# Errata Sheet

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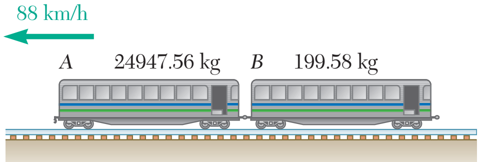
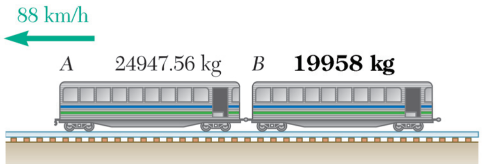
<table>
<tr><th>Page No.</th><th>Current version</th><th>Corrected version</th></tr>
<tr><td>707</td><td>

<br>**Fig.** ***P12.14***</td><td>

<br>**Fig.** ***P12.14***</td></tr>
<tr><td>780</td><td>**13.50** A power specification formula is to be derived for electric motors which drive conveyor belts moving solid material at different rates to different heights and distances. Denoting the efficiency of the motors by $\eta$ and neglecting the power needed to drive the belt itself, derive a formula (*a*) in the SI system of units, for the power *P* in kW, in terms of the mass flow rate *m* in kg/h, the height *b*, and the horizontal distance *l* in meters, and (*b*) in U.S. customary units, for the power in hp, in terms of the mass flow rate *m* in tons/h, and the height *b* and horizontal distance *l* in feet.</td><td>**13.50** A power specification formula is to be derived for electric motors which drive conveyor belts moving solid material at different rates to different heights and distances. Denoting the efficiency of the motors by $\eta$ and neglecting the power needed to drive the belt itself, derive a formula for the power *P* in kW, in terms of the mass flow rate *m* in kg/h, the height *b*, and the horizontal distance *l* in meters.</td></tr>
<tr><td>841</td><td>**13.187** A 9-kg sphere *A* of radius 11.4 cm moving with a velocity of magnitude $v_0$ = 1.8 m/s strikes a .9-kg sphere *B* of radius 5 cm which is hanging from an inextensible cord and is initially at rest. Sphere *B* swings to a maximum height *h* after the impact. Determine the range of values of *h* for values of the coefficient of restitution *e* between zero and one.</td><td>**13.187** A **22.7**-kg sphere *A* of radius 11.4 cm moving with a velocity of magnitude $v_0$ = 1.8 m/s strikes a **2**-kg sphere *B* of radius 5 cm which is hanging from an inextensible cord and is initially at rest. Sphere *B* swings to a maximum height *h* after the impact. Determine the range of values of *h* for values of the coefficient of restitution *e* between zero and one.</td></tr>
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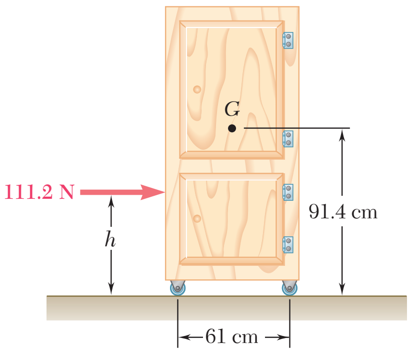
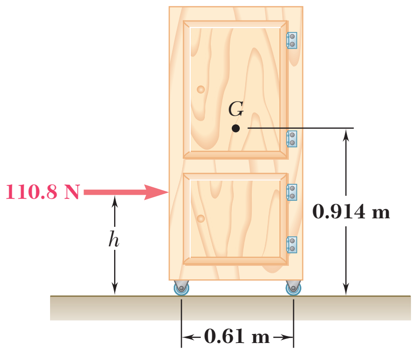
<tr><td>1041</td><td>

<br>**Fig.** ***P16.9***</td><td>

<br>**Fig.** ***P16.9***</td></tr>
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| | | |
|---|---|---|
| **1065** | **16.91** A homogeneous sphere *S*, a uniform cylinder *C*, and a thin pipe *P* are in contact when they are released from rest on the incline shown. Knowing that all three objects roll without slipping, determine, after 6 s of motion, the clear distance between (*a*) the pipe and the cylinder, (*b*) the cylinder and the sphere. Give the answers in both U.S. customary and SI units. | **16.91** A homogeneous sphere *S*, a uniform cylinder *C*, and a thin pipe *P* are in contact when they are released from rest on the incline shown. Knowing that all three objects roll without slipping, determine, after 6 s of motion, the clear distance between (*a*) the pipe and the cylinder, (*b*) the cylinder and the sphere. |
| **1103** | **17.41** The shaft-disk-belt arrangement shown is used to transmit 2386.2 Nm/s from point *A* to point *D*. Knowing that the maximum allowable couples that can be applied to shafts *AB* and *CD* are 24.4 N · m and 78.6 N · m, respectively, determine the required minimum speed of shaft *AB*. | **17.41** The shaft-disk-belt arrangement shown is used to transmit 2386.2 **N · m/s** from point *A* to point *D*. Knowing that the maximum allowable couples that can be applied to shafts *AB* and *CD* are 24.4 N · m and 78.6 N · m, respectively, determine the required minimum speed of shaft *AB*. |
| **1224** | **19.11** A variable-speed motor is rigidly attached to beam *BC*. The rotor is slightly unbalanced and causes the beam to vibrate with a frequency equal to the motor speed. When the speed of the motor is less than 600 rpm or more than 1200 rpm, a small object placed at *A* is observed to remain in contact with the beam. For speeds between 600 rpm and 1200 rpm the object is observed to "dance" and actually to lose contact with the beam. Determine the amplitude of the motion of *A* when the speed of the motor is (*a*) 600 rpm, (*b*) 1200 rpm. Give answers in both SI and U.S. customary units. | **19.11** A variable-speed motor is rigidly attached to beam *BC*. The rotor is slightly unbalanced and causes the beam to vibrate with a frequency equal to the motor speed. When the speed of the motor is less than 600 rpm or more than 1200 rpm, a small object placed at *A* is observed to remain in contact with the beam. For speeds between 600 rpm and 1200 rpm the object is observed to "dance" and actually to lose contact with the beam. Determine the amplitude of the motion of *A* when the speed of the motor is (*a*) 600 rpm, (*b*) 1200 rpm. |

# Errata — Answers to Problems

The following are the corrected answers to the problems.

## CHAPTER 11

**11.43** (*b*) 2.8 m.
**11.59** (*a*) 5.07 s.
**11.71** (*b*) $v = 0.38$ m/s, $x = 2.93$ m.
**11.72** (*b*) 3 m.
**11.76** 3.97 s after the elevator starts.
**11.91** (*b*) $\mathbf{v} = 3.82$ m/s ⦪ 38.3°; $\mathbf{a} = 5.15$ m/s$^2$ ⦣ 67.2°.
**11.96** (*a*) $\mathbf{r} = 0.5$ m ↑; $\mathbf{v} = 1.09$ m/s ⦪ 46.3°;
$\mathbf{a} = 2.38$ m/s$^2$ ⦥ 85.4°.
(*b*) $\mathbf{r} = 0.5$ m ⦪ 6.0°; $\mathbf{v} = 0.14$ m/s ⦣ 31.8°;
$\mathbf{a} = 0.2$ m/s$^2$ ⦫ 86.9°.
**11.101** (*a*) 5.0 m/s. (*b*) 4.8 m/s $< v_0 <$ 6.1 m/s.
**11.102** (*a*) 264.4 m. (*b*) 161.3 m.
**11.114** (*a*) 14.9°.
**11.166** (*b*) $\theta = 2\,N\pi$, N = 0, 1, 2. . . .
**11.174** $v = 152.7$ m/s, $\alpha = 26°$.
**11.184** $x = 11 + 2.15t + 0.002t^4$ m, $v = 2.15 + 0.00829t^3$ m/s.
**11.188** (*c*) 9 s, 49.5 s.

## CHAPTER 12

**12.8** (*a*) 0.955. (*b*) 64.8 m.
**12.9** (*b*) 4.53 m.
**12.19** (*b*) $T_A = 67.76$ N, $T_C = 81.25$ N.
**12.20** *System 3:* (*c*) 13.04 s.
**12.21** (*a*) $\mathbf{a} = 8.3$ m/s$^2$ →; $T = 14.6$ kN.
**12.26** 0.347 $m_0 v_0^2/F_0$.
**12.54** (*b*) 13.3°.
**12.61** 0.324.
**12.65** $\dfrac{d}{l} > \dfrac{1.085}{v_0}\sqrt{\dfrac{eV}{mv_0^2}}$
**12.81** (*a*) 35800 km. (*b*) 3.07 km/h.
**12.105** (*a*) $1.636 \times 10^3$ m/s.
**12.114** 1.036 h.
**12.115** 95.1 min.
**12.124** (*a*) 64.06 m/s.
**12.131** (*a*) $F_r = 2.4465 \tan^2\theta \sec\theta$ N, $F_\theta = 2.4465 \tan\theta \sec\theta$ N.
(*b*) $\mathbf{P} = 2.4465 \tan\theta \sec^3\theta$ N ⦬ $\theta$,
$\mathbf{Q} = 2.4465 \tan^2\theta \sec^2\theta$ N →.
**12.134** (*a*) $(a_B)_r = (a_B)_\theta = a_\theta = 0$.

## CHAPTER 13

**13.27** (*b*) 0.046 m.
**13.42** 12.3°
**13.71** (*a*) $v = 1.16$ m/s, $N = 16.32$ N →.
**13.80** (*a*) Not conservative, $U_{ABCA} = (k - 1)a^2/2$.
(*b*) Conservative, $U_{ABCA} = 0$.
**13.88** (*a*) $6.92 \times 10^9$ N · m (*b*) $168.1 \times 10^9$ N · m
**13.93** $V_{2r} = 6.44$ m/s, $V_{\theta 2} = 2.4$ m/s.
**13.95** (*b*) 3.6 rad/s.
**13.96** (*a*) 0.91 m.
**13.109** (*a*) 10.66 km/s.
**13.124** (*a*) 39.9 m/s. (*b*) 10.88 kN.
**13.141** 1.86*W*.
**13.151** (*a*) 187.9 N · s, 589 J.
**13.180** (*a*) $v'_C = 0$, $v'_A = 1.372$ m/s ↓.
**13.181** (*a*) $v_C = 2.74$ m/s ↓, $v_A = 1.372$ m/s ↓.
**13.186** 0.309

## CHAPTER 14

**14.2** (*b*) 0.576 m from left of *B*.
**14.12** (*c*) (121.8 N · m · s)$\mathbf{i}$ − (61 N · m · s)$\mathbf{j}$ −
(91.4 N · m · s)$\mathbf{k}$.
**14.17** 83.5 m/s, 7.8 s
**14.23** 798.3 m/s east, 215.8 m/s south, 1190 m/s down.
**14.39** $v_A = 2.29$ m/s; $v_B = 1.97$ m/s; $v_C = 3.43$ m/s.
**14.50** (*c*) $mv_0^2$.
**14.53** (*a*) $\mathbf{v}_A = 2.075$ m/s ↑; $\mathbf{v}_B = 5.98$ m/s ⦪ 28°.
**14.61** 117.2 N →; 56.8 N ↑
**14.80** (*a*) $11.51 \times 10^6$ W. (*b*) $20.97 \times 10^6$ W. (*c*) 0.55.
**14.93** 3888 kN.
**14.94** 4550 N/s.
**14.111** −1001.3 m, 657.7 m.
**14.115** (*a*) 41.94°. (*b*) 200.3 N ↓.
**14.116** $\mathbf{C} = 134.1$ N ↓; D = 178.6 N ↑.

## CHAPTER 15

**15.9** $\mathbf{v}_B = -(0.95\text{ m/s})\mathbf{i} + (0.305\text{ m/s})\mathbf{j} - (0.396\text{ m/s})\mathbf{k}$.
$\mathbf{a}_B = -(3.2\text{ m/s})\mathbf{i} - (1.88\text{ m/s}^2)\mathbf{j} + (6.23\text{ m/s}^2)\mathbf{k}$.
**15.10** $\mathbf{v}_B = -(0.475\text{ m/s})\mathbf{i} + (0.15\text{ m/s})\mathbf{j} - (0.198\text{ m/s})\mathbf{k}$.
$\mathbf{a}_B = -(0.8\text{ m/s}^2)\mathbf{i} - (0.7\text{ m/s}^2)\mathbf{j} + (1.85\text{ m/s}^2)\mathbf{k}$.
**15.15** $2.967 \times 10^4$ m/s, $5.9 \times 10^{-3}$ m/s$^2$.
**15.19** (*b*) 109.5 m/s$^2$ ⦥ 15.52°.
**15.24** (*b*) $\mathbf{a}_A = 7.94$ m/s$^2$ ↓; $\mathbf{a}_B = 1.58$ m/s$^2$ ↓.
**15.29** (*b*) $\mathbf{v}_B = 1.425$ m/s ↓; $\Delta y_B = 2.58$ m/s ↓.
(*c*) 0.707 m/s$^2$ ⦣ 32.0°.
**15.35** $a = b\omega_0^2/2\pi$ →.
**15.36** $\alpha = bv^2/2\pi r^3$ ↻.
**15.45** (*b*) 0.63 m/s ⦣ 69.4°.
**15.49** (*a*) 6.03 m/s. (*c*) 1508.
**15.58** (*a*) $\theta = 22.9°$, $\beta = 22.9°$; $\theta = 192.6°$, $\beta = 12.6°$.
(*b*) For $\theta = 22.9°$: $\omega_{BD} = 5.60$ rad/s ↻; For $\theta = 192.6°$:
$\omega_{BD} = 5.60$ rad/s ↺.
**15.65** (*b*) 4.4 m/s ⦣ 55.4°.
**15.73** (*a*) *Gear A:* 0.375 m left of A; *Gear C:* 0.75 m left of C.
**15.82** (*a*) 16.1 rad/s ↺.
**15.87** (*c*) 2 m/s ⦣ 20°.
**15.88** (*c*) 6.48 m/s ⦫ 19.10°.
**15.92** (*a*) $\omega_{AB} = 1.023$ rad/s ↺; $\omega_{BD} = 0.341$ rad/s ↻.
**15.110** $x = -0.1464$ m, $y = -0.1098$ m.
**15.111** (*b*) 3.27 m/s$^2$ ⦪ 35.5°.
**15.116** 1.02 m/s$^2$ ⦪ 33.6°.
**15.127** (*a*) 227 rad/s$^2$ ↺. (*b*) 100 rad/s$^2$ ↻.

**15.128** $(b)$ 62 m/s$^2$ ⦣ 19.5°.
**15.148** $(b)$ 1.340 m/s ⦬ 60°.
**15.164** $(b)$ $\mathbf{v}_D = 3.57$ m/s ←; $\mathbf{a}_D = 52.46$ m/s$^2$ ⦩ 36.8°.
**15.165** $(a)$ $\omega_{PD} = 20.8$ rad/s ↺; $\omega_{DE} = 2.2$ rad/s ↺.
$(b)$ $\alpha_{PD} = 76.65$ rad/s$^2$ ↻; $\alpha_{DE} = 272.5$ rad/s$^2$ ↺.
**15.166** $(b)$ 2.55 m/s$^2$ ⦬ 3.24°.
**15.178** $\omega_S = 0.38$ rad/s ↻; $\alpha_S = 4.5$ rad/s$^2$ ↻.
**15.179** $\omega_S = 1.487$ rad/s ↻; $\alpha_S = 59$ rad/s$^2$ ↻.
**15.190** $(c)$ $\mathbf{v}_P = -(1.675 \text{ m/s})\mathbf{i} + (0.5584 \text{ m/s})\mathbf{j} - (0.3228 \text{ m/s})\mathbf{k}$;
$\mathbf{a}_P = (0.338 \text{ m/s}^2)\mathbf{i} - (0.056 \text{ m/s}^2)\mathbf{j} - (0.9743 \text{ m/s}^2)\mathbf{k}$.
**15.191** $(c)$ $-(5.7 \text{ m/s}^2)\mathbf{i} - (60.9 \text{ m/s}^2)\mathbf{j}$.
**15.214** $(a)$ $(1.83 \text{ m/s})\mathbf{i} + (0.762 \text{ m/s})\mathbf{j} - (1.218 \text{ m/s})\mathbf{k}$.
**15.224** $(a)$ $-(1.54 \text{ m/s})\mathbf{i} - (1.368 \text{ m/s})\mathbf{j} + (2.05 \text{ m/s})\mathbf{k}$.
$(b)$ $(32.3 \text{ m/s}^2)\mathbf{i} - (31.6 \text{ m/s}^2)\mathbf{j} - (26.66 \text{ m/s}^2)\mathbf{k}$.
**15.230** $\mathbf{v}_A = (0.0905 \text{ m/s})\mathbf{i} + (3.55 \text{ m/s})\mathbf{j} - (3.55 \text{ m/s})\mathbf{k}$;
$\mathbf{a}_A = -(5.68 \text{ m/s}^2)\mathbf{i} - (111.7 \text{ m/s}^2)\mathbf{j} - (111.7 \text{ m/s}^2)\mathbf{k}$.
**15.249** $\mathbf{a}_A = 54$ m/s$^2$ ⦪ 88°; $\mathbf{a}_B = 53.1$ m/s$^2$ ⦩ 0.98°;
$\mathbf{a}_C = 54$ m/s$^2$ ↑.

## CHAPTER 16

**16.3** $(b)$ $\mathbf{A} = 0.242$ N ⦩ 60°; $\mathbf{C} = 7$ N ⦣ 60°.
**16.5** $(a)$ 11.0 m $(b)$ 12.7 m.
**16.7** $(a)$ $0.419g$
**16.8** $(a)$ $0.295g$
**16.13** $(a)$ 1.572 m/s$^2$.
**16.17** *Just above B:* $|V| = 15.3$ N, $|M| = 3.516$ N · m.
**16.22** $(a)$ 0.327 m $(b)$ 11 250 rev.
**16.23** 127.9 N.
**16.25** $(a)$ 2.25 rad/s$^2$ ↻.
**16.31** $(b)$ $T_A = 38.74$ N, $T_B = 27.7$ N.
**16.32** $(a)$ $\alpha_A = 9.05$ rad/s$^2$ ↻; $\alpha_B = 13.5$ rad/s$^2$ ↺.
**16.33** $(a)$ $\alpha_A = 13.42$ rad/s$^2$ ↺; $\alpha_B = 30.14$ rad/s$^2$ ↻.
**16.34** $(a)$ $\alpha_A = 15.3$ rad/s$^2$ ↻; $\alpha_B = 15.3$ rad/s$^2$ ↺. $(b)$ 0.4875.
**16.35** $(a)$ $\alpha_A = 20.8$ rad/s$^2$ ↻; $\alpha_B = 28.7$ rad/s$^2$ ↺.
**16.40** $(a)$ $\alpha_A = 13.5$ rad/s$^2$ ↺; $\alpha_B = 3.2$ rad/s$^2$ ↺.
$(b)$ $\omega_A = 897$ rpm ↺; $\omega_B = 538$ rpm ↻.
**16.43** $(a)$ 2.47 m/s$^2$.
**16.47** $(a)$ 0.8148 m/s$^2$. $(b)$ 2.28 m/s$^2$.
**16.48** $(a)$ $(1.3 \text{ m/s}^2)\mathbf{i} - (1.085 \text{ m/s}^2)\mathbf{k}$
$(b)$ $(1.3 \text{ m/s}^2)\mathbf{i} + (1.085 \text{ m/s}^2)\mathbf{k}$.
**16.51** $(b)$ 0.32 rad/s$^2$ ↺.
**16.72** $(b)$ 96.53 rad/s$^2$ ↻.
**16.78** $(a)$ $\mathbf{M} = 0.0687$ N · m ↺; $\mathbf{R} = 5.12$ N ⦬ 71.5°.
**16.93** $(a)$ 15.4 rad/s$^2$ ↻; 3.126 m/s$^2$ →.
**16.95** $(a)$ 7.76 rad/s$^2$ ↻; 1.575 m/s$^2$ →. $(b)$ 0.338.
**16.96** $(a)$ 7.76 rad/s$^2$ ↺; 1.575 m/s$^2$ ←.
**16.102** $(b)$ 1.435 N ⦩ 45°.

## CHAPTER 17

**17.4** $(a)$ 0.3268 m $(b)$ 11 204 rev.
**17.17** 6.8 rad/s.
**17.27** 1.497 N · m.
**17.32** 1.35 rad/s ↻.
**17.33** 0.99 rad/s ↺.
**17.41** 1157 rpm.
**17.44** $(b)$ 11.2 min.
**17.45** 17 rad/s ↻.
**17.52** $\omega_A = 230.2$ rad/s ↻; $\omega_B = 96.2$ rad/s ↺.
**17.55** $(a)$ 22.9 N. $(b)$ 8.75 N.
**17.56** $m\bar{\mathbf{v}}$; $\bar{k}^2\omega/\bar{v}$.
**17.61** $(a)$ 28.5 rad/s ↺.
**17.67** $(b)$ *Pipe:* 0.857 m/s →; *Plate:* 1.714 m/s →.
**17.72** $\omega_A = \omega_B = 159.3$ rpm ↻; $\omega_P = 20.68$ rpm ↺.
**17.73** $\omega_{AB} = 71.23$ rpm ↺; $\omega_{DISK} = 288.77$ rpm ↺.
**17.80** $\omega = 17.13$ rad/s, $I_{CD} = 0.0554$ N.m$^2$ s.
**17.86** 4.9 rad/s ↻.
**17.105** 8.4°.
**17.111** $(a)$ 2.975 rad/s ↻.
**17.112** $(a)$ 5.961 rad/s ↻. $(b)$ 1.456 m/s →.
**17.128** −24.4 rpm.
**17.131** 60.6°

## CHAPTER 18

**18.3** $(2.0037 \text{ kg}\cdot\text{m}^2\text{/s})\mathbf{i} + (5.505 \text{ kg}\cdot\text{m}^2\text{/s})\mathbf{j}$.
**18.4** 9.7°.
**18.9** $(a)$ 8.97 rad/s. $(b)$ 0.016 rad/s.
**18.10** $(0.88 \text{ kg}\cdot\text{m}^2\text{/s})\mathbf{i} - (0.0025 \text{ kg}\cdot\text{m}^2\text{/s})\mathbf{j} - (14.5 \text{ kg}\cdot\text{m}^2\text{/s})\mathbf{k}$.
**18.17** $(a)$ $(1.45 \text{ kg}\cdot\text{m}^2\text{/s})\mathbf{i} - (0.87096 \text{ kg}\cdot\text{m}^2\text{/s})\mathbf{k}$.
**18.18** $(a)$ $(1.45 \text{ kg}\cdot\text{m}^2\text{/s})\mathbf{i} - (0.87096 \text{ kg}\cdot\text{m}^2\text{/s})\mathbf{k}$.
$(b)$ $(1.45 \text{ kg}\cdot\text{m}^2\text{/s})\mathbf{i} - (0.87096 \text{ kg}\cdot\text{m}^2\text{/s})\mathbf{k}$.
**18.32** $(a)$ $(5ma\omega_0/24)\mathbf{k}$. $(b)$ $-(ma\omega_0/24)\mathbf{k}$.
**18.65** $\mathbf{A} = -(1.836 \text{ N})\mathbf{j}$; $\mathbf{B} = (1.836 \text{ N})\mathbf{j}$.
**18.66** $\mathbf{A} = (2.417 \text{ N})\mathbf{k}$; $\mathbf{B} = -(2.417 \text{ N})\mathbf{k}$.
**18.70** $(a)$ $(24.8 \times 10^{-3} \text{ N}\cdot\text{m})\mathbf{k}$.
$(b)$ $\mathbf{A} = (7.50 \times 10^{-3} \text{ N})\mathbf{i} + (15.00 \times 10^{-3} \text{ N})\mathbf{j}$;
$\mathbf{B} = -(7.50 \times 10^{-3} \text{ N})\mathbf{i} - (15.00 \times 10^{-3} \text{ N})\mathbf{j}$.
**18.72** $(b)$ $\mathbf{A} = (0.906 \text{ N})\mathbf{j}$; $\mathbf{B} = -(0.906 \text{ N})\mathbf{j}$.
**18.78** 1°; $A$ will move up.
**18.92** $\mathbf{A} = -(51.9 \text{ N})\mathbf{i}$; $\mathbf{M}_A = (3.8988 \text{ kg}\cdot\text{m}^2\text{/s}^2)\mathbf{i} +$
$(7.8128 \text{ kg}\cdot\text{m}^2\text{/s}^2)\mathbf{k}$.
**18.101** $\mathbf{R} = -(15.02 \text{ N})\mathbf{i} - (11.285 \text{ N})\mathbf{k}$; $\mathbf{M}_A^R = (94.185 \text{ N}\cdot\text{m})\mathbf{i}$.
**18.102** $(a)$ $(7.89 \text{ N}\cdot\text{m})\mathbf{j}$.
$(b)$ $\mathbf{R} = -(75.4 \text{ N})\mathbf{i} - (74.94 \text{ N})\mathbf{k}$; $\mathbf{M}_A^R = (222.96 \text{ N}\cdot\text{m})\mathbf{i}$.
**18.105** 31 rpm, 632.3 rpm.
**18.106** $(c)$ −5.14%.
**18.112** $\cos\beta = \dfrac{2d^2\psi}{(h^2 + d^2)\phi}$.
**18.114** $2.163 \times 10^{21}$ kg · m
**18.124** Precession axis: $\theta_x = 125.0°$, $\theta_y = 36.6°$, $\theta_z = 80.7°$;
precession, 0.9426 rad/s (retrograde); spin, 0.1583 rad/s.
**18.125** Precession axis: $\theta_x = 90°$, $\theta_y = 26.0°$, $\theta_z = 64.0°$;
precession, 0.845 rad/s (retrograde); spin, 0.161 rad/s.
**18.128** Precession axis: $\theta_x = 99.04°$, $\theta_y = 90°$, $\theta_z = 9.04°$;
precession, 121.8 rpm (retrograde); spin, 60.3 rpm.
**18.134** $(a)$ $\sqrt{17g/11a}$. $(b)$ $\sqrt{44g/17a}$.
**18.136** $(a)$ 41 rad/s. $(b)$ Spin, 55.46 rad/s; precession,
−16.7 rad/s.
**18.145** 0.3347 kg · m$^2$/s; $\theta_x = 48.7°$, $\theta_y = 41.4°$, $\theta_z = 90°$.
**18.148** $(b)$ $\Delta t_B = 2.24$ s, $\Delta t_C = 3.82$ s.
**18.151** $-(1.767 \text{ N}\cdot\text{m})\mathbf{i} - (2.008 \text{ N}\cdot\text{m})\mathbf{j} + (3.0123 \text{ N}\cdot\text{m})\mathbf{k}$.
**18.152** $(a)$ 0.00145 m above the axis,
$I_{xy} = 2.383 \times 10^{-3}$ N · m · s$^2$, $I_{zx} = 0$.

## CHAPTER 19

**19.1** 7.312 m/s$^2$; 1.571 s.
**19.5** $(a)$ 0.0982 s; 10.183 Hz.
**19.20** 2.634 s.
**19.36** $(a)$ 1.7943 s.

**19.37** 1.94 m.
**19.41** (*a*) 7.53 Hz. (*b*) 97.3 rad/$s^2$.
**19.55** $f_n = (1/2\pi)\sqrt{\frac{6k}{5m} + \frac{9g}{10l}}$ Hz.
**19.56** $f_n = (1/2\pi)\sqrt{\frac{2k}{3m} + \frac{4g}{3L}}$ Hz.
**19.58** 1.9 Hz.
**19.65** 5.2654 s.
**19.71** $f_n = (1/2\pi)\sqrt{\frac{k}{5m}}$ Hz.
**19.77** 5.32 Hz.
**19.78** $f_n = (1/2\pi)\sqrt{\frac{2k}{3m} + \frac{4g}{3L}}$ Hz.
**19.84** 1.627 s.
**19.86** 1.073 s.
**19.90** $f_n = (1/2\pi)\sqrt{\frac{12k}{7m} + \frac{8g}{7\sqrt{3}l}}$ Hz.
**19.92** 1.305 s.
**19.97** (*a*) 0.214 s. (*b*) 0.214 s.
**19.101** 37.67 rad/s $< \omega_f <$ 46.77 rad/s.
**19.102** 0.0929 m $< b <$ 3.55 m
**19.112** $\omega_f \leq$ 310 rpm; $\omega_f \geq$ 316 rpm.
**19.116** –5.63 mm or 22.5 mm.
**19.123** (*b*) 0.2775 m (out of phase).
**19.133** (*a*) 114.1 kN/m.
**19.138** (*a*) 297.5 rpm. (*c*) 0.02 m, .018 m
**19.164** 0.8289 s.

