3C$.

4.5 Equations of motion: $(M+m)\ddot{x} + Ml\ddot{\theta}\cos\theta - Ml\dot{\theta}^2 \sin\theta = 0$

$Ml^2\ddot{\theta} + Ml\ddot{x}\cos\theta + mgl\sin = 0$.

Constant of the motion: $(M+m)\dot{x} + Ml\dot{\theta}\cos\theta$.

4.7 $\ddot{s} = \frac{g \sin\alpha}{1 - [m/(m+M)]\cos^2\alpha}$ and $\ddot{X} = -\frac{m}{m+M}\left(\frac{g\sin\alpha}{1-[m/(m+M)]\cos^2\alpha}\right)\cos\alpha$.

4.9 $L = \left(\frac{1}{2}M + 3m\right)\dot{s}^2 + (M+4m)gs\sin\alpha$.

4.11 (a) $L = \frac{1}{2}(M+m)\dot{X}^2 + m\dot{X}\dot{s}\cos\alpha + \frac{1}{2}m\dot{s}^2 + mgs\sin\alpha - \frac{1}{2}ks^2$.

(b) $p_X = (m+M)\dot{X} + m\dot{s}\cos\alpha, p_s = m\dot{X}\cos\alpha + m\dot{s}$.

(c) $(m+M)\ddot{X} + m\ddot{s}\cos\alpha = 0, m\ddot{X}\cos\alpha + m\ddot{s} - mg\sin\alpha + ks = 0$.

4.13 (a) $L = m\dot{x}^2 + mg(l-x) - \frac{1}{2}k(d-x)^2$.

(b) $2m\ddot{x} + kx = kd - mg$ or $\frac{2m}{k}\ddot{x} = -x - C$.

(c) $\sqrt{k/2m}$.

4.15 $a\sqrt{1 + \phi'^2 \sin^2\theta}$.

4.17 $y = \pm 2c\sqrt{x - c^2} + d$.

4.19 $\Phi = y\sqrt{1 + y'^2}$.

4.21 $-\frac{\hbar^2}{2m}\left[\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}\right]$.

4.23 $H = \frac{p_\theta^2}{2ml^2} - mgl\cos\theta, \dot{p}_\theta = -mgl\sin\theta, \dot{\theta} = \frac{p_\theta}{ml^2}$.

Chapter 5

5.1 49.5 J.

5.3 $2kR^2$.

5.5 (a) $h_{11}^2 = 1$ $\quad h_{22}^2 = r^2$ $\quad h_{12}^2 = 0$ $\quad h_{21}^2 = 0$

(b) $d\mathbf{s} = \hat{\mathbf{r}}dr + \hat{\boldsymbol{\theta}}rd\theta, da = rdrd\theta$.

5.7
$$\begin{pmatrix} a(\sinh^2 u\cos^2 v + \cosh^2 u \sin^2 v)^{1/2} & 0 & 0 \\ 0 & a(\cosh^2 u \sin^2 v + \sinh^2 u\cos^2 v)^{1/2} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$d\mathbf{s} = a(\sinh^2 u\cos^2 v + \cosh^2 u\sin^2 v)^{1/2} du\hat{\mathbf{e}}_u + a(\cosh^2 u\sin^2 v + \sinh^2 u\cos^2 v)^{1/2} dv\hat{\mathbf{e}}_v + dz\hat{\mathbf{k}}.$$

5.9
$$\boldsymbol{\nabla} = \hat{\mathbf{e}}_\eta \left(1/a\left[\cosh^2\eta\sin^2\theta + \sinh^2\eta\cos^2\theta\right]^{1/2}\right)\frac{\partial}{\partial\eta} + \hat{\mathbf{e}}_\theta\left(1/a\left[\sinh^2\eta\cos^2\theta + \cosh^2\eta\sin^2\theta\right]^{1/2}\right)\frac{\partial}{\partial\theta} + \hat{\mathbf{e}}_\phi\left(1/a\left[2\sinh^2\eta\sin^2\theta\right]^{1/2}\right)\frac{\partial}{\partial\phi}.$$

5.11 $\frac{4}{3}\pi R^3$.

5.13 (b) $\boldsymbol{\nabla} f = -\hat{\boldsymbol{\rho}}$.

