Chapter 5: Forces

Practice Problems

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1. When a shot–putter exerts a net force of 140 N on a shot, the shot has an acceleration of 19 m/s². What is the mass of the shot?

$$m = \frac{F}{a} = \frac{+140\ \text{N}}{+19\ \text{m/s}^2} = 7.4\ \text{kg}$$

2. Together a motorbike and rider have a mass of 275 kg. The motorbike is slowed down with an acceleration of – 4.50 m/s². What is the net force on the motorbike? Describe the direction of this force and the meaning of the negative sign.

$F = ma = (275\ \text{kg})(-4.50\ \text{m/s}^2)$
$= -1.24 \times 10^3\ \text{N}$
The negative sign of the acceleration slowing down the motorbike tells us that the motorbike has a velocity in the positive direction. The negative sign on the force indicates that it is directed opposite to the motorbike velocity.

3. A car, mass 1225 kg, traveling at 105 km/h, slows to a stop in 53 m. What is the size and direction of the force that acted on the car? What provided the force?

Given: $v_i = 105\ \text{km/h} = 29.2\ \text{m/s}$,
$v_f = 0$, $d = 53\ \text{m}$,

$$a = \frac{(v_f^2 - v_i^2)}{2d} = -8.0\ \text{m/s}^2.$$

$F = ma = (1225\ \text{kg})(-8.0\ \text{m/s}^2) = -9.8 \times 10^3\ \text{N}$
The force is directed opposite to the car motion and is provided by the road surface pushing against the car tires.

4. Imagine a spider with mass 7.0×10^{-5} kg moving downward on its thread. The thread exerts a force that results in a net upward force on the spider of 1.2×10^{-4} N.

a. What is the acceleration of the spider?

$$a = \frac{F}{m} = \frac{(+1.2 \times 10^{-4}\ \text{N})}{(7.0 \times 10^{-5}\ \text{kg})} = +1.7\ \text{m/s}^2$$

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b. Explain the sign of the velocity and describe in words how the thread changes the velocity of the spider.

The upward force being given as a positive number means that the downward motion of the spider is represented as a negative velocity. The positive acceleration is opposed to this negative velocity and gives rise to a slowing down of the spider.

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In these problems, use $g = 9.80\ \text{m/s}^2$.

5. What is the weight of each of the following objects?

a. 0.133–kg hockey puck

$W = mg = (0.133\ \text{kg})(9.8\ \text{m/s}^2) = 1.11\ \text{N}$

b. 108–kg football player

$W = mg = (108\ \text{kg})(9.80\ \text{m/s})^2$
$= 1.06 \times 10^3\ \text{N}$

c. 870–kg automobile

$W = mg = (870\ \text{kg})(9.80\ \text{m/s}^2)$
$= 8.50 \times 10^3\ \text{N}$

6. Find the masses of each of these weights.

a. 98 N

$$m = \frac{W}{g} = \frac{98\ \text{N}}{9.80\ \text{m/s}^2} = 10\ \text{kg}$$

b. 80 N

$$m = \frac{W}{g} = \frac{80\ \text{N}}{9.80\ \text{m/s}^2} = 8.2\ \text{kg}$$

c. 0.98 N

$$m = \frac{W}{g} = \frac{0.98\ \text{N}}{9.80\ \text{m/s}^2} = 0.10\ \text{kg}$$

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7. A 20-N stone rests on a table. What is the force the table exerts on the stone? In what direction?

20 N, upward

8. An astronaut with mass 75 kg travels to Mars. What is his weight

a. on Earth?

$$W = mg = (75\text{ kg})(9.80\text{ m/s}^2) = 7.4 \times 10^2\text{ N}$$

b. on Mars, where $g = 3.8\text{ m/s}^2$?

$$W = mg = (75\text{ kg})(3.8\text{ m/s}^2) = 2.9 \times 10^2\text{ N}$$

c. What is the value of g on top of a mountain if the astronaut weighs 683 N?

$$g = \frac{W}{m} = \frac{683\text{ N}}{75\text{ kg}} = 9.1\text{ m/s}^2$$

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9. Suppose Joe, who weighs 625 N, stands on a bathroom scale calibrated in newtons.

a. What force would the scale exert on Joe? In what direction?

625 N, upward

b. If Joe now holds a 50-N cat in his arms, what force would the scale exert on him?

675 N

c. After Joe puts down the cat, his father comes up behind him and lifts upward on his elbows with a 72-N force. What force does the scale now exert on Joe?

