be in equilibrium. The type of equilibrium—stable, unstable, or neutral—is determined by noting whether the object tends to return to its original state of rest or uniform motion when it is disturbed slightly.

The second law states that the net force **F** needed to produce an acceleration **a** satisfies

$$\mathbf{F} = m\mathbf{a}$$

Here m is the mass or inertia of the object.

The third law states that if object A exerts a force B, then B exerts an equal and opposite force on A. Since the forces act on different objects, their effects do not cancel.

All objects exert gravitational forces on each other. The forces between two spheres or point particles are proportional to the products of their masses and inversely proportional to the square of their separation. The mass of an object is the same everywhere in the universe; its weight $\mathbf{w} = m\mathbf{g}$ depends on the acceleration due to gravity at that object's location. The perceived or effective weight also depends on the acceleration and is given by

$$\mathbf{w}^e = m(\mathbf{g} - \mathbf{a})$$

A person in free fall has zero effective weight.

When the force applied to an object resting on a surface exceeds the maximum static friction force $\mu_s N$, it starts to move. The force of sliding or kinetic friction $\mu_k N$ is usually smaller than the maximum static friction force. The coefficients μ_s and μ_k depend on the surfaces and are usually less than 1. The frictional forces between two surfaces are independent of their contact area.

Checklist

Define or explain:

force
contact force
weight
newton
gravitational mass
kilogram
density
relative density
specific gravity
Newton's first law of motion
inertial coordinate system
equilibrium: stable, unstable, neutral
normal force
tension
Newton's third law of motion
action–reaction forces
Newton's second law of motion
inertial mass
law of universal gravitation
gravitational constant
inverse square law
effective weight
friction force
coefficients of static and kinetic or sliding friction

REVIEW QUESTIONS

Q3-1 Forces exerted only when two objects are touching are called _____.

Q3-2 The weight of an object is the _____ force on that object.

Q3-3 The mass of an object is its weight divided by the _____.

Q3-4 The density is the ratio of the mass of an object to its _____.

Q3-5 A material with a specific gravity of 1 has the same density as _____.

Q3-6 According to Newton's first law, an object in motion with a constant velocity relative to an inertial frame has _____ acting on it.

Q3-7 If an object returns to its original resting place when moved slightly, it is in _____.

Q3-8 If object A exerts a force on object B, B exerts _____ on A.

Q3-9 The acceleration of an object is equal to the net force acting on the object divided by its _____.

Q3-10 The universal law of gravitation is referred to as an inverse square law because the gravitational force varies as _____.

Q3-11 The gravitational mass of an object equals its _____.

Q3-12 The _____ of an object is the same everywhere; its _____ depends on where the object is located in the universe.

Q3-13 The effective weight of an object is zero when it is in _____.

Q3-14 The maximum frictional force between two given surfaces is independent of the _____ and proportional to the _____.

Q3-15 The force needed to keep an object sliding is smaller than that required to _____.

Q3-16 The coefficient of static friction is usually less than _____ and greater than the coefficient of _____.

EXERCISES

Section 3.1 | Force, Weight, and Gravitational Mass

3-1 Find the direction and magnitude of the net force on the object in Fig. 3.22.

3-2 Find the direction and magnitude of the net force on the object in Fig. 3.23.

3-3 Find the direction and magnitude of the net force on the object in Fig. 3.24.

3-4 A man weighs 980 N. What is his mass in kilograms?

3-5 A woman has a mass of 50 kg. What is her weight in newtons?

3-6 What is the weight of a 1-kg steak?

3-7 Find the weight of 500 g of candy in (a) newtons; (b) pounds.

3-8 A candy bar weighs 1 ounce (1 oz) (16 oz = 1 lb). Find its mass in kilograms.

3-9 A woman weighs 120 lb. What is her mass in kilograms?

3-10 A large oil tanker weighs 200,000 tons, where 1 ton = 2000 lb. What is its mass in kilograms?

Section 3.2 | Density (See Table 3.2 for required densities.)

3-11 Sphere A has twice the mass and three times the radius of sphere B. What is the ratio of their densities?

3-12 Bricks with identical dimensions are made from lead and from aluminum. What is the ratio of their masses?

3-13 What is the mass of a litre of whole blood? (1 litre = 10^{-3} m^3)

3-14 Hydrogen atoms are the most common type of matter in many regions of interstellar space. A hydrogen atom has a mass of 1.67×10^{-27} kg. If there is an average of one hydrogen atom in each cubic centimetre of an interstellar "gas cloud," what is the density of hydrogen in S.I. units?

