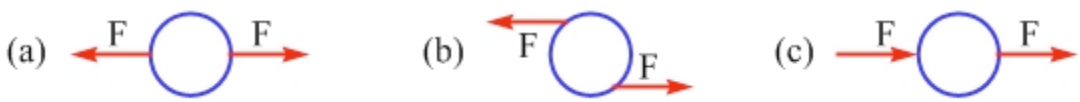
Answers to selected problems from Essential Physics, Chapter 10

1. (a) The red ones have the same speed as one another. The blue ones also have the same speed as one another, with a value twice the speed of the red ones. (b) None of them have the same velocity. Velocity is a vector, and the velocity of each object is in a different direction. (c) All four objects have the same angular velocity. (d) Once again, the magnitude of the acceleration of the two red objects is the same, and the blue objects also have the same magnitude acceleration as one another. However, none of the objects have the same acceleration because the directions of the accelerations are all different. (e) They all have the same angular acceleration, which is zero for all four objects.

3. (a) – (c) clockwise (d) counterclockwise

5. The answer is Yes in all three cases. The pictures below show just one of many examples for each situation.

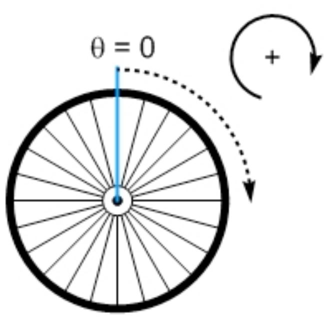


7. As the angle θ decreases, the torque associated with the force F must **stay the same** while the magnitude of the force F must **increase** so that the rod remains in equilibrium.

9. The cube has a mass of 300 g; the ellipsoid has a mass of 100 g; and the sphere has a mass of 1200 g.

11. $M = 2m$

13. (a) – (c)



(d)

Parameter	Value
Initial angular position	$\theta_i = 0$
Final angular position	$\theta_f = \frac{\pi}{2}$ rad/s
Initial angular velocity	$\omega_i = 0$
Final angular velocity	$\omega_f = ?$
Angular acceleration	$\alpha = +5.0$ rad/s^2
Time	$t = ?$

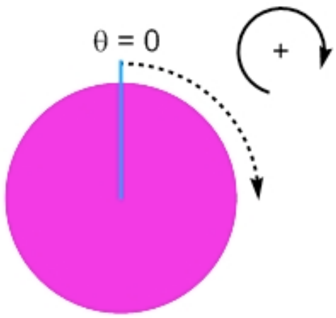
(e) $\omega_f^2 = \omega_i^2 + 2\alpha(\theta_f - \theta_i)$

(f) 4.0 rad/s, clockwise

(g) One possibility is $\Delta\theta = \omega_i t + \frac{1}{2}\alpha t^2$

(h) 0.79 s

15. (a) – (c)



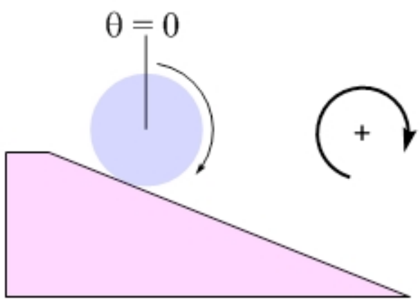
(d)

Parameter	Value
Initial angular position	$\theta_i = 0$
Final angular position	$\theta_f = ?$
Initial angular velocity	$\omega_i = +2.4$ rad/s
Final angular velocity	$\omega_f = 0$
Angular acceleration	$\alpha = -1.2$ rad/s^2
Time	$t = ?$

(e) $\omega_f^2 = \omega_i^2 + 2\alpha(\theta_f - \theta_i)$

(f) 2.4 rad, clockwise

17. (a) – (c)



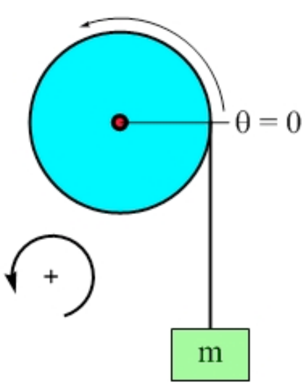
(d)