5.15 (a) $\boldsymbol{\nabla} T_{1,2,3} = -2(\hat{\mathbf{i}}+\hat{\mathbf{j}}+\hat{\mathbf{k}}) \Rightarrow -3.46$ K/m.

(b) 4.15 K.

(c) The rate of temperature decrease is getting larger the further we move from the origin.

5.17 $v_{\max} = \left[\frac{2}{m}\left\{\frac{q(Q_1+Q_2)}{4\pi\epsilon_0}\left(\frac{1}{a} - \frac{1}{\sqrt{b^2+a^2}}\right)\right\}\right]^{\frac{1}{2}}$ at $y = 0$.

5.19 $609N$.

5.21 $1.99 \times 10^{-25}$ kg.

5.23 $h = G\frac{M_e m}{|E|} - R_e$.

5.27 (a) $\mathbf{F} = -A\frac{\hat{\imath}x+\hat{\jmath}y+\hat{\mathbf{k}}z}{(x^2+y^2+z^2)^{3/2}}$,

(b) $W = A/\sqrt{x_1^2+y_1^2+z_1^2}$,

(c) $\mathbf{F} = -A\frac{\mathbf{r}}{r^3}$.

5.29 $\frac{Q_1Q_2}{4\pi\varepsilon_0}\frac{1}{r} - \frac{Q_1Q_2}{4\pi\varepsilon_0}\frac{1}{r_0}$.

5.31 $-\frac{Gm_1m_2}{r}$.

5.33 (b) 4.24 m/s, (c) +5.77, and $x = -2.77$ m.

5.35 $x(t) = v_{0x}\sqrt{\frac{m}{a}}\sin\sqrt{\frac{a}{m}}t, y(t) = v_{0y}\sqrt{\frac{m}{b}}\sin\sqrt{\frac{b}{m}}t$.

Chapter 6

6.1 (a) 5 m/s (b) 3.45 m/s.

6.3 $v = \frac{m+M}{m}\sqrt{2gh}$.

6.7 (a) $v = v_0m_0/\left[m_0^{4/3} + \frac{4kv_0m_0}{3K^{2/3}}t\right]^{3/4}$ where $k = \rho_d\pi$ and $K = m/r^3$.

(b) $F = -\frac{k(v_0m_0)^2}{K^{2/3}}\left[1/\left(m_0^{4/3} + \frac{4kv_0m_0}{3K^{2/3}}t\right)\right]$.

6.9 $\cos^{-1}\left[\left(\frac{m_M}{m_M+m_W}\right)^2(0.13) - 1\right]$.

6.11 $kmV$.

6.15 $v(t) = -gt + \frac{2mg}{k}\ln\frac{2m}{2m-kt}$.

6.17 15 kg/s, 16.2 kg/s.

6.19 $t =$660 s =11 m.

6.21 8.70 times the height from which it was dropped.

6.23 $\sqrt{12}$ m/s., 30°.

6.25 25 km/s.

Chapter 7

7.1 (b) Total torque is zero so angular momentum is constant.

(c) Particles have the same linear momentum, so angular momentum is independent of the choice of origin.

7.5 $\mathbf{l} = -(1/2)v_{0x}F_et^2\hat{\imath}$.

7.7 $d = \frac{D\mu R}{h}$.

7.9 $.51 \times 10^4$ rad/s.

7.13 $\frac{1}{2}M(R_2^2 + R_1^2)$.

7.15 $\frac{5}{4}MR^2$.

7.17 Number of turns $= \omega_0^2 I\sqrt{\mu^2+1}/4\pi a\mu mg, t = \left(1+\sqrt{2}\right)\frac{\omega_0 I\sqrt{\mu^2+1}}{a\mu mg}$.

7.19 (a)$W = \frac{d}{2}mg$, (b) $\omega_f = \sqrt{\omega_i^2 + gd/a^2}$, (c) $F = \frac{1}{2}mg$.

7.21 (a) $\omega = 0.09v/l$. (b) $\omega = \frac{0.2}{1.1}\frac{v}{l}$.

Chapter 8

8.1 Energy.

8.3 Yes.

Chapter 9

9.1 $1.03 \times 10^6$ m/s.

9.3 $\sqrt{\frac{3\pi}{G\rho}}$.