# Problems†

**11.1** The motion of a particle is defined by the relation $x = t^2 - (t - 3)^3$ where $x$ and $t$ are expressed in meters and seconds, respectively. Determine (*a*) when the acceleration is zero, (*b*) the position and velocity of the particle at that time.

**11.2** The motion of a particle is defined by the relation $x = t^3 - (t - 2)^2$ where $x$ and $t$ are expressed in meters and seconds, respectively. Determine (*a*) when the acceleration is zero, (*b*) the position and velocity of the particle at that time.

**11.3** The motion of a particle is defined by the relation $x = 5t^4 - 4t^3 + 3t - 2$, where $x$ and $t$ are expressed in meters and seconds, respectively. Determine the position, the velocity, and the acceleration of the particle when $t = 2$ s.

**11.4** The motion of a particle is defined by the relation $x = 6t^4 + 8t^3 - 14t^2 - 10t + 16$, where $x$ and $t$ are expressed in meters and seconds, respectively. Determine the position, the velocity, and the acceleration of the particle when $t = 3$ s.

**11.5** The motion of the slider $A$ is defined by the relation $x = 500 \sin kt$, where $x$ and $t$ are expressed in millimeters and seconds, respectively, and $k$ is a constant. Knowing that $k = 10$ rad/s, determine the position, the velocity, and the acceleration of slider $A$ when $t = 0.05$ s.

**11.6** The motion of the slider $A$ is defined by the relation $x = 50 \sin(k_1 t - k_2 t^2)$, where $x$ and $t$ are expressed in millimeters and seconds, respectively. The constants $k_1$ and $k_2$ are known to be 1 rad/s and 0.5 rad/s$^2$, respectively. Consider the range $0 < t < 2$ s and determine the position and acceleration of slider $A$ when $v = 0$.

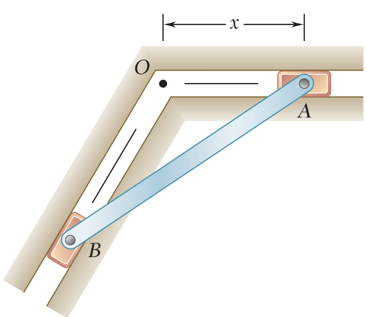

**Fig. P11.5 and P11.6**

***11.7*** The motion of a particle is defined by the relation $x = t^3 - 6t^2 + 9t + 5$, where $x$ is expressed in meters and $t$ in seconds. Determine (*a*) when the velocity is zero, (*b*) the position, acceleration, and total distance traveled when $t = 5$ s.

***11.8*** The motion of a particle is defined by the relation $x = t^2 - (t - 2)^3$, where $x$ and $t$ are expressed in meters and seconds, respectively. Determine (*a*) the two positions at which the velocity is zero, (*b*) the total distance traveled by the particle from $t = 0$ to $t = 4$ s.

**11.9** The acceleration of a particle is defined by the relation $a = 3e^{-0.2t}$, where $a$ and $t$ are expressed in m/s$^2$ and seconds, respectively. Knowing that $x = 0$ and $v = 0$ at $t = 0$, determine the velocity and position of the particle when $t = 0.5$ s.

†Answers to all problems set in straight type (such as **11.1**) are given at the end of the book. Answers to problems with a number set in italic type (such as ***11.7***) are not given.

**11.49** Block $A$ moves down with a constant velocity of 1 m/s. Determine (*a*) the velocity of block $C$, (*b*) the velocity of collar $B$ relative to block $A$, (*c*) the relative velocity of portion $D$ of the cable with respect to block $A$.

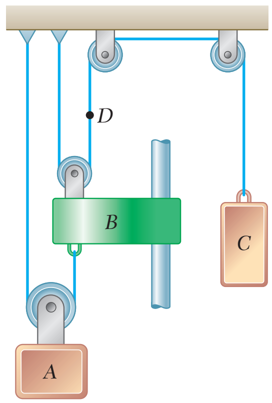


**Fig. P11.49 and P11.50**

**11.50** Block $C$ starts from rest and moves down with a constant acceleration. Knowing that after block $A$ has moved 0.5 m, its velocity is 0.2 m/s, determine (*a*) the accelerations of $A$ and $C$, (*b*) the velocity and the change in position of block $B$ after 2 s.

**11.51** Block $C$ moves downward with a constant velocity of 0.6 m/s. Determine (*a*) the velocity of block $A$, (*b*) the velocity of block $D$.

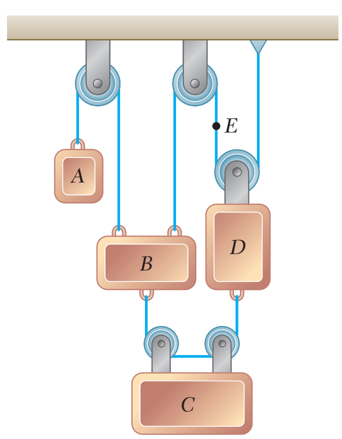


**Fig. P11.51 and P11.52**

**11.52** Block $C$ starts from rest and moves downward with a constant acceleration. Knowing that after 5 s, the velocity of block $A$ relative to block $D$ is 2.4 m/s, determine (*a*) the acceleration of block $C$, (*b*) the acceleration of portion $E$ of the cable.

**11.53** In the position shown, collar *B* moves to the left with a constant velocity of 300 mm/s. Determine (*a*) the velocity of collar *A*, (*b*) the velocity of portion *C* of the cable, (*c*) the relative velocity of portion *C* of the cable with respect to collar *B*.

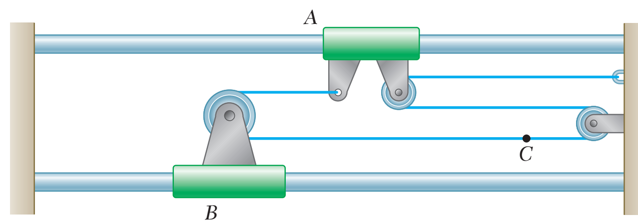


**Fig. P11.53 and P11.54**

**11.54** Collar *A* starts from rest and moves to the right with a constant acceleration. Knowing that after 8 s, the relative velocity of collar *B* with respect to collar *A* is 610 mm/s, determine (*a*) the accelerations of *A* and *B*, (*b*) the velocity and the change in position of *B* after 6 s.

***11.55*** At the instant shown, slider block *B* is moving to the right with a constant acceleration, and its speed is 15.2 cm/s. Knowing that after slider block *A* has moved 25.4 cm to the right, its velocity is 6 cm/s, determine (*a*) the accelerations of *A* and *B*, (*b*) the acceleration of portion *D* of the cable, (*c*) the velocity and the change in position of slider block *B* after 4 s.

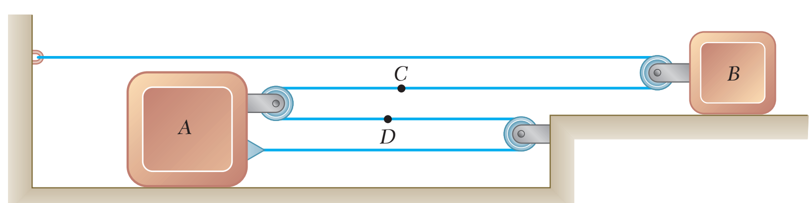


**Fig. *P11.55* and *P11.56***

***11.56*** Slider block *B* moves to the right with a constant velocity of 30.4 cm/s. Determine (*a*) the velocity of slider block *A*, (*b*) the velocity of portion *C* of the cable, (*c*) the velocity of portion *D* of the cable, (*d*) the relative velocity of portion *C* of the cable with respect to slider block *A*.

**11.57** Slider block *B* moves to the left with a constant velocity of 50 mm/s. At $t = 0$, slider block *A* is moving to the right with a constant acceleration and a velocity of 100 mm/s. Knowing that at $t = 2$ s, slider block *C* has moved 40 mm to the right, determine (*a*) the velocity of slider block *C* at $t = 0$, (*b*) the velocity of portion *D* of the cable at $t = 0$, (*c*) the accelerations of *A* and *C*.

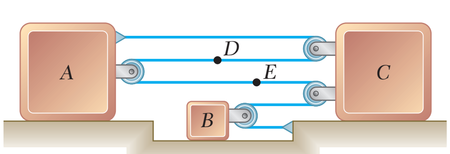


**Fig. P11.57 and P11.58**

**11.58** Slider block *A* starts with an initial velocity at $t = 0$ and a constant acceleration of 270 mm/s to the right. Slider block *C* starts from rest at $t = 0$ and moves to the right with constant acceleration. Knowing that at $t = 2$ s, the velocities of *A* and *B* are 420 mm/s to the right and 30 mm/s to the left, respectively, determine (*a*) the accelerations of *B* and *C*, (*b*) the initial velocities of *A* and *B*, (*c*) the initial velocity of portion *E* of the cable.

**11.97** The three-dimensional motion of a particle is defined by the position vector $\mathbf{r} = (Rt \cos \omega_n t)\mathbf{i} + ct\mathbf{j} + (Rt \sin \omega_n t)\mathbf{k}$. Determine the magnitudes of the velocity and acceleration of the particle. (The space curve described by the particle is a conic helix.)

***11.98** The three-dimensional motion of a particle is defined by the position vector $\mathbf{r} = (At \cos t)\mathbf{i} + (A\sqrt{t^2 + 1})\mathbf{j} + (Bt \sin t)\mathbf{k}$, where $r$ and $t$ are expressed in meters and seconds, respectively. Show that the curve described by the particle lies on the hyperboloid $(y/A)^2 - (x/A)^2 - (z/B)^2 = 1$. For $A = 3$ and $B = 1$, determine (*a*) the magnitudes of the velocity and acceleration when $t = 0$, (*b*) the smallest nonzero value of $t$ for which the position vector and the velocity vector are perpendicular to each other.

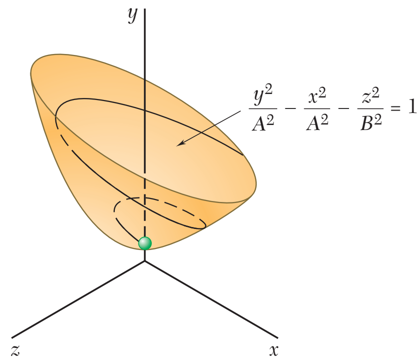


**Fig. P11.98**

**11.99** A ski jumper starts with a horizontal take off velocity of 25 m/s and lands on a straight landing hill inclined at 30°. Determine (*a*) the time between take-off and landing, (*b*) the length $d$ of the jump, (*c*) the maximum vertical distance between the jumper and the landing hill.

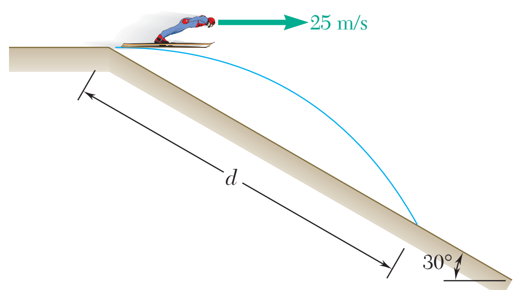


**Fig. P11.99**

**11.100** A golfer aims his shot to clear the top of a tree by a distance $h$ at the peak of the trajectory and to miss the pond on the opposite side. Knowing that the magnitude of $\mathbf{v}_0$ is 30 m/s, determine the range of values of $h$ which must be avoided.

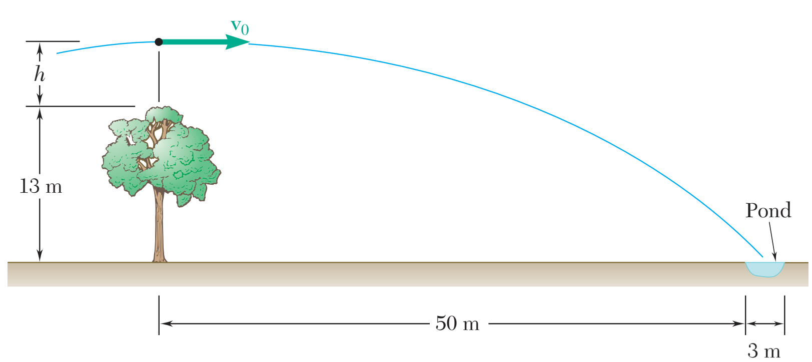


**Fig. P11.100**

**11.101** A handball player throws a ball from $A$ with a horizontal velocity $\mathbf{v}_0$. Knowing that $d = 4.57$ m, determine (*a*) the value of $v_0$ for which the ball will strike the corner $C$, (*b*) the range of values of $v_0$ for which the ball will strike the corner region $BCD$.

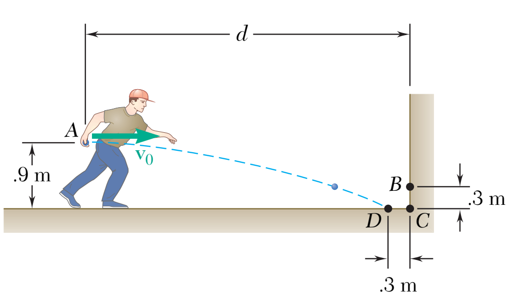


**Fig. P11.101**

**11.102** A helicopter is flying with a constant horizontal velocity of 144.2 km/h and is directly above point $A$ when a loose part begins to fall. The part lands 6.5 s later at point $B$ on an inclined surface. Determine ($a$) the distance $d$ between points $A$ and $B$, ($b$) the initial height $h$.

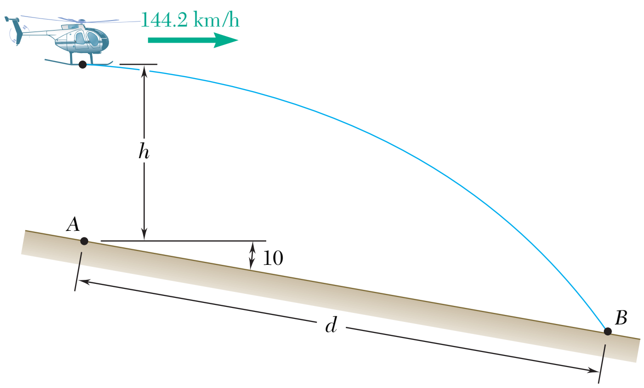


**Fig. P11.102**

**11.103** A pump is located near the edge of the horizontal platform shown. The nozzle at $A$ discharges water with an initial velocity of 7.62 m/s at an angle of 55° with the vertical. Determine the range of values of the height $h$ for which the water enters the opening $BC$.

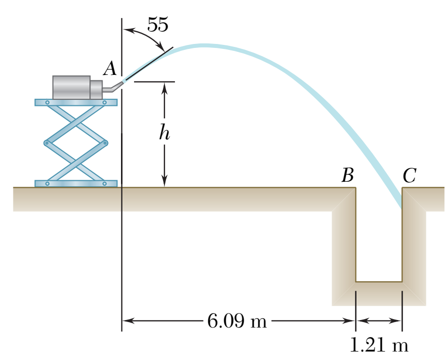


**Fig. *P11.103***

**11.104** An oscillating water sprinkler is operated at point $A$ on an incline that forms an angle $\alpha$ with the horizontal. The sprinkler discharges water with an initial velocity $\mathbf{v}_0$ at an angle $\phi$ with the vertical which varies from $-\phi_0$ to $+\phi_0$. Knowing that $v_0 = 24$ m/s, $\phi_0 = 40°$, and $\alpha = 10°$, determine the horizontal distance between the sprinkler and points $B$ and $C$ which define the watered area.

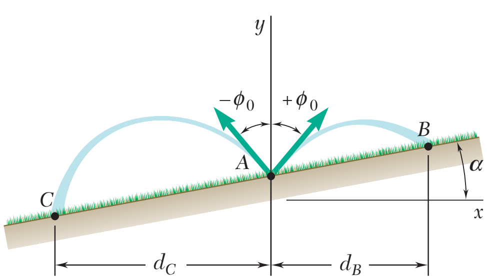


**Fig. *P11.104***

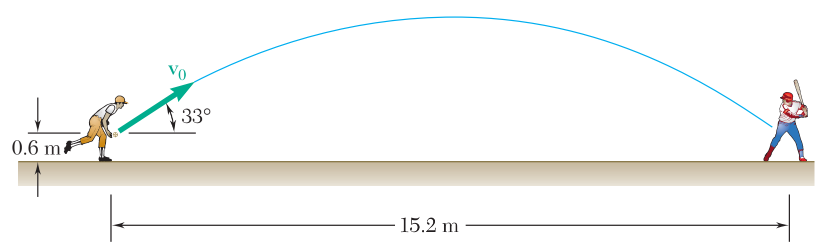


**Fig. P11.105**

**11.105** In slow-pitch softball, the underhand pitch must reach a maximum height of between 1.8 m and 3.7 m above the ground. A pitch is made with an initial velocity $\mathbf{v}_0$ of magnitude 13 m/s at an angle of 33° with the horizontal. Determine ($a$) if the pitch meets the maximum height requirement, ($b$) the height of the ball as it reaches the batter.

**11.119** Airplane $A$ is flying due east at 700 km/h, while airplane $B$ is flying at 500 km/h at the same altitude and in a direction to the west of south. Knowing that the speed of $B$ with respect to $A$ is 1125 km/h, determine the direction of the flight path of $B$.

**11.120** Instruments in an airplane which is in level flight indicate that the velocity relative to the air (airspeed) is 120 km/h and the direction of the relative velocity vector (heading) is 70° east of north. Instruments on the ground indicate that the velocity of the airplane (ground speed) is 110 km/h and the direction of flight (course) is 60° east of north. Determine the wind speed and direction.

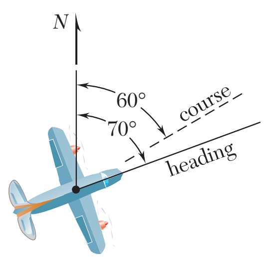


**Fig. P11.120**

**11.121** At an intersection, car $A$ is traveling south with a velocity of 40 km/h when it is struck by car $B$ traveling 30° north of east with a velocity of 48 km/h. Determine the relative velocity of car $B$ with respect to car $A$.

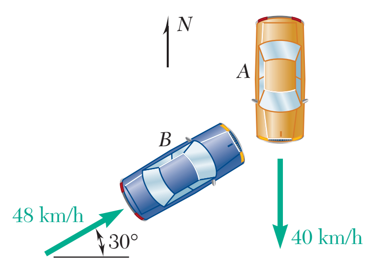


**Fig. P11.121**

**11.122** Small wheels attached to the ends of rod $AB$ roll along two surfaces. Knowing that at the instant shown, the velocity $\mathbf{v}_A$ of wheel $A$ is 1.4 m/s to the right and the relative velocity $\mathbf{v}_{B/A}$ of wheel $B$ with respect to wheel $A$ is perpendicular to rod $AB$, determine (*a*) the relative velocity $\mathbf{v}_{B/A}$, (*b*) the velocity $\mathbf{v}_B$ of wheel $B$.

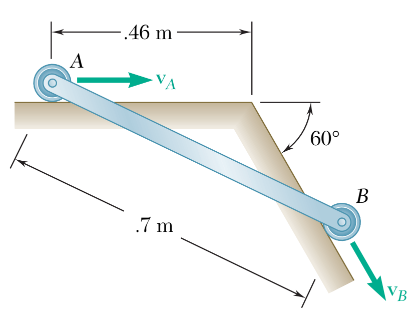


**Fig. P11.122**

**12.9** A .09-kg model rocket is launched vertically from rest at time $t = 0$ with a constant thrust of 4 N for one second and no thrust for $t > 1$ s. Neglecting air resistance and the decrease in mass of the rocket, determine (*a*) the maximum height $h$ reached by the rocket, (*b*) the time required to reach this maximum height.

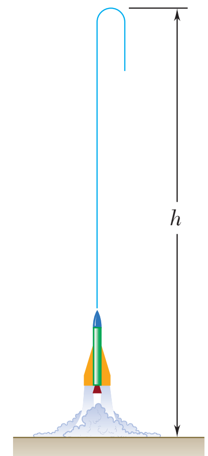


**Fig. P12.9**

**12.10** A 40-kg package is at rest on an incline when a force **P** is applied to it. Determine the magnitude of **P** if 4 s is required for the package to travel 10 m up the incline. The static and kinetic coefficients of friction between the package and the incline are 0.30 and 0.25, respectively.

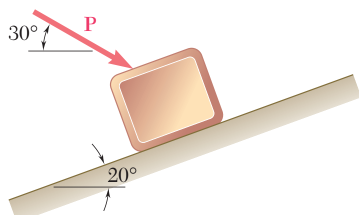


**Fig. P12.10**

**12.11** If an automobile's braking distance from 100 km/h is 60 m on level pavement, determine the automobile's braking distance from 100 km/h when it is (*a*) going up a 6° incline, (*b*) going down a 2-percent incline.

***12.12*** The two blocks shown are originally at rest. Neglecting the masses of the pulleys and the effect of friction in the pulleys and between the blocks and the incline, determine (*a*) the acceleration of each block, (*b*) the tension in the cable.

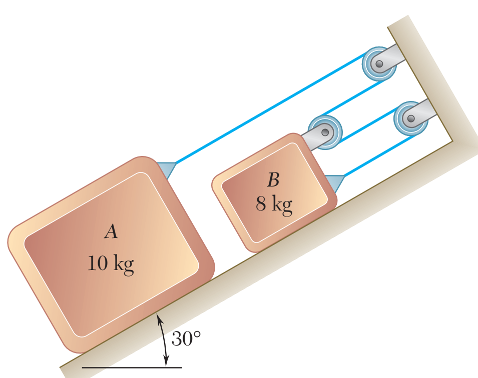


**Fig. *P12.12* and P12.13**

**12.13** The two blocks shown are originally at rest. Neglecting the masses of the pulleys and the effect of friction in the pulleys and assuming that the coefficients of friction between both blocks and the incline are $\mu_s = 0.25$ and $\mu_k = 0.20$, determine (*a*) the acceleration of each block, (*b*) the tension in the cable.

***12.14*** A light train made up of two cars is traveling at 88 km/h when the brakes are applied to both cars. Knowing that car $A$ has a weight of 24,947.56 kg and car $B$ has a weight of 19,958 kg and that the braking force is 31,137.5 N on each car, determine (*a*) the distance traveled by the train before it comes to a stop, (*b*) the force in the coupling between the cars while the train is slowing down.

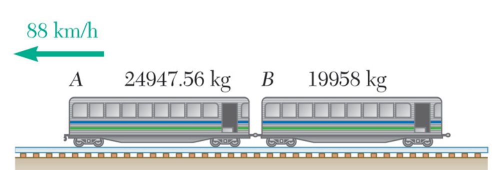


**Fig. *P12.14***

**13.48** (*a*) A 60-kg woman rides a 7-kg bicycle up a 3 percent slope at a constant speed of 2 m/s. How much power must be developed by the woman? (*b*) A 90-kg man on a 9-kg bicycle starts down the same slope and maintains a constant speed of 6 m/s by braking. How much power is dissipated by the brakes? Ignore air resistance and rolling resistance.

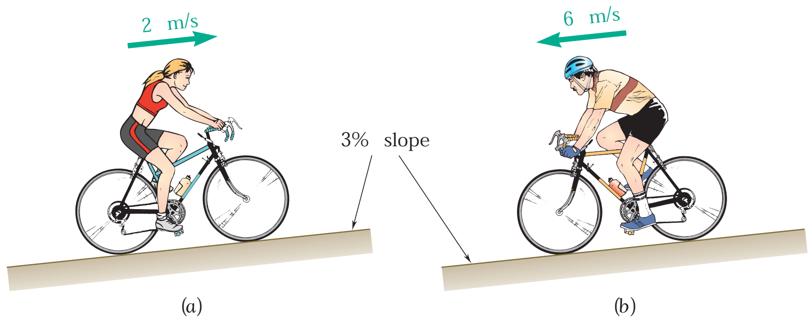


**Fig. *P13.48***

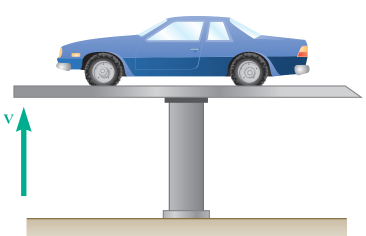


**Fig. *P13.49***

**13.49** It takes 16 s to raise a 1270-kg car and the supporting 295-kg hydraulic car-lift platform to a height of 2 m. Knowing that the overall conversion efficiency from electric to mechanical power for the system is 82 percent, determine (*a*) the average output power delivered by the hydraulic pump to lift the system, (*b*) the average electric power required.

**13.50** A power specification formula is to be derived for electric motors which drive conveyor belts moving solid material at different rates to different heights and distances. Denoting the efficiency of the motors by $\eta$ and neglecting the power needed to drive the belt itself, derive a formula for the power $P$ in kW, in terms of the mass flow rate $m$ in kg/h, the height $b$, and the horizontal distance $l$ in meters.

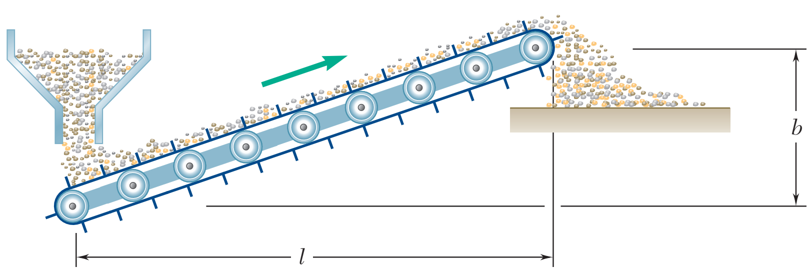


**Fig. P13.50**

**13.51** The fluid transmission of a 15-Mg truck allows the engine to deliver an essentially constant power of 50 kW to the driving wheels. Determine the time required and the distance traveled as the speed of the truck is increased (*a*) from 36 km/h to 54 km/h, (*b*) from 54 km/h to 72 km/h.

**13.52** A 60-kg runner increases her speed from 2 m/s to 4.3 m/s in 5 s. Assuming she develops constant power during this time interval and neglecting air resistance, determine (*a*) the power developed, (*b*) the distance traveled.

**13.53** A 1361-kg automobile starts from rest and travels 366 m during a performance test. The motion of the automobile is defined by the relation $x = 12{,}000 \ln(\cosh 0.03t)$, where $x$ and $t$ are expressed in meter and seconds, respectively. The magnitude of the aerodynamic drag is $D = 0.01v^2$, where $D$ and $v$ are expressed in N and m/s, respectively. Determine the power dissipated by the aerodynamic drag when (*a*) $t = 10$ s, (*b*) $t = 15$ s.

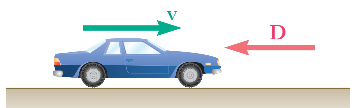


**Fig. *P13.53* and *P13.54***

**13.54** A 1361-kg automobile starts from rest and travels 366 m during a performance test. The motion of the automobile is defined by the relation $a = 11e^{-0.0005x}$, where $a$ and $x$ are expressed in m/s$^2$ and meters, respectively. The magnitude of the aerodynamic drag is $D = 0.01\,v^2$, where $D$ and $v$ are expressed in N and m/s, respectively. Determine the power dissipated by the aerodynamic drag when (*a*) $x = 183$ m, (*b*) $x = 366$ m.

## 13.6. POTENTIAL ENERGY†

Let us consider again a body of weight **W** which moves along a curved path from a point $A_1$ of elevation $y_1$ to a point $A_2$ of elevation $y_2$ (Fig. 13.4). We recall from Sec. 13.2 that the work of the force of gravity **W** during this displacement is

$$U_{1\rightarrow 2} = Wy_1 - Wy_2 \qquad (13.4)$$

The work of **W** may thus be obtained by subtracting the value of the function $Wy$ corresponding to the second position of the body from its value corresponding to the first position. The work of **W** is independent of the actual path followed; it depends only upon the initial and final values of the function $Wy$. This function is called the *potential energy* of the body with respect to the *force of gravity* **W** and is denoted by $V_g$. We write

$$U_{1\rightarrow 2} = (V_g)_1 - (V_g)_2 \qquad \text{with } V_g = Wy \qquad (13.16)$$

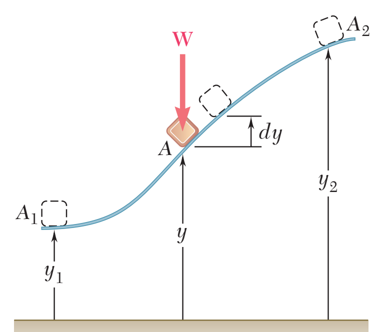


**Fig. 13.4 (*repeated*)**

We note that if $(V_g)_2 > (V_g)_1$, that is, *if the potential energy increases* during the displacement (as in the case considered here), *the work* $U_{1\rightarrow 2}$ *is negative*. If, on the other hand, the work of **W** is positive, the potential energy decreases. Therefore, the potential energy $V_g$ of the body provides a measure of the work which can be done by its weight **W**. Since only the *change* in potential energy, and not the actual value of $V_g$, is involved in formula (13.16), an arbitrary constant can be added to the expression obtained for $V_g$. In other words, the level, or datum, from which the elevation $y$ is measured can be chosen arbitrarily. Note that potential energy is expressed in the same units as work, that is, in joules if SI units are used and in ft · lb or in · lb if U.S. customary units are used.