Parameter	Value
Initial angular position	$\theta_i = 0$
Final angular position	$\theta_f = +80$ rad
Initial angular velocity	$\omega_i = +30$ rad/s
Final angular velocity	$\omega_f = ?$
Angular acceleration	$\alpha = ?$
Time	$t = 2$ s

(e) $\Delta\theta = \omega_i t + \frac{1}{2}\alpha t^2$

(f) +10 rad/s^2

19. (a) – (c)



(d)

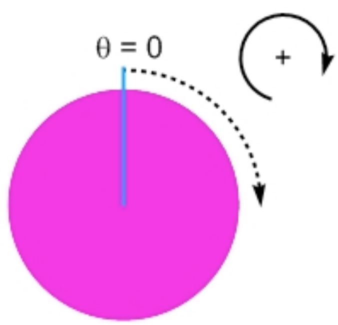
Parameter	Pulley	Block
Initial position	$\theta_i = 0$	$y_i = 0$
Final position	$\theta_f = ?$	$y_f = ?$
Initial velocity	$\omega_i = +0.5$ rad/s	$v_i = +0.1$ m/s
Final velocity	$\omega_f = 0$	$v_f = 0$
acceleration	$\alpha = ?$	$a = ?$
Time	$t = 3$ s	$t = 3$ s

(e) You have a lot of freedom about how to solve this problem. You could immediately convert the angular velocity of the pulley into the linear velocity of the block, and then do everything with the block's straight-line motion, or, you can solve everything for the pulley first, and then convert for the block at the end. Note that we're using half the time, 3 seconds, because the block will move up for the first half of the time, and then fall back down during the second half of the time.

$$\omega_f = \omega_i + \alpha t\,,\ \omega_f^2 = \omega_i^2 + 2\alpha(\theta_f - \theta_i) \quad \text{and} \quad \Delta y = r(\Delta\theta)$$

(f) $\alpha = -(0.5/3)\ \text{rad/s}^2$; $\theta_f = +0.75\ \text{rad}$; $\Delta y = +0.15\ \text{m}$

21. (a) – (c)



(d)

Parameter	Value
Initial angular position	$\theta_i = 0$
Final angular position	$\theta_f = 75° = \dfrac{5\pi}{12}$ rad
Initial angular velocity	$\omega_i = +0$
Final angular velocity	$\omega_f = 8$ rev/s $= 16\pi$ rad/s
Angular acceleration	$\alpha = ?$
Time	$t = ?$

(e) $\omega_f^2 = \omega_i^2 + 2\alpha(\theta_f - \theta_i)$ gives $\alpha = +965\ \text{rad/s}^2$

(f) $\omega_f = \omega_i + \alpha t$ gives 0.052 s

23. (a) counterclockwise (b) $\tau = (4.0\ \text{m})F\sin 30°$ (c) $\tau = (4.0\ \text{m})(F\sin 30°)\sin 90°$
(d) $\tau = (4.0\ \text{m} \times \sin 30°)F\sin 90°$

25. (a) 8.0 N m (clockwise) (b) zero (c) 8.0 N m (counterclockwise)
(d) 16 N m (counterclockwise) (e) 16 N m, counterclockwise

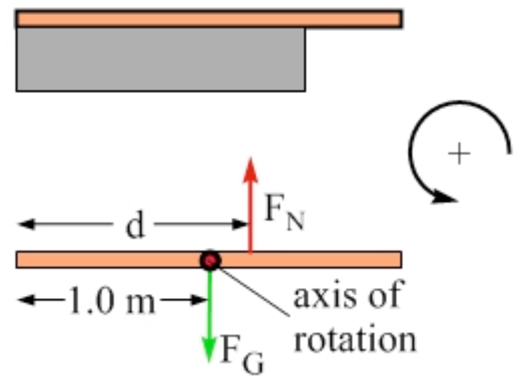
27. (a) 18 kg m^2 (b) 45 kg m^2

29. (a) The rotational inertia is minimized for an axis that passes through the center-of-mass of the system. Thus, the axis should pass through the center-of-mass, which is located between the balls at a distance of 0.40 m away from the ball of mass 2*M*.