9.5 $-\frac{2GM}{R^2L}\left[L - \sqrt{Z^2+R^2} - \sqrt{(Z-L)^2+R^2}\right]$.

9.7 $\frac{2G\lambda m}{d}$.

9.9 $-2G\rho r\hat{\mathbf{r}}$.

9.11 Outside $\Phi = -\frac{GM}{r}$, $\mathbf{g} = -\frac{GM}{r^2}\hat{\mathbf{r}}$,

Inside $\mathbf{g} = -GM\frac{r}{R^3}\hat{\mathbf{r}}, \Phi = -\frac{GM}{2}\left[\frac{3}{R} - \frac{r^2}{R^3}\right]$.

9.13 (a) $\Phi = \int -\frac{G\lambda a d\phi'}{s} = -\frac{GM}{s} = -\frac{GM}{\sqrt{z^2+a^2}}$,

(b) $\Phi = -\frac{GM}{r}\left[1 - \frac{1}{2}\frac{a^2}{r^2}\left(1 + \frac{3}{2}\sin^2\theta\right)\right]$.

9.15 84 min.

9.17 (a) For sphere outside and inside, $g = -\frac{GM}{r^2}, g = -\frac{GM}{R^3}r$.

(b)For shell outside and inside, $g = -\frac{GM}{r^2}, 0$.

9.19 $g = 2\pi G\sigma$ (towards plane).

9.21 $\frac{5kr^2}{4\pi G}$. For the second field, the mass density $\rho$ is a delta function, zero everywhere except at the origin.

Chapter 10

10.1

| n | r (Å) | E(eV) |
|---|---|---|
| 1 | 0.53 | -13.60 |
| 2 | 2.13 | -3.40 |
| 3 | 4.76 | -1.51 |
| 4 | 8.47 | -0.85 |

10.5 $\Delta\tau = 3(2\pi GM)^{-2/3}T^{5/3}V\Delta V$.

10.7 (a) $\mathbf{r}'_1 = -\frac{m_2}{m_1+m_2}\mathbf{r}, \mathbf{r}'_2 = +\frac{m_1}{m_1+m_2}\mathbf{r}$.

(b)$L = \frac{1}{2}(m_1+m_2)\dot{R}^2 + \frac{1}{2}\frac{m_1m_2}{m_1+m_2}\dot{r}^2 + G\frac{m_1m_2}{r}$.

(c) $\mu\ddot{r} - \mu r\dot{\theta}^2 + G\frac{m_1m_2}{r^2} = 0$, $\frac{d}{dt}\left(\mu r^2\dot{\theta}\right) = 0$.

(d) $\ddot{r} - \frac{l^2}{\mu^2r^3} = -G\frac{(m_1+m_2)}{r^2}$.

(e) $\tau^2 = \frac{4\pi^2}{G(m_1+m_2)} a^3$.

10.9 (a) $r = (a/2)(1+\cos\theta)$, (b) $3\pi/8\sqrt{3ma^5/2K}$.

10.13 1300 km.

10.21 $e = (v_{\max} - v_{\min}) / (v_{\min} + v_{\max})$.

Chapter 11

11.1 $b^2/4m = k$.

11.3 $k = 3.43 \times 10^4$N/m, $b = 3.1 \times 10^3$ kg/s.

11.5 $t \le \sqrt{0.6}/\sqrt{\frac{k}{m} - \frac{b}{2m}}$.

11.7 $\gamma_2 x_0 + v_0 = 0$.

11.11 $x(t) = \left(x_0 + A\left[-\left(\omega_0^2 - \omega_d^2\right) + \left[\gamma_c A\left(\omega_0^2 - \omega_d^2\right) - A\left(\omega_d^2 b/m\right)\right] t\right]\right) e^{-\gamma_c t}$
$+A\left[\left(\omega_0^2 - \omega_d^2\right)\cos\omega_d t + (\omega_d b/m)\sin\omega_d t\right]$.

11.13 $x(t) = Ae^{-\gamma t}\cos(\omega_1 t + \theta) + \frac{F_0}{4a^2 m}\left(1 - e^{-at}\right)$.

11.15 $\omega = \sqrt{k\frac{m_1+m_2}{m_1 m_2}}$.