3-15 (a) Using the solar and terrestrial data tabulated on the inside back cover of this book, calculate the average density of the sun. (b) Is this density consistent with that given for the sun in Table 3.2? Explain.

3-16 A cylindrical iron rod has a radius of 1 cm and a length of 20 cm. What is its mass?

3-17 The nucleus of a uranium atom is approximately described as a sphere of radius 8.7×10^{-15} m and of mass 3.5×10^{-25} kg. (a) What is its average density? (b) What is its specific gravity?

3-18 Neutron stars are a late stage in stellar evolution. A typical neutron star has a radius of 10^4 m and a mass of 2×10^{30} kg. (a) What is its average density? (b) Find the ratio of this density to the density of lead.

3-19 What is the specific gravity of water at a temperature of 0°C and a pressure of 50 atmospheres?

3-20 A gold foil has a thickness of 10 micrometres (1 μm = 10^{-6} m). What is the mass of a square of side 10 cm?

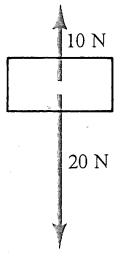

Figure 3.23. Exercise 3-2.

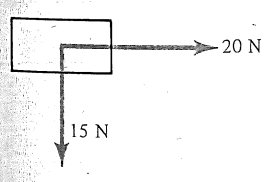

Figure 3.22. Exercise 3-1.

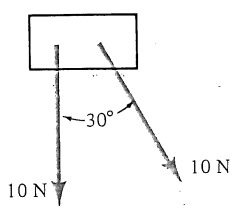

Figure 3.24. Exercise 3-3.

3-21 In the petroleum industry, a barrel is defined to be 42 gallons, where 1 gallon = 3.786 litres = 3.786×10^{-3} m^3. Find the mass in kilograms of one barrel of oil with a relative density of 0.8.

3-22 Find the density of gasoline if 5 kg has a volume of 7.35×10^{-3} m^3.

3-23 Battery acid has a density of 1290 kg m^{-3} and contains 35 percent sulfuric acid by weight. What is the mass of the sulfuric acid in 1 litre? (1 litre = 10^{-3} m^3 of battery acid.)

3-24 (a) Calculate the percentage change in the density of air when it is heated at atmospheric pressure from 0°C to 100°C. (b) Calculate the corresponding change for water.

3-25 (a) What is the specific gravity of lead? (b) What is the mass of a cube of lead whose side is 10 cm?

Section 3.3 | Newton's First Law and Section 3.4 | Equilibrium

3-26 For which of the following observers does Newton's first law of motion hold true in the form stated in this chapter? (a) A person on a plane moving at constant speed in a constant direction. (b) A parachutist who has just stepped out of an airplane. (c) A parachutist who has reached terminal velocity and is falling at constant speed. (d) The pilot of a plane that is taking off from a runway. Explain your reasoning.

3-27 A person is in a car traveling around a circular track. Do the observations of this person agree with Newton's first law as stated in this chapter? Does your answer depend on whether the speed is constant? Explain.

3-28 A car is moving at a constant speed on a straight road, which is at an angle of 10° to the horizontal direction. (a) Is it in equilibrium? (b) What forces act on the car?

3-29 A 2000-kg airplane is in level flight at constant velocity. (a) What is the net force on the plane? (b) What is the upward lift force on the plane due to the air?

3-30 A man with a mass of 80 kg sits on a chair of mass 10 kg. (a) Find the weights of the man and the chair. (b) The chair exerts an upward force of 700 N on the man. What force does the floor exert on his feet? (c) What force does the floor exert on the chair?

3-31 In Fig. 3.3, the cables are at an angle of 30° to the horizontal direction. How large are the forces $\mathbf{F}_1$ and $\mathbf{F}_2$ they exert on the traffic light if its weight is $\mathbf{w}$?

3-32 (a) A pencil is placed on its side on a table. If its cross section is hexagonal (six sided), what type of equilibrium is the pencil in? (b) What type of equilibrium is it if the pencil has a circular cross section? (c) Suppose the pencil is balanced on its point. What type of equilibrium is this?

3-33 Which type of equilibrium is illustrated by the traffic light in Fig. 3.3? Explain what will happen if it is slightly displaced horizontally or vertically.