(b) The rotational inertia in this case is 0.32 + 0.64 = 0.96 kg m^2.

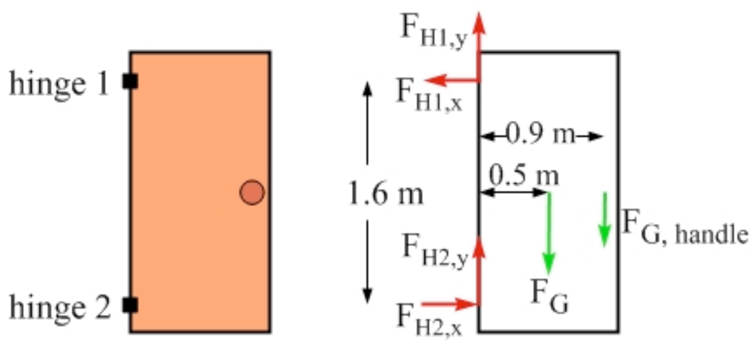
31. (a) $2Md^2$ (b) $4Md^2$ (c) $6Md^2$

33. (a) + (b)



(c) The normal force has to balance the weight, so it must be 40 N up. (d) Let's take torques about the center of gravity of the board, because that eliminates *mg* from the torque equation. (e) $r \times F_N = 0$, so $r = 0$, where *r* is the distance of the normal force from the center of the board. The only way to make the torques balance is for the normal force to act at the center of gravity of the board.

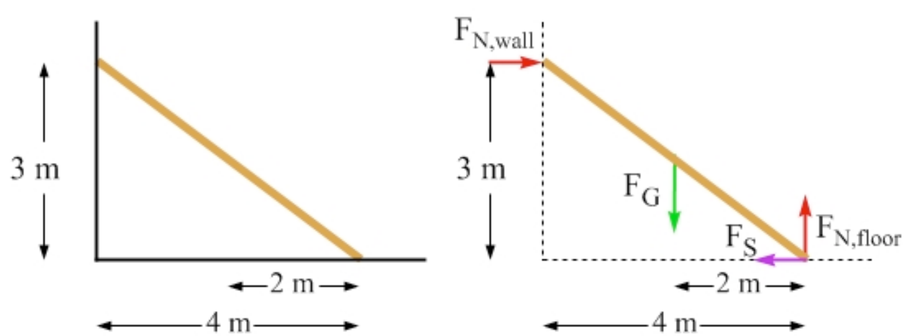
35. (a) + (b)



(c) The horizontal component of one hinge force is equal and opposite to the horizontal component of the other hinge force – they are the only two horizontal forces acting on the door. (d) Taking torques around the upper hinge eliminates both components of the force acting on the upper hinge, as well as the vertical component of the force applied to the lower hinge. $+(0.5 \text{ m})(20 \text{ N}) + (0.9 \text{ m})(10 \text{ N}) - (1.6 \text{ m})(F_{H2,x}) = 0$

(e) Rounding to 2 significant figures, we get 12 N, toward the door.
(f) 12 N, away from the door.

37.



(c) There are four forces here, two vertical and two horizontal. Thus, the two vertical forces must balance one another, and the two horizontal forces must balance one another. Vertically, the upward normal force applied by the ground on the ladder must balance the weight of the ladder, so that normal force must be 600 N. Horizontally, the normal force from the wall on the ladder must balance the force of static friction applied by the ground on the ladder.

(d) Let's sum torques about the axis that passes through the point where the ladder touches the ground. That eliminates, from the torque equation, both the normal force applied by the ground and the force of friction applied by the ground on the ladder (that's especially critical, because we don't know the size of that force).

(e) Taking counterclockwise to be positive, $+(2.0 \text{ m})(600 \text{ N}) - (3.0 \text{ m})(F_{N,wall}) = 0$, which gives a normal force, applied by the wall on the ladder, of 400 N.