†Some of the material in this section has already been considered in Sec. 10.7.

**13.186** A 22.7-kg sphere $A$ of radius 11.4 cm moving with a velocity of magnitude $v_0 = 1.8$ m/s strikes a 2-kg sphere $B$ of radius 5 cm which is hanging from an inextensible cord and is initially at rest. Knowing that sphere $B$ swings to a maximum height $h = .23$ m, determine the coefficient of restitution between the two spheres.

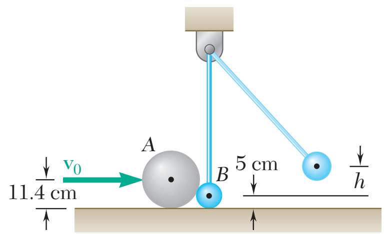


**Fig. P13.186 and P13.187**

**13.187** A 22.7-kg sphere $A$ of radius 11.4 cm moving with a velocity of magnitude $v_0 = 1.8$ m/s strikes a 2-kg sphere $B$ of radius 5 cm which is hanging from an inextensible cord and is initially at rest. Sphere $B$ swings to a maximum height $h$ after the impact. Determine the range of values of $h$ for values of the coefficient of restitution $e$ between zero and one.

***13.188*** A 340-g ball $B$ is hanging from an inextensible cord attached to a support $C$. A 170-g ball $A$ strikes $B$ with a velocity $\mathbf{v}_0$ of magnitude 1.5 m/s at an angle of 60° with the vertical. Assuming perfectly elastic impact ($e = 1$) and no friction, determine the height $h$ reached by ball $B$.

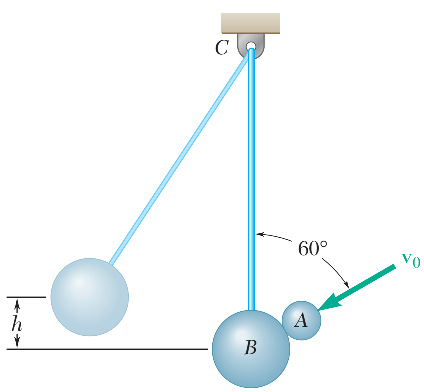


**Fig. *P13.188***

***13.189*** A 2-kg sphere $A$ strikes the frictionless inclined surface of a 6-kg wedge $B$ at a 90° angle with a velocity of magnitude 4 m/s. The wedge can roll freely on the ground and is initially at rest. Knowing that the coefficient of restitution between the wedge and the sphere is 0.50 and that the inclined surface of the wedge forms an angle $\theta = 40°$ with the horizontal, determine ($a$) the velocities of the sphere and of the wedge immediately after impact, ($b$) the energy lost due to the impact.

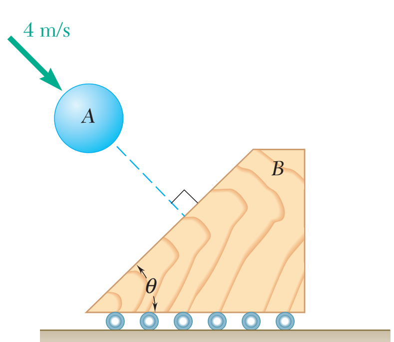


**Fig. *P13.189***

**14.92** A chain of length $l$ and mass $m$ falls through a small hole in a plate. Initially, when $y$ is very small, the chain is at rest. In each case shown, determine (*a*) the acceleration of the first link $A$ as a function of $y$, (*b*) the velocity of the chain as the last link passes through the hole. In case *1* assume that the individual links are at rest until they fall through the hole; in case *2* assume that at any instant all links have the same speed. Ignore the effect of friction.

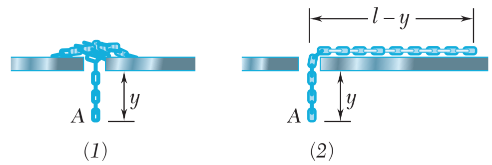


**Fig. *P14.92***

**14.93** The main propulsion system of a space shuttle consists of three identical rocket engines, each of which burns the hydrogen-oxygen propellant at the rate of 340.2 kg/s and ejects it with a relative velocity of 3810 m/s. Determine the total thrust provided by the three engines.

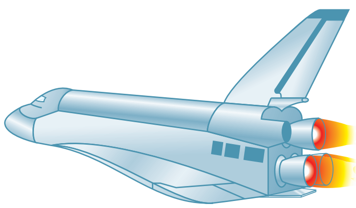

**Fig. P14.93 and P14.94**

**14.94** The main propulsion system of a space shuttle consists of three identical rocket engines which provide a total thrust of 5300 kN. Determine the rate at which the hydrogen-oxygen propellant is burned by each of the three engines, knowing that it is ejected with a relative velocity of 3810 m/s.

**14.95** A rocket has a mass of 1500 kg, including 1200 kg of fuel, which is consumed at the rate of 15 kg/s. Knowing that the rocket is fired vertically from the ground and that its acceleration increases by 220 m/s$^2$ from the time it is fired to the time the last particle of fuel has been consumed, determine the relative velocity with which the fuel is being ejected.

**14.96** A rocket of mass 1500 kg (not including the fuel) is fired vertically at time $t = 0$. The fuel is consumed at a constant rate $q = dm/dt$ and is expelled at a constant speed of 450 m/s relative to the rocket. Knowing that the rocket is designed to achieve a maximum acceleration of 25 m/s$^2$ in 15.6 s, determine (*a*) the fuel consumption rate $q$, (*b*) the mass of fuel consumed.

**14.97** A weather satellite of mass 5000 kg, including fuel, has been ejected from a space shuttle describing a low circular orbit around the earth. After the satellite has slowly drifted to a safe distance from the shuttle, its engine is fired to increase its velocity by 2430 m/s as a first step to its transfer to a geosynchronous orbit. Knowing that the fuel is ejected with a relative velocity of 4200 m/s, determine the mass of fuel consumed in this maneuver.

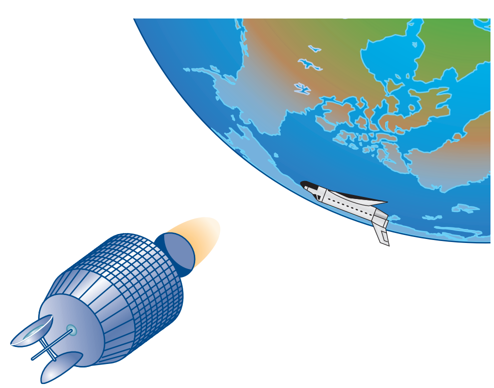

**Fig. P14.97 and P14.98**

# Problems

**15.1** The motion of a rotor is defined by the relation $\theta = 8t^3 - 6(t - 2)^2$, where $\theta$ and $t$ are expressed in radians and seconds, respectively. Determine (*a*) when the angular acceleration is zero, (*b*) the angular coordinate and angular velocity at that time.

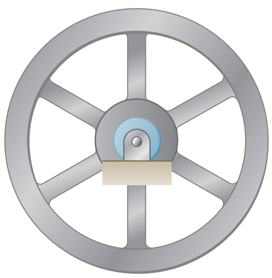

Fig. P15.2 and P15.3

**15.2** The motion of an oscillating flywheel is defined by the relation $\theta = \theta_0 e^{-3\pi t} \cos 4\pi t$, where $\theta$ is expressed in radians and $t$ in seconds. Knowing that $\theta_0 = 0.5$ rad, determine the angular coordinate, the angular velocity, and the angular acceleration of the flywheel when (*a*) $t = 0$, (*b*) $t = 0.125$ s.

**15.3** The motion of an oscillating flywheel is defined by the relation $\theta = \theta_0 e^{-7\pi t/6} \sin 4\pi t$, where $\theta$ is expressed in radians and $t$ in seconds. Knowing that $\theta_0 = 0.4$ rad, determine the angular coordinate, the angular velocity, and the angular acceleration of the flywheel when (*a*) $t = 0.125$ s, (*b*) $t = \infty$.

**15.4** A flywheel executes 1800 revolutions while it coasts to rest from a speed of 6000 rpm. Assuming uniformly accelerated motion, determine (*a*) the time required for the flywheel to coast to rest, (*b*) the time required for the flywheel to execute the first 900 revolutions.

**15.5** When the power to an electric motor is turned on, the motor reaches its rated speed of 2400 rpm in 4 s, and when the power is turned off, the motor coasts to rest in 40 s. Assuming uniformly accelerated motion, determine the number of revolutions that the motor executes (*a*) in reaching its rated speed, (*b*) in coasting to rest.

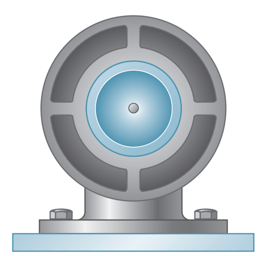

Fig. P15.5

**15.6** The angular acceleration of a flywheel is defined by the relation $\alpha = 30e^{-0.2t}$, where $\alpha$ and $t$ are expressed in rad/s$^2$ and seconds, respectively. Knowing that $\theta = 0$ and $\omega = 0$ at $t = 0$, determine the angular velocity and angular coordinate of the particle when $t = 0.5$ s.

***15.7*** The angular acceleration of a shaft is defined by the relation $\alpha = -0.5\omega$, where $\alpha$ is expressed in rad/s$^2$ and $\omega$ in rad/s. Knowing that at $t = 0$ the angular velocity of the shaft is 30 rad/s, determine (*a*) the number of revolutions the shaft will execute before coming to rest, (*b*) the time required for the shaft to come to rest, (*c*) the time required for the angular velocity of the shaft to reduce to 2 percent of its initial value.

**16.7** The support bracket shown is used to transport a cylindrical can from one elevation to another. Knowing that $\mu_s = 0.30$ between the can and the bracket, determine (*a*) the magnitude of the upward acceleration **a** for which the can will slide on the bracket, (*b*) the smallest ratio $h/d$ for which the can will tip before it slides.

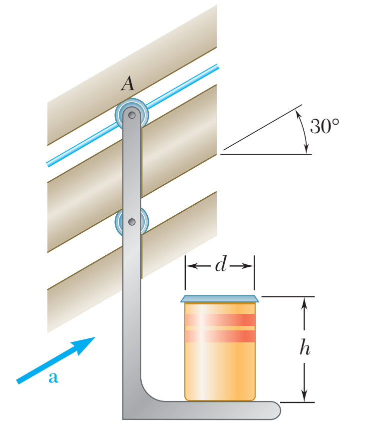


**Fig. P16.7**

**16.8** Solve Prob. 16.7 assuming that the acceleration **a** of the bracket is downward.

***16.9*** A 22.7-kg cabinet is mounted on casters that allow it to move freely ($\mu = 0$) on the floor. If a 11.3-kg force is applied as shown, determine (*a*) the acceleration of the cabinet, (*b*) the range of values of $h$ for which the cabinet will not tip.

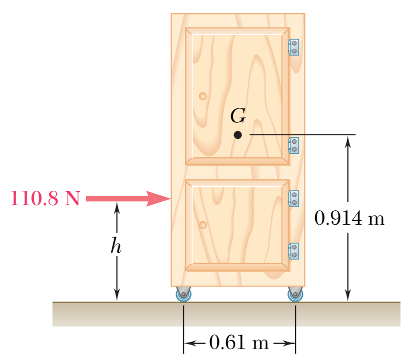


**Fig. *P16.9***

***16.10*** Solve Prob. 16.9 assuming that the casters are locked and slide on the rough floor ($\mu_s = 0.25$).

**16.11** Bars *AB* and *BE*, each of weight 3.6 kg, are welded together and are pin-connected to two links *AC* and *BD*. Knowing that the assembly is released from rest in the position shown and neglecting the masses of the links, determine (*a*) the acceleration of the assembly, (*b*) the forces in the links.

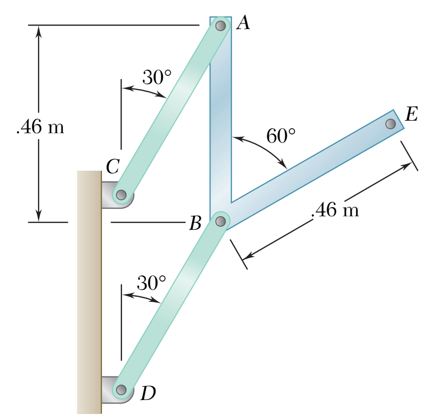


**Fig. P16.11**

**16.12** Members *ACE* and *DCB* are each 76.2 cm long and are connected by a pin at *C*. The mass center of the 9-kg member *AB* is located at *G*. Determine (*a*) the acceleration of *AB* immediately after the system has been released from rest in the position shown, (*b*) the corresponding force exerted by roller *A* on member *AB*. Neglect the weight of members *ACE* and *DCB*.

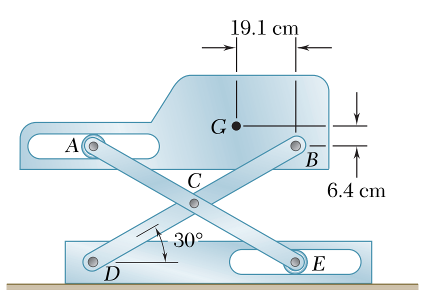


**Fig. P16.12**

**16.89** A flywheel is rigidly attached to a shaft of 30-mm radius that can roll along parallel rails as shown. When released from rest, the system rolls 5 m in 40 s. Determine the centroidal radius of gyration of the system.

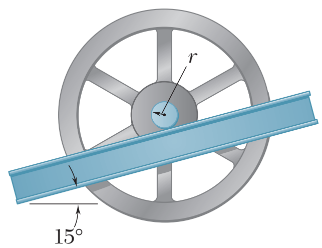


**Fig. P16.89 and P16.90**

**16.90** A flywheel of centroidal radius of gyration $\bar{k}$ is rigidly attached to a shaft that can roll along parallel rails. Denoting by $\mu_k$ the coefficient of static friction between the shaft and the rails, derive an expression for the largest angle of inclination $\beta$ for which no slipping will occur.

**16.91** A homogeneous sphere *S*, a uniform cylinder *C*, and a thin pipe *P* are in contact when they are released from rest on the incline shown. Knowing that all three objects roll without slipping, determine, after 6 s of motion, the clear distance between (*a*) the pipe and the cylinder, (*b*) the cylinder and the sphere.

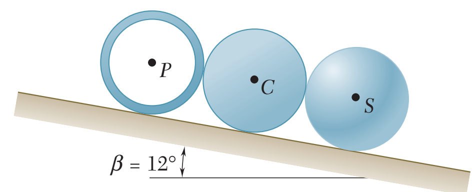


**Fig. P16.91**

**16.92** An 355.8-N uniform cylinder is acted upon by a 222.4-N force as shown. Knowing that the cylinder rolls without slipping, determine (*a*) the acceleration of its center *G*, (*b*) the minimum value of the coefficient of static friction compatible with this motion.

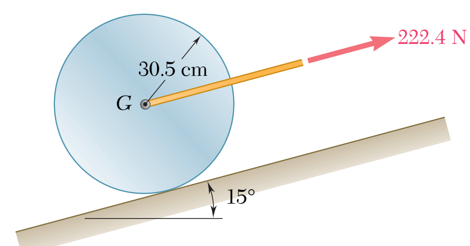


**Fig. P16.92**

**16.93 through 16.96** A drum of 10.2-cm radius is attached to a disk of 20.3-cm radius. The disk and drum have a total weight of 44.5 N and combined radius of gyration of 15.2 cm. A cord is attached as shown and pulled with a force **P** of magnitude 22.2 N. Knowing that the disk rolls without sliding, determine (*a*) the angular acceleration of the disk and the acceleration of *G*, (*b*) the minimum value of the coefficient of static friction compatible with this motion.

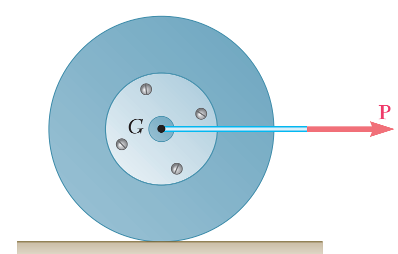


**Fig. P16.93 and P16.97**

**16.97 through *16.100*** A drum of 80-mm radius is attached to a disk of 160-mm radius. The disk and drum have a combined mass of 5 kg and combined radius of gyration of 120 mm. A cord is attached as shown and pulled with a force **P** of magnitude 20 N. Knowing that the coefficients of static and kinetic friction are $\mu_s = 0.25$ and $\mu_k = 0.20$, respectively, determine (*a*) whether or not the disk slides, (*b*) the angular acceleration of the disk and the acceleration of *G*.

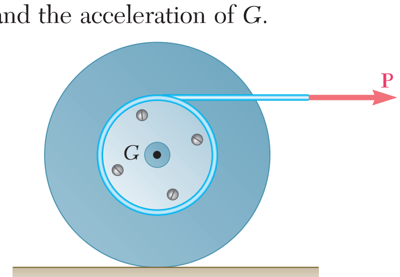


**Fig. P16.94 and P16.98**

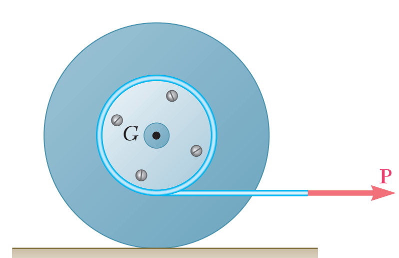


**Fig. P16.95 and *P16.99***

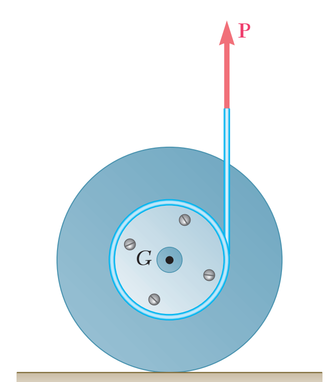


**Fig. P16.96 and *P16.100***

**16.120** The collar $B$ of negligible mass can slide freely on the 4-kg uniform rod $CD$. Knowing that in the position shown crank $AB$ rotates with an angular velocity of 5 rad/s and an angular acceleration of 60 rad/s$^2$, both clockwise, determine the force exerted on rod $CD$ by collar $B$.

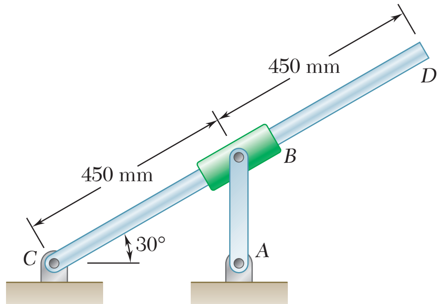


**Fig. P16.120 and P16.121**

**16.121** The collar $B$ of negligible mass can slide freely on the 4-kg uniform rod $CD$. Knowing that in the position shown, crank $AB$ rotates with an angular velocity of 5 rad/s and an angular acceleration of 60 rad/s$^2$, both counterclockwise, determine the force exerted on rod $CD$ by collar $B$.

***16.122*** The uniform 3.65-kg bar $AGB$ is attached to two collars of negligible weight that slide with negligible friction along fixed rods. Its motion is controlled by the force **P** applied to collar $A$. Knowing that at the instant shown, the speed and acceleration of collar $A$ are .6 m/s and zero, respectively, determine ($a$) the applied force **P**, ($b$) the force exerted by the fixed rod on the collar at $A$.

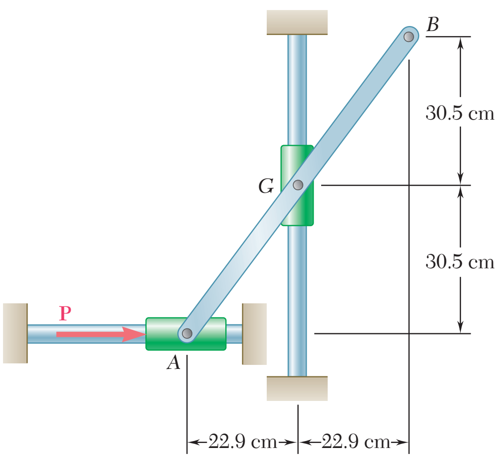


**Fig. *P16.122***

***16.123*** The 4.5-kg uniform rod $ABD$ is attached to the crank $BC$ and is fitted with a small wheel that can roll without friction along a vertical slot. Knowing that at the instant shown, crank $BC$ rotates with an angular velocity of 6 rad/s clockwise and an angular acceleration of 15 rad/s$^2$ counterclockwise, determine the reaction at $A$.

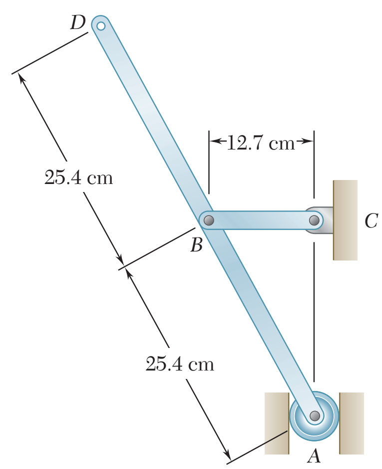


**Fig. *P16.123***

**16.124** A driver starts his car with the door on the passenger's side wide open ($\theta = 0$). The 36-kg door has a centroidal radius of gyration $\bar{k} = 250$ mm, and its mass center is located at a distance $r = 440$ mm from its vertical axis of rotation. Knowing that the driver maintains a constant acceleration of 2 m/s$^2$, determine the angular velocity of the door as it slams shut ($\theta = 90°$).

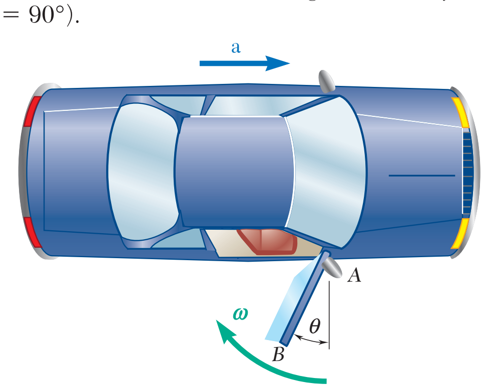


**Fig. P16.124**

**16.125** For the car of Prob. 16.124, determine the smallest constant acceleration that the driver can maintain if the door is to close and latch, knowing that as the door hits the frame, its angular velocity must be at least 2 rad/s for the latching mechanism to operate.

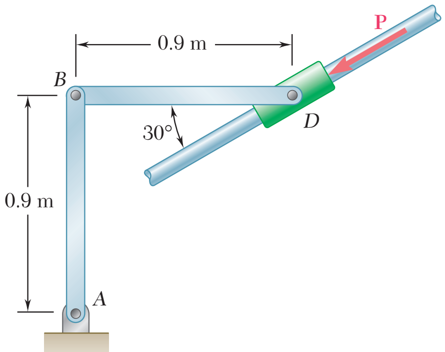


Fig. P16.126

**16.126** The linkage *ABD* is formed by connecting two 4-kg bars and a collar of negligible mass. The motion of the linkage is controlled by the force **P** applied to the collar. Knowing that at the instant shown, the angular velocity and angular acceleration of bar *AB* are zero and 10 rad/s$^2$ counterclockwise, respectively, determine the force **P**.

**16.127** Solve Prob. 16.126 assuming that at the instant shown, the angular velocity and angular acceleration of bar *AB* are 5 rad/s clockwise and zero, respectively.

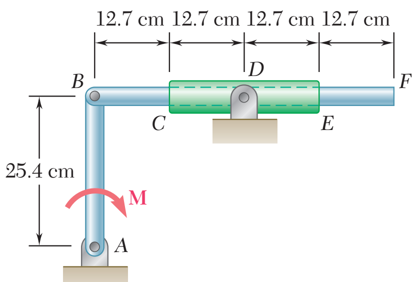


Fig. P16.128 and P16.129

**16.128** The 1.8-kg uniform slender rod *AB*, the 3.6-kg uniform slender rod *BF*, and the 1.8-kg uniform thin sleeve *CE* are connected as shown and move without friction in a vertical plane. The motion of the linkage is controlled by the couple **M** applied to rod *AB*. Knowing that at the instant shown the angular velocity of rod *AB* is 15 rad/s and the magnitude of the couple **M** is 6.78 N, determine (*a*) the angular acceleration of rod *AB*, (*b*) the reaction at point *D*.

**16.129** The 1.8-kg uniform slender rod *AB*, the 3.6-kg uniform slender rod *BF*, and the 1.8-kg uniform thin sleeve *CE* are connected as shown and move without friction in a vertical plane. The motion of the linkage is controlled by the couple **M** applied to rod *AB*. Knowing that at the instant shown the angular velocity of rod *AB* is 30 rad/s and the angular acceleration of rod *AB* is 96 rad/s$^2$ clockwise, determine (*a*) the magnitude of the couple **M**, (*b*) the reaction at point *D*.

**16.130** The 2-kg rod *AB* and the 3-kg rod *BC* are connected as shown to a disk that is made to rotate in a vertical plane at a constant angular velocity of 6 rad/s clockwise. For the position shown, determine the forces exerted at *A* and *B* on rod *AB*.

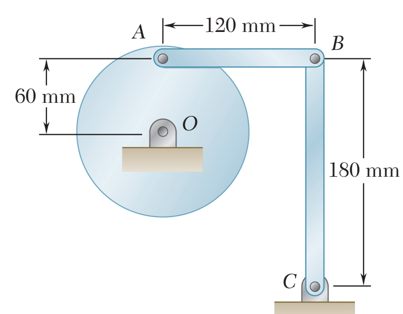


Fig. P16.130 and P16.131

**16.131** The 2-kg rod *AB* and the 3-kg rod *BC* are connected as shown to a disk that is made to rotate in a vertical plane. Knowing that at the instant shown, the disk has an angular acceleration of 18 rad/s$^2$ clockwise and no angular velocity, determine the components of the forces exerted at *A* and *B* on rod *AB*.

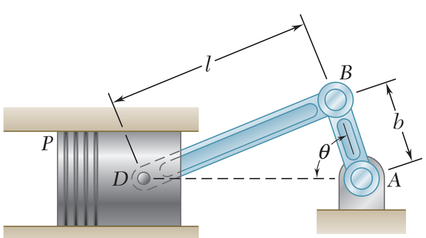


Fig. *P16.132*

***16.132*** In the engine system shown $l = 25.4$ cm and $b = 10.2$ cm. The connecting rod *BD* is assumed to be a 1.36 kg uniform slender rod and is attached to the 2-kg piston *P*. During a test of the system, crank *AB* is made to rotate with a constant angular velocity of 600 rpm clockwise with no force applied to the face of the piston. Determine the forces exerted on the connecting rod at *B* and *D* when $\theta = 180°$. (Neglect the effect of the weight of the rod.)

# Review Problems

**16.144** At the instant shown, the angular velocity of links *BE* and *CF* is 6 rad/s counterclockwise and is decreasing at the rate of 12 rad/s$^2$. Knowing that the length of each link is 38.1 cm and neglecting the weight of the links, determine (*a*) the force **P**, (*b*) the corresponding force in each link. The weight of rod *AD* is 6.8 kg.

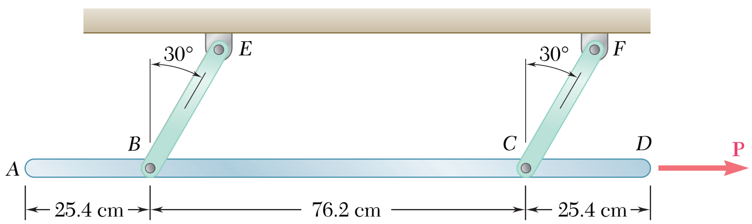


**Fig. P16.144**

**16.145** The 160-mm-radius brake drum is attached to a larger flywheel that is not shown. The total mass moment of inertia of the drum and the flywheel is 18 kg · m$^2$ and the coefficient of kinetic friction between the drum and the brake shoe is 0.35. Knowing that the angular velocity of the flywheel is 360 rpm counterclockwise when a force **P** of magnitude 300 N is applied to the pedal *C*, determine the number of revolutions executed by the flywheel before it comes to rest.