Since $F_{\text{father on Joe}} + F_{\text{scale on Joe}} = W_{\text{Joe}}$,

$$F_{\text{scale on Joe}} = W_{\text{Joe}} - F_{\text{father on Joe}} = 625\text{ N} - 72\text{ N} = 553\text{ N, upward.}$$

10. **a.** A 52-N sled is pulled across a cement sidewalk at a constant speed. A horizontal force of 36 N is exerted. What is the coefficient of sliding friction between the sidewalk and the metal runners of the sled?

$F_f = \mu F_N$ with $F_N = W$, so

$$\mu = \frac{F_f}{F_N} = \frac{36\text{ N}}{52\text{ N}} = 0.69$$

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b. Suppose the sled now runs on packed snow. The coefficient of the friction is now only 0.12. If a person weighing 650 N sits on the sled, what force is needed to slide the sled across the snow at constant speed?

The force must equal the friction force.

$$F_f = \mu F_N = \mu(W + W_1) = (0.12)(52\text{ N} + 650\text{ N}) = 84\text{ N}$$

11. The coefficient of sliding friction between rubber tires and wet pavement is 0.50. The brakes are applied to a 750-kg car traveling 30 m/s, and the car skids to a stop.

a. What is the size and direction of the force of friction that the road exerts on the car?

$F_f = \mu F_N$ where $F_N = W = mg$, so

$$F_f = -(0.50)(750\text{ kg})(9.80\text{ m/s}^2) = -3.7 \times 10^3\text{ N}$$

b. What would be the size and direction of the acceleration of the car? Why would it be constant?

$$a = \frac{F_f}{m} = \frac{(-3.7 \times 10^3\text{ N})}{750\text{ kg}} = -4.9\text{ m/s}^2$$

directed opposite car velocity and constant because F_f is constant.

c. How far would the car travel before stopping?

$v_f^2 = v_i^2 + 2ad$, so

$$d = \frac{(v_f^2 - v_i^2)}{2a} = \frac{(0 - (30\text{ m/s})^2)}{-9.8\text{ m/s}^2} = 92\text{ m}$$

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Practice Problems

12. If the tires of the car in Practice Problem 11 did not skid, the coefficient of friction would have been 0.70. Would the force of friction have been larger, smaller, or the same? Would the car have come to a stop in a shorter, the same, or a longer distance?

Larger, since F_f is proportional to μ; shorter distance since, from the solution to Practice Problem 11, d is inversely proportional to a, and a is proportional to F_f.

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13. A rubber ball weighs 49 N.

a. What is the mass of the ball?

$$m = \frac{W}{g} = \frac{49\text{ N}}{9.80\text{ m/s}^2} = 5.0\text{ kg}$$

b. What is the acceleration of the ball if an upward force of 69 N is applied?

$$ma = F_{net} = F_{appl} + W = 69\text{ N} + (-49\text{ N}) = 20\text{ N}$$

$$\text{So, } a = \frac{F_{net}}{m} = \frac{20\text{ N}}{5.0\text{ kg}} = 4.0\text{ m/s}^2$$

14. A small weather rocket weighs 14.7 N.

a. What is its mass?

$$m = \frac{W}{g} = \frac{14.7\text{ N}}{9.80\text{ m/s}^2} = 1.50\text{ kg}$$

b. The rocket is carried up by a balloon. The rocket is released from the balloon and fired, but its engine exerts an upward force of 10.2 N. What is the acceleration of the rocket?

$$ma = F_{net} = F_{appl} + W = 10.2\text{ N} + (-14.7\text{ N}) = -4.50\text{ N}$$

$$\text{Thus, } a = \frac{F_{net}}{m} = \frac{-4.50\text{ N}}{1.5\text{ kg}} = -3.00\text{ m/s}^2$$

Practice Problems

15. The space shuttle has a mass of 2.0×10^6 kg. At lift–off the engines generate an upward force of 30×10^6 N.

a. What is the weight of the shuttle?

$$W = mg = (2 \times 10^6\text{ kg})(9.80\text{ m/s}^2) = 20 \times 10^6\text{ N}$$

b. What is the acceleration of the shuttle when launched?

$$ma = F_{net} = F_{appl} + W = 30 \times 10^6\text{ N} + (-20 \times 10^6\text{ N}) = 10 \times 10^6\text{ N}$$

$$\text{Thus, } a = \frac{F_{net}}{m} = \frac{(10 \times 10^6\text{ N})}{(2 \times 10^6\text{ kg})} = 5.0\text{ m/s}^2$$

c. The average acceleration of the shuttle during its 10 minute launch is 13 m/s². What velocity does it attain?

$$v = at = (13\text{ m/s}^2)(600\text{ s}) = 7.8 \times 10^3\text{ m/s} = 7.8\text{ km/s}$$

d. As the space shuttle engines burn, the mass of the fuel becomes less and less. Assuming the force exterted by the engines remains the same, would you expect the acceleration to increase, decrease, or remain the same? Why?