(f) The force of static friction is also 400 N, and the normal force applied by the ground on the ladder is 600 N. $F_{S,\max} = \mu_S F_N$, and, for the ladder to remain in equilibrium, the maximum possible force of static friction must be greater than or equal to the force of static friction we need in this case. Thus:

$$\mu_S F_N \geq 400 \text{ N} \quad \Rightarrow \quad \mu_S \geq \frac{400 \text{ N}}{F_N} = \frac{400 \text{ N}}{600 \text{ N}} = \frac{2}{3}.$$

Thus, the minimum coefficient of static friction we need is 2/3.

39. In many ways, the motions are very similar. At any instant in time, for instance, the velocity of the ball, in m/s, has the same numerical value as the angular velocity of the disk, in rad/s. At any instant in time, the displacement of the ball, in m, has the same numerical value as the angular displacement of the disk, in radians. A big difference is that the center-of-mass of the disk does not move in this situation, but if we compare the straight-line motion of the ball to the rotational motion of the disk, we see many parallels.

41. 1.0 m

43. Let's estimate that the distance from Boston to Seattle is 3000 miles, or about 5000 km, which is 5×10^6 m. A tire has a diameter of about 60 cm, which is a radius of 30 cm. In each revolution of the tire, the car covers a distance of $2\pi r \approx 2$ m. Dividing the total distance of the trip by the distance per revolution gives something like 2 – 3 million revolutions.

45. (a) 0.2 rad/s (b) 4 m/s^2 (c) 4 m/s^2 (d) 0.04 rad/s^2

47. With a lever, there are basically three forces to consider. A see-saw is an example of a lever in action. On a see-saw, the forces are the force of gravity acting on the person on one side, the force of gravity acting on the person on the other side, and the support force provided by the fulcrum, in the middle. Taking torques about the center, there is no torque from the support force, so we conclude that the torque from the force of gravity on one side is balanced by the torque from the force of gravity acting on the other side. This is how a light person can balance a heavy person – the light person sits far from the center, and/or the heavy person sits close to the center, so their torques can balance. Archimedes simply took this logic to an extreme. If we think of the heavy person as the Earth, and the light person as Archimedes, then with the Earth very close to the fulcrum, and Archimedes very far away (hence, the need for a very long lever/seesaw), Archimedes could balance the Earth and, by moving a little farther out, could move the Earth.

49. Note that, in calculating the torque, the mass of the rod is irrelevant.
(a) 5.0 N m clockwise (b) 2.5 N m clockwise (c) 5.0 N m clockwise
(d) 2.5 N m clockwise

51. (a) 200 N (b) 160 N to the left (c) 60 N down

53. (a) 48 N (b) 27 N to the right (c) 20 N up

55. (a) The biceps force increases by 200 N (b) Yes, the humerus force changes. The humerus force is still directed down, and its magnitude increases by 180 N.

57. The force is 2 N, directed horizontally to the left, and it is applied at the lower end.

59. (a) The mobile is clearly not in equilibrium. At the very least, the section at the bottom right is not in equilibrium, because 2 balls 10 cm from the supporting string cannot balance 1 ball 30 cm away. (b) No, adding one ball is not sufficient. We can add one ball to the system at the bottom right, making a chain of 3 balls 10 cm from the supporting string to balance the 1 ball 30 cm away. However, that gives 8 balls on the right hanging from the top rod, and that can't be balanced by the three balls, twice as far from the support string, on the left of the top rod. (c) We can add two balls to bring the system into equilibrium. One ball is added to the system at the bottom right, as explained in part (b). Then, the other ball needs to be added to the chain of three at the top left, giving a chain of four that can balance the other eight balls.

61. No, the answer does not change. In this situation, the torque due to the force of gravity acting on Julie balances the torque due to the force of gravity acting on the board. If the system is moved to the Moon, both these torques are reduced by the same factor, so they are still equal. In other words, g cancels out from the torque equation.