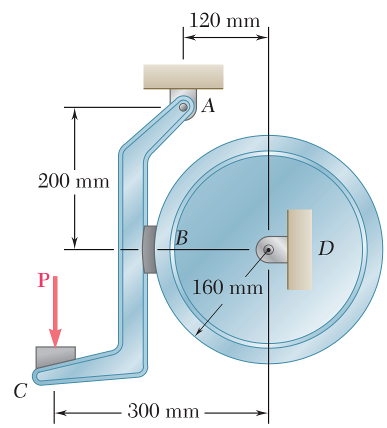


**Fig. P16.145**

**16.146** Disk *A* has a mass of 8 kg and an initial angular velocity of 480 rpm clockwise; disk *B* has a mass of 4 kg and is initially at rest. The disks are brought together by applying a horizontal force of magnitude 30 N to the axle of disk *A*. Knowing that $\mu_k = 0.15$ between the disks and neglecting bearing friction, determine (*a*) the angular acceleration of each disk, (*b*) the final angular velocity of each disk.

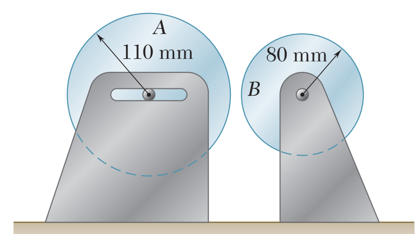


**Fig. P16.146**

***16.147*** A force **P** of magnitude 3.3 N is applied to a tape wrapped around a uniform 2.7-kg disk. Knowing that the disk rests on a frictionless horizontal surface, determine the acceleration of (*a*) point *A*, (*b*) point *B*.

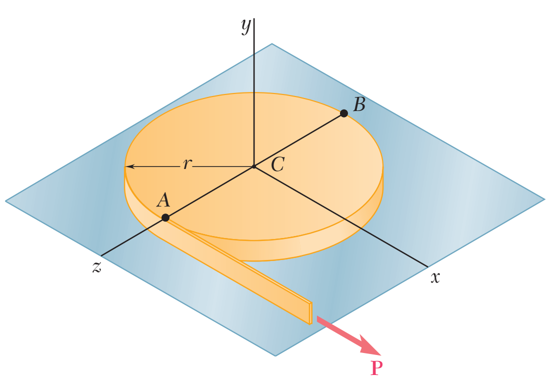


**Fig.** ***P16.147***

**16.148** The 181.4-kg crate shown is lowered by means of two overhead cranes. Knowing that at the instant shown, the deceleration of cable $A$ is 0.9 m/s$^2$ and that of cable $B$ is 0.3 m/s$^2$, determine the tension in each cable.

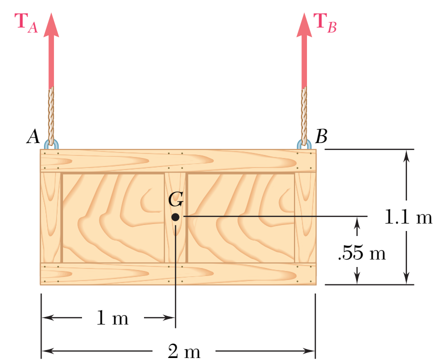


Fig. P16.148

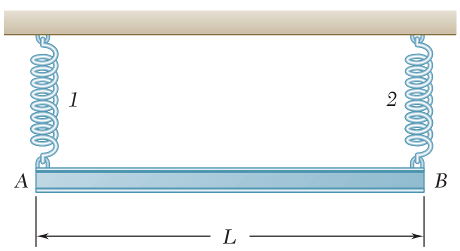


Fig. *P16.149*

***16.149*** A beam $AB$ of mass $m$ and of uniform cross section is suspended from two springs as shown. If spring 2 breaks, determine at that instant (*a*) the angular acceleration of the beam, (*b*) the acceleration of point $A$, (*c*) the acceleration of point $B$.

**16.150** A uniform rod of length $L$ and mass $m$ is supported as shown with $b = 0.2L$ when the cable attached to end $B$ suddenly breaks. Determine at this instant (*a*) the acceleration of end $B$, (*b*) the reaction at the pin support.

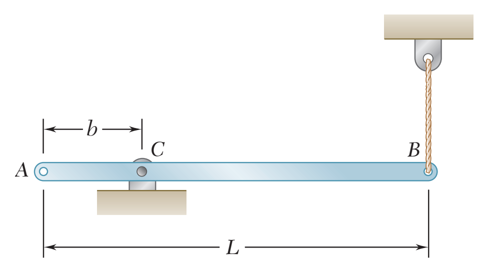


Fig. P16.150

**16.151** A wheel of radius $r$ and centroidal radius of gyration $\bar{k}$ is released from rest on the incline and rolls without sliding. Derive an expression for the acceleration of the center of the wheel in terms of $r$, $\bar{k}$, $\beta$, and $g$.

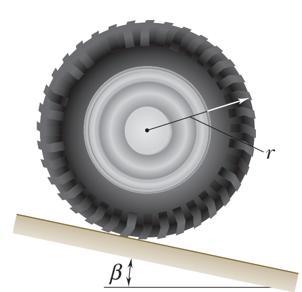


Fig. P16.151

# Problems

**17.1** The rotor of an electric motor has an angular velocity of 3600 rpm when the load and power are cut off. The 50-kg rotor, which has a centroidal radius of gyration of 23 cm, then coasts to rest. Knowing that the kinetic friction of the rotor produces a couple of magnitude 3.4 N · m, determine the number of revolutions that the rotor executes before coming to rest.

**17.2** A 200-kg flywheel is at rest when a constant 300 N · m couple is applied. After executing 560 revolutions, the flywheel reaches its rated speed of 2400 rpm. Knowing that the radius of gyration of the flywheel is 400 mm, determine the average magnitude of the couple due to kinetic friction in the bearing.

**17.3** The flywheel of a small punching machine rotates at 360 rpm. Each punching operation requires 2034 J of work and it is desired that the speed of the flywheel after each punching be not less than 95 percent of the original speed. (*a*) Determine the required moment of inertia of the flywheel. (*b*) If a constant 24.4-N · m couple is applied to the shaft of the flywheel, determine the number of revolutions that must occur between two successive punchings, knowing that the initial velocity is to be 360 rpm at the start of each punching.

**17.4** A 227-kg flywheel is at rest when a constant 271-N · m couple is applied. After executing 750 revolutions, the flywheel reaches its rated speed of 3000 rpm and the couple is removed. Assuming that the kinetic friction results in a constant couple of magnitude 17 N · m, determine (*a*) the radius of gyration of the flywheel, (*b*) the number of revolutions that the flywheel executes after the couple is removed and before it comes to rest.

**17.5** The uniform cylinder $A$, of mass $m$ and radius $r$, has an angular velocity $\omega_0$ when it is brought into contact with an identical cylinder $B$ which is at rest. The coefficient of kinetic friction at the contact point $D$ is $\mu_k$. After a period of slipping, the cylinders attain constant angular velocities of equal magnitude and opposite direction at the same time. Knowing that the final kinetic energy of the system is one-half the initial kinetic energy of cylinder $A$, derive expressions for the number of revolutions executed by each cylinder before it attains a constant angular velocity.

**17.6** The uniform 4-kg cylinder $A$, of radius $r$ = 150 mm has an angular velocity $\omega_0$ = 50 rad/s when it is brought into contact with an identical cylinder $B$ which is at rest. The coefficient of kinetic friction at the contact point $D$ is $\mu_k$. After a period of slipping, the cylinders attain constant angular velocities of equal magnitude and opposite direction at the same time. Knowing that cylinder $A$ executes three revolutions before it attains a constant angular velocity and cylinder $B$ executes one revolution before it attains a constant angular velocity, determine (*a*) the final angular velocity of each cylinder, (*b*) the coefficient of kinetic friction $\mu_k$.

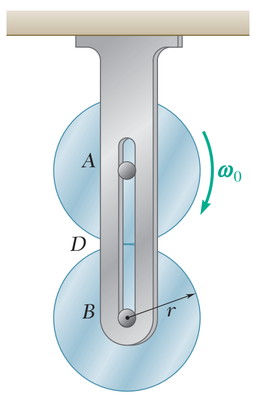


**Fig. P17.5 and P17.6**

**17.39** Knowing that the maximum allowable couple that can be applied to a shaft is 1.75 kN · m, determine the maximum power that can be transmitted by the shaft at (*a*) 180 rpm, (*b*) 480 rpm.

**17.40** The flywheel shown has a radius of 500 mm, a mass of 110 kg and a radius of gyration of 375 mm. A 20-kg block *A* is attached to a wire that is wrapped around the flywheel. Determine the power delivered by the electric motor attached to the shaft of the flywheel at the instant when the velocity of block *A* is 7.5 m/s up and its acceleration is (*a*) zero, (*b*) 0.9 m/s$^2$ up.

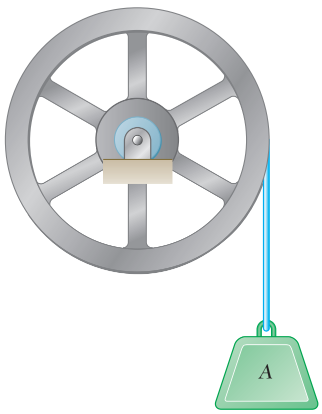


**Fig. P17.40**

**17.41** The shaft-disk-belt arrangement shown is used to transmit 2386.2 N · m/s from point *A* to point *D*. Knowing that the maximum allowable couples that can be applied to shafts *AB* and *CD* are 24.4 N · m and 78.6 N · m, respectively, determine the required minimum speed of shaft *AB*.

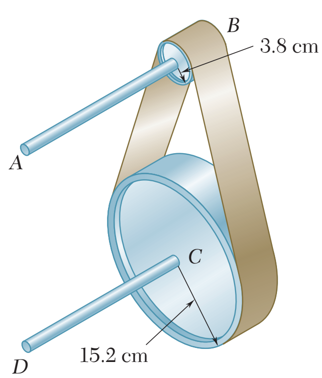


**Fig. P17.41**

**17.42** The experimental setup shown is used to measure the power output of a small turbine. When the turbine is operating at 200 rpm, the readings of the two spring scales are 4.5 kg and 10 kg, respectively. Determine the power being developed by the turbine.

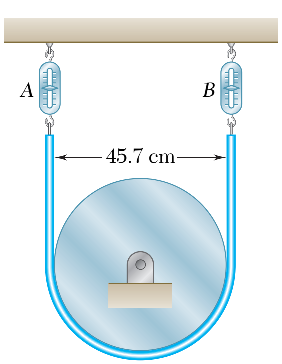


**Fig. P17.42**

# Problems

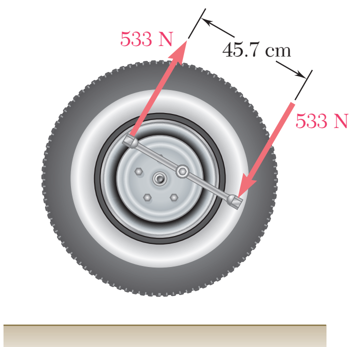


Fig. P17.45

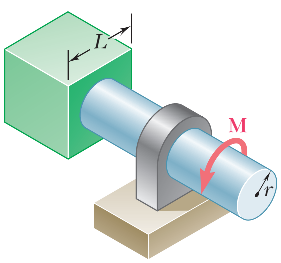


Fig. P17.46 and P17.47

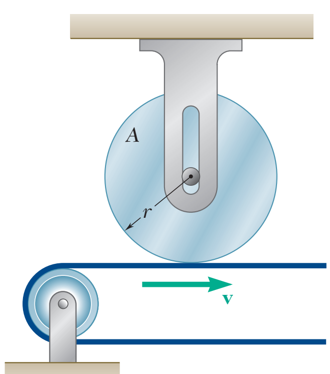


Fig. P17.48 and P17.49

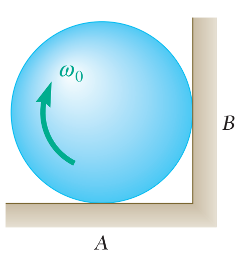


Fig. P17.50

**17.43** A 181-kg flywheel is at rest when a constant 24.4 N · m couple is applied. It is observed that 4.3 min is required for the flywheel to reach its rated speed of 2400 rpm. Knowing that the radius of gyration of the flywheel is 35.6 cm, determine the average magnitude of the couple due to kinetic friction in the bearing.

**17.44** A 250-kg flywheel is at rest when a constant 300-N · m couple is applied at time $t = 0$. At $t = 28$ s the flywheel reaches its rated speed of 3000 rpm and the couple is removed. Assuming that the kinetic friction results in a constant couple of magnitude 12.5 N · m, determine (*a*) the radius of gyration of the flywheel, (*b*) the time at which the flywheel comes to rest.

**17.45** A bolt located 5 cm from the center of an automobile wheel is tightened by applying the couple shown for 0.10 s. Assuming that the wheel is free to rotate and is initially at rest, determine the resulting angular velocity of the wheel. The wheel weighs 19 kg and has a radius of gyration of 27.4 cm.

**17.46** A uniform 65.3-kg cube is attached to a uniform 61.7-kg circular shaft as shown and a couple **M** of constant magnitude is applied to the shaft when the system is at rest. Knowing that $r = 10.2$ cm, $L = 30.5$ cm, and the angular velocity of the system is 960 rpm after 4 s, determine the magnitude of the couple **M**.

**17.47** A uniform 75-kg cube is attached to a uniform 70-kg circular shaft as shown and a couple **M** of constant magnitude 20 N · m is applied to the shaft. Knowing that $r = 100$ mm and $L = 300$ mm, determine the time required for the angular velocity of the system to increase from 1000 rpm to 2000 rpm.

**17.48** A disk of constant thickness, initially at rest, is placed in contact with a belt that moves with a constant velocity **v**. Denoting by $\mu_k$ the coefficient of kinetic friction between the disk and the belt, derive an expression for the time required for the disk to reach a constant angular velocity.

**17.49** Disk *A*, of mass 2 kg and radius $r = 60$ mm, is at rest when it is placed in contact with a belt which moves at a constant speed $v = 15$ m/s. Knowing that $\mu_k = 0.20$ between the disk and the belt, determine the time required for the disk to reach a constant angular velocity.

**17.50** A sphere of radius $r$ and weight $W$ with an initial clockwise angular velocity $\boldsymbol{\omega}_0$ is placed in the corner formed by the floor and a vertical wall. Denoting by $\mu_k$ the coefficient of kinetic friction at *A* and *B*, derive an expression for the time required for the sphere to come to rest.

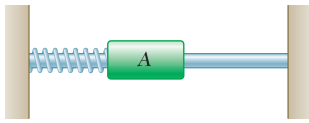


Fig. *P19.9*

***19.9*** A 1.8-kg collar is attached to a spring of constant 1051 N/m and can slide without friction on a horizontal rod. The collar is at rest when it is struck with a mallet and given an initial velocity of 1.4 m/s. Determine the amplitude and the maximum acceleration of the collar during the resulting motion.

**19.10** The motion of a particle is described by the equation $x = 60 \cos 10\pi t + 45 \sin(10\pi t - \pi/3)$, where $x$ is expressed in millimeters and $t$ in seconds. Determine (*a*) the period of the resulting motion, (*b*) its amplitude, (*c*) its phase angle.

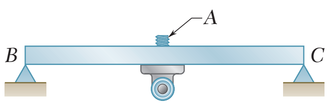


Fig. P19.11

**19.11** A variable-speed motor is rigidly attached to beam $BC$. The rotor is slightly unbalanced and causes the beam to vibrate with a frequency equal to the motor speed. When the speed of the motor is less than 600 rpm or more than 1200 rpm, a small object placed at $A$ is observed to remain in contact with the beam. For speeds between 600 rpm and 1200 rpm the object is observed to "dance" and actually to lose contact with the beam. Determine the amplitude of the motion of $A$ when the speed of the motor is (*a*) 600 rpm, (*b*) 1200 rpm.

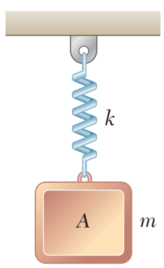


Fig. P19.12

**19.12** A 1.4-kg block is supported as shown by a spring of constant $k = 400$ N/m which can act in tension or compression. The block is in its equilibrium position when it is struck from below by a hammer which imparts to the block an upward velocity of 2.5 m/s. Determine (*a*) the time required for the block to move 60 mm upward, (*b*) the corresponding velocity and acceleration of the block.

**19.13** In Prob. 19.12, determine the position, velocity, and acceleration of the block 0.90 s after it has been struck by the hammer.

**19.14** A 32-kg block attached to a spring of constant $k = 131$ kN/m can move without friction in a slot as shown. The block is given an initial 38-cm displacement downward from its equilibrium position and released. Determine 1.5 s after the block has been released (*a*) the total distance traveled by the block, (*b*) the acceleration of the block.

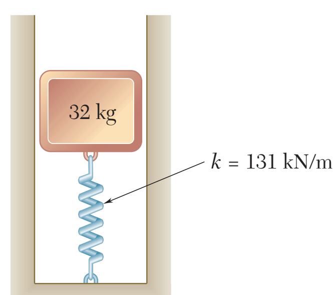


Fig. P19.14

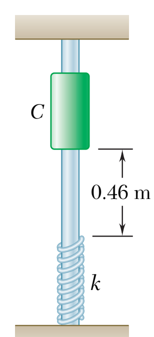


Fig. P19.15

**19.15** A 4.5-kg collar $C$ is released from rest in the position shown and slides without friction on a vertical rod until it hits a spring of constant $k = 730$ N/m which it compresses. The velocity of the collar is reduced to zero, and the collar reverses the direction of its motion and returns to its initial position. The cycle is then repeated. Determine (*a*) the period of the motion of the collar, (*b*) the velocity of the collar 0.4 s after it was released. (*Note:* This is a periodic motion, but not simple harmonic motion.)

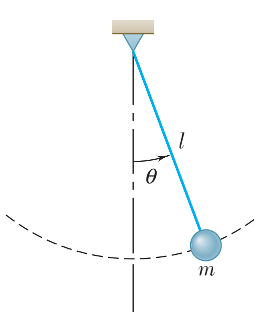


Fig. *P19.16*

***19.16*** The bob of a simple pendulum of length $l = 1.2$ m is moving with a velocity of 180 mm/s to the right at time $t = 0$ when $\theta = 0$. Assuming simple harmonic motion, determine at $t = 1.5$ s (*a*) the angle $\theta$, (*b*) the magnitudes of the velocity and acceleration of the bob.

# Answers to Problems

**Answers to problems with a number set in straight type are given on this and the following pages. Answers to problems set in italic are not listed. Answers to computer problems are given at www.mhhe.com/beerjohnston8.**

## CHAPTER 11

**11.1** (*a*) $t$ = 3.33 s. (*b*) $x$ = 11.07 m, $v$ = 6.33 m/s.
**11.2** (*a*) $t$ = 0.333 s. (*b*) $x$ = −2.74 m, $v$ = 3.67 m/s.
**11.3** $x$ = 52 m, $v$ = 115 m/s, $a$ = 192 m/s$^2$.
**11.4** $x$ = 562 m, $v$ = 770 m/s, $a$ = 764 m/s$^2$.
**11.5** $x$ = 240 mm, $v$ = 4.39 m/s, $a$ = −24.0 m/s$^2$.
**11.6** $x$ = 24.0 mm, $a$ = −43.9 mm/s$^2$.
**11.9** $v$ = 1.427 m/s, $x$ = 0.363 m.
**11.10** $v$ = 0.1273 m/s, $x$ = 0.598 m.
**11.11** $v$ = −1.360 m/s, $x$ = 0.393 m.
**11.12** $v$ = −1070 mm/s, $x$ = −520 mm, 2580 mm.
**11.13** $v$ = 0.3 m/s, $x$ = −10.38 m, 0.975 m.
**11.16** (*a*) 1.921 m/s. (*b*) 0.0981 m, 0.402 m.
**11.17** $x$ = 0.271 m, $v$ = 0.455 m/s.
**11.18** 3.84 m$^{-2}$.
**11.19** $v$ = 34.3 m/s, $x$ = 0.779 m.
**11.22** 67.5 m.
**11.23** (*a*) 187.5 mm. (*b*) 11.51 s.
**11.24** (*a*) 56.8 m. (*b*) ∞.
**11.25** (*a*) 5.74 m/s. (*b*) 1.079 s.
**11.26** (*a*) 22.5 m. (*b*) 38.4 m/s.
**11.29** (*a*) $x$ = 29.8 m, $a$ = 6.65 m/s$^2$. (*b*) $x$ = 122.5 m, $a$ = 6.30 m/s$^2$.
**11.30** (*a*) 7.15 km. (*b*) −52.1 × 10$^{-6}$ m/s$^2$. (*c*) 49.9 min.
**11.34** (*a*) $x = 2.36 v_0 T$, $a = \pi v_0/T$. (*b*) $0.363 v_0$.
**11.35** (*a*) 3.05 m/s$^2$. (*b*) 8.77 m/s$^2$.
**11.36** (*a*) 125.3 m. (*b*) 3.17 s.
**11.37** (*a*) 1.8 m/s$^2$ . (*b*) 54 m/s.
**11.38** (*a*) 6 s. (*b*) 55.8 m.
**11.41** 11.60 s, 50.4 m.
**11.42** (*a*) 9.63 s, 68.0 m. (*b*) $v_A$ = 35.8 km/h, $v_B$ = 9.13 km/h.
**11.43** (*a*) 340 m. (*b*) 2.8 m.
**11.44** (*a*) 42.67 m/s ↑. (*b*) 39.24 m/s ↑.
**11.45** (*a*) 2.08 m/s$^2$. (*b*) 3.27 m/s$^2$.
**11.46** (*a*) 3.59 m/s$^2$. (*b*) 7.08 s. (*c*) 278 m.
**11.49** (*a*) 4 m/s ↑. (*b*) 1 m/s ↓. (*c*) 3 m/s ↓.
**11.50** (*a*) $\mathbf{a}_A$ = 0.04 m/s$^2$ ↑; $\mathbf{a}_C$ = 0.16 m/s$^2$ ↓. (*b*) $\mathbf{v}_B$ = 0.16 m/s ↑; 0.16 m.
**11.51** (*a*) 2.4 m/s ↑. (*b*) 1.2 m/s ↑.
**11.52** (*a*) 0.24 m/s$^2$ ↓. (*b*) 0.96 m/s$^2$ ↑.
**11.53** (*a*) 600 mm/s →. (*b*) 1200 mm/s ←. (*c*) 900 mm/s ←.
**11.54** (*a*) $\mathbf{a}_A$ = 50.8 mm/s$^2$ →; $\mathbf{a}_B$ = 25.4 mm/s$^2$ ←. (*b*) $\mathbf{v}_B$ = 152.5 mm/s ←; 458 mm ←.
**11.57** (*a*) 50 mm/s →. (*b*) 0. (*c*) $\mathbf{a}_A$ = 40 mm/s$^2$ ←; $\mathbf{a}_C$ = 30 mm/s$^2$ ←.
**11.58** (*a*) $\mathbf{a}_B$ = 105 mm/s$^2$ ←; $\mathbf{a}_C$ = 150 mm/s$^2$→. (*b*) $\mathbf{v}_A$ = 120 mm/s ←; $\mathbf{v}_B$ = 180 mm/s →. (*c*) 360 mm/s ←.
**11.59** (*a*) 5.07 s. (*b*) 0.036 cm. ↓.
**11.60** (*a*) 3 s. (*b*) 19 cm. ↓.
**11.63** (*b*) $x$ = −4 m, $v$ = 4 m/s, 44 m.
**11.64** (*b*) 5.83 s.
**11.65** (*a*) 49.1 m. (*b*) 18 s, 30 s.
**11.66** (*a*) 80.2 m. (*b*) 8 s, 36 s.
**11.69** (*a*) 300 s. (*b*) 1.778 m/s. (*c*) 0.0474 m/s$^2$.
**11.70** 1.64 m/s$^2$.
**11.71** (*a*) 0.609 s. (*b*) $v$ = 0.38 m/s, $x$ = 2.93 m.
**11.72** (*a*) $t_A$ = 50 s, $t_B$ = 50.2 s. (*b*) 3 m.
**11.75** 622 m.
**11.76** 3.97 s after the elevator starts.
**11.77** 11.23 s.
**11.78** 112.0 km/h.
**11.79** (*a*) 1.973 s. (*b*) 0.365 m/s, 0.1825 m/s.
**11.80** (*a*) 9.58 min. (*b*) 31.3 km/h.
**11.83** (*a*) 1.913 m/s. (*b*) 0.836 m.
**11.84** (*a*) 97.7 m/s. (*b*) 1980 m.
**11.85** (*a*) 3.19 s. (*b*) 62.6 m.
**11.86** (*a*) 5.6 m/s$^2$. (*b*) 3.33 m/s$^2$.
**11.88** −8 m.
**11.91** (*a*) **v** = 8.25 m/s ↘ 76.0°; **a** = 24.1 m/s$^2$ ↗ 85.2°. (*b*) **v** = 3.82 m/s ↘ 38.3°; **a** = 5.15 m/s$^2$ ↗ 67.2°.
**11.92** (*a*) **v** = 6 m/s ↘ 36.9°; **a** = 6 m/s$^2$ ↘ 36.9°. (*b*) **v** = 9 m/s ↘ 36.9°; **a** = 0. (*c*) **v** = 6 m/s ↘ 36.9°; **a** = 6 m/s$^2$ ↖ 36.9°.
**11.93** (*a*) 9.42 m/s ↑. (*b*) 7.26 m/s ←. (*c*) 3.14 m/s ↓.
**11.96** (*a*) **r** = 0.5 m ↑; **v** = 1.09 m/s ↘ 46.3°; **a** = 2.38 m/s$^2$ ↙ 85.4°. (*b*) **r** = 0.5 m ↘ 6.0°; **v** = 0.14 m/s ↗ 31.8°; **a** = 0.2 m/s$^2$ ↖ 86.9°.
**11.97** $v = \sqrt{R^2(1 + \omega_n^2 t^2) + c^2}$, $a = \omega_n R \sqrt{4 + \omega_n^2 t^2}$.
**11.98** (*a*) $v$ = 3 m/s, $a$ = 3.61 m/s$^2$. (*b*) 3.82 s.
**11.99** (*a*) 2.94 s. (*b*) 84.9 m. (*c*) 10.62 m.
**11.100** 0.625 m < $h$ < 2.31 m.
**11.101** (*a*) 5.0 m/s. (*b*) 4.8 m/s < $v_0$ < 6.1 m/s.
**11.102** (*a*) 264.4 m. (*b*) 161.3 m.
**11.105** (*a*) Yes. (*b*) 0.937 m.
**11.106** (*a*) 2.38 m. (*b*) 6.46 m.
**11.107** (*a*) 6.4 m/s. (*b*) 1.33 m.
**11.108** (*a*) $v_0$ = 36.1 m/s, $d$ = 18.3 m. (*b*) $v_0$ = 38.7 m/s, $d$ = 26.6 m.
**11.109** 6.98 m/s.
**11.110** (*a*) 9.34 m/s. (*b*) 9.27 m/s.
**11.113** (*a*) 3.96°. (*b*) 375 m. (*c*) 17.51 s.
**11.114** (*a*) 14.9°. (*b*) 0.1052 s.
**11.117** (*a*) 2.55 m. (*b*) 61.8°.
**11.118** (*a*) 91 m. (*b*) 30°. (*c*) 22.8 m.
**11.119** 48.7° west of south.
**11.120** 22.4 km/h, 51.4° west of north.
**11.121** 76.3 km/h ↗ 57.0°.
**11.122** (*a*) 1.44 m/s ↙ 62.8°. (*b*) 1.48 m/s ↘ 60°.
**11.125** (*a*) 0.4 m/s$^2$ ↑. (*b*) 0.89 m/s ↗ 63.4°.
**11.126** (*a*) 17.4 cm/s ↖ 66.6°. (*b*) 14.3 cm/s ↘ 68.6°.