It would increase.

$a = \frac{F}{m}$. F is constant, m decreases, so a increases.

16. A certain sports car accelerates from 0 to 60 mph in 9.0 s (average acceleration = 3.0 m/s²). The mass of the car is 1354 kg. The average backward force due to air drag during acceleration is 280 N. Find the force required to give the car this acceleration.

$$F_{net} = ma = (1354\text{ kg})(3.0\text{ m/s}^2) = 4.1 \times 10^3\text{ N}$$

$F_{net} = F_{appl} + F_{drag}$, so

$$F_{appl} = F_{net} - F_{drag} = 4.1 \times 10^3\text{ N} - (-280\text{ N}) = 4.4 \times 10^3\text{ N}$$

Chapter Review Problems

Chapter Review Problems

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1. A 873–kg (1930 lb) dragster, starting from rest, attains a speed of 26.3 m/s (58.9 miles/hour) in 0.59 s.

a. Find the average acceleration of the dragster during this time interval.

$$a = \frac{\delta v}{\delta t} = \frac{(26.4 \text{ m/s} - 0)}{0.59 \text{ s}} = 45 \text{ m/s}^2$$

b. What is the size of the average force on the dragster during this time interval?

$F = ma = (873 \text{ kg})(45 \text{ m/s}^2) = 3.9 \times 10^4 \text{ N}$

c. Assume the driver has a mass of 68 kg. What horizontal force does the seat exert on the driver?

$F = ma = (68 \text{ kg})(45 \text{ m/s}^2) = 3.1 \times 10^3 \text{ N}$

d. Is the driver's mass in part c an inertial mass or a gravitational mass?

Inertial mass.

2. The dragster in Problem 1 completed the 402.3 m (0.2500 mile) run in 4.936 s. If the car had constant acceleration, what would be its acceleration and final velocity?

$d = \frac{1}{2}at^2$, so

$a = 2d/t^2 = 2(402.3 \text{ m})/(4.936 \text{ s})_2 = 33.02 \text{ m/s}$

$d = \frac{1}{2}vt$, so

$v = 2d/t = 2(402.3 \text{ m})/4.936 \text{ s}) = 163.0 \text{ m/s}$

3. The dragster crossed the finish line going 126.6 m/s (283.1 mph). Is the assumption of constant acceleration good? What other piece of evidence could you use to see if the acceleration is constant?

126.6 m/s is slower than found in Problem 2, so the acceleration cannot be constant. Further, we found that the acceleration in the first half–second was 45 m/s², which is not equal to 33.02 m/s².

4. In Chapter 4 you found that when a karate strike hits wooden blocks, the hand undergoes an acceleration of -6500 m/s^2. Medical data indicates the mass of the forearm and hand to be about 0.7 kg. What is the force exerted on the hand by the blocks? What is its direction?

$F = ma = (0.7 \text{ kg})(-6500 \text{ m/s}^2)$
$= -5 \times 10^3 \text{ N}$ (upward)

5. After a day of testing race cars, you decide to take your own 1550–kg car out onto the test track. While moving down the track at 10 m/s, you suddenly accelerate to 30 m/s in 10 s. What is the net average force that you have applied to the car during the 10–s interval?

$F = ma = m\Delta v/t$
$= (1550 \text{ kg})(30 \text{ m/s} - 10 \text{ m/s})/10 \text{ s} =$
$= 3.1 \times 10^3 \text{ N}$

6. A race car has a mass of 710 kg. It starts from rest and travels 40 m in 3.0 s. The car is uniformly accelerated during the entire time. What net force is applied to it?

$F = ma$, where, since d and t are known, a can be found from $d = v_i t + (1/2)at^2$. Since $v_i = 0$, $a = 2d/t^2 = 2(40 \text{ m})/(3.0 \text{ s})^2 = 8.9 \text{ m/s}^2$, so $F = (710 \text{ kg})(8.9 \text{ m/s}^2) = 6.3 \times 10^3 \text{ N}$.

7. A force of -9000 N is used to stop a 1500–kg car traveling at 20 m/s. What braking distance is needed to bring the car to a halt?

$a = F/m = (-9.0 \times 10^3 \text{ N})/(1.5 \times 10^3 \text{ kg})$
$= -6.0 \text{ m/s}^2$
Use $v_f^2 = v_i^2 + 2ad$,
so $d = (v_f^2 - v_i^2)/2a$.
$= (0 - (20 \text{ m/s})^2)/(2)(-6.0 \text{ m/s}^2)$
$= 33 \text{ m}$

8. A 65–kg swimmer jumps off a 10–m high tower.

a. Find the swimmer's velocity when hitting the water.