11.19 Normal mode frequencies: $\omega = \pm\sqrt{\frac{m_1+m_3}{m_3}}\sqrt{\frac{k_1}{m_1}}, \omega = \pm\sqrt{\frac{m_2+m_3}{m_3}}\sqrt{\frac{k_2}{m_2}}$.

Chapter 12

12.1 Work $= \frac{1}{2} I\dot{\phi}^2\Big|_i^f = \Delta T$.

12.3 $\frac{9}{64}\sin^4\frac{\theta_m}{2}$.

12.5 (a) $L = \frac{1}{2}ml^2\dot{\theta}^2 - mlA\dot{\theta}f\sin\theta\sin ft + \frac{m}{2}A^2 f^2\sin^2 ft$
$-mg(-l\cos\theta + A\cos ft)$.
(b) $\ddot{\theta} = \left[\frac{Af^2}{l}\cos ft + \frac{g}{l}\right]\sin\theta$.
(c) $\omega = \sqrt{\frac{Af^2}{l}\cos ft + \frac{g}{l}}$.

12.7 (a) 2.85 s, (b) 2.02 m.

12.9 $1.73r$.

12.11 $T = 2\pi\sqrt{m/2k}$.

12.13 $\frac{4k_0}{\sqrt{gh}}F\left(\sin\frac{\theta_{\max}}{2}\right)$.

12.15 4.08 rad/sec.

12.17 $T = \frac{2E}{l} - 3mg\cos\theta,\ \cos^{-1}\left(\frac{2E}{3mgl}\right)$.

12.19 $H = \frac{1}{2}\frac{p_\theta^2}{ml^2} + \frac{p_\phi^2}{2ml^2\sin^2\theta} + mgl\cos\theta, \dot{p}_\phi = 0, \dot{\phi} = \frac{2p_\phi}{ml^2\sin^2\theta}$.

Chapter 13

13.3 $\mathbf{a} = \mathbf{a}''' + \mathbf{2}\left(\boldsymbol{\Omega} + \boldsymbol{\omega}\right)\times\mathbf{v}''' + 2\boldsymbol{\omega}\times\left(\boldsymbol{\Omega}\times\mathbf{r}'''\right) + \boldsymbol{\omega}\times\left(\boldsymbol{\omega}\times\mathbf{r}_E\right)$.

13.5 $a_{\text{cent}} = 0, a_{\text{cor}} = -2\frac{V^2}{R}\hat{\mathbf{x}}'$.

13.7 $d = \frac{2h}{3g}\Omega\sin\lambda\sqrt{2h\left[\frac{h}{2}\Omega^2\cos^2\lambda + 1\right]} = 0.79$ cm.

13.9 3.5 km South and 3.5 km East of the expected target. It is in flight 2.3 seconds longer than expected.

13.11 76.7 km/hr.
13.13 32 m.
13.15 $3.3 \times 10^{-3}$ rad.
13.17 (a) $2\Omega v\hat{\boldsymbol{\phi}}$, (b) $2\Omega v\hat{\mathbf{r}}$, (c) 0, (d) $d_\phi = -\frac{4}{3}\frac{\Omega v_0^3}{g_e^2}$.
13.19 28.8 m (North).
13.21 (a) $\omega_0 = \sqrt{\frac{k}{m}}$,(b) $r(t) = a + \eta_0 \cos(2\omega_o t)$.

## Chapter 14

14.1 $\tan\alpha = \frac{1}{2}(\tan\theta - \tan\phi), T_1 = \left[mg/\left(\sin\theta + \cos\theta\tan\phi\right)\right],$
$T_2 = \left[mg/\left(\sin\theta + \cos\theta\tan\phi\right)\right]\frac{\cos\theta}{\cos\phi}$.
14.3 $71.8^o$.
14.7 1.67 $Mg$ at a point $0.86l$ along the rod. $\theta = -13.87°$.
14.9 (a) CW rotation and linear acceleration along the $x$ axis.
(b) $-10$ newtons acting at a distance $y = 1.866$ m from $x$ axis.
14.15 $r_{cg} = \left[(a/2)^2 + y^2\right]^{3/4}/y^{1/2}$.
14.17 7.85 m.
14.19 $9.77 \times 10^{-3}$ K/m.