**11.127** (*a*) 52.5 mm/s$^2$ ∠ 31.4°. (*b*) 157.5 mm/s ∠ 31.4°.
**11.128** (*a*) 0.979 m. (*b*) 12.55 m/s ∠ 86.5°.
**11.129** 6 m/s ∠ 85.1°.
**11.130** 3.43 m/s ∠ 21.0°.
**11.131** 14.30 km/h ∠ 36.4°.
**11.132** (*a*) 405 km/h ∠ 30.6°. (*b*) 74.7 km/h ∠ 26.6°.
**11.135** (*a*) 0.1235 m/s$^2$. (*b*) 0.01008 m/s$^2$. (*c*) 0.001796 m/s$^2$.
**11.136** (*a*) 25 m/s. (*b*) 24 m/s.
**11.139** (*a*) 1.694 m/s$^2$. (*b*) 1.406 m/s$^2$.
**11.140** 2.18 m/s$^2$.
**11.141** 8.56 s.
**11.142** (*a*) 24.1 m/s. (*b*) 3.27 m/s$^2$.
**11.145** (*a*) 7.96 m. (*b*) 4.38 m.
**11.146** (*a*) 14.48 m/s. (*b*) 21.3 m.
**11.147** (*a*) 273 m. (*b*) 52.4 m.
**11.148** (*a*) 0.75 m. (*b*) 1.155 m. (*c*) 0.75 m.
**11.149** $\mathbf{a} = 1.5$ m/s$^2$ ↑, $\rho = 26.3$ m.
**11.150** $v_B^3/gv_A$.
**11.153** $(R^2 + c^2)/2\omega_n R$.
**11.154** 2.50 m.
**11.155** 149.8 Gm.
**11.156** 1425 Gm.
**11.157** $7.2 \times 10^3$ m/s.
**11.158** $3.42 \times 10^3$ m/s.
**11.161** 3670 km/h.
**11.162** 50.7 h.
**11.164** (*a*) (0.204 mm/s)$\boldsymbol{e}_r$ − (5.71 mm/s)$\boldsymbol{e}_\theta$.
(*b*) −(22.8 mm/s$^2$)$\boldsymbol{e}_r$ + (1.633 mm/s$^2$)$\boldsymbol{e}_\theta$.
(*c*) (0.0583 mm/s$^2$)$\boldsymbol{e}_r$.
**11.165** (*a*) $v = A$, $a = A^2/B$. (*b*) Path is circle of radius $\rho = B$.
**11.166** (*a*) $\mathbf{v} = 3\pi b\,\boldsymbol{e}_\theta$; $\mathbf{a} = -4\pi^2 b\,\boldsymbol{e}_r$.
(*b*) $\theta = 2\,N\pi$, N = 0, 1, 2. . . .
**11.167** (*a*) $\mathbf{v}$ = (6 m/s)$\boldsymbol{e}_r$; $\mathbf{a}$ = (24 m/s$^2$)$\boldsymbol{e}_\theta$.
(*b*) $\mathbf{v}$ = (12.73 m/s)$\boldsymbol{e}_r$ + (4.24 m/s)$\boldsymbol{e}_\theta$;
$\mathbf{a}$ = (16.97 m/s$^2$)$\boldsymbol{e}_r$ + (16.97 m/s$^2$)$\boldsymbol{e}_\theta$.
**11.168** (*a*) $v = 6\sqrt{2}\,t$ m/s, $a = 6\sqrt{2}$ m/s$^2$. (*b*) $\rho = \infty$, Path is a straight line.
**11.171** $\dfrac{\dot\theta d \sin\beta}{\sin^2(\beta - \theta)}$.
**11.172** (*a*) $\dot r = -\omega d/2$, $\dot\theta = \omega/2$. (*b*) $\ddot r = -\sqrt{3}\omega^2 d/4$, $\ddot\theta = 0$.
**11.173** 306 m/s.
**11.174** $v = 152.7$ m/s, $\alpha = 26°$.
**11.177** $b\theta\omega^2 e^{\frac{1}{2}\theta^2}\sqrt{4 + \theta^2}$.
**11.178** $\dfrac{b\omega^2}{\theta^4}\sqrt{36 + 4\theta^2 + \theta^4}$.
**11.182** $\tan^{-1}\left[R(2 + \omega_n^2 t^2)/c\sqrt{4 + \omega_n^2 t^2}\right]$.
**11.183** (*a*) $\theta_x = 90°$, $\theta_y = 123.7°$, $\theta_z = 33.7°$.
(*b*) $\theta_x = 103.4°$, $\theta_y = 134.3°$, $\theta_z = 47.4°$.
**11.184** $x = 11 + 2.15t + 0.002t^4$ m, $v = 2.15 + 0.00829t^3$ m/s.
**11.185** (*a*) 0.1328 s/m. (*b*) 434 m. (*c*) 7.53 m/s.
**11.187** (*a*) $\mathbf{a}_A$ = 38 mm/s$^2$ ↓; $\mathbf{a}_B$ = 25.3 mm/s$^2$ ↑;
$\mathbf{a}_C$ = 12.67 mm/s$^2$ ↓.
(*b*) $\mathbf{v}_B$ = 203 mm/s ↑; 811 mm ↑ .
**11.188** (*b*) 1383 m. (*c*) 9 s, 49.5 s.
**11.190** (*a*) 115.3 km/h ≤ $v_0$ ≤ 148.0 km/h.
(*b*) 6.66°, 4.05°.
**11.191** 2.67 m/s.
**11.193** (*a*) 2 cm/s$^2$. (*b*) 2.67 cm/s$^2$.
**11.194** (*a*) 0.634 m. (*b*) 9.07 m.

## CHAPTER 12

**12.1** 75 N.
**12.2** $m$ = 2.000 kg at all latitudes. (*a*) 19.56 N. (*b*) 19.61 N. (*c*) 19.64 N.
**12.5** 1.5 m/s
**12.6** (*a*) 5 s. (*b*) 0.612.
**12.7** 63.9 m.
**12.8** (*a*) 0.955. (*b*) 64.8 m.
**12.9** (*a*) 78.3 m (*b*) 4.53 m.
**12.10** 612 N.
**12.11** (*a*) 51.7 m. (*b*) 61.9 m.
**12.13** (*a*) $\mathbf{a}_A$ = 1.327 m/s$^2$ ∠ 30°; $\mathbf{a}_B$ = 0.442 m/s$^2$ ∠ 30°.
(*b*) 18.79 N.
**12.16** (*a*) 0.99 m/s$^2$ ∠ 25°. (*b*) 46.8 N.
**12.17** (*a*) 2.55 m/s$^2$ ∠ 25°. (*b*) 58.13 N.
**12.19** (*a*) $\mathbf{a}_A$ = 2.3 m/s$^2$ ↓; $\mathbf{a}_B$ = 0.75 m/s$^2$ ↑;
$\mathbf{a}_C$ = 0.75 m/s$^2$ ↓.
(*b*) $T_A$ = 67.76 N, $T_C$ = 81.25 N.
**12.20** *System 1:* (*a*) 3.22 m/s$^2$ ↓. (*b*) 3.1 m/s ↓. (*c*) 0.932 s.
*System 2:* (*a*) 4.85 m/s$^2$ ↓. (*b*) 3.8 m/s ↓. (*c*) 0.618 s.
*System 3:* (*a*) 0.23 m/s$^2$ ↓. (*b*) 0.83 m/s ↓. (*c*) 13.04 s.
**12.21** (*a*) $\mathbf{a}$ = 8.3 m/s$^2$ →; $T$ = 14.6 kN. (*b*) 2.45 m/s$^2$.
**12.22** 0.357
**12.23** (*a*) 11.52 m/s$^2$ ←. (*b*) 0.787 m →.
**12.26** $0.347\ m_0 v_0^2/F_0$.
**12.29** $\sqrt{k/m}\,(\sqrt{l^2 + x_0^2} - l)$.
**12.30** (*a*) 0.409 m ↑. (*b*) 65.4 N.
**12.31** (*a*) 2.78 m/s$^2$ ∠ 30°. (*b*) 0.637 m/s ∠ 30°.
**12.32** (*a*) $\mathbf{a}_A$ = 8.9 m/s$^2$ →; $\mathbf{a}_B$ = 11.9 m/s$^2$ →;
$\mathbf{a}_C$ = 12.6 m/s$^2$ →.
(*b*) 27 N.
**12.33** (*a*) $\mathbf{a}_A$ = 6.14 m/s$^2$ →; $\mathbf{a}_B$ = 8.8 m/s$^2$ →;
$\mathbf{a}_C$ = 9 m/s$^2$ →.
(*b*) 24.5 N. (*c*) 197.4 N →.
**12.36** (*a*) 34.2°. (*b*) 23.7 N.
**12.37** 2.49 m/s.
**12.40** (*a*) 3.13 m/s. (*b*) 13.87 N.
**12.41** (*a*) 2.24 N. (*b*) 1.421 N ∠ 53.8°
**12.42** 0.732 m/s ≤ $v$ ≤ 4.34 m/s.
**12.44** (*a*) 0.742*W*. (*b*) 0.940*W*.
**12.45** $t$ = 11.32 s.
**12.46** 331 N.
**12.47** (*a*) 607 N ∠ 74.6°. (*b*) 581.2 N ∠ 80°.
**12.48** (*a*) 201 m. (*b*) 515 N ↑.
**12.49** 0.534 m/s ↓.
**12.52** $\sqrt{gr\tan(\theta - \phi_s)} \le v \le \sqrt{gr\tan(\theta + \phi_s)}$.
**12.53** (*a*) 51.9°. (*b*) 0.449. (*c*) 115.5 km/h.
**12.54** (*a*) 0.247*W*. (*b*) 13.3°.
**12.55** 6.90°.
**12.56** 0°, 69.6°, 180°.
**12.57** (*a*) Does not slide; 0.611 N ∠ 75°. (*b*) Slides up; 0.957 N ∠ 40°.
**12.60** (*a*) 14.8 m/s. (*b*) $2587 \times 10^{-6}$ N.
**12.61** 0.324.
**12.64** $elVL/mdv_0^2$.
**12.65** $\dfrac{d}{l} > \dfrac{1.085}{v_0}\sqrt{\dfrac{eV}{mv_0^2}}$.
**12.66** (*a*) 1.226 m/s ∠ 60°. (*b*) 10.90 m/s$^2$ ∠ 60°.
**12.67** (*a*) 7.47 N ∠ 45°. (*b*) 6.94 m/s$^2$ ∠ 45°.
**12.68** (*a*) $F_r$ = 10.8 N, $F_\theta$ = 0. (*b*) $F_r$ = −57.6 N, $F_\theta$ = 57.6 N.

**12.69** (*a*) $F_r = -319.7$ N, $F_\theta = 0$. (*b*) $F_r = -106.6$ N, $F_\theta = 213.2$ N.
**12.72** (*a*) 335 mm. (*b*) 1.304 m/s.
**12.73** $a_r = -84.2$ m/s$^2$, $a_\theta = 90.1$ m/s$^2$.
**12.74** (*a*) 114.26 N. (*b*) 5.5 m/s$^2$ $\rightarrow$. (*c*) 4.76 m/s$^2$ $\downarrow$.
**12.75** (*a*) 127.3 N. (*b*) 6.1 m/s$^2$ $\rightarrow$. (*c*) 4.2 m/s$^2$ $\downarrow$.
**12.76** $v_r = v_0 \sin 2\theta/\sqrt{\cos 2\theta}$, $v_\theta = v_0\sqrt{\cos 2\theta}$.
**12.81** (*a*) 35800 km. (*b*) 3.07 km/h.
**12.82** 0.0247 m/s$^2$.
**12.83** (*a*) $2.1 \times 10^{30}$ kg. (*b*) 273 m/s$^2$.
**12.84** (*a*) $1.071 \times 10^6$ km. (*b*) 8.21 km/s.
**12.85** (*a*) 1685 km. (*b*) 25.2 min.
**12.88** $7.35 \times 10^3$ m/s $\measuredangle$ 45°.
**12.89** $2.73 \times 10^3$ m/s
**12.91** 15.94 m/s.
**12.92** (*a*) $T = 21.6$ N, $\mathbf{a}_{A/OE} = 8.5$ m/s$^2$ $\rightarrow$. (*b*) 1.2 m/s.
**12.93** (*a*) 1.05 m/s. (*b*) $T = 10.4$ N, $\mathbf{a}_{A/OE} = 0.99$ m/s$^2$ $\leftarrow$.
**12.102** 105.5.
**12.103** 3760 m/s, 1426 m/s.
**12.105** (*a*) $1.636 \times 10^3$ m/s. (*b*) $0.73 \times 10^3$ m/s (*c*) 0.333.
**12.108** (*a*) 159.0 m/s. (*b*) 70.1 m/s. (*c*) $2.37 \times 10^3$ m/s.
**12.109** (*a*) $499 \times 10^3$ km. (*b*) $\Delta v_B = 43.2$ m/s, $\Delta v_C = 2.42 \times 10^3$ m/s.
**12.110** 123.6 h.
**12.111** $5.27 \times 10^9$ km.
**12.114** 1.036 h.
**12.115** 95.1 min.
**12.116** $\cos^{-1}[(1 - n\beta^2)/(1 - \beta^2)]$.
**12.117** 80 m/s.
**12.121** (*a*) $(r_1 - r_0)/(r_1 + r_0)$. (*b*) $606\,514.4 \times 10^9$ m.
**12.124** (*a*) 64.06 m/s. (*b*) 51.5 m/s.
**12.125** (*a*) 60.4 m. (*b*) 19.16 kN.
**12.127** (*a*) 693.25 N. (*b*) 1017.8 N.
**12.128** (*a*) 33.0 km/h. (*b*) 51.8 km/h.
**12.130** (*a*) $F_r = -31.6$ N, $F_\theta = -6.96$ N. (*b*) $F_r = -2.41$ N, $F_\theta = 4.93$ N.
**12.131** (*a*) $F_r = 2.4465 \tan^2\theta \sec\theta$ N, $F_\theta = 2.4465 \tan\theta \sec\theta$ N. (*b*) $\mathbf{P} = 2.4465 \tan\theta \sec^3\theta$ N $\measuredangle\,\theta$, $\mathbf{Q} = 2.4465 \tan^2\theta \sec^2\theta$ N $\rightarrow$.
**12.133** (*a*) 1.819 kN. (*b*) 2510 km. (*c*) 1.617 m/s$^2$.
**12.134** (*a*) $(a_B)_r = (a_B)_\theta = a_\theta = 0$. (*b*) 18.4 m/s$^2$. (*c*) 0.89 m/s.

## CHAPTER 13

**13.1** 8.8 MN · m
**13.2** 2.36 GJ.
**13.5** 6.06 m.
**13.6** (*a*) 15.7 m. (*b*) 7.86 m/s $\measuredangle$ 20°. (*c*) 987 N · m
**13.7** (*a*) 17.54 m/s. (*b*) 0.893.
**13.8** −56.0 kJ.
**13.11** 2.86 m/s $\measuredangle$ 15°.
**13.12** −4.94 J.
**13.15** (*a*) 47.1 m. (*b*) $F_{AB} = 83.6$ kN *T*; $F_{BC} = 36.6$ kN *T*.
**13.16** (*a*) 107.7 m. (*b*) $F_{AB} = 83.6$ kN *C*; $F_{BC} = 36.6$ kN *C*.
**13.17** 8.12 m/s.
**13.18** (*a*) 9.5 m. (*b*) 5999 N.
**13.19** (*a*) 1.7 m/s $\measuredangle$ 30°. (*b*) 59.7 N · m
**13.20** (*a*) 1.09 m/s $\measuredangle$ 30°. (*b*) 17.14 N.
**13.23** 1.683 m/s.
**13.24** (*a*) 3.96 m/s. (*b*) 5.60 m/s.
**13.27** (*a*) 0.41 m/s $\uparrow$. (*b*) 0.046 m.
**13.28** (*a*) 0.41 m/s $\uparrow$. (*b*) 0.045 m.
**13.29** (*a*) 0.1590. (*b*) 1.8 m/s.
**13.32** (*a*) 3.72 m. (*b*) 120 m/s$^2$.
**13.33** $0.759\sqrt{\dfrac{paA}{m}}$.
**13.34** $g_h = \dfrac{g_0}{[(h/R) + 1]^2}$. (*a*) 0.0314%. (*b*) 25.3%.
**13.35** $1/[1 - (v_0^2 - v^2)/2g_m R_m]$
**13.38** (*a*) 111.1 km. (*b*) 118.7 km.
**13.39** (*a*) 0.635 m/s. (*b*) 0.648 m/s.
**13.40** (*a*) 0.782 m/s. (*b*) 0.827 m/s.
**13.41** (*a*) $v_0 = \sqrt{3gl}$. (*b*) $v_0 = \sqrt{2gl}$.
**13.42** 12.3°
**13.45** 731 N.
**13.46** $N_{min} = 731$ N at *B*; $N_{max} = 5520$ N at *D*.
**13.47** 962.8 N · m/s
**13.50** (*a*) $0.278 \times 10^{-6}\, mgb/\eta$.
**13.51** (*a*) $t = 18.75$ s, $x = 238$ m. (*b*) $t = 26.2$ s, $x = 462$ m.
**13.52** (*a*) 86.9 W. (*b*) 16.45 m.
**13.55** (*a*) $k_e = k_1k_2/(k_1 + k_2)$. (*b*) $k_e = k_1 + k_2$.
**13.56** (*a*) 0.526 m, $v_m = 4$ m/s. (*b*) 0.526 m, $v_m = 2.53$ m/s.
**13.57** 21.9 m/s.
**13.58** 23.1 m/s.
**13.61** (*a*) 1.12 m. (*b*) 4.67 m/s.
**13.62** (*a*) 0.01 m. (*b*) 0.02 m.
**13.63** (*a*) 0.292 m. (*b*) 2.39 m/s.
**13.64** (*a*) 43.1°. (*b*) 2.43 m/s.
**13.67** (*a*) 1.044 m/s. (*b*) 1.075 m/s. (*c*) 392 mm.
**13.68** (*a*) 1.004 m/s. (*b*) 0.576 m/s.
**13.69** (*a*) 2.39 m/s. (*b*) 5.78 N $\uparrow$.
**13.70** (*a*) 2.92 m/s. (*b*) $-(33.9\text{ N})\mathbf{i} + (33.3\text{ N})\mathbf{j}$.
**13.71** (*a*) $v = 1.16$ m/s, $N = 16.32$ N $\rightarrow$. (*b*) $v = 1$ m/s, $N = 33$ N $\downarrow$.
**13.72** (*a*) 300 N/m. (*b*) 1.132 m/s.
**13.75** $a = \dfrac{3}{5}l$.
**13.76** (*a*) 1089 N $\uparrow$. (*b*) 284 N $\uparrow$. (*c*) Yes.
**13.78** (*b*) $V = -\ln xyz$.
**13.79** (*b*) $V = \dfrac{1}{\sqrt{x^2 + y^2 + z^2}}$.
**13.80** (*a*) Not conservative, $U_{ABCA} = (k - 1)a^2/2$. (*b*) Conservative, $U_{ABCA} = 0$.
**13.85** $v_B = 25.1$ Mm/h.
**13.86** (*a*) 2810 kJ/kg. (*b*) 1345 kJ/kg.
**13.87** $5842.5 \times 10^3$ m.
**13.88** (*a*) $6.92 \times 10^9$ N · m (*b*) $168.1 \times 10^9$ N · m
**13.89** (*a*) 90.5 GJ. (*b*) 208 GJ.
**13.90** (*a*) $V = mgR[1 - (R/r)]$. (*b*) $T = \dfrac{1}{2}mgR^2/r$. (*c*) $E = mgR[1 - (R/2r)]$.
**13.93** $V_{2r} = 6.44$ m/s, $V_{\theta 2} = 2.4$ m/s.
**13.94** (*a*) 0.760 m. (*b*) 1.580 m/s.
**13.95** (*a*) 1.06 m. (*b*) 3.6 rad/s. (*c*) 144.1 N · m
**13.96** (*a*) 0.91 m. (*b*) 2.27 m. (*c*) 5 rad/s.
**13.100** (*a*) 1704 m/s. (*b*) 29.6 m/s.
**13.101** (*a*) 2.44 km/s. (*b*) 1.470 km/s.
**13.102** (*a*) 2.9 km/s. (*b*) 2.6 km/s.
**13.103** (*a*) 5613.3 km. (*b*) $16.98 \times 10^{23}$ kg.
**13.106** 3450 m/s.
**13.107** 1478 km.
**13.108** (*a*) 7.34 km/s. (*b*) 44.5°.
**13.109** (*a*) 10.66 km/s. (*b*) $15.43 \times 10^3$ km.

**13.112** (*a*) 3.45 km/s. (*b*) 4.17 km/s.
**13.113** 9.39 km/s; 58.9°.
**13.118** (*b*) $v_{esc}\sqrt{\alpha/(1+\alpha)} \le v_0 \le v_{esc}\sqrt{(1+\alpha)/(2+\alpha)}$.
**13.119** 4.87 m/s ↖ 76.4°
**13.121** 73.3 N.
**13.122** (*a*) 3.06 s. (*b*) 0.963 s.
**13.123** (*a*) 11.1 kN. (*b*) 3 s.
**13.124** (*a*) 39.9 m/s. (*b*) 10.88 kN.
**13.125** (*a*) 88.1 km/h. (*b*) 33.6 s.
**13.126** 206 N
**13.129** (*a*) 5.28 s. (*b*) 17.05 kN *C*.
**13.130** (*a*) 16.32 s. (*b*) 3.06 kN *T*.
**13.131** (*a*) 32.6 s. (*b*) 11.03 kN *T*.
**13.132** (*a*) 1.64 m/s ↙ 30°. (*b*) 14.63 N.
**13.133** (*a*) $v_A$ = 2.5 m/s →; $v_B$ = 4.95 m/s →; $v_C$ = 4.35 m/s →.
(*b*) 0.114 N.
**13.136** (*a*) 5.19 m/s ↑. (*b*) 15.38 m/s ↑.
**13.137** (*a*) 15.38 m/s ↑. (*b*) 4.57 s.
**13.140** 180.8 N ↘ 51.5°.
**13.141** 1.86*W*.
**13.142** 111.2 kN ↘ 69.0°
**13.143** 3.86 N · s.
**13.146** (*a*) 1.71 m/s →. (*b*) 11000 N · s.
**13.147** (*a*) 432.2 m/s. (*b*) 12.88 N · s.
**13.148** (*a*) 6.30 N · s ↘ 34.7°. (*b*) 11.28 J.
**13.149** (*a*) 1.154 m/s ←. (*b*) 1.292 m/s ←. (*c*) 1.280 m/s ←.
**13.150** (*a*) 1.85 m/s ↓. (*b*) 0.085 N · m.
**13.151** (*a*) 187.9 N · s, 589 J. (*b*) 150.3 N · s, 471 J.
**13.152** (*a*) 4.5 N · s, 13.5 J. (*b*) 3.79 N · s, 11.37 J.
**13.157** (*a*) $v'_A$ = 2.3 m/s ←; $v'_B$ = 2.2 m/s →. (*b*) 2.84 J.
**13.158** 0.875
**13.159** (*a*) 3.2 m/s →. (*b*) 6.96 m/s ←.
**13.160** (*a*) 2.07 m/s ←. (*b*) 1.874 m/s →.
**13.163** (*a*) 0.82 m/s →. (*b*) 0.59 m/s →.
**13.164** $\mathbf{v}'_A$ = 1.773 m/s ↙ 15.00°; $\mathbf{v}'_B$ = 2.19 m/s ↖ 50°.
**13.165** $\mathbf{v}'_A$ = 0.711 $v_0$ ↗ 39.3°; $\mathbf{v}'_B$ = 0.636 $v_0$ ↖ 45°.
**13.166** $\mathbf{v}'_A$ = 1.56 m/s →; $\mathbf{v}'_B$ = 2.76 m/s ↗ 22.6°.
**13.167** $\mathbf{v}'_A$ = 1.53 m/s →; $\mathbf{v}'_B$ = 2.97 m/s → .
**13.171** (*a*) 0.941 m/s ↗ 89.0°. (*b*) 0.01090.
**13.172** 156.1 mm.
**13.173** (*a*) 0.6. (*b*) 0.9.
**13.174** 3.96 m.
**13.176** (*a*) 0.2 m. (*b*) 0.269 m.
**13.177** (*a*) 2.65 m/s →. (*b*) 75.7 N · m.
**13.178** (*a*) 31.2 km/h. (*b*) 0.241.
**13.179** (*a*) $e_{AB}$ = 0.506, $e_{BC}$ = 0.333. (*b*) 44.0 mm.
**13.180** (*a*) $v'_C$ = 0, $v'_A$ = 1.372 m/s ↓. (*b*) 6.86 N · s ↑.
**13.181** (*a*) $v_C$ = 2.74 m/s ↓, $v_A$ = 1.372 m/s ↓.
(*b*) $v_C$ = 1.372 m/s ↓, $v_A$ = 2.47 m/s ↓.
**13.184** 96.0 mm.
**13.185** (*a*) 3.70 m/s ↗ 62.2°. (*b*) 1175 N.
**13.186** 0.309
**13.187** 0.13 m ≤ *h* ≤ 0.52 m.
**13.190** 265 km/h.
**13.191** (*a*) 106.3 mm. (*b*) 2.36 m/s.
**13.193** 2.06 m/s.
**13.194** 7.59 km/s.
**13.196** 2.86 kN.
**13.198** $\mathbf{v}_A$ = 0.9 m/s ←; $\mathbf{v}_B$ = 0.3 m/s ←; $\mathbf{v}_C$ = 0.137 m/s ←.
**13.199** $\mathbf{v}_A$ = 3.52 m/s ↙ 72.2°; $\mathbf{v}_B$ = 0.035 m/s ↗ 40°.
**13.201** (*a*) 62.7°. (*b*) 0.14 $v_0^2$ N · m (for $v_0$ in m/s).

## CHAPTER 14

**14.1** $\mathbf{v}_A$ = 10.67 km/h ←; $\mathbf{v}_B = \mathbf{v}_C$ = 4.27 km/h ←.
**14.2** (*a*) 1.706 m/s. (*b*) 0.576 m from left of *B*.
**14.3** 0.219 m/s →.
**14.4** 221 kN.
**14.5** (*a*) 5.2 km/h →. (*b*) 4 km/h →.
**14.6** (*a*) 43.4 g. (*b*) 293 m/s.
**14.9** (*a*) (1.333 m/s)**j**; (0.333 m/s)**i**; (1 m/s)**k**.
(*b*) (1.8 kg · m²/s)**i** + (0.9 kg · m²/s)**j** − (3.6 kg · m²/s)**k**.
**14.10** (*a*) (3.33 m/s)**j**; (1.667 m/s)**i**; (3.33 m/s)**k**.
(*b*) (9 kg · m²/s)**i** + (4.5 kg · m²/s)**j** − (9 kg · m²/s)**k**.
**14.11** zero
**14.12** (*a*) (0.8 m)**i** + (0.4 m)**j** + (0.8 m)**k**.
(*b*) (114.3 N · s)**j** − (76 N · s)**k**.
(*c*) (121.8 N · m · s)**i** − (61 N · m · s)**j** −
(91.4 N · m · s)**k**.
**14.15** (120 m)**i** − (26.0 m)**j** + (13.33 m)**k**.
**14.16** (3300 m)**i** + (750 m)**j** + (900 m)**k**.
**14.17** 83.5 m/s, 7.8 s
**14.18** $v_B$ = 19 m/s; $v_C$ = 46 m/s.
**14.21** (*a*) 2.13 m/s →. (*b*) θ = 36.6°, $v_C$ = 3.46 m/s,
$v_D$ = 2.91 m/s.
**14.22** (*a*) 2.01 m/s. (*b*) 2.27 m/s.
**14.23** 798.3 m/s east, 215.8 m/s south, 1190 m/s down.
**14.24** (15.75 m)**i** + (2.79 m)**k**.
**14.25** $v_A$ = 919 m/s; $v_B$ = 717 m/s; $v_C$ = 619 m/s.
**14.31** (*a*) 3550 J. (*b*) 1830 J.
**14.32** 2670 J.
**14.33** 4339.8 N · m
**14.34** 391 348.8 N · m.
**14.37** (*a*) $\mathbf{v}_A$ = 0.2 $v_0$ ←; $\mathbf{v}_B$ = 0.693 $v_0$ ↗ 30°;
$\mathbf{v}_C$ = 0.693 $v_0$ ↖ 30°.
(*b*) $\mathbf{v}_A$ = 0.25 $v_0$ ↙ 60°; $\mathbf{v}_B$ = 0.866 $v_0$ ↗ 30°;
$\mathbf{v}_C$ = 0.433 $v_0$ ↖ 30°.
**14.38** (*a*) $\dfrac{m_A}{m_A + m_B} v_0$ →. (*b*) $\dfrac{m_A}{m_A + m_B}\dfrac{v_0^2}{2g}$.
**14.39** $v_A$ = 2.29 m/s; $v_B$ = 1.97 m/s; $v_C$ = 3.43 m/s.
**14.40** $v_A$ = 3.23 m/s; $v_B$ = 2.79 m/s; $v_C$ = 1.6 m/s.
**14.41** $\mathbf{v}_A$ = 0.1714 $v_0$ ↖ 19.5°; $\mathbf{v}_B$ = 0.985 $v_0$ ↖ 80.1°;
$\mathbf{v}_C$ = 0.0286 $v_0$ ↑.
**14.42** (*a*) $\mathbf{v}_A$ = 0.1667 $v_0$ ↖ 19.5°; $\mathbf{v}_B$ = 0.957 $v_0$ ↙ 80.5°;
$\mathbf{v}_C$ = 0. (*b*) 0.0556.
**14.45** (*a*) $v_C$ = 3.50 m/s; $v_D$ = 1.750 m/s. (*b*) 0.786.
**14.46** (*a*) $v_C$ = 4.25 m/s; $v_D$ = 2.13 m/s. (*b*) 0.727.
**14.47** (*a*) $\mathbf{L} = mv_0\,\mathbf{i}$; $\mathbf{H}_G = -\dfrac{2}{3} lmv_0\,\mathbf{k}$. (*b*) $\mathbf{v}_A = -\dfrac{1}{3} v_0\,\mathbf{i}$;
$\mathbf{v}_B = \dfrac{2}{3} v_0\,\mathbf{i}$.
**14.48** (60.9 m/s)**i** + (955 m/s)**j** + (5033.8 m/s)**k**.
**14.49** (*a*) 0.5 $v_0$. (*b*) 0.75 $v_0$. (*c*) 0.1875.
**14.50** (*a*) −(0.25*l*)**i** − (0.25$v_0$ *t*)**j**. (*b*) (1.75*mlv*$_0$)**k**. (*c*) $mv_0^2$.
**14.53** (*a*) $\mathbf{v}_A$ = 2.075 m/s ↑; $\mathbf{v}_B$ = 5.98 m/s ↖ 28°. (*b*) 3.15 m.
**14.54** (*a*) 1.4 m/s ↗ 38.7°. (*b*) 0.54 m. (*c*) 10.00 rad/s ↺.
**14.55** (*a*) $\mathbf{v}_B$ = 2.4 m/s ↗ 53.1°; $\mathbf{v}_C$ = 2.56 m/s →.
(*b*) *c* = 1.059 m.
**14.56** (*a*) $\mathbf{v}_A$ = 2.4 m/s ↓; $\mathbf{v}_B$ = 3 m/s ↗ 53.1°.
(*b*) *a* = 1.864 m.
**14.59** 312 N.
**14.60** 4.18 m/s.
**14.61** 117.2 N →; 56.8 N ↑.
**14.62** 146 N →; 71 N ↑.
**14.65** 4040 N ↑.