3-34 A package of emergency supplies is parachuted from a plane. The air resistance force increases roughly as the velocity squared, so the package rapidly reaches a constant, maximum velocity directed straight down. (a) Once it reaches this velocity, is this package in equilibrium? (b) What will happen to its state of motion if a brief gust of wind pushes it sideways? (c) What will happen to its state of motion if there is a sudden brief downdraft of air?

3-35 A car goes around a circular track at a constant speed. Is it in equilibrium? Explain.

Section 3.5 | Newton's Third Law

3-36 A boat in a flowing river is tied by a rope to a post on a dock. (a) Draw a diagram showing all the forces acting on the boat. (b) Identify the horizontal forces acting on the boat and the associated reaction forces. (c) Identify the vertical forces acting on the boat and the associated reaction forces. (d) What is the net force on the boat?

3-37 A large airplane is pulled at constant velocity relative to the runway by a truck. The two are connected by an iron bar. (a) What are the forces on the airplane? (b) What are the forces on the truck? (c) What is the net force on the airplane? (d) What is the net force on the truck? (e) What is the net force on the iron bar? (f) Identify the action–reaction forces acting on the airplane, bar, and truck.

3-38 An airplane is flying horizontally with a constant velocity. The propellers are pushing backward on the air. (a) Is the airplane in equilibrium? (b) What forces are acting in the horizontal plane?

3-39 (a) A girl holds a ball motionless in her hand. Identify the forces acting on the ball and their reactions. (b) She throws the ball into the air. What are the forces on the ball while it is in the air? What are the reactions to these forces?

3-40 A car coasts to a stop on a flat, straight road. (a) What are the forces acting on the car? (b) What are the reactions to those forces?

Section 3.6 | Newton's Second Law

3-41 On a horizontal air track, a spring exerts an average force of 2 N on a cart of mass 0.4 kg. (a) Find the acceleration of the cart. (b) If the car accelerates from rest to 0.3 m s^{-1}, for how long a time is the force applied?

3-42 A box weighing 100 N falls from an airplane. As its speed increases, the air resistance force opposing its motion also increases. How large is the acceleration when the air resistance is 100 N?

3-43 A force **F** acts on a brick of mass m and an acceleration **a** results. If the force is halved and applied to two such bricks, what is the new acceleration?

3-44 What acceleration is produced when a 100-N net force is applied to a 10-kg rock?

3-45 What net force is needed to give a 1000-kg car an acceleration of 3 m s^{-2}?

3-46 A baseball of mass 0.15 kg is struck by a bat with a force of 5000 N. What is the acceleration of the ball?

Section 3.8 | Some Examples of Newton's Laws

3-47 An elevator of mass 900 kg accelerates upward at 3 m s^{-2}. What is the tension in the cable where it is attached to the elevator?

3-48 A horse can exert a horizontal force of 3.5×10^4 N on a rope that passes over a pulley to lift loads vertically. What is the acceleration of a load of weight (a) 3.5×10^4 N; (b) 3×10^4 N? (Neglect the masses of the rope and pulley.)

3-49 An elevator cable that is light in weight compared to the elevator car can support a weight of 10,000 N. If the elevator and occupants weigh 8000 N, what is the maximum possible vertical acceleration of the elevator?

3-50 A 60-kg man hangs from a light cable suspended from a helicopter. Find the tension in the cable if the acceleration is (a) 5 m s^{-2} upward; (b) 5 m s^{-2} downward.

3-51 A human femur will fracture if the compressional force is 2×10^5 N. A person of mass 60 kg lands on one leg, so that there is a compressional force on the femur. (a) What acceleration will produce fracture? (b) How many times the acceleration of gravity is this?

3-52 A 55-kg woman wishes to slide down a stationary rope that will support a force of 400 N. What is the minimum acceleration of the woman if she safely slides down the rope?

3-53 An engine with a mass of 4×10^4 kg pulls a train with a mass of 2×10^5 kg on a level track with an acceleration of 0.5 m s^{-2}. What would the acceleration be if the train had a mass of 10^5 kg?

3-54 In a collision, an automobile of mass 1000 kg stops with constant acceleration in 2 m from an initial speed of 20 m s^{-1}. (a) What is the acceleration of the car? (b) What is the net force on the car during the collision?

3-55 A tennis ball of mass 0.058 kg initially at rest is served at a velocity of 45 m s^{-1}. If the racket is in contact with the ball for 0.004 s, what is the net force on the ball during the serve? (Assume the acceleration is constant.)