$v_f^2 = v_i^2 + 2gd$. $v_i = 0$,
so $v_f^2 = 2gd = 2(9.80 \text{ m/s}^2)(10 \text{ m})$
so $v_f = 14 \text{ m/s}$.

b. The swimmer comes to a stop 2.0 m below the surface. Find the net force exerted by the water.

$v_f^2 = v_i^2 + 2ad$, or

$$a = \frac{v_f^2 - v_i^2}{2d} = \frac{0^2 - (14\ m/s)^2}{2(2.0\ m)} = -49\ m/s^2$$

and

$$F = ma = (65\ kg)(-49\ m/s) = 3.2 \times 10^3\ N$$

9. When you drop a 0.40-kg apple, Earth exerts a force on it which accelerates it at 9.8 m/s^2 towards Earth's surface. According to Newton's Third Law of Motion, the apple must exert an equal and opposite force on Earth. If the mass of Earth is 5.85 × 10^{24} kg, what's the magnitude of Earth's acceleration?

$F_{a\ on\ E} = -F_{E\ on\ a}$, $m_a a_a = -m_E a_E$,

$a_E = -(m_a a_a)/m_E$

$= -(4.0\ kg)(-9.8\ m/s^2)/(5.98 \times 10^{24}\ kg)$

$= 6.6 \times 10^{-25}\ m/s^2$

10. A 60.0-kg boy and a 40.0-kg girl use an elastic rope while engaged in a tug-of-war on an icy frictionless surface. If the acceleration of the girl toward the boy is 3.0 m/s^2, determine the magnitude of the acceleration of the boy toward the girl.

$F_{1,2} = -F_{2,1}$ so $m_1 a_1 = -m_2 a_2$, and

$$a_1 = \frac{-(m_2 a_2)}{m_1}$$

$$= \frac{(40.0\ kg)(3.0\ m/s^2)}{(60.0\ kg)}$$

$$= -2.0\ m/s^2$$

11. A 95.0-kg (209 lb) boxer has his first match in the Canal Zone ($g = 9.782\ m/s^2$) and his second match at the North Pole ($g = 9.832\ m/s^2$).

a. What is his mass in the Canal Zone?

95.0 kg

b. What is his weight in the Canal Zone?

$W = mg = (95.0)(9.782\ m/s^2) = 929\ N$

c. What is his mass at the North Pole?

95.0 kg

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d. What is his weight at the North Pole?

$W = mg = (95.0)(9.832\ m/s^2) = 934\ N$

e. Does he 'weigh-in' or does he really 'mass-in'?

Mass-in. We sometimes use the word weight when we mean mass.

12. Your new motorcycle weighs 2450 N. What is its mass in kilograms?

$W = mg$, so

$m = W/g = (-2450\ N)/(-9.80\ m/s^2)$

$= 250\ kg$

13. You place a 7.50-kg television set on a spring scale. If the scale reads 78.4 N, what is the acceleration of gravity at that location?

W = mg, so

$g = W/m = (78.4\ N)(7.50\ kg)$

$= 10.5\ m/s^2$, downward

14. In Chapter 4 you calculated the braking acceleration for a car based on data in a drivers' handbook. The acceleration was $-12.2\ m/s^2$.

If the car has a mass of 925 kg, find the frictional force and state the direction.

$F_f = ma = (925\ kg)(-12.2\ m/s^2)$

$= 1.13 \times 10^4$ N, opposite direction of motion

15. If you use a horizontal force of 30.0 N to slide a 12.0-kg wooden crate across a floor at a constant velocity, what is the coefficent of sliding friction between crate and floor?

$$\mu = \frac{F_f}{F_N}$$

$$= \frac{F_f}{W} = \frac{F_f}{mg}$$

$$= \frac{(30.0\ N)}{(12.0\ kg)(9.80\ m/s^2)} = 0.255$$

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16. You are driving a 2500.0-kg car at a constant speed of 14.0 m/s along an icy, but straight and level, road. While approaching a traffic light, it turns red. You slam on the brakes. Your wheels lock, the tires begin skidding and the car slides to a halt in a distance of 25.0 m. What is the coefficient of sliding friction (μ) between your tires and the icy roadbed?