**14.67** $\mathbf{A} = 274$ N ⦣ 20.0°; $M_A = 46.0$ N · m ↻.
**14.68** $C_x = 0$, $C_y = 130.6$ N ↓; $D_x = 215.2$ N →, $D_y = 242.18$ N ↓.
**14.71** 100 kg/s.
**14.72** 25.6 m/s ←.
**14.73** $\mathbf{A} = 1245$ N ↑; $\mathbf{B} = 25\,582.7$ N ⦥ 84.3°.
**14.74** (*a*) 42.0 kN, 1.143 m below *B*. (*b*) 30.0 kN, 3.20 m below *B*.
**14.75** 29.3 kN.
**14.76** 233.4 m/s.
**14.79** (*a*) $\frac{1}{2} v_A$ →. (*b*) $\frac{1}{4}\rho A v_A^3(1 - \cos\theta)$.
(*c*) $2\left(1 - \frac{V}{v_A}\right)\frac{V}{v_A}(1 - \cos\theta)$.
**14.80** (*a*) $11.51 \times 10^6$ W. (*b*) $20.97 \times 10^6$ W. (*c*) 0.55.
**14.83** $b\sqrt{\frac{1}{2} g d_1 d_2 (d_1 + d_2)}$.
**14.84** 15.09 $m^3/s$.
**14.87** (*a*)$m_0 e^{qL/m_0 v_0}$. (*b*) $v_0 e^{-qL/m_0 v_0}$.
**14.88** $\mathbf{C} = 1.712$ kN ↑; $\mathbf{D} = 2.29$ kN ↑.
**14.89** (*a*) $\frac{m}{l}\left(gy + v^2\right)$. (*b*) $mg\left(1 - \frac{y}{l}\right)$↑.
**14.90** (*a*) $mgy/l$. (*b*) $(m/l)\left[g(l - y) + v^2\right]$ ↑.
**14.93** 3888 kN.
**14.94** 4550 N/s.
**14.95** 5500 m/s.
**14.96** (*a*) 116.0 kg/s. (*b*) 1810 kg.
**14.97** 2200 kg.
**14.98** 1498 m/s.
**14.101** 4150 m.
**14.102** 87.2 km.
**14.103** (*a*) 153.4 km. (*b*) 5670 m/s ↑.
**14.104** 56.4 km.
**14.107** (*a*) 1.3 m/s →. (*b*) 1.3 m/s →.
**14.109** $-(4.8 \text{ kg} \cdot \text{m}^2/\text{s})\mathbf{j} + (9.6 \text{ kg} \cdot \text{m}^2/\text{s})\mathbf{k}$.
**14.110** (*a*) $(1.867 \text{ m})\mathbf{i} + (1.533 \text{ m})\mathbf{j} + (0.667 \text{ m})\mathbf{k}$.
(*b*) $(12 \text{ kg} \cdot \text{m/s})\mathbf{i} + (28 \text{ kg} \cdot \text{m/s})\mathbf{j} + (14 \text{ kg} \cdot \text{m/s})\mathbf{k}$.
(*c*) $-(2.8 \text{ kg} \cdot \text{m}^2/\text{s})\mathbf{i} + (13.33 \text{ kg} \cdot \text{m}^2/\text{s})\mathbf{j} -$
$(24.3 \text{ kg} \cdot \text{m}^2/\text{s})\mathbf{k}$.
**14.111** −1001.3 m, 657.7 m.
**14.113** $\mathbf{v}_A = 9.67$ m/s ∠ 60.3°; $\mathbf{v}_B = 12.87$ m/s ⦣ 17.8°.
**14.115** (*a*) 41.94°. (*b*) 200.3 N ↓.
**14.116** $\mathbf{C} = 134.1$ N ↓; D = 178.6 N ↑.
**14.117** (*a*) 30.8 m/s. (*b*) 96.7 $m^3/s$. (*c*) 55.4 kW.

## CHAPTER 15

**15.1** (*a*) $t = 0.25$ s. (*b*) $\theta = -18.25$ rad, $\omega = 22.5$ rad/s.
**15.2** (*a*) 0.5 rad; −4.71 rad/s; −34.5 rad/s². (*b*) 0; −1.934 rad/s; 36.5 rad/s².
**15.3** (*a*) 0.253 rad; −0.927 rad/s; −36.6 rad/s². (*b*) 0; 0; 0.
**15.4** (*a*) 36 s. (*b*) 10.54 s.
**15.5** (*a*) 80 rev. (*b*) 800 rev.
**15.6** $\omega = 14.27$ rad/s, $\theta = 3.63$ rad.
**15.9** $\mathbf{v}_B = -(0.95 \text{ m/s})\mathbf{i} + (0.305 \text{ m/s})\mathbf{j} - (0.396 \text{ m/s})\mathbf{k}$.
$\mathbf{a}_B = -(3.2 \text{ m/s})\mathbf{i} - (1.88 \text{ m/s}^2)\mathbf{j} + (6.23 \text{ m/s}^2)\mathbf{k}$.
**15.10** $\mathbf{v}_B = -(0.475 \text{ m/s})\mathbf{i} + (0.15 \text{ m/s})\mathbf{j} - (0.198 \text{ m/s})\mathbf{k}$.
$\mathbf{a}_B = -(0.8 \text{ m/s}^2)\mathbf{i} - (0.7 \text{ m/s}^2)\mathbf{j} + (1.85 \text{ m/s}^2)\mathbf{k}$.
**15.11** $\mathbf{v}_E = (1.08 \text{ m/s})\mathbf{i} + (2.4 \text{ m/s})\mathbf{j}$; $\mathbf{a}_E = -(11.52 \text{ m/s}^2)\mathbf{i} + (5.18 \text{ m/s}^2)\mathbf{j} + (23.1 \text{ m/s}^2)\mathbf{k}$.
**15.12** $\mathbf{v}_C = -(2.4 \text{ m/s})\mathbf{j} - (1.8 \text{ m/s})\mathbf{k}$; $\mathbf{a}_C = (18 \text{ m/s}^2)\mathbf{i} + (19.2 \text{ m/s}^2)\mathbf{j} - (15.6 \text{ m/s}^2)\mathbf{k}$.
**15.15** $2.967 \times 10^4$ m/s, $5.9 \times 10^{-3}$ m/s².
**15.17** (*a*) $\omega = 2.5$ rad/s ↺; $\alpha = 1.5$ rad/s² ↻.
(*b*) 771 mm/s² ⦣ 76.5°.
**15.18** 12 rad/s², ↺ or ↻.
**15.19** (*a*) $\omega_A = 18$ rad/s ↻; $\alpha_A = 144$ rad/s² ↻; $\omega_C = 28.8$ rad/s ↻;
$\alpha_C = 230$ rad/s² ↻. (*b*) 109.5 m/s² ⦤ 15.52°.
**15.20** (*a*) 24 m/s². (*b*) 244.6 m/s² ⦤ 5.64°.
**15.23** (*a*) $r_1\omega_A/r_2$. (*b*) $\mathbf{a}_A = r_1\omega_A^2$ ↓; $\mathbf{a}_B = r_1^2\omega_A^2/r_2$ ↓.
**15.24** (*a*) 5 rad/s. (*b*) $\mathbf{a}_A = 7.94$ m/s² ↓; $\mathbf{a}_B = 1.58$ m/s² ↓.
(*c*) 2.225 m/s².
**15.27** (*a*) 1.6 m/s² →. (*b*) 150 mm ←.
**15.28** (*a*) 1.934 m/s² →. (*b*) 183.0 mm ←.
**15.29** (*a*) 2.75 rev. (*b*) $\mathbf{v}_B = 1.425$ m/s ↓; $\Delta y_B = 2.58$ m/s ↓.
(*c*) 0.707 m/s² ∠ 32.0°.
**15.30** (*a*) $\mathbf{v}_A = .96$ m/s ↑; $\Delta y_A = 1.92$ m ↑.
(*b*) $\mathbf{v}_B = 1.44$ m/s ↓; $\Delta y_B = 2.88$ m ↓.
**15.31** (*a*) 3.14 rad/s². (*b*) 8 s.
**15.32** (*a*) $\alpha_A = 4.34$ rad/s² ↻; $\alpha_B = 1.832$ rad/s² ↻. (*b*) 3.70 s.
**15.35** $a = b\omega_0^2/2\pi$ →.
**15.36** $\alpha = bv^2/2\pi r^3$ ↻.
**15.37** (*a*) 0.378 rad/s ↻. (*b*) 160.4 mm/s ↑.
**15.38** (*a*) 0.615 rad/s ↺. (*b*) 276 mm/s ⦣ 15°.
**15.39** (*a*) 2.7 rad/s ↻. (*b*) 1.18 m/s ⦤ 67.4°.
**15.40** (*a*) 1.98 m/s →. (*b*) 1.85 m/s ∠ 67.4°.
**15.43** (*a*) $-(2 \text{ rad/s})\mathbf{k}$. (*b*) $(100 \text{ mm/s})\mathbf{i} + (175 \text{ mm/s})\mathbf{j}$.
**15.45** (*a*) 1.8 rad/s ↺. (*b*) 0.63 m/s ∠ 69.4°.
**15.46** (*a*) 2.81 rad/s ↺. (*b*) 0.44 m/s ∠ 35.3°.
**15.47** (*a*) 8.33 rad/s ↻. (*b*) 2.78 rad/s ↻.
**15.48** (*a*) 30 rad/s ↺. (*b*) 13.33 rad/s ↺.
**15.49** (*a*) 6.03 m/s. (*b*) 9000 rpm. (*c*) 1508.
**15.50** (*a*) 3 rad/s ↻. (*b*) 1.5 rad/s ↻.
**15.51** (*a*) 105 rpm ↻. (*b*) 127.5 rpm ↻.
**15.52** (*a*) 1.5. (*b*) $\omega_A/3$ ↺.
**15.55** 497 mm/s ←.
**15.56** 791 mm/s ←.
**15.57** (*a*) $\omega_{BD} = 4.38$ rad/s ↻; $\mathbf{v}_D = 0.31$ m/s ↑.
(*b*) $\omega_{BD} = 0$; $\mathbf{v}_D = 1.065$ m/s ↓.
(*c*) $\omega_{BD} = 4.38$ rad/s ↺; $\mathbf{v}_D = 0.31$ m/s ↓.
**15.58** (*a*) $\theta = 22.9°$, $\beta = 22.9°$; $\theta = 192.6°$, $\beta = 12.6°$.
(*b*) For $\theta = 22.9°$: $\omega_{BD} = 5.60$ rad/s ↻; For $\theta = 192.6°$: $\omega_{BD} = 5.60$ rad/s ↺.
**15.59** (*a*) 4.27 rad/s ↻. (*b*) 1.330 m/s ↓. (*c*) 1.557 m/s ∠ 34.7°.
**15.60** (*a*) 5.13 rad/s ↺. (*b*) 0.924 m/s ←. (*c*) 1.873 m/s ⦤ 34.7°.
**15.63** $\omega_{BD} = 2.5$ rad/s ↺; $\omega_{DE} = 6.67$ rad/s ↻.
**15.64** $\omega_{AB} = \omega_{BD} = 16.04$ rad/s ↺; $\omega_{DE} = 16.04$ rad/s ↻.
**15.65** (*a*) 14.43 rad/s ↻. (*b*) 4.4 m/s ∠ 55.4°.
**15.66** (*a*) 35 rad/s ↺. (*b*) 0.203 m above *D*.
**15.69** $\mathbf{v}_B = 44.4$ m/s →; $\mathbf{v}_C = 0$; $\mathbf{v}_D = 42.9$ m/s ∠ 15°;
$\mathbf{v}_E = 31.4$ m/s ⦣ 45°.
**15.70** (*a*) $\mathbf{v}_B = 0.43$ m/s ←; $\omega_{AB} = 0$. (*b*) $\mathbf{v}_B = 0.896$ m/s ←;
$\omega_{AB} = 2.37$ rad/s ↻.
**15.71** Vertical line intersecting *zx* plane at $x = 0$, $z = 2.65$ m.
**15.72** (*a*) 0.5 m to the right of *A*. (*b*) 0.1667 m/s ↑.
**15.73** (*a*) *Gear A:* 0.375 m left of A; *Gear C:* 0.75 m left of C.
(*b*) $\omega_A = 4$ rad/s ↻; $\omega_C = 2$ rad/s ↺.
**15.74** (*a*) 6 rad/s ↺. (*b*) 0.76 m/s ←. (*c*) 0.61 m/s, wound.
**15.75** (*a*) 42.9 mm below *A*. (*b*) 22.5 m/s →.
(*c*) 15.95 m/s ∠ 41.2°.
**15.76** (*a*) 33.3 mm above *A*. (*b*) 25.5 m/s →.
(*c*) 18.06 m/s ⦣ 48.4°.
**15.79** (*a*) 4.27 rad/s ↻. (*b*) 1.330 m/s ↓. (*c*) 1.557 m/s ∠ 34.7°.
**15.80** (*a*) 12 rad/s ↺. (*b*) 3.9 m/s ⦤ 67.4°

**15.81** (*a*) 31.5 rad/s ↻. (*b*) 18 rad/s ↺. (*c*) 4.57 m/s ∠ 30°.
**15.82** (*a*) 16.1 rad/s ↺. (*b*) 9.36 rad/s ↻. (*c*) 9.36 rad/s ↻.
**15.85** (*a*) 0.9 m. (*b*) 10.8 m/s ↓.
**15.86** (*a*) 3 rad/s ↺. (*b*) 1.559 m/s ↑.
**15.87** (*a*) 2.55 m/s ∠ 45°. (*b*) 2.57 rad/s ↻. (*c*) 2 m/s ∠ 20°.
**15.88** (*a*) 8 rad/s ↻. (*b*) 41.6 rad/s ↺. (*c*) 6.48 m/s ∠ 19.10°.
**15.91** (*a*) 1.5 m/s ↑. (*b*) 1.25 rad/s ↺.
**15.92** (*a*) $\omega_{AB}$ = 1.023 rad/s ↺; $\omega_{BD}$ = 0.341 rad/s ↻. (*b*) 0.086 m/s →.
**15.93** (*a*) 2.49 rad/s ↺. (*b*) 3.73 rad/s ↻. (*c*) 0.835 m/s ∠ 53.6°.
**15.94** (*a*) 4.8 rad/s ↻. (*b*) 8 rad/s ↺. (*c*) 1.5 m/s ∠ 53.1°.
**15.97** *Space centrode:* Lower rack. *Body centrode:* Circumference of gear.
**15.98** *Space centrode:* Quarter circle of 300-mm radius centered at intersection of tracks. *Body centrode:* Semicircle of 150-mm radius with center on rod *AB* equidistant from *A* and *B*.
**15.103** (*a*) 3.66 m/s$^2$ ←. (*b*) 4.58 m/s$^2$ ←.
**15.104** (*a*) 3.66 m/s$^2$ →. (*b*) 10.08 m/s$^2$ →.
**15.105** (*a*) 16 rad/s$^2$ ↺. (*b*) 7.2 m/s$^2$ ∠ 60°. (*c*) 12.47 m/s$^2$ ↓.
**15.106** (*a*) 5.4 m/s$^2$ ←. (*b*) 5.4 m/s$^2$ ∠ 60°; (*c*) 9.35 m/s$^2$ ↑.
**15.109** (*a*) 2 rad/s$^2$ ↻. (*b*) 0.224 m/s$^2$ ∠ 63.4°.
**15.110** $x = -0.1464$ m, $y = -0.1098$ m.
**15.111** (*a*) 1.37 m/s$^2$ ∠ 33.7°. (*b*) 3.27 m/s$^2$ ∠ 35.5°. (*c*) 3.04 m/s$^2$ ↑.
**15.112** (*a*) 267 mm/s$^2$ ∠ 61.0°. (*b*) 252 mm/s$^2$ ∠ 64.0°.
**15.115** $\mathbf{a}_C$ = 0.57 m/s$^2$ ∠ 58.0°; $\mathbf{a}_D$ = 0.6 m/s$^2$ ∠ 66.0°.
**15.116** 1.02 m/s$^2$ ∠ 33.6°.
**15.117** (*a*) 28.8 rad/s$^2$ ↺. (*b*) 17.28 rad/s$^2$ ↻.
**15.118** (*a*) 3 rad/s$^2$ ↺. (*b*) 3 rad/s$^2$ ↻.
**15.119** 151.4 m/s$^2$ ↓.
**15.120** 301.56 m/s$^2$ ↑.
**15.121** (*a*) 24.4 m/s$^2$ ←. (*b*) 19.86 m/s$^2$ ← .
**15.122** (*a*) 4.83 m/s$^2$ ←. (*b*) 8.05 m/s$^2$ ∠ 72.5°.
**15.125** (*a*) 57.7 rad/s$^2$ ↺. (*b*) 28.9 rad/s$^2$ ↻.
**15.126** (*a*) 24.8 rad/s$^2$ ↺. (*b*) 30.6 rad/s$^2$ ↻.
**15.127** (*a*) 227 rad/s$^2$ ↺. (*b*) 100 rad/s$^2$ ↻.
**15.128** (*a*) 42 m/s$^2$ ∠ 78.6°. (*b*) 62 m/s$^2$ ∠ 19.5°.
**15.129** (*a*) 4 rad/s ↺. (*b*) 24 rad/s$^2$ ↺. (*c*) 10 m/s$^2$ ↑.
**15.131** (*a*) 11.10 rad/s$^2$ ↻. (*b*) 4.53 rad/s$^2$ ↻.
**15.137** $b\omega\left\{\sin\theta - \dfrac{b(1+\sin\theta)\cos\theta}{\sqrt{l^2 - b^2(1+\sin\theta)^2}}\right\}\downarrow$.
**15.138** $\omega^2\left\{\dfrac{b^3\cos^2\theta(1+\sin\theta)}{\left[l^2 - b^2(1+\sin\theta)^2\right]^{3/2}} - \dfrac{b\sin\theta}{\left[l^2 - b^2(1+\sin\theta)^2\right]^{1/2}}\right\}$ ↻.
**15.140** $\omega = \dfrac{bv_A}{b^2 + x_A^2}$ ↺; $\alpha = \dfrac{2bx_Av_A^2}{(b^2+x_A^2)^2}$ ↺.
**15.141** $(v_B)_x = v_A - \dfrac{lb^2v_A}{(b^2+x_A^2)^{3/2}}$ →; $(v_B)_y = \dfrac{lbx_Av_A}{(b^2+x_A^2)^{3/2}}$ ↑.
**15.144** $\omega_{BD} = \dfrac{\omega b(b + l\cos\theta)}{l^2 + b^2 + 2bl\cos\theta}$ ↻;
$\mathbf{v}_E = \dfrac{\omega bl\sin\theta}{\sqrt{l^2 + b^2 + 2bl\cos\theta}}$ ∠ $\tan^{-1}\left(\dfrac{b\sin\theta}{l + b\cos\theta}\right)$.
**15.145** $\dfrac{\omega^2 bl(l^2 - b^2)\sin\theta}{(l^2 + b^2 + 2bl\cos\theta)^2}$ ↺.
**15.146** $\mathbf{v}_P = r\omega\left[\cos\dfrac{r\omega t}{R-r} - \cos\omega t\right]\mathbf{i} + r\omega\left[\sin\dfrac{r\omega t}{R-r} + \sin\omega t\right]\mathbf{j}$.
**15.147** $\mathbf{v} = (R\omega\sin\omega t)\mathbf{j}$; $\mathbf{a} = (R\omega^2\cos\omega t)\mathbf{j}$ .
**15.148** (*a*) 5.16 rad/s ↻. (*b*) 1.340 m/s ∠ 60°.
**15.149** 1167 mm/s ∠ 51.8°.
**15.150** (*a*) $\omega_{BD}$ = 3.81 rad/s ↻; $\mathbf{v}_{P/BD}$ = 8.3 m/s ∠ 16.26°. (*b*) $\omega_{BD}$ = 3.00 rad/s ↻; $\mathbf{v}_{P/BD}$ = 5.08 m/s →.
**15.151** $\omega_{BD}$ = 3.82 rad/s ↻; $\mathbf{v}_{P/BD}$ = 7.7 m/s ∠ 10.49°.
**15.152** (*a*) 11.25 rad/s ↺. (*b*) 1.875 m/s →.
**15.153** (*a*) 13.33 rad/s ↺. (*b*) 0.625 m/s →.
**15.158** $\mathbf{a}_1 = r\omega^2\,\mathbf{i} - 2u\omega\,\mathbf{j}$; $\mathbf{a}_2 = 2u\omega\,\mathbf{i} - r\omega^2\,\mathbf{j}$; $\mathbf{a}_3 = -(r\omega^2 + u^2/r + 2u\omega)\mathbf{i}$; $\mathbf{a}_4 = (r\omega^2 + 2u\omega)\mathbf{j}$.
**15.159** $\mathbf{a}_1 = r\omega^2\mathbf{i} + 2u\omega\mathbf{j}$; $\mathbf{a}_2 = -2u\omega\mathbf{i} - r\omega^2\mathbf{j}$; $\mathbf{a}_3 = (-r\omega^2 - u^2/r + 2u\omega)\mathbf{i}$; $\mathbf{a}_4 = (r\omega^2 - 2u\omega)\mathbf{j}$.
**15.160** (*a*) 54 rad/s$^2$ ↻. (*b*) 10 m/s$^2$ ∠ 45°.
**15.161** (*a*) 38.8 rad/s$^2$ ↻. (*b*) 12 m/s$^2$ ↑.
**15.162** 0.025 m/s$^2$ to left of sled.
**15.164** (*a*) $\mathbf{v}_P$ = 4.42 m/s ∠ 35.8°; $\mathbf{a}_P$ = 27 m/s$^2$ ∠ 72.0°. (*b*) $\mathbf{v}_D$ = 3.57 m/s ←; $\mathbf{a}_D$ = 52.46 m/s$^2$ ∠ 36.8°.
**15.165** (*a*) $\omega_{PD}$ = 20.8 rad/s ↺; $\omega_{DE}$ = 2.2 rad/s ↺. (*b*) $\alpha_{PD}$ = 76.65 rad/s$^2$ ↻; $\alpha_{DE}$ = 272.5 rad/s$^2$ ↺.
**15.166** (*a*) 1.702 m/s$^2$ ∠ 21.5°. (*b*) 2.55 m/s$^2$ ∠ 3.24°.
**15.167** (*a*) 2.38 m/s$^2$ ∠ 48.3°. (*b*) 1.438 m/s$^2$ ∠ 64.3°.
**15.170** (*a*) 2.32 m/s$^2$ ↑. (*b*) 11.94 m/s$^2$ ∠ 37.1°. (*c*) 16.72 m/s$^2$ ↓.
**15.172** (*a*) 0.436 rad/s ↺. (*b*) 0.271 rad/s$^2$ ↺.
**15.173** (*a*) 0.354 rad/s ↺. (*b*) 0.125 rad/s$^2$ ↺.
**15.174** (*a*) 8.3 rad/s$^2$ ↻. (*b*) 10.67 m/s$^2$ ∠ 16.26°.
**15.175** (*a*) 25.8 rad/s$^2$ ↺. (*b*) 60.58 m/s$^2$ ←.
**15.178** $\omega_S$ = 0.38 rad/s ↻; $\alpha_S$ = 4.5 rad/s$^2$ ↻.
**15.179** $\omega_S$ = 1.487 rad/s ↻; $\alpha_S$ = 59 rad/s$^2$ ↻.
**15.180** 11.43 m/s$^2$ ∠ 36.7°.
**15.181** 100 mm/s.
**15.182** (*a*) (30.3 rad/s)$\mathbf{i}$ − (40.4 rad/s)$\mathbf{k}$. (*b*) (4.4 m/s)$\mathbf{i}$ + (3.3 m/s)$\mathbf{k}$.
**15.183** (*a*) (40.4 rad/s)$\mathbf{i}$ − (30.3 rad/s)$\mathbf{k}$. (*b*) (3.3 m/s)$\mathbf{i}$ + (4.4 m/s)$\mathbf{k}$.
**15.184** −(20 rad/s$^2$)$\mathbf{i}$.
**15.185** −(14.80 rad/s$^2$)$\mathbf{k}$.
**15.188** (*a*) −(20 rad/s$^2$)$\mathbf{j}$. (*b*) −(0.96 m/s$^2$)$\mathbf{i}$ + (2.4 m/s$^2$)$\mathbf{k}$. (*c*) −(2.46 m/s$^2$)$\mathbf{j}$.
**15.189** −(0.831 m/s$^2$)$\mathbf{i}$ − (1.230 m/s$^2$)$\mathbf{j}$ + (2.08 m/s$^2$)$\mathbf{k}$.
**15.190** (*a*) −(0.1745 rad/s)$\mathbf{i}$ − (0.524 rad/s)$\mathbf{j}$. (*b*) −(0.0914 rad/s$^2$)$\mathbf{k}$. (*c*) $\mathbf{v}_P$ = −(1.675 m/s)$\mathbf{i}$ + (0.5584 m/s)$\mathbf{j}$ − (0.3228 m/s)$\mathbf{k}$; $\mathbf{a}_P$ = (0.338 m/s$^2$)$\mathbf{i}$ − (0.056 m/s$^2$)$\mathbf{j}$ − (0.9743 m/s$^2$)$\mathbf{k}$.
**15.191** (*a*) (20 rad/s)$\mathbf{i}$ − (7.5 rad/s)$\mathbf{j}$. (*b*) −(150 rad/s$^2$)$\mathbf{k}$. (*c*) −(5.7 m/s$^2$)$\mathbf{i}$ − (60.9 m/s$^2$)$\mathbf{j}$.
**15.192** $\omega_1^2 r\sin\theta\left(\dfrac{L}{r}\sin\theta - \cos\theta\right)\left[\left(\dfrac{L}{r}\cos\theta + \sin\theta\right)\mathbf{i} + \left(\dfrac{L}{r}\sin\theta - \cos\theta\right)\mathbf{j}\right]$.
**15.193** (*a*) $\omega_1/\sin\beta$. (*b*) $-(\omega_1/\tan\beta)\mathbf{i}$. (*c*) $(\omega_1^2/\tan\beta)\mathbf{k}$.
**15.196** (0.417 m/s)$\mathbf{j}$.
**15.197** −(1.2 m/s)$\mathbf{j}$.
**15.198** −(1.2 m/s)$\mathbf{i}$ − (0.8 m/s)$\mathbf{j}$.
**15.199** (0.45 m/s)$\mathbf{i}$ + (0.3 m/s)$\mathbf{j}$.
**15.202** −(0.333 m/s)$\mathbf{j}$.
**15.203** −(0.12 m/s)$\mathbf{j}$.
**15.204** $\omega_1/\cos 20°$.
**15.205** $\omega_1\cos 20°$.
**15.206** (*a*) (1.45 rad/s)$\mathbf{i}$ + (0.1563 rad/s)$\mathbf{j}$ + (0.1249 rad/s)$\mathbf{k}$. (*b*) −(0.065 m/s)$\mathbf{i}$.
**15.210** (1.45 m/s$^2$)$\mathbf{i}$ + (0.99 m/s$^2$)$\mathbf{j}$.
**15.211** (3.69 m/s$^2$)$\mathbf{i}$ + (2.48 m/s$^2$)$\mathbf{j}$.