## Chapter 15

15.5 The rotation has a magnitude of 53.27°. The axis of rotation is in the equatorial plane and directed at an angle of $119°47' - 90°$ west of Greenwich.

15.7 $\begin{pmatrix} 1 \\ 0 \\ 3 \end{pmatrix}, \begin{pmatrix} -3/\sqrt{35} \\ 5/\sqrt{35} \\ 1/\sqrt{35} \end{pmatrix}, \begin{pmatrix} -3/\sqrt{14} \\ -2/\sqrt{14} \\ 1/\sqrt{14} \end{pmatrix}$

15.9 (a) A reflection through the $x$-axis. (b) A rotation of 180° about the $z$-axis.

15.11 $\lambda = 3$ and $\lambda = -1$.
$\begin{pmatrix} 2/\sqrt{5} \\ 1/\sqrt{5} \end{pmatrix}, \begin{pmatrix} 2/\sqrt{5} \\ -1/\sqrt{5} \end{pmatrix}, \begin{pmatrix} 2/\sqrt{5} & 2/\sqrt{5} \\ 1/\sqrt{5} & -1/\sqrt{5} \end{pmatrix}$

## Chapter 16

16.3 $5Ma^2, 5Ma^2, 8Ma^2,$
$\begin{pmatrix} 1/\sqrt{2} \\ 1/\sqrt{2} \\ 0 \end{pmatrix}, \begin{pmatrix} -1 \\ 1 \\ 0 \end{pmatrix}, \begin{pmatrix} -1/\sqrt{2} \\ 1/\sqrt{2} \\ 0 \end{pmatrix}.$

16.9 $T = \frac{1}{2}I_1\left[\dot{\theta}^2 + \dot{\phi}^2\sin^2\theta\right] + \frac{1}{2}I_3\left(\dot{\psi} + \dot{\phi}\cos\theta\right)^2,$
$\mathbf{L} = \left(I_1\dot{\phi}\sin\theta\sin\psi\right)\hat{\mathbf{e}}_1 + \left(I_1\dot{\phi}\sin\theta\cos\psi\right)\hat{\mathbf{e}}_2 + \left(I_3\left(\dot{\psi} + \dot{\phi}\cos\theta\right)\right)\hat{\mathbf{e}}_3.$

16.11 (a) $p_\phi = I_3\cos\theta_1\omega_3, p_\psi = I_3\omega_3,$
$V'(\theta) = \frac{I_3^2\omega_3^2(\cos\theta_1 - \cos\theta)^2}{2I_1\sin^2\theta} + mgd\cos\theta + \frac{1}{2}I_3\omega_3^2,$
$E = mgd\cos\theta + \frac{1}{2}I_3\omega_3^2.$

(b) $\cos\theta_2 = \frac{1}{2\alpha}\left[1-\left(1-4\alpha\cos\theta_1+4\alpha^2\right)^{1/2}\right]$.

16.13 $\dot{\phi} = 2.18$ rad/s.

Chapter 17

17.3 $y(x,t) = A\sin\frac{\pi x}{L}\cos\sqrt{F/\rho}\frac{\pi}{L}t$.

17.5 $y(x,t) \simeq -\frac{L^2}{24R} + \sum_n \frac{L^2}{2\pi^2 n^2 R}(-1)^n \cos\frac{2\pi n x}{L}\cos\omega_n t$ where $\omega_n = n\pi c/L$.

17.7 (a) $\rho\frac{\partial^2 y}{\partial t^2} + bdx\frac{\partial y}{\partial t} - F\frac{\partial}{\partial x}\left[\frac{\partial y}{\partial x}\right] = 0$.

(b) $\rho\ddot{\phi}_m + b\dot{\phi}_m + \left[Fm^2\pi^2/L^2\right]\phi_m = 0$.

(c) $\phi_m = e^{-bt/2\rho}(A_m\sin\omega'_m t + B_m\cos\omega'_m t)$ where $\omega'_m = \sqrt{\frac{m^2\pi^2}{L^2}\frac{F}{\rho} - \frac{b^2}{4\rho^2}}$.