$F_f = \mu F_N = ma$
$-\mu mg = m(v_f^2 - v_i^2)/2d$ where $v_f = 0$.
(The − sign indicates the force is acting opposite to the direction of motion.)
$\mu = v_i^2/2dg = (14.0\ \text{m/s})^2/2(25.0\ \text{m})(9.80\ \text{m/s}^2)$
$= 0.400$

17. A person fishing hooks a 2.0-kg fish on a line that can only sustain a maximum of 38 N of force before breaking. At one point while reeling in the fish, it fights back with a force of 40 N. What is the minimum acceleration with which he must play out line during this time in order to keep the line from breaking?

Take the direction from the fish to the person as positive. The acceleration of the fish, and hence the line, will be obtained from
$ma = F_{net} = F_{appl} + F_{fish}$.
Thus, $a = (F_{appl} + F_{fish})/m$
$= (38\ \text{N} - 40\ \text{N})/(2.0\ \text{kg})$
$= -1.0\ \text{m/s}^2$.

18. A 4500-kg helicopter accelerates upward at 2 m/s². What lift force is exerted by the air on the propellers?

$ma = F_{net} = F_{appl} + W = F_{appl} + mg$, so
$F_{appl} = ma - mg$
$= (4500\ \text{kg})(2\ \text{m/s}^2) - (4500\ \text{kg})(-9.8\ \text{m/s}^2)$
$= 5.3 \times 10^4\ \text{N}$.

19. The maximum force a grocery sack can withstand and not rip is 250 N. If 20 kg of groceries are lifted from the floor to a table with an acceleration of 5 m/s², will the sack hold?

$ma = F_{net} = F_{appl} + W = F_{appl} + mg$, so
$F_{appl} = ma - mg$
$= (20\ \text{kg})(5\ \text{m/s}^2) - (20\ \text{kg})(-9.8\ \text{m/s}^2)$
$= 300\ \text{N}$.
No, this force is greater than 250 N, hence the sack rips.

20. A student stands on a bathroom scale in an elevator at rest on the 64th floor of a building. The scale reads 836 N.

The basic equation to be applied is $ma = F_{net} = F_{appl} - W$, where the positive direction is taken upward and F_{appl} is the force exerted by the scale. The mass of the student is $m = W/g = (836\ \text{N})/(9.80\ \text{m/s}^2) = 85.3\ \text{kg}$.

a. As the elevator moves up, the scale reading increases to 935 N, then decreases back to 836 N. Find the acceleration of the elevator.

$a = (F_{appl} - W)/m$
$= (935\ \text{N} - 836\ \text{N})/(85.3\ \text{kg})$
$= 1.2\ \text{m/s}^2$

b. As the elevator approaches the 74th floor, the scale reading drops as low as 782 N. What is the acceleration of the elevator?

$a = (F_{appl} - W)/m$
$= (782\ \text{N} - 836\ \text{N})/(85.3\ \text{kg})$
$= -0.63\ \text{m/s}^2$

c. Using your results from parts **a** and **b**, explain which change in velocity, starting or stopping, would take the longer time.

Stopping, because the acceleration is less and $t = -v_i/a$

d. Explain the changes in the scale you would expect on the ride back down.

$F_{appl} = W + ma = 836\ \text{N} + ma$. As the elevator starts to descend a is negative and the scale reads less than 836 N. When constant downward velocity is reached, the scale reads 836 N since the acceleration is then zero. When the elevator is slowing at the bottom, the acceleration is positive and the scale reads more than 836 N.

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21. A 2.1×10^{-4}–kg spider is suspended from a thin strand of spider web. The greatest tension the strand can withstand without breaking is 2.2×10^{-3} N. What is the maximum acceleration with which the spider can safely climb up the strand?

$ma = F_{net} = F_{appl} + W$
The tension (T) is F_{appl}. Take up as positive.
Therefore $ma = T - W$.

$$\frac{((2.2 \times 10^{-3}\text{ N}) - (2.1 \times 10^{-4})(9.8\text{ m/s}^2))}{2.1 \times 10^{-4}\text{ kg}}$$

$= 0.68\text{ m/s}^2$

22. A sled of mass 50 kg is pulled along snow–covered, flat ground. The static friction coefficient is 0.30, and the sliding friction coefficient is 0.10.

a. What does the sled weigh?

$W = mg = (50\text{ kg})(9.8\text{ m/s}^2) = 4.9 \times 10^2\text{ N}$

b. What force will be needed to start the sled moving?

$F_i = \mu F_N = \mu W = (0.30)(490\text{ N}) = 150\text{ N}$, static friction.

c. What force is needed to keep the sled moving at a constant velocity?

$F_i = \mu F_N = \mu W = (0.10)(490\text{ N}) = 49\text{ N}$, sliding friction.

d. Once moving, what total force must be applied to the sled to accelerate it 3.0 m/s²?