**15.212** $-(0.01\ \text{m/s}^2)\mathbf{j}$.
**15.213** $-(0.011\ \text{m/s}^2)\mathbf{j}$.
**15.214** (*a*) $(1.83\ \text{m/s})\mathbf{i} + (0.762\ \text{m/s})\mathbf{j} - (1.218\ \text{m/s})\mathbf{k}$.
(*b*) $-(7.3\ \text{m/s}^2)\mathbf{i} - (21.96\ \text{m/s}^2)\mathbf{k}$.
**15.215** (*a*) $(0.685\ \text{m/s})\mathbf{i} + (1.186\ \text{m/s})\mathbf{j} - (2.2\ \text{m/s})\mathbf{k}$.
(*b*) $-(26.67\ \text{m/s}^2)\mathbf{i} + (2.7\ \text{m/s}^2)\mathbf{j} - (13.7\ \text{m/s}^2)\mathbf{k}$.
**15.216** (*a*) $(0.48\ \text{m/s})\mathbf{i} + (1.5\ \text{m/s})\mathbf{j} + (2.64\ \text{m/s})\mathbf{k}$.
(*b*) $-(22.8\ \text{m/s}^2)\mathbf{j} + (15\ \text{m/s}^2)\mathbf{k}$.
**15.217** (*a*) $-(1.125\ \text{m/s})\mathbf{i} + (0.915\ \text{m/s})\mathbf{j} - (0.78\ \text{m/s})\mathbf{k}$.
(*b*) $-(7.28\ \text{m/s}^2)\mathbf{i} - (6.75\ \text{m/s}^2)\mathbf{j}$.
**15.220** (*a*) $(0.493\ \text{m/s})\mathbf{i} + (1.353\ \text{m/s})\mathbf{j} - (1.015\ \text{m/s})\mathbf{k}$.
(*b*) $-(8.46\ \text{m/s}^2)\mathbf{i} + (1.970\ \text{m/s}^2)\mathbf{j} - (2.96\ \text{m/s}^2)\mathbf{k}$.
**15.221** (*a*) $(1.033\ \text{m/s})\mathbf{i} + (1.353\ \text{m/s})\mathbf{j} - (1.015\ \text{m/s})\mathbf{k}$.
(*b*) $-(8.46\ \text{m/s}^2)\mathbf{i} + (1.970\ \text{m/s}^2)\mathbf{j} - (4.58\ \text{m/s}^2)\mathbf{k}$.
**15.222** (*a*) $(0.48\ \text{m/s})\mathbf{i} + (1.5\ \text{m/s})\mathbf{j} + (2.64\ \text{m/s})\mathbf{k}$.
(*b*) $(2.4\ \text{m/s}^2)\mathbf{i} - (25.1\ \text{m/s}^2)\mathbf{j} + (8.7\ \text{m/s}^2)\mathbf{k}$.
**15.223** (*a*) $-(1.125\ \text{m/s})\mathbf{i} + (0.915\ \text{m/s})\mathbf{j} - (0.78\ \text{m/s})\mathbf{k}$.
(*b*) $-(7.58\ \text{m/s}^2)\mathbf{i} - (9.6\ \text{m/s}^2)\mathbf{j} + (5.2\ \text{m/s}^2)\mathbf{k}$.
**15.224** (*a*) $-(1.54\ \text{m/s})\mathbf{i} - (1.368\ \text{m/s})\mathbf{j} + (2.05\ \text{m/s})\mathbf{k}$.
(*b*) $(32.3\ \text{m/s}^2)\mathbf{i} - (31.6\ \text{m/s}^2)\mathbf{j} - (26.66\ \text{m/s}^2)\mathbf{k}$.
**15.225** (*a*) $\omega_1 \sin\theta\left[\left(\cos\theta - \frac{L}{r}\sin\theta\right)\mathbf{i} + \left[\left(\sin\theta + \frac{L}{r}\cos\theta\right)\mathbf{j}\right]\right.$.
(*b*) $\omega_1^2 \sin\theta\left(\frac{L}{r}\sin\theta - \cos\theta\right)\mathbf{k}$.
**15.226** (*a*) $(\omega_1 - \omega_2)\left(\cos\theta - \frac{L}{r}\sin\theta\right)(\sin\theta\,\mathbf{i} - \cos\theta\,\mathbf{j}) + \omega_1\,\mathbf{j}$.
(*b*) $\omega_1(\omega_1 - \omega_2)\left(\frac{L}{r}\sin\theta - \cos\theta\right)\mathbf{k}$.
**15.229** $\mathbf{v}_B = (1.299\ \text{m/s})\mathbf{i} - (1.853\ \text{m/s})\mathbf{j} + (1.590\ \text{m/s})\mathbf{k}$;
$\mathbf{a}_B = (0.795\ \text{m/s}^2)\mathbf{i} - (0.792\ \text{m/s}^2)\mathbf{j} - (0.976\ \text{m/s}^2)\mathbf{k}$.
**15.230** $\mathbf{v}_A = (0.0905\ \text{m/s})\mathbf{i} + (3.55\ \text{m/s})\mathbf{j} - (3.55\ \text{m/s})\mathbf{k}$;
$\mathbf{a}_A = -(5.68\ \text{m/s}^2)\mathbf{i} - (111.7\ \text{m/s}^2)\mathbf{j} - (111.7\ \text{m/s}^2)\mathbf{k}$.
**15.231** $\mathbf{v}_A = -(1.4\ \text{m/s})\mathbf{i} + (0.8\ \text{m/s})\mathbf{j} - (1.2\ \text{m/s})\mathbf{k}$;
$\mathbf{a}_A = -(21.08\ \text{m/s}^2)\mathbf{i} - (11.2\ \text{m/s}^2)\mathbf{j} + (33.6\ \text{m/s}^2)\mathbf{k}$.
**15.232** $\mathbf{v}_A = -(1.4\ \text{m/s})\mathbf{i} + (0.8\ \text{m/s})\mathbf{j} - (1.2\ \text{m/s})\mathbf{k}$;
$\mathbf{a}_A = -(22.56\ \text{m/s}^2)\mathbf{i} - (10.18\ \text{m/s}^2)\mathbf{j} + (35.2\ \text{m/s}^2)\mathbf{k}$.
**15.235** $\mathbf{v}_A = -(6.35\ \text{m/s})\mathbf{i} - (1.5\ \text{m/s})\mathbf{k}$;
$\mathbf{a}_A = -(12\ \text{m/s}^2)\mathbf{i} - (32.9\ \text{m/s}^2)\mathbf{j} + (72.8\ \text{m/s}^2)\mathbf{k}$.
**15.236** $\mathbf{v}_B = -(0.85\ \text{m/s})\mathbf{i} - (1.5\ \text{m/s})\mathbf{k}$;
$\mathbf{a}_B = -(12\ \text{m/s}^2)\mathbf{i} + (32.9\ \text{m/s}^2)\mathbf{j} - (15.2\ \text{m/s}^2)\mathbf{k}$.
**15.237** $\mathbf{v}_A = (60\ \text{mm/s})\mathbf{i} - (36\ \text{mm/s})\mathbf{j}$;
$\mathbf{a}_A = -(270\ \text{mm/s}^2)\mathbf{i} + (180\ \text{mm/s}^2)\mathbf{j} + (172.8\ \text{mm/s}^2)\mathbf{k}$.
**15.238** $\mathbf{v}_A = (180\ \text{mm/s})\mathbf{i} - (156\ \text{mm/s})\mathbf{j} + (144\ \text{mm/s})\mathbf{k}$;
$\mathbf{a}_A = (180\ \text{mm/s}^2)\mathbf{i} - (443\ \text{mm/s}^2)\mathbf{j} - (115.2\ \text{mm/s}^2)\mathbf{k}$.
**15.241** (*a*) $(544\ \text{mm/s}^2)\mathbf{i} - (135\ \text{mm/s}^2)\mathbf{j}$.
(*b*) $(256\ \text{mm/s}^2)\mathbf{i} - (153.6\ \text{mm/s}^2)\mathbf{k}$.
**15.242** (*a*) $-(32\ \text{mm/s}^2)\mathbf{i} + (135\ \text{mm/s}^2)\mathbf{j}$.
(*b*) $(256\ \text{mm/s}^2)\mathbf{i} + (153.6\ \text{mm/s}^2)\mathbf{k}$.
**15.243** $\mathbf{v}_C = -(0.6\ \text{m/s})\mathbf{i} - (1.6\ \text{m/s})\mathbf{j} + (2\ \text{m/s})\mathbf{k}$.
$\mathbf{a}_C = (9.6\ \text{m/s}^2)\mathbf{i} + (13.6\ \text{m/s}^2)\mathbf{j} + (8\ \text{m/s}^2)\mathbf{k}$.
**15.244** (*a*) $v_C = 6.38$ m/s, $a_C = 1602.5\ \text{m/s}^2$.
(*b*) $v_C = 0.638$ m/s, $a_C = 16\ \text{m/s}^2$.
**15.246** $\omega_{AB} = 42.4$ rad/s ↻; $\omega_{BD} = 30$ rad/s ↺;
$\omega_{DE} = 33.9$ rad/s ↻.
**15.247** (*a*) 3 rad/s ↻. (*b*) 180 mm/s →. (*c*) unwound 300 mm/s.
**15.249** $\mathbf{a}_A = 54\ \text{m/s}^2$ ⦩ 88°; $\mathbf{a}_B = 53.1\ \text{m/s}^2$ ⦨ 0.98°;
$\mathbf{a}_C = 54\ \text{m/s}^2$ ↑.
**15.251** 2.40 m/s ⦩ 73.9°.
**15.252** $\mathbf{a}_1 = 0.381\ \text{m/s}^2$ →; $\mathbf{a}_2 = 0.213\ \text{m/s}^2$ ⦨ 57.7°.
**15.254** (*a*) $(0.3\ \text{m/s})\mathbf{i} + (0.520\ \text{m/s})\mathbf{j} + (0.48\ \text{m/s})\mathbf{k}$.
(*b*) $-(2.60\ \text{m/s}^2)\mathbf{i} - (2.34\ \text{m/s}^2)\mathbf{j} + (8.31\ \text{m/s}^2)\mathbf{k}$.

## CHAPTER 16

**16.1** (*a*) **A** = 295 N ⦣ 85.2°; **B** = 145.0 N ←. (*b*) 0.0848.
**16.2** (*a*) $5.66\ \text{m/s}^2$ →. (*b*) 0.577.
**16.3** (*a*) $4.9\ \text{m/s}^2$.
(*b*) **A** = 0.242 N ⦨ 60°; **C** = 7 N ⦣ 60°.
**16.4** (*a*) 18.43°. (*b*) $3.1\ \text{m/s}^2$ ⦩ 18.43°.
**16.5** (*a*) 11.0 m (*b*) 12.7 m.
**16.6** (*a*) $7.85\ \text{m/s}^2$. (*b*) $3.74\ \text{m/s}^2$. (*c*) $4.06\ \text{m/s}^2$.
**16.7** (*a*) $0.419g$ (*b*) 3.33
**16.8** (*a*) $0.295g$ (*b*) 3.33
**16.11** (*a*) $4.9\ \text{m/s}^2$ ⦩ 30°. (*b*) $F_{AC} = 0$; $F_{BD} = 61.14$ NC.
**16.12** (*a*) $8.5\ \text{m/s}^2$ ⦩ 60°. (*b*) 10 N ↑.
**16.13** (*a*) $1.572\ \text{m/s}^2$. (*b*) 20.8 N.
**16.14** (*a*) 1.629 N · m. (*b*) 18.04 N.
**16.17** *Just above B:* $|V| = 15.3$ N, $|M| = 3.516$ N · m.
**16.18** $V_B = -194.0$ N; $|M|_{\max} = 36.4$ N · m.
**16.21** (*a*) 12.77 N · m. (*b*) $t = 658$ s.
**16.22** (*a*) 0.327 m (*b*) 11 250 rev.
**16.23** 127.9 N.
**16.24** 74.5 s.
**16.25** (*a*) $2.25\ \text{rad/s}^2$ ↻. (*b*) 77.2 N *C*.
**16.26** (*a*) 13.68 N · m. (*b*) 176.4 N ⦪ 44.0°.
**16.29** $27.57\ \text{N} \cdot \text{m} \cdot \text{s}^2$.
**16.30** $\alpha_A = 22.5\ \text{rad/s}^2$ ↺; $\alpha_B = 15.00\ \text{rad/s}^2$ ↺.
**16.31** (*a*) $11.87\ \text{rad/s}^2$ ↺. (*b*) $T_A = 38.74$ N, $T_B = 27.7$ N.
**16.32** (*a*) $\alpha_A = 9.05\ \text{rad/s}^2$ ↻; $\alpha_B = 13.5\ \text{rad/s}^2$ ↺.
(*b*) 1.85 N ↓.
**16.33** (*a*) $\alpha_A = 13.42\ \text{rad/s}^2$ ↺; $\alpha_B = 30.14\ \text{rad/s}^2$ ↻.
(*b*) 8.3 N ↓.
**16.34** (*a*) $\alpha_A = 15.3\ \text{rad/s}^2$ ↻; $\alpha_B = 15.3\ \text{rad/s}^2$ ↺. (*b*) 0.4875.
**16.35** (*a*) $\alpha_A = 20.8\ \text{rad/s}^2$ ↻; $\alpha_B = 28.7\ \text{rad/s}^2$ ↺.
**16.36** $\dfrac{2\mu_k g \sin\phi}{r(\sin 2\phi - \mu_k \cos 2\phi)}$ ↺.
**16.37** $(2g/r)\sin\phi$ ↺.
**16.40** (*a*) $\alpha_A = 13.5\ \text{rad/s}^2$ ↺; $\alpha_B = 3.2\ \text{rad/s}^2$ ↺.
(*b*) $\omega_A = 897$ rpm ↺; $\omega_B = 538$ rpm ↻.
**16.43** (*a*) $2.47\ \text{m/s}^2$. (*b*) 0.
**16.45** (*a*) $2.67\ \text{m/s}^2$ →. (*b*) $1.333\ \text{m/s}^2$ ←.
**16.46** (*a*) $\boldsymbol{\alpha} = -(1.200\ \text{rad/s}^2)\mathbf{j}$; $\mathbf{a}_G = 0$;
(*b*) $\boldsymbol{\alpha} = -(0.900\ \text{rad/s}^2)\mathbf{j}$; $\mathbf{a}_G = -(0.1350\ \text{m/s}^2)\mathbf{i}$.
**16.47** (*a*) $0.8148\ \text{m/s}^2$. (*b*) $2.28\ \text{m/s}^2$.
**16.48** (*a*) $(1.3\ \text{m/s}^2)\mathbf{i} - (1.085\ \text{m/s}^2)\mathbf{k}$
(*b*) $(1.3\ \text{m/s}^2)\mathbf{i} + (1.085\ \text{m/s}^2)\mathbf{k}$.
**16.50** (*a*) $0.690\ \text{rad/s}^2$ ↺. (*b*) $0.136\ \text{m/s}^2$ ↑.
**16.51** (*a*) 3108 N. (*b*) $0.32\ \text{rad/s}^2$ ↺.
**16.52** $\mathbf{a}_A = 2.71\ \text{m/s}^2$ ↑; $\mathbf{a}_B = 1.496\ \text{m/s}^2$ ↑.
**16.53** 170.9 mm.
**16.56** (*a*) $11\ \text{rad/s}^2$ ↺. (*b*) $3.92\ \text{m/s}^2$ ⦨ 32.6°.
**16.57** (*a*) $10\ \text{rad/s}^2$ ↺. (*b*) $3.50\ \text{m/s}^2$ ⦨ 31.1°.
**16.58** (*a*) $3g/2L$ ↻. (*b*) $g/4$ ↑. (*c*) $5g/4$ ↓.
**16.59** (*a*) $2g/L$ ↻. (*b*) $g/3$ ↑. (*c*) $5g/3$ ↓.
**16.60** (*a*) $3g/L$ ↻. (*b*) $1.323g$ ⦣ 49.1°. (*c*) $2.18g$ ⦩ 66.6°.
**16.61** (*a*) $g/4$ ↑. (*b*) $5g/4$ ↓.
**16.62** (*a*) 0. (*b*) $g$ ↓.
**16.64** (*a*) $5v_0/2r$. (*b*) $v_0/\mu_k g$. (*c*) $v_0^2/2\mu_k g$.
**16.65** (*a*) 1.718 s. (*b*) 3.31 m/s. (*c*) 7.14 m.
**16.66** (*a*) 1.980 s. (*b*) 3.06 m/s. (*c*) 7.98 m.
**16.67** (*a*) $2v_1/7\mu_k g$. (*b*) $\mathbf{v} = 2v_1/7$ →; $\omega = 5v_1/7r$ ↺.
**16.71** (*a*) $11.36\ \text{rad/s}^2$ ↻. (*b*) $\mathbf{C}_x = 54.9$ N ←; $\mathbf{C}_y = 44.5$ N ↑.
**16.72** (*a*) 0.152 m (*b*) $96.53\ \text{rad/s}^2$ ↻.
**16.73** (*a*) $11.67\ \text{rad/s}^2$ ↻. (*b*) $\mathbf{A}_x = 1.75$ N ←; $\mathbf{A}_y = 9.81$ N ↑.

**16.74** (*a*) 600 mm. (*b*) 7.78 rad/s² ↻.
**16.77** 505 N →.
**16.78** (*a*) **M** = 0.0687 N · m ↺; **R** = 5.12 N ⦩ 71.5°. (*b*) **M** = 0; **R** = 6.11 N ↑.
**16.79** (*a*) $mg/4$ ↑. (*b*) $3g/2$ ↓.
**16.80** (*a*) $L/3$. (*b*) $g/2$ ↑; 3 $mg/4$ ↑.
**16.81** (*a*) $-(24g/19)\mathbf{j}$. (*b*) $-(4g/19)[(4/\pi)\mathbf{i} + 3\mathbf{j}]$.
**16.82** (*a*) $3g/4L$ ↺. (*b*) $T_{AE} = mg/2$, $T_{BF} = 3\,mg/8$.
**16.84** (*a*) 4 rad/s² ↻. (*b*) 6.4 N.
**16.85** (*a*) 10.8 rad/s² ↻. (*b*) 5.56 N · m.
**16.89** 604 mm.
**16.90** $\tan\beta = \mu_s[1 + (r/\bar{k})^2]$.
**16.91** (*a*) 6.12 m. (*b*) 1.748 m.
**16.92** (*a*) 2.4 m/s² ⦟ 15°. (*b*) 0.1264.
**16.93** (*a*) 15.4 rad/s² ↻; 3.126 m/s² →. (*b*) 0.18.
**16.94** (*a*) 23.2 rad/s² ↻; 4.7 m/s² →. (*b*) 0.02.
**16.95** (*a*) 7.76 rad/s² ↻; 1.575 m/s² →. (*b*) 0.338.
**16.96** (*a*) 7.76 rad/s² ↺; 1.575 m/s² ←. (*b*) 0.32.
**16.97** (*a*) Does not slide. (*b*) 16 rad/s² ↻; 2.56 m/s² →.
**16.98** (*a*) Does not slide. (*b*) 24 rad/s² ↻; 3.84 m/s² →.
**16.101** (*a*) 7.5 m/s² ↙ 45°. (*b*) 1.87 N ↓.
**16.102** (*a*) 7.25 m/s² ↙ 45°. (*b*) 1.435 N ↙ 45°.
**16.103** (*a*) 72.4 rad/s² ↻. (*b*) 7.24 m/s² ↓.
**16.104** (*a*) 72.4 rad/s² ↺. (*b*) 7.24 m/s² ↓.
**16.105** $\dfrac{25g\sin\theta}{26r}$ ↺.
**16.106** $\dfrac{2(3\pi - 4)g\sin\theta}{(9\pi - 16)r}$ ↺.
**16.107** (*a*) 0.688 $P/mr$ ↻. (*b*) 0.25 $P/(mg + P)$.
**16.108** (*a*) 0.1843 $P/mr$ ↻. (*b*) 0.933 $P/mg$.
**16.111** (*a*) 11.56 rad/s² ↻. (*b*) 25 N (*c*) 41.7 N ↑.
**16.112** (*a*) 6.28 rad/s² ↻. (*b*) 43 N.
**16.113** (*a*) 31.4 rad/s² ↻. (*b*) 5.71 N ←.
**16.114** 27.5 rad/s² ↻.
**16.117** 34.28 N →.
**16.118** 22.7 N →.
**16.119** 25.9 N ⦩ 60°.
**16.120** 15.01 N ⦨ 60°.
**16.121** 57.0 N ⦩ 60°.
**16.124** 2.62 rad/s ↻.
**16.125** 1.164 m/s² →.
**16.126** 35.2 N ↙ 30°.
**16.127** 13.57 N ↙ 30°.
**16.128** (*a*) 24.8 rad/s² ↻. (*b*) 1.32 N ↑.
**16.129** (*a*) 26.4 N · m. (*b*) 3.67 N ↑.
**16.130** **A** = 8.13 N ↑; **B** = 8.61 N ↑.
**16.131** $\mathbf{A}_x$ = 3.24 N →; $\mathbf{A}_y$ = 9.81 N ↑; $\mathbf{B}_x$ = 1.08 N ←; $\mathbf{B}_y$ = 9.81 N ↑.
**16.134** $\alpha_{AB}$ = 26.1 rad/s² ↻; $\alpha_{BD}$ = 26.1 rad/s² ↺; $\alpha_{DE}$ = 26.1 rad/s² ↺.
**16.135** (*a*) 9.34 rad/s² ↻. (*b*) 9.93 m/s² ⦨ 20°. (*c*) 27.3 N ⦟ 70°.
**16.136** (*a*) 50.2 N ⦟ 60.3°. (*b*) 0.273.
**16.137** (*a*) $\alpha_A = 2g/5r$ ↺; $\alpha_B = 2g/5r$ ↻. (*b*) $mg/5$. (*c*) $4g/5$ ↓.
**16.138** $\mathbf{a}_A = 2P/7m$ →; $\mathbf{a}_B = 22P/7m$ ←.
**16.139** $\alpha_{AB}$ = 11.04 rad/s² ↻; $\alpha_{BC}$ = 55.2 rad/s² ↺
**16.140** (*a*) 0.29 m (*b*) 7.03 rad/s² ↺.
**16.143** Just to the right of *A*, $V = mg/4$; $L/3$ to the right of *A*, $M = mgL/27$.
**16.144** (*a*) 29 N ←. (*b*) $F_{CF} = F_{BE}$ = 94 N *T*.
**16.145** 125.2 rev.
**16.146** (*a*) $\alpha_A$ = 10.23 rad/s² ↺; $\alpha_B$ = 28.1 rad/s² ↺. (*b*) $\omega_A$ = 320 rpm ↻; $\omega_B$ = 440 rpm ↺.
**16.148** $T_A$ = 955.5 N, $T_B$ = 932.8 N.
**16.150** (*a*) $45g/26$ ↓. (*b*) $25mg/52$ ↑.
**16.151** $\dfrac{r^2 g\sin\beta}{(r^2 + \bar{k}^2)}$.
**16.153** (*a*) 6.30 rad/s² ↺. (*b*) 37.4 N ⦩ 30°.
**16.154** 98.7 N ↑.

## CHAPTER 17

**17.1** 8798 rev.
**17.2** 12.77 N · m.
**17.3** (*a*) 29.4 kg · m² . (*b*) 13.27 rev.
**17.4** (*a*) 0.3268 m (*b*) 11 204 rev.
**17.5** $\theta_A = \dfrac{3r\omega_0^2}{32\pi\mu_k g}$ rev ↻; $\theta_B = \dfrac{r\omega_0^2}{32\pi\mu_k g}$ rev ↺.
**17.6** (*a*) $\omega_A$ = 25 rad/s ↻; $\omega_B$ = 25 rad/s ↺. (*b*) 0.380.
**17.7** 0.24 m
**17.8** 1.260*L*.
**17.9** (*a*) 2.93 m/s ↓. (*b*) 2.36 m.
**17.10** 317 N ↓.
**17.11** 365 N ↓.
**17.14** (*a*) $l/\sqrt{12}$. (*b*) $\omega = 1.861\sqrt{g/l}$; **C** = 2*mg* ↑.
**17.15** (*a*) 6.10 rad/s ↻. (*b*) 4 rad/s ↻.
**17.16** (*a*) 54.0° (*b*) $0.767\sqrt{gr}$ ⦨ 54.0°.
**17.17** 6.8 rad/s.
**17.20** $\sqrt{4gs/3}$ ↓.
**17.21** (*a*) 3.16 m/s →. (*b*) 33.3 N ←.
**17.22** (*a*) $1.142\sqrt{g/r}$ ↻. (*b*) 1.553 *mg* ↑.
**17.23** $0.392\sqrt{g/r}$.
**17.26** (*a*) 8.9 rad/s ↻. (*b*) 21.7 rad/s ↺.
**17.27** 1.497 N · m.
**17.29** $\mathbf{v}_A = 0.775\sqrt{gL}$ ←; $\mathrm{v}_B = 0.775\sqrt{gL}$ ↙ 60°
**17.30** 4.65 m/s →.
**17.31** 806 N/m.
**17.32** 1.35 rad/s ↻.
**17.33** 0.99 rad/s ↺.
**17.36** 0.490 J.
**17.37** 3.87 m/s →.
**17.38** 1.1 m/s ←.
**17.39** (*a*) 33.0 kW. (*b*) 88.0 kW.
**17.40** (*a*) 1.471 kW. (*b*) 2.02 kW.
**17.41** 1157 rpm.
**17.42** 258.2 N · m/s
**17.43** 2.1 N · m
**17.44** (*a*) 320 mm. (*b*) 11.2 min.
**17.45** 17 rad/s ↻.
**17.46** 33.5 N · m
**17.47** 7.72 s.
**17.48** $\dfrac{v}{2g\mu_k}$.
**17.49** 3.82 s.
**17.50** $\dfrac{2r\omega_0(1 + \mu_k^2)}{5g\mu_k(1 + \mu_k)}$
**17.51** $\left(\dfrac{M}{mr^2} - \dfrac{2\mu_k g}{r}\right)t$ ↺.
**17.52** $\omega_A$ = 230.2 rad/s ↻; $\omega_B$ = 96.2 rad/s ↺.
**17.55** (*a*) 22.9 N. (*b*) 8.75 N.