Section 3.9 | Gravitational Forces

3-56 The moon is 3.9×10^5 km from the center of the earth. The mass of the moon is 7.3×10^{22} kg, and the mass of the earth is 6.0×10^{24} kg. How far from the earth's center are the gravitational forces on an object due to the earth and moon equal and opposite? (Assume the object is on the line connecting the earth and moon.)

3-57 The mass of the sun is 2.0×10^{30} kg, and the distance from the moon to the sun is 1.5×10^8 km. Using the data of the preceding

exercise, find the ratio of the forces exerted by the earth and the sun on the moon.

3-58 When a rocket ship is at a distance R_E from the surface of the earth, the earth's gravitational attraction on the ship is 144,000 N. What is the earth's gravitational attraction when the ship is at a distance $3R_E$ from the surface? (R_E is the radius of the earth.)

3-59 (a) Find the average density of the earth. (b) Using the data in Table 3.2, explain whether its density is consistent with models that state that the earth has a large iron core.

Section 3.10 | Weight

3-60 Would you prefer to have a piece of gold that weighs 1 N on the earth or one that weighs 1 N on the moon? Explain. (Ignore shipping charges!)

3-61 If the radius of the earth were halved and its mass stayed constant, how would your weight change?

3-62 Find the acceleration due to gravity on a planet twice the mass of the earth and three times the radius of the earth.

3-63 The acceleration of gravity on the surface of Mars is 3.62 m s^{-2}. How much would a person who weighs 800 N on earth weigh on Mars?

3-64 The mass of Mars is 6.42×10^{23} kg and the acceleration of gravity on its surface is 3.62 m s^{-2}. What is the radius of Mars?

3-65 The acceleration of gravity at the surface of a planet is half that on the surface of the earth. If the radius of the planet is half the radius of the earth, how is its mass related to the mass of the earth?

3-66 Planet Y has a radius one-third times that of the earth, and a mass $(\frac{1}{3})^3 = \frac{1}{27}$ times that of the earth. On the surface of Planet Y, what is the weight of an astronaut with a mass of 70 kg?

3-67 On the moon, $g = 1.62$ m s^{-2}. An astronaut has a weight of 600 N on the earth. (a) What is her mass on the earth? (b) What is her mass on the moon? (c) What is her weight on the moon?

3-68 An airline stewardess has a mass of 50 kg. (a) What is her weight on the ground? (b) By what fraction does her weight change when she is in a plane 6.38 km above the ground? (The radius of the earth is 6380 km.)

Section 3.11 | Effective Weight

3-69 A fighter plane dives straight down with an acceleration of $3g$. What is the magnitude and direction of the pilot's effective weight if his weight is w?

3-70 A racing car accelerates with an acceleration equal to g on a straight, flat track. If the driver has a mass of 60 kg, what is the magnitude and direction of her effective weight?

3-71 A car initially moving on a straight, flat road at 30 m s^{-1} comes to a stop in 10 s. (a) Assuming the acceleration is constant, how large is it? (b) The driver has a mass m. What is the magnitude and direction of his effective weight as the car slows down?

3-72 An astronaut of mass m is in a spaceship that takes off straight up from the surface of the earth. Its acceleration is kept equal to 9.8 m s^{-2}. (a) What is the effective weight of the astronaut just after takeoff? (b) What is his effective weight when the spaceship is at a distance from the surface of the earth equal to the radius of the earth?

Section 3.12 | Friction

3-73 A horse weighing 7500 N is able to exert a horizontal force of 6500 N on a load. What is the coefficient of static friction between the horse's feet and the ground? (Assume the force exerted by the horse is limited by its tendency to slip.)

3-74 A refrigerator weighs 1000 N. A horizontal force of 200 N is applied, but the refrigerator does not move. (a) What is the frictional force? (b) What can we conclude about the coefficient of static friction?

3-75 A box weighing 100 N is at rest on a horizontal floor. The coefficient of static friction is 0.3. What is the minimum force needed to start the box in motion?

3-76 A box weighing 100 N is pushed on a horizontal floor. The coefficient of sliding friction is 0.2. What acceleration will result if a horizontal force of 40 N is applied?

3-77 On racing cars, surfaces called *spoilers* are sometimes placed so that there will be a downward force due to the air rushing over the car. What is their purpose?