$ma = F_{net} = F_{appl} - Fi$ so
$F_{appl} = ma + F_i$
$= (50\text{ kg})(3.0\text{ m/s}^2) + 49\text{ N}$
$= 2.0 \times 10^2$

23. A force of 40 N accelerates a 5.0–kg block at 6.0 m/s² along a horizontal surface.

a. How large is the frictional force?

$ma = F_{net} = F_{appl} - F_i$, so
$F_f = F_{appl} - ma$
$= 40\text{ N} - (5.0\text{ kg})(6.0\text{ m/s}^2) = 10\text{ N}$

b. What is the coefficient of fricion?

$F_i = \mu F_N = \mu mg$ so
$\mu = F_f/mg = (10\text{ N})/(5.0\text{ kg})(9.8\text{ m/s}^2)$
$= 0.20$

24. A 200–kg crate is pushed horizontally with a force of 700 N. If the coefficient of friction is 0.20, calculate the acceleration of the crate.

$ma = F_{net} = F_{appl} - F_i$ where $F_i = \mu F_N = \mu mg$.
Therefore
$a = (F_{appl} - \mu mg)/m$

$$= \frac{(700\text{ N} - (0.20)(200\text{ kg})(9.8\text{ m/s}^2)}{200\text{ kg}}$$

$= 1.5\text{ m/s}^2$.

25. Safety engineers estimate that an elevator can hold 20 persons of 75–kg average mass. The elevator itself has a mass of 500 kg. Tensile strength tests show that the cable supporting the elevator can tolerate a maximum force of 2.96×10^4 N. What is the greatest acceleration that the elevator's motor can produce without breaking the cable?

$m = (20)(75\text{ kg}) + 500\text{ kg} = 2.0 \times 10^3\text{ kg}$.
$W = mg = (2.0 \times 10^3\text{ kg})(9.8\text{ m/s}^2)$
$= 2.0 \times 10^4\text{ N}$.
$ma = F_{net} = F_{appl} - W$,
$a = (F_{appl} - W)/m$
$= (2.96 \times 10^4\text{ N} - 2.0 \times 10^4)/(2.0 \times 10^3)$
$= 4.8\text{ m/s}^2$.

26. The instruments attached to a weather balloon have a mass of 5.0 kg.

a. The balloon is released, and exerts an upward force of 98 N on the instruments. What is the acceleration of the balloon and instruments?

$ma = F_{net} = F_{appl} + W = 98\text{ N} + (-49\text{ N})$
$= +49\text{ N (up)}$
$a = (+49\text{ N})/(5.0\text{ kg}) = +9.8\text{ m/s}^2\text{ (up)}$

b. After the balloon has been accelerating for 10.0 seconds, the instruments are released. What is the velocity of the instruments at the moment of their release?

$v = at = (+9.80\text{ m/s}^2)(10\text{ s}) = +98\text{ m/s (up)}$

c. What net force acts on the instruments after their release?

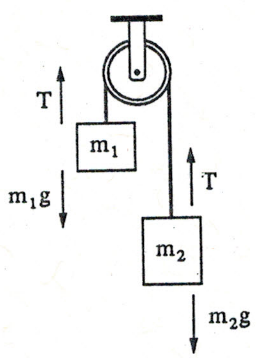
Just the instrument weight, – 49 N (down)

d. When does the direction of their velocity first become downward?

The velocity becomes negative after it passes through zero. Thus, use $v_f = v_i + gt$, where $v_f = 0$, or
$t = -v_i/g = -(+98 \text{ m/s})/(-9.80 \text{ m/s}^2)$
$= 10$ s.

27. A 2.0-kg mass (m_1) and a 3.0-kg mass (m_2) are attached to a lightweight cord that passes over a frictionless pulley, as diagrammed. The hanging masses are free to move. Take the direction of the physical motion, smaller mass upward and larger mass downward, to be the positive direction of motion.

a. Draw the situation, showing all forces.



b. In what direction does the smaller mass move?

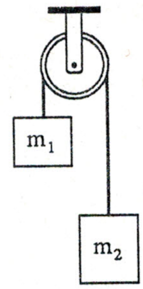
upward

c. What is its acceleration?

$ma = F_{net}$ where m is the total mass being accelerated.
For m_1, $m_1a = T - m_1g$
For m_2, $m_2a = -T + m_2g$ or $T = m_2g - m_2a$
Substituting into the equation for m_1 gives
$m_1a = m_2g - m_2a - m_1g$ or
$(m_1 + m_2)a = (m_2 - m_1)g$
Therefore $a = ((m_2 - m_1)/(m_1 + m_2))g$
$= ((3.0 - 2.0)/(3.0 + 2.0))9.80$
$= (1.0/5.0)9.80 = 2.0 \text{ m/s}^2$

Chapter Review Problems

28. You change the masses in Figure 5–18 to 1.00 kg and 4.00 kg.



5

a. What can you expect the acceleration of the 4.00-kg mass to be?