**17.56** $m\bar{\mathbf{v}}$; $\bar{k}^2\omega/\bar{v}$.
**17.60** 0.850 m.
**17.61** (*a*) 28.5 rad/s ↺. (*b*) 40.9 N · s ⦣ 30°.
**17.62** (*a*) $\frac{1}{2}gt\downarrow$. (*b*) $\frac{2}{3}gt\downarrow$.
**17.63** (*a*) 4.57 m/s →. (*b*) 0.152 m/s →.
**17.66** $P_A = 5.25$ N, $P_B = 9$ N.
**17.67** (*a*) Pipe rolls without sliding.
(*b*) *Pipe:* 0.857 m/s →; *Plate:* 1.714 m/s →.
**17.68** (*a*) $\frac{2r\omega_0}{7\mu_k g}$. (*b*) $\mathbf{v} = 2r\omega_0/7$ →; $\omega = 2\omega_0/7$ ↻.
**17.69** (*a*) $5\bar{v}_0/2r$. (*b*) $\bar{v}_0/\mu_k g$.
**17.70** $5\omega_0/6$.
**17.71** (*a*) 2.54 rad/s. (*b*) 1.902 J.
**17.72** $\omega_A = \omega_B = 159.3$ rpm ↻; $\omega_P = 20.68$ rpm ↺.
**17.73** $\omega_{AB} = 71.23$ rpm ↺; $\omega_{DISK} = 288.77$ rpm ↺.
**17.74** (*a*) 5 rad/s. (*b*) 3.13 rad/s.
**17.75** $\omega_{BC} = 36.6$ rpm ↻; $\omega_A = 16.87$ rpm ↺.
**17.78** 2.51 m/s.
**17.79** (*a*) 15 rad/s. (*b*) 7.86 m/s.
**17.80** $\omega = 17.13$ rad/s, $I_{CD} = 0.0554$ N.m$^2$ s.
**17.81** (*a*) 0.6 m (*b*) 3.18 rad/s.
**17.84** $\mathbf{v} = 0.044$ m/s ←; $\omega = 0.770$ rad/s ↻.
**17.85** (*a*) 7.8 m/s ←. (*b*) 1.8 m/s →.
**17.86** 4.9 rad/s ↻.
**17.87** 274 m.
**17.88** $\omega = 1.534$ rad/s ↺; $\mathbf{v}_A = 0.460$ m/s ↓.
**17.89** (*a*) (0.367 rad/s)**i**. (*b*) −(1144 N)**k**.
**17.90** (*a*) 0.5 m. (*b*) −(0.1049 m/s)**k**.
**17.93** 2.4 rad/s ↻.
**17.94** (*a*) 19.47°. (*b*) 6.81 N · s ⦤ 75.6°.
**17.95** $\frac{L}{\sqrt{3}}$.
**17.96** $\omega = \frac{1}{7}(2 + 5\cos\beta)\omega_1$ ↺; $\bar{\mathbf{v}} = \frac{1}{7}(2 + 5\cos\beta)\bar{v}_1$ ←.
**17.97** $\pi L/3$.
**17.98** (*a*) $\omega = 3\bar{v}_1/L$ ↻; $\bar{v}_1/2\downarrow$. (*b*) $\omega = 3\bar{v}_1/L$ ↺; $\bar{v}_1/2\uparrow$.
(*c*) $\omega = 0$; $\bar{v}_1\uparrow$.
**17.101** $\omega = 3\sqrt{2}v_0/5a$ ↺; $\bar{\mathbf{v}} = 0.825\ v_0$ ⦨ 76.0°.
**17.102** (*a*) $\sqrt{3g\sin\beta/L}$ ↺. (*b*) $\mathbf{A}\Delta t = m\sqrt{gL\sin\beta}/3\uparrow$;
$\mathbf{B}\Delta t = 2m\sqrt{gL\sin\beta}/3\uparrow$.
**17.103** (*a*) 0.816.
**17.104** 399.4 m/s.
**17.105** 8.4°.
**17.108** (*a*) $\omega_0/4$ ↻. (*b*) 15/16. (*c*) 3.05°.
**17.109** $0.606\sqrt{gL}$ →.
**17.110** $\sqrt{3gL}/2$.
**17.111** (*a*) 2.975 rad/s ↻. (*b*) 0.727 m/s →.
**17.112** (*a*) 5.961 rad/s ↻. (*b*) 1.456 m/s →.
**17.115** 0.41 m.
**17.116** 105.4°.
**17.117** (*a*) $3v_0(1+e)/2L$ ↻. (*b*) $v_0(1+e)\left(m_C + \frac{m_{AB}}{4}\right)\uparrow$.
**17.118** (*a*) $\bar{\mathbf{v}}_A = 0$, $\omega_A = \bar{v}_1/r$ ↻; $\bar{\mathbf{v}}_B = \bar{v}_1$ →, $\omega_B = 0$.
(*b*) $\bar{\mathbf{v}}_A = 2\bar{v}_1/7$ → ; $\bar{\mathbf{v}}_B = 5\bar{v}_1/7$ →.
**17.119** $5v_0/4r$.
**17.120** (*a*) $\bar{\mathbf{v}}_A = \bar{v}_0\sin\theta\,\mathbf{j}$, $\bar{\mathbf{v}}_B = \bar{v}_0\cos\theta\,\mathbf{i}$;
$\omega_A = (\bar{v}_0/r)(-\sin\theta\,\mathbf{i} + \cos\theta\,\mathbf{j})$, $\omega_B = 0$.
(*b*) $\frac{5}{7}(v_0\cos\theta)\mathbf{i}$.
**17.121** 10.25 rad/s ↺.
**17.122** 5.44 rad/s ↻.
**17.124** (*a*) $0.926\sqrt{gL}$ ←. (*b*) $1.225\sqrt{gL}$ ←.
**17.125** 5.30 s.
**17.127** 84.2 rpm.
**17.128** −24.4 rpm.
**17.130** (*a*) 1/3. (*b*) $\omega_1 L/4\uparrow$. (*c*) $m\omega_1 L/4\uparrow$.
**17.131** 60.6°

## CHAPTER 18

**18.1** (1.296 kg · m$^2$/s)**i** − (0.702 kg · m$^2$/s)**k**.
**18.2** $\frac{ma^2\omega}{12}[3\mathbf{j} + 2\mathbf{k}]$.
**18.3** (2.0037 kg · m$^2$/s )**i** + (5.505 kg · m$^2$/s)**j**.
**18.4** 9.7°.
**18.7** (0.08 kg · m$^2$/s)**j** + (0.48 kg · m$^2$/s)**k**.
**18.8** (0.307 kg · m$^2$/s)**i** + (1.229 kg · m$^2$/s)**j**.
**18.9** (*a*) 8.97 rad/s. (*b*) 0.016 rad/s.
**18.10** (0.88 kg · m$^2$/s)**i** − (0.0025 kg · m$^2$/s)**j** − (14.5 kg · m$^2$/s)**k**.
**18.15** (*a*) (5.65 kg · m$^2$/s)**i** − (1.885 kg · m$^2$/s)**j** +
(12.57 kg · m$^2$/s)**k**. (*b*) 25.4°.
**18.16** (*a*) (5.65 kg · m$^2$/s)**i** − (1.885 kg · m$^2$/s)**j** +
(12.57 kg · m$^2$/s)**k**. (*b*) 154.6°.
**18.17** (*a*) (1.45 kg · m$^2$/s)**i** − (0.87096 kg · m$^2$/s)**k**. (*b*) 31.0°.
**18.18** (*a*) (1.45 kg · m$^2$/s)**i** − (0.87096 kg · m$^2$/s)**k**.
(*b*) (1.45 kg · m$^2$/s)**i** − (0.87096 kg · m$^2$/s)**k**.
**18.21** (*a*) (1.439 m/s)**j**.
(*b*) −(3.61 rad/s)**i** − (3.20 rad/s)**j** + (9.59 rad/s)**k**.
**18.22** (*a*) −(1.439 m/s)**i**. (*b*) −(2.47 rad/s)**j** − (3.20 rad/s)**k**.
**18.23** (*a*) 0. (*b*) $(3F\Delta t/4md)(4\mathbf{i} - \mathbf{k})$.
**18.24** (*a*) $-(F\Delta t\ /\ 3m)\mathbf{k}$. (*b*) $-(3F\Delta t/4md)(4\mathbf{i} + \mathbf{j})$.
**18.25** (*a*) 0. (*b*) $\left(\frac{F\Delta t}{ma}\right)(2.50\mathbf{i} - 1.454\mathbf{j} + 2.19\mathbf{k})$.
**18.26** (*a*) $-(F\Delta t/m)\mathbf{k}$. (*b*) $\left(\frac{F\Delta t}{ma}\right)(3.75\mathbf{i} - 1.875\mathbf{j} + 1.250\mathbf{k})$.
**18.29** (0.0125 rad/s)**i** − (0.1396 rad/s)**j** − (0.1814 rad/s)**k**.
**18.30** (*a*) −0.726 rad/s. (*b*) −(729 m/s)**i** − (2880 m/s)**j** +
(558 m/s)**k**.
**18.31** (*a*) $(\omega_0/6)(-\mathbf{i} + \mathbf{j})$. (*b*) $(a\omega_0/6)\mathbf{k}$.
**18.32** (*a*) $(5ma\omega_0/24)\mathbf{k}$. (*b*) $-(ma\omega_0/24)\mathbf{k}$.
**18.33** (*a*) $\Delta t_A = 0.1290$ s; $\Delta t_B = 1.086$ s. (*b*) −(50.6 mm/s)**j**.
**18.34** (*a*) 941 ms. (*b*) (0.016 93 rad/s)**k**. (*c*) −(39.2 mm/s)**j**.
**18.39** 6.48 J
**18.40** $ma^2\omega^2/8$.
**18.41** 346 kg · m$^2$/s$^2$.
**18.42** 0.235 $mr^2\ \omega^2$.
**18.45** 9.59 J.
**18.46** 23.5 J.
**18.47** 237 J.
**18.48** 8.7 kg · m$^2$/s$^2$.
**18.49** 27 J.
**18.50** $\frac{7(F\Delta t)^2}{2m}$
**18.53** $5\ ma^2\omega_0^2/48$.
**18.54** $m\bar{v}_0^2/14$.
**18.55** (7.02 N · m)**j**.
**18.56** $(ma^2\omega^2/6)\mathbf{i}$.
**18.57** −(252 kg · m$^2$/s$^2$.)**k**.
**18.58** $(\frac{1}{8}mr^2\omega^2\sin 2\beta)\mathbf{k}$.

**18.59** $(1.92\ \text{N}\cdot\text{m})\mathbf{i}$.
**18.60** $(9.83\ \text{N}\cdot\text{m})\mathbf{k}$.
**18.63** $\mathbf{A} = -(4.74\ \text{N})\mathbf{j} - (3.95\ \text{N})\mathbf{k}$; $\mathbf{B} = (4.74\ \text{N})\mathbf{j} + (3.95\ \text{N})\mathbf{k}$.
**18.64** $\mathbf{A} = -(10.66\ \text{N})\mathbf{j} - (8.88\ \text{N})\mathbf{k}$; $\mathbf{B} = (10.66\ \text{N})\mathbf{j} + (8.88\ \text{N})\mathbf{k}$.
**18.65** $\mathbf{A} = -(1.836\ \text{N})\mathbf{j}$; $\mathbf{B} = (1.836\ \text{N})\mathbf{j}$.
**18.66** $\mathbf{A} = (2.417\ \text{N})\mathbf{k}$; $\mathbf{B} = -(2.417\ \text{N})\mathbf{k}$.
**18.69** (*a*) 60 rad/s$^2$. (*b*) $\mathbf{A} = -(15\ \text{N})\mathbf{k}$; $\mathbf{B} = +(15\ \text{N})\mathbf{k}$.
**18.70** (*a*) $(24.8 \times 10^{-3}\ \text{N}\cdot\text{m})\mathbf{k}$. (*b*) $\mathbf{A} = (7.50 \times 10^{-3}\ \text{N})\mathbf{i} + (15.00 \times 10^{-3}\ \text{N})\mathbf{j}$; $\mathbf{B} = -(7.50 \times 10^{-3}\ \text{N})\mathbf{i} - (15.00 \times 10^{-3}\ \text{N})\mathbf{j}$.
**18.71** (*a*) $(223.16\ \text{rad/s}^2)\mathbf{i}$. (*b*) $\mathbf{A} = (4.1\ \text{N})\mathbf{k}$; $\mathbf{B} = -(4.1\ \text{N})\mathbf{k}$.
**18.72** (*a*) 0.434 kg · m$^2$/s$^2$. (*b*) $\mathbf{A} = (0.906\ \text{N})\mathbf{j}$; $\mathbf{B} = -(0.906\ \text{N})\mathbf{j}$.
**18.75** (*a*) $(0.9\ \text{N}\cdot\text{m})\mathbf{i}$. (*b*) $\mathbf{A} = -(0.938\ \text{N})\mathbf{j} + (1.125\ \text{N})\mathbf{k}$; $\mathbf{B} = (0.938\ \text{N})\mathbf{j} - (1.125\ \text{N})\mathbf{k}$.
**18.76** (*a*) $(7.2\ \text{rad/s})\mathbf{k}$. (*b*) $\mathbf{A} = -(57.3\ \text{mN})\mathbf{i} + (47.4\ \text{mN})\mathbf{j}$; $\mathbf{B} = (57.3\ \text{mN})\mathbf{i} - (47.4\ \text{mN})\mathbf{j}$.
**18.77** 34.3 N ↑.
**18.78** 1°; *A* will move up.
**18.79** $\mathbf{A} = (1.527\ \text{N})\mathbf{j}$; $\mathbf{B} = -(1.527\ \text{N})\mathbf{j}$.
**18.80** 4290 N · m.
**18.83** (*a*) 27.0°. (*b*) 8.09 rad/s.
**18.84** (*a*) 7.53 rad/s. (*b*) 7.00 rad/s.
**18.85** (*a*) 71.2°. (*b*) 5.67 rad/s.
**18.86** (*a*) 5.51 rad/s. (*b*) 4.63 rad/s.
**18.89** 7.89 rad/s.
**18.90** 15.24 rad/s.
**18.91** $\mathbf{A} = -\frac{1}{4}ma\omega_1\omega_2\mathbf{k}$; $\mathbf{B} = \frac{1}{4}ma\omega_1\omega_2\mathbf{k}$.
**18.92** $\mathbf{A} = -(51.9\ \text{N})\mathbf{i}$; $\mathbf{M}_A = (3.8988\ \text{kg}\cdot\text{m}^2/\text{s}^2)\mathbf{i} + (7.8128\ \text{kg}\cdot\text{m}^2/\text{s}^2)\mathbf{k}$.
**18.93** $\mathbf{A} = (0.884\ \text{N})\mathbf{k}$; $\mathbf{B} = -(0.884\ \text{N})\mathbf{k}$.
**18.94** 6.79 rad/s.
**18.95** (*a*) $\mathbf{C} = -(592\ \text{N})\mathbf{j}$; $\mathbf{D} = (592\ \text{N})\mathbf{j}$. (*b*) $\mathbf{C} = \mathbf{D} = 0$.
**18.96** 35.5 rpm.
**18.99** (*a*) $\frac{1}{4}ma^2\alpha_1\,\mathbf{i}$. (*b*) $\mathbf{A} = -\frac{1}{4}ma\omega_1\omega_2\mathbf{k}$; $\mathbf{B} = \frac{1}{4}ma\omega_1\omega_2\mathbf{k}$.
**18.100** $\mathbf{A} = -(0.0075\ \text{N})\mathbf{j} + (0.135\ \text{N})\mathbf{k}$; $\mathbf{B} = (0.0075\ \text{N})\mathbf{j} - (0.135\ \text{N})\mathbf{k}$.
**18.101** $\mathbf{R} = -(15.02\ \text{N})\mathbf{i} - (11.285\ \text{N})\mathbf{k}$; $\mathbf{M}_A^R = (94.185\ \text{N}\cdot\text{m})\mathbf{i}$.
**18.102** (*a*) $(7.89\ \text{N}\cdot\text{m})\mathbf{j}$. (*b*) $\mathbf{R} = -(75.4\ \text{N})\mathbf{i} - (74.94\ \text{N})\mathbf{k}$; $\mathbf{M}_A^R = (222.96\ \text{N}\cdot\text{m})\mathbf{i}$.
**18.105** 31 rpm, 632.3 rpm.
**18.106** (*c*) −5.14%.
**18.109** 44.8°.
**18.110** 2340 rpm.
**18.111** (*a*) 4.51 rpm. (*b*) 4.57 rpm, 363 rpm
**18.112** $\cos\beta = \dfrac{2d^2\psi}{(h^2 + d^2)\phi}$.
**18.113** (*a*) 131.27 rad/s. (*b*) 0.055 m
**18.114** $2.163 \times 10^{21}$ kg · m
**18.122** (*a*) $\beta = 23.8°$. (*b*) Precession, 82.6 rpm; spin, 128.8 rpm.
**18.123** (*a*) 13.19°. (*b*) 1242 rpm (retrograde).
**18.124** Precession axis: $\theta_x = 125.0°$, $\theta_y = 36.6°$, $\theta_z = 80.7°$; precession, 0.9426 rad/s (retrograde); spin, 0.1583 rad/s.
**18.125** Precession axis: $\theta_x = 90°$, $\theta_y = 26.0°$, $\theta_z = 64.0°$; precession, 0.845 rad/s (retrograde); spin, 0.161 rad/s.
**18.128** Precession axis: $\theta_x = 99.04°$, $\theta_y = 90°$, $\theta_z = 9.04°$; precession, 121.8 rpm (retrograde); spin, 60.3 rpm.
**18.129** (*a*) 8 rad/s. (*b*) 11.31 rad/s.
**18.130** (*a*) $-45° \le \theta \le 45°$. (*b*) 6 rad/s. (*c*) 4.90 rad/s.
**18.131** (*a*) 4 rad/s. (*b*) 5.66 rad/s.
**18.134** (*a*) $\sqrt{17g/11a}$. (*b*) $\sqrt{44g/17a}$.
**18.135** (*a*) 48.7°. (*b*) Spin, 54.5 rad/s; precession, −6.87 rad/s.
**18.136** (*a*) 41 rad/s. (*b*) Spin, 55.46 rad/s; precession, −16.7 rad/s.
**18.145** 0.3347 kg · m$^2$/s; $\theta_x = 48.7°$, $\theta_y = 41.4°$, $\theta_z = 90°$.
**18.146** 1.328 N · m
**18.148** (*a*) *B* and *C*. (*b*) $\Delta t_B = 2.24$ s, $\Delta t_C = 3.82$ s. (*c*) 0.242 s.
**18.149** (*a*) $\frac{1}{8}\omega_0\,(-\mathbf{i} + \mathbf{j})$. (*b*) $0.0884\omega_0\,a\mathbf{k}$.
**18.151** $-(1.767\ \text{N}\cdot\text{m})\mathbf{i} - (2.008\ \text{N}\cdot\text{m})\mathbf{j} + (3.0123\ \text{N}\cdot\text{m})\mathbf{k}$.
**18.152** (*a*) 0.00145 m above the axis, $I_{xy} = 2.383 \times 10^{-3}\ \text{N}\cdot\text{m}\cdot\text{s}^2$, $I_{zx} = 0$. (*b*) 1.53 N at *A*; 0.137 N at *E*.
**18.154** $\mathbf{D} = -(34.4\ \text{N})\mathbf{j} + (21.6\ \text{N})\mathbf{k}$; $\mathbf{E} = -(8.8\ \text{N})\mathbf{j} + (21.6\ \text{N})\mathbf{k}$.
**18.155** (*a*) $(2.00\ \text{N}\cdot\text{m})\mathbf{i}$. (*b*) $\mathbf{D} = -(32.4\ \text{N})\mathbf{j} + (23.6\ \text{N})\mathbf{k}$; $\mathbf{E} = -(6.78\ \text{N})\mathbf{j} + (23.6\ \text{N})\mathbf{k}$.

## CHAPTER 19

**19.1** 7.312 m/s$^2$; 1.571 s.
**19.2** 10 mm; 3.18 Hz.
**19.3** 0.032 m; 45.48 m/s$^2$.
**19.4** (*a*) 0.0056 m; 6.66 Hz. (*b*) 0.234 m/s; 9.8 m/s$^2$.
**19.5** (*a*) 0.0982 s; 10.183 Hz. (*b*) 0.047 m; 192.4 m/s$^2$.
**19.6** (*a*) 280 rpm. (*b*) 1.703 m/s.
**19.7** (*a*) 11.29°. (*b*) 1.933 m/s$^2$.
**19.10** (*a*) 0.2 s. (*b*) 30.8 mm. (*c*) 43.1°.
**19.11** (*a*) 2.48 mm. (*b*) 0.621 mm.
**19.12** (*a*) 0.0247 s. (*b*) 2.29 m/s ↑; 17.14 m/s$^2$ ↓.
**19.13** 70.3 mm ↑; 2.20 m/s ↓; 20.1 m/s$^2$ ↓.
**19.14** (*a*) 23.52 m (*b*) 161.78 m/s$^2$.
**19.15** (*a*) 0.892 s. (*b*) 3 m/s ↓.
**19.18** (*a*) 0.361 s; 2.77 Hz. (*b*) 0.765 m/s; 13.31 m/s$^2$.
**19.19** (*a*) 0.203 s; 4.93 Hz. (*b*) 1.859 m/s; 57.6 m/s$^2$.
**19.20** 2.634 s.
**19.21** 4 or 1/4.
**19.24** (*a*) 45.0 kg. (*b*) 14.22 kN/m.
**19.25** (*a*) 6.22 kN/m. (*b*) 2.27 kg.
**19.26** (*a*) 7451.55 N/m. (*b*) 30054.6 N/m.
**19.27** (*a*) 86.9 N. (*b*) 136.63 N/m.
**19.28** (*a*) 2.91 kN/m. (*b*) 763 N/m.
**19.29** (*a*) 427 kg. (*b*) 68.5 mm/s.
**19.33** (*a*) 60.1 mm. (*b*) 1.437 Hz.
**19.35** 23.1°.
**19.36** (*a*) 1.7943 s. (*b*) 1.825 s. (*c*) 2.12 s.
**19.37** 1.94 m.
**19.38** (*a*) 3.65 Hz. (*b*) 0.00763°.
**19.39** (*a*) 0.529 s. (*b*) 238 mm/s.
**19.40** (*a*) 0.858 s. (*b*) 0.093 m/s.
**19.41** (*a*) 7.53 Hz. (*b*) 97.3 rad/s$^2$.
**19.42** (*a*) 2.45 kg. (*b*) 457 mm/s.

**19.45** (*a*) 2.79 s. (*b*) 1.933 m.
**19.46** 0.776 s.
**19.47** (*a*) $6.82\sqrt{r/g}$. (*b*) $7.38\sqrt{r/g}$.
**19.48** (*a*) $6.33\sqrt{b/g}$. (*b*) $6.67\sqrt{b/g}$.
**19.49** (*a*) 0.5. (*b*) 0.707.
**19.50** 128.8 mm.
**19.55** $f_n = (1/2\pi)\sqrt{\dfrac{6k}{5m} + \dfrac{9g}{10l}}$ Hz.
**19.56** $f_n = (1/2\pi)\sqrt{\dfrac{2k}{3m} + \dfrac{4g}{3L}}$ Hz.
**19.57** (*a*) 3 Hz. (*b*) 81.57 N/m.
**19.58** 1.9 Hz.
**19.59** 1.407 rad/s$^2$ ↻.
**19.60** 0.365 m/s$^2$.
**19.63** 11.17 mm.
**19.64** (*a*) 1.125 s. (*b*) 4.39 m/s.
**19.65** 5.2654 s.
**19.66** (*a*) 0.400 s. (*b*) 0.089 m/s.
**19.69** 0.351 m/s.
**19.70** 19.02 mm.
**19.71** $f_n = (1/2\pi)\sqrt{\dfrac{k}{5m}}$ Hz.
**19.72** (*a*) 0.368 s. (*b*) 0.574 m/s.
**19.73** 1.460 kg · m$^2$.
**19.74** $\dfrac{l}{\sqrt{12}}$.
**19.77** 5.32 Hz.
**19.78** $f_n = (1/2\pi)\sqrt{\dfrac{2k}{3m} + \dfrac{4g}{3L}}$ Hz.
**19.79** (*a*) 0.720 s. (*b*) 0.0873 m/s.
**19.80** 2.05 Hz.
**19.83** 1.586 s.
**19.84** 1.627 s.
**19.85** 0.567 Hz.
**19.86** 1.073 s.
**19.89** 0.918 Hz.
**19.90** $f_n = (1/2\pi)\sqrt{\dfrac{12k}{7m} + \dfrac{8g}{7\sqrt{3}l}}$ Hz.
**19.91** 1.192 s.
**19.92** 1.305 s.
**19.93** $f_n = \dfrac{a}{2\pi l}\sqrt{\dfrac{6k}{m}}$.
**19.94** $f_n = (1/2\pi)\sqrt{\dfrac{3g}{l}}$.
**19.97** (*a*) 0.214 s. (*b*) 0.214 s.
**19.98** (*a*) 37.1 mm (in phase). (*b*) 260 mm (in phase).
**19.99** (*a*) 160 N/m. (*b*) 40 N/m.
**19.101** 37.67 rad/s $< \omega_f <$ 46.77 rad/s.
**19.102** 0.0929 m $< b <$ 3.55 m
**19.104** $\omega_f <$ 11.07 rad/s; $\omega_f >$ 19.18 rad/s.
**19.105** (*a*) 174.6 mm. (*b*) 8.73 N.
**19.106** $\omega_f <$ 9.09 rad/s.
**19.107** (*a*) 0.94 m/s$^2$. (*b*) 2.42 N.
**19.108** (*a*) 0.450 rad/s. (*b*) 2.70 m/s$^2$.
**19.109** 3.21 m/s$^2$.
**19.112** $\omega_f \leq$ 310 rpm; $\omega_f \geq$ 316 rpm.
**19.113** 2.95 mm.
**19.114** 1557 N.
**19.116** –5.63 mm or 22.5 mm.
**19.117** 1.286 mm or 1.800 mm.
**19.120** Transmissibility $= \dfrac{1}{(1 - \omega_f^2/\omega_n^2)}$.
**19.121** (*a*) 1400 rpm. (*b*) 0.416 mm.
**19.122** (*a*) 4.9 m/s. (*b*) 0.084 m (out of phase).
**19.123** (*a*) 80 N/m. (*b*) 0.2775 m (out of phase).
**19.132** (*a*) 0.1178. (*b*) 38.4 mm.
**19.133** (*a*) 114.1 kN/m. (*b*) 0.1935 s.
**19.134** 8.82 N.
**19.135** 106.5 mm/s ↑.
**19.137** (*a*) $0.1534\dfrac{d^2\theta}{dt^2} + 0.2756\dfrac{d\theta}{dt} + 5.0325\,\theta = 0$ (*b*) 0.1565.
**19.138** (*a*) 297.5 rpm. (*b*) 273 rpm. (*c*) 0.02 m, .018 m
**19.139** (*a*) 297 rpm. (*b*) 252 rpm. (*c*) 0.085 m, 0.009 m
**19.140** $c/c_c \geq \sqrt{1/2}$.
**19.143** (*a*) 0.1269. (*b*) 462 N · s/m.
**19.144** 3.13 mm.
**19.145** 0.487.
**19.151** $m\dfrac{d^2x_A}{dt^2} + c\left(\dfrac{dx_A}{dt} - \dfrac{dx_B}{dt}\right) + 2k(x_A - x_B) = P_m \sin \omega_f t$.
$m\dfrac{d^2x_B}{dt^2} + 3c\dfrac{dx_B}{dt} - c\dfrac{dx_A}{dt} + 3kx_B - 2kx_A = 0$.
**19.152** $R < 2\sqrt{L/C}$.
**19.153** (*a*) $E/R$. (*b*) $L/R$.
**19.156** (*a*) $c\dfrac{d}{dt}(x_A - x_m) + kx_A = 0$.
$m\dfrac{d^2x_m}{dt^2} + c\dfrac{d}{dt}(x_m - x_A) = P_m \sin \omega_f t$.
(*b*) $R\dfrac{d}{dt}(q_A - q_m) + \dfrac{1}{C}q_A = 0$.
$L\dfrac{d^2q_m}{dt^2} + R\dfrac{d}{dt}(q_m - q_A) = E_m \sin \omega_f t$.
**19.157** (*a*) $c_1\dfrac{dx_A}{dt} + (k_1 + k_2)x_A - k_2x_m = 0$.
$m\dfrac{d^2x_m}{dt^2} + c_2\dfrac{dx_m}{dt} + k_2(x_m - x_A) = 0$.
(*b*) $R_1\dfrac{dq_A}{dt} + \left(\dfrac{1}{C_1} + \dfrac{1}{C_2}\right)q_A - \dfrac{1}{C_2}q_m = 0$.
$L\dfrac{d^2q_m}{dt^2} + R_2\dfrac{dq_m}{dt} + \dfrac{1}{C_2}(q_m - q_A) = 0$.
**19.158** (*a*) 1.22°. (*b*) 0.2675 m/s; 0.6776 m/s$^2$.
**19.160** $(1/2\pi)\sqrt{2\mu_k g/l}$.
**19.161** (*a*) 0.534 s. (*b*) 0.491 rad/s.
**19.162** 75.5°.
**19.164** 0.8289 s.
**19.165** $\tau_n = 2\pi\sqrt{\dfrac{60r^2 + 10l^2}{9gl}}$.
**19.167** 222.26 N.
**19.168** 211 mm.