3-78 A refrigerator of mass 120 kg is at rest on

a kitchen floor ($\mu_s = 0.4$ and $\mu_k = 0.2$). (a) If nobody touches the refrigerator, what is the frictional force exerted on the refrigerator by the floor? (b) A boy of mass 40 kg leans on the refrigerator, exerting a horizontal force on it equal to half his weight. What is the frictional force exerted by the floor on the refrigerator?

3-79 A sled weighing 1000 N is pulled along flat, snow-covered ground. The coefficient of static friction is 0.3, and the coefficient of sliding friction is 0.15. Find the force needed to (a) start the sled moving; (b) keep it moving at constant velocity.

3-80 A stone boat of total weight 60,000 N is used in a horse-pulling contest. The coefficient of static friction between the stone boat and the earth is 0.6, and the coefficient of sliding friction is 0.4. (a) What force must a pair of horses exert to start the stone boat moving? (b) What force must the horses exert to keep the stone boat moving at a constant velocity?

3-81 How can the adjustable inclined plane in Fig. 3.21 be used to measure the coefficient of kinetic friction for an object on the plane?

PROBLEMS

3-82 A planet of radius R is made up of a core of radius $R/2$ and density ρ and an outer shell of density $\rho/2$ (Fig. 3.25). What is the average density of the planet as a whole?

3-83 A 1000-kg automobile is traveling at 15 m s^{-1} and skids to a stop with constant acceleration in 100 m. What is the frictional force on the car?

3-84 A 0.5-kg ball is initially at rest. If a 10-N force is applied for 2 s, what is the final velocity of the ball?

3-85 A hockey player who weighs 800 N comes to rest from 10 m s^{-1} in 1 s. (a) What is his mass? (b) What is his average acceleration? (c) What force is required to provide this acceleration?

3-86 A runner's foot strikes the ground with a velocity of 10 m s^{-1} downward. If the effective mass of the foot and leg that is brought to rest is 9 kg, what is the force on the foot as it comes to rest with constant acceleration in (a) 0.03 m on a soft surface; (b) 0.005 m on a hard surface?

3-87 A woman of mass 55 kg steps off a rock, striking the ground at 5 m s^{-1}. (a) If she lands on her feet with her body held rigid, she stops in 0.15 m. What average force is exerted upward on the woman by the ground during the impact? (b) If she flexes her legs and body during impact, she stops in 0.5 m. What average force does she now experience during impact?

3-88 A boy is fishing with a line that will sustain a maximum force of 40 N. If he hooks a 3-kg fish, which can exert a force of 60 N for several seconds, what is the minimum acceleration with which the line must be played out during that time interval?

3-89 A subway train has three cars, each weighing 1.2×10^5 N. The frictional force on each car is 10^3 N, and the first car, acting as an engine, exerts a horizontal force of 4.8×10^4 N on the rails. (a) What is the acceleration of the train? (b) What is the tension in the coupling between the first and second cars? (c) What is the tension between the second and third cars?

3-90 In Fig. 3.26, the string and the pulley are massless, and there is no friction. If $m_1 = m_2 =$

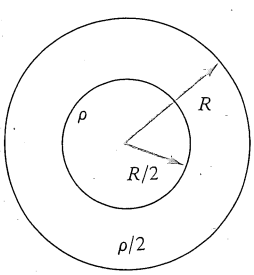

Figure 3.25. Problem 3-82.

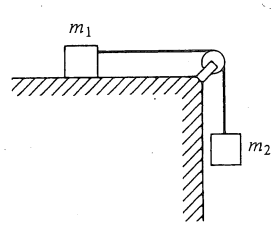

Figure 3.26. Problems 3-90, 3-91, 3-92, and 3-93.

5 kg, find (a) the tension in the string; (b) the acceleration.

3-91 Repeat the preceding problem if the coefficient of kinetic friction between the block and the surface is 0.2.

3-92 In Fig. 3.26, the string and the pulley are massless, and there is no friction. If $m_1 = 10$ kg and $m_2 = 5$ kg, find (a) the tension in the string; (b) the acceleration.

3-93 In Fig. 3.26, the string and the pulley are massless; $m_1 = 10$ kg and $m_2 = 5$ kg. The system remains at rest. Find (a) the tension in the string; (b) the minimum value of the coefficient of static friction between the block and the surface.