Take the direction of the physical motion, smaller mass upward and larger mass downward, to be the positive direction of motion.
For m_1, $m_1a = T - m_1g$
For m_2, $m_2a = -T + m_2g$ or $T = m_2g - m_2a$
Substituting into the equation for m_1 gives
$m_1a = m_2g - m_2a - m_1g$ or
$(m_1 + m_2)a = (m_2 - m_1)g$
Therefore,
$a = ((m_2 - m_1)/(m_1 + m_2))g$
$= ((4.00 - 1.00)/(4.00 + 1.00))9.80$
$= (3.00/5.00)(9.80) = 5.9 \text{ m/s}^2$

b. What is the tension force acting on the cord?

$T = m_2g - m_2a = m_1(g - a)$
$= 4.00(9.80 - 5.9) = 16$ N

29. You then decide to replace the 1.00-kg object from Problem 28 with a 2.00-kg object.

a. What is the acceleration of the 2.00-kg object?

The acceleration will be the same for both masses. From Problem 28,
$a = ((m_2 - m_1)/(m_2 + m_1))g$
$= ((4.00 - 2.00)/(4.00 + 2.00))9.80$
$= (2.00/6.00)9.80 = 3.3 \text{ m/s}^2$

b. What is the new tension force acting on the cord?

From Problem 28,
$T = m_2(g - a) = 4.00(9.80 - 3.27) = 26.1$ N

Supplemental Problems

1. A towrope is used to pull a 1750-kg car, giving it an acceleration of 1.35 m/s². What force does the rope exert?

$F = ma = (1750 \text{ kg})(1.35 \text{ m/s}^2)$
$= 2.36 \times 10^3$ N, in the direction of the acceleration.

2. A race car undergoes a uniform acceleration of 4.00 m/s². If the net force causing the acceleration is 3.00 × 10³ N, what is the mass of the car?

$m = F/a = (3.00 \times 10^3 \text{ N})/(4.00 \text{ m/s}^2)$
$= 750$ kg

3. A 5.2-kg bowling ball is accelerated from rest to a velocity of 12 m/s as the bowler covers 5.0 m of approach before releasing the ball. What average force is exterted on the ball during this time?

$v_f^2 - v_i^2 = 2ad$

$$a = \frac{v_f^2 - vi^2}{2d} = \frac{(12 \text{ m/s})^2 - 0^2}{2(5.0 \text{ m})} = 14.4 \text{ m/s}^2$$

$F = ma = (5.2 \text{ kg})(14.4 \text{ m/s}^2) = 75$ N.

4. A high jumper falling at 4.0 m/s lands on a foam pit and comes to rest, compressing the pit .40 m. If the pit is able to exert an average force of 1200 N on the high jumper in breaking the fall, what is the jumper's mass?

$v_f^2 - v_i^2 = 2ad$

$$a = \frac{v_f^2 - v_i^2}{2d} = \frac{0^2 - (4.0 \text{ m/s}^2)}{2(0.40 \text{ m})} = -20 \text{ m/s}^2$$

where the positive direction is downward.
$F = ma$

$$m = \frac{F}{a} = \frac{-1200}{-20} = 60 \text{ kg}$$

5. When a 20-kg child steps off a 3.0-kg stationary skateboard with an acceleration of .50 m/s², with what acceleration will the skateboard travel in the opposite direction?

$F_{child} = ma = (20 \text{ kg})(0.50 \text{ m/s}^2) = 10$ N
$F_{child} = F_{skateboard}$ so for skateboard
$F = ma$, or

$$a = \frac{F}{m} = \frac{10 \text{ N}}{3.0 \text{ kg}} = 3.3 \text{ m/s}^2$$

6. On planet X a 50-kg barbell can be lifted by only exerting a force of 180 N.

a. What is the acceleration of gravity on planet X?

$W = mg$

$$g = \frac{W}{m} = \frac{180 \text{ N}}{50 \text{ kg}} = 3.6 \text{ m/s}^2$$

b. If the same barbell was lifted on earth, what minimal force is needed?