17.9 (a) $\ddot{Q}_n + \frac{\pi^2 F_0}{\rho l}n^2 Q_n = 0$ ( b) $Q_n = A_n\cos\sqrt{\frac{\pi^2 F_0}{\rho l}}nt + B_n\sin\sqrt{\frac{\pi^2 F_0}{\rho l}}nt$.

Chapter 18

18.1 Assume $x_1$ and $x_2$ are measured in opposite directions from the equilibrium points. Mass matrix is $m\begin{pmatrix}1 & 0\\ 0 & 1\end{pmatrix}$ and the potential matrix is $k\begin{pmatrix}2 & 1\\ 1 & 2\end{pmatrix}$.

18.3 $\omega^2 = \frac{k}{m}\begin{cases}2.62\\ 0.38\end{cases}$, $\boldsymbol{\rho}^{(1)} = \frac{1}{\sqrt{1.384m}}\begin{pmatrix}1\\ -0.62\end{pmatrix}$, $\boldsymbol{\rho}^{(1)} = \frac{1}{\sqrt{3.62m}}\begin{pmatrix}1\\ 1.62\end{pmatrix}$.

18.5 $\frac{k}{m}, 2\frac{k}{m}, 3\frac{k}{m}$.

18.7 (a) $L = \frac{1}{2}m(\dot{\eta}_1^2 + \dot{\eta}_2^2) - k\eta_1^2 + k\eta_2\eta_1 - k\eta_2^2$,
$\ddot{\eta}_1 + 2\frac{k}{m}\eta_1 - \frac{k}{m}\eta_2 = 0$,
$\ddot{\eta}_2 + 2\frac{k}{m}\eta_2 - \frac{k}{m}\eta_1 = 0$.

18.9 $\eta_1(t) = C_1\cos(\omega_1 t + \phi_1) + C_2\cos(\omega_2 t + \phi_2) + K_1\sin\omega t$,
$\eta_2(t) = C_1\cos(\omega_1 t + \phi_1) - C_2\cos(\omega_2 t + \phi_2) + K_2\sin\omega t$.

18.11 $\mathcal{M} = \begin{pmatrix} m+M & -M\\ -M & m+M\end{pmatrix}$,
$\mathcal{V} = \begin{pmatrix} k & 0\\ 0 & k\end{pmatrix}$,
$\omega^2 = \begin{cases}\frac{k}{m}\\ \frac{k}{m}\frac{m}{m+2M}\end{cases}$.

18.13 (a) $L = \frac{1}{2}m\sum_{i=1}^{N}\dot{\eta}_i^2 - \frac{mg}{2l}\sum_{i=1}^{N}\eta_i^2 - \frac{1}{2}k\sum_{i=1}^{N-1}\left[\left(\eta_i - \eta_{i-1}\right)^2 + \left(\eta_{i+1} - \eta_i\right)^2\right]$,
(b) $m\ddot{\eta}_i + \frac{mg}{l}\eta_i + 2k\eta_i - k\left(\eta_{i+1} + \eta_{i-1}\right) = 0$,
(c) $\omega^2 = \frac{g}{l} + 4\frac{k}{m}\sin^2\frac{ka}{2}$.

Chapter 19

19.1 (a) $x^* = 2.175$ m, $t^* = 1.25$ ns. (b) $x^* = 1.74$ m, $t^* = 7\times 10^{-9}$ s.

19.5 (a) $x^* = -1.73\times 10^8$ m, $t^* = 2.87$ sec.

(b) $x^* = 8.66 \times 10^8$ m, $t^* = 4.04$ s.

19.9 $\frac{\sqrt{3}}{2}c$.

19.11 $0.8c$.

19.13 6.4 cm.

19.15 (a) $0.83c$ (b) $5.53\mu s$.

19.17 (b)$f = 0.151$ (c) $9.64°$.

(d) The same amount of light is concentrated into a smaller cone.

19.19 $v = \frac{1}{\sqrt{2}}c = 0.707c, T = 0.414 m_0 c^2$.

19.21 $T = 1.35 \times 10^{-9}$ J, $p = 4.99 \times 10^{-20}$ kg m/s.

19.23 (a) $p_f = 1.33 m_0 c$, (b)$v_f = 0.553c$, (c) classically, $v_f = 0.4c$.

19.25 $2.31 \times 10^{-10}$ g.

19.27 Fractional change in area = 0.6.