$W = mg$
$= (50 \text{ kg})(9.8 \text{ m/s}^2)$
$= 4.9 \times 10^2$ N

7. A proton has a mass of 1.672 × 10⁻²⁷ kg. What is its weight?

$W = mg$
$= (1.672 \times 10^{-27} \text{ kg})(9.8 \text{ m/s}^2)$
$= 1.6 \times 10^{-26}$ N

8. A force of 20 N accelerates a 9.0-kg wagon at 2.0 m/s² along the sidewalk.

a. How large is the frictional force?

$F_{net} = ma = (9.0 \text{ kg})(2.0 \text{ m/s}^2) = 18$ N
$F_f = F_{appl} - F_{net} = 20 \text{ N} - 18 \text{ N} = 2$ N

b. What is the coefficient of friction?

$F_N = W = mg = (9.0 \text{ kg})(9.8 \text{ m/s}^2) = 88$ N

$$\mu = \frac{F_f}{F_N} = \frac{2 \text{ N}}{88 \text{ N}} = 0.02$$

9. A 2.0-kg brick has a sliding coefficient of friction of .38. What force must be applied to the brick for it to move at a constant velocity?

$F_f = \mu F_N$ where
$F_N = W = mg = (2.0\text{ kg})(9.8\text{ m/s}^2) = 19.6\text{ N}$ so
$F_f = \mu F_N = (0.38)(19.6\text{ N}) = 7.4\text{ N}$

10. In bench pressing 100 kg, a weight lifter applies a force of 1040 N. How large is the upward acceleration of the weights during the lift?

$W = mg = (100\text{ kg})(9.80\text{ m/s}^2) = 980\text{ N}$
$F_{net} = F_{appl} - W = 1040\text{ N} - 980\text{ N} = 60\text{ N}$
$F_{net} = ma$

$$a = \frac{F_{net}}{m} = \frac{60\text{ N}}{100\text{ kg}} = 0.60\text{ m/s}^2$$

11. An elevator that weighs 3.0×10^3 N is accelerated upward at 1.0 m/s². What force does the cable exert to give it this acceleration?

The mass of the elevator is
$m = W/g = (-3.0 \times 10^3\text{ N})/(-9.8\text{ m/s}^2)$
$= 3.1 \times 10^2$ kg.
Now $ma = F_{net} = F_{appl} + W$ so that
$F_{appl} = ma - W$
$= (3.1 \times 10^2\text{ kg})(1.0\text{ m/s}^2)$
$- (-3.0 \times 10^3\text{ N})$
$= 3.3 \times 10^3$ N.

12. A person weighing 490 N stands on a scale in an elevator.

The basic equation to be applied is $ma = F_{net} = F_{appl} - W$, where the positive direction is taken upward and F_{appl} is the force exerted by the scale. The mass of the person is $m = W/g = (490\text{ N})/(9.8\text{ m/s}^2) = 50$ kg.

a. What does the scale read when the elevator is at rest?

$a = 0$ so $F_{appl} = W = 490$ N

b. What is the reading on the scale when the elevator rises at a constant velocity?

$a = 0$ so $F_{appl} = W = 490$ N

c. The elevator slows down at -2.2 m/s² as it reaches the desired floor. What does the scale read?

$F_{appl} = ma + W$
$= (50\text{ kg})(-2.2\text{ m/s}^2) + 490\text{ N}$
$= 3.8 \times 10^2$ N

d. The elevator descends, accelerating at -2.7 m/s². What does the scale read?

$F_{appl} = ma + W$
$= (50\text{ kg})(-2.7\text{ m/s}^2) + 490\text{ N}$
$= 3.6 \times 10^2$ N

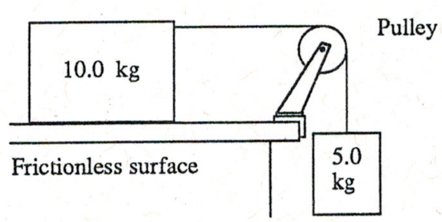
e. What does the scale read when the elevator descends at a constant velocity?

$a = 0$ so $F_{appl} = W = 490$ N

f. Suppose the cable snapped and the elevator fell freely. What would the scale read?

$a = -g$ so
$F_{appl} = ma + W = m(-g) + mg = 0$

13. A 10.0-kg mass (m_1) on a frictionless table is accelerated by a 5.0-kg mass (m_2) hanging from the table as shown below. What is the acceleration of the mass along the table?



$F = ma$ where
$m = m_1 + m_2 =$ the total mass being accelerated and $F = m_2 g =$ the applied force. Thus,
$m_2 g = (m_1 + n_2)a$ or
$a = m_2 g/(m_1 + m_2)$
$= (5.0\text{ kg})(9.80\text{ m/s}^2)/(5.0\text{ kg} + 10.0\text{ kg})$
$= 3.3$ m/s², to the right.