3-94 A wagon weighing 5×10^3 N is pulled along a muddy, horizontal road by a 500-kg horse. The coefficient of friction between the wagon wheels and the road is 0.2. (a) If the wagon is pulled at constant speed, what force must the horse exert on the ground to pull the wagon? (b) If the wagon is accelerated from rest to a velocity of 5 m s^{-1} in 5 s, what force must the horse exert on the ground?

3-95 The radius of the planet Venus is 6.1×10^3 km and that of the earth is 6.4×10^3 km. The mass of Venus is 82 percent of the earth's mass. What is the acceleration of gravity on the surface of Venus?

3-96 Two lead spheres of radius 0.1 m are in contact. (a) What is the mass of each sphere? (b) What is the gravitational force between them?

3-97 Neutron stars with a density comparable to that of atomic nuclei, 10^{17} kg m^{-3}, are believed to exist. Suppose two spheres of radius 0.01 m of such a density were somehow placed 1 m apart on the earth. (a) What would be the weight of each sphere? (b) What would be the gravitational attraction between them?

3-98 A 60-kg man wishes to run on ice. The coefficient of static friction between his shoes and the ice is 0.1. What is his maximum possible acceleration?

3-99 A girl of mass 40 kg skis down a slope, which is at an angle of 37° with the horizontal. (Neglect air resistance.) If the coefficient of kinetic friction between her skis and the snow is 0.1, what is her acceleration?

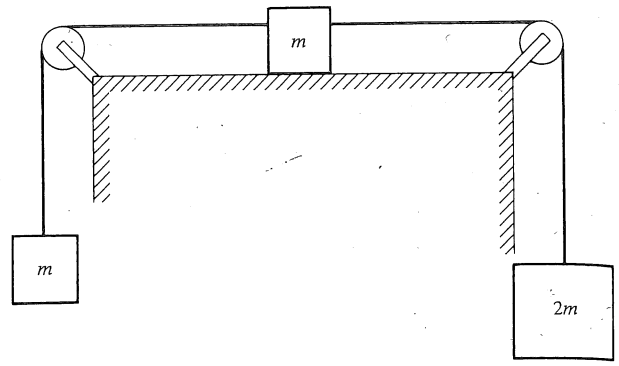

Figure 3.27. Problems 3-100 and 3-101.

3-100 In Fig. 3-27, the strings and pulleys are massless, and there is no friction. Find (a) the tensions in the strings; (b) the acceleration of the system.

3-101 Repeat the preceding problem if the coefficient of kinetic friction between the block on the surface and the surface is 0.1.

3-102 In Fig. 3-28, the string and pulley are massless, and there is no friction. Find (a) the tension in the string; (b) the acceleration.

3-103 In the preceding problem, $m_1 = 2$ kg and $m_2 = 3$ kg. Find (a) the tension in the string; (b) the acceleration. (c) If the system is released from rest, what are its velocity and position after 0.5 s?

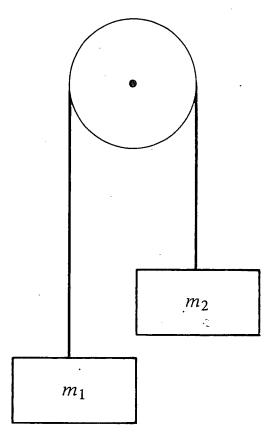

Figure 3.28. Problems 3-102 and 3-103.

***3-104** Two people wish to push a food freezer weighing 2000 N up a ramp inclined at an angle of 37° with the horizontal. The coefficient of sliding friction between the freezer and ramp is 0.5. (a) What minimum force must the people exert to slide the freezer up the ramp? (b) What acceleration will the freezer have if it is released and slides down the ramp? (c) If it slides 4 m down the ramp and strikes a heavy object, coming to rest in 0.5 m, what average force does it exert on the heavy object?

***3-105** A man can exert a force of 700 N on a rope attached to a sled. The rope is at an angle of 30° with the horizontal. If the coefficient of kinetic friction between the sled and ground is 0.4, what is the maximum load on the sled that the man can pull at constant speed?

***3-106** A box weighing 600 N is at rest on a ramp at an angle of 37° with the horizontal. The coefficient of static friction between the box and ramp is 0.8. Find the minimum force required to move the box down the ramp if the force is applied (a) parallel to the ramp; (b) horizontally.

***3-107** In a ski jump, the slope is initially at an angle of 45° to the horizontal. If the coefficient of kinetic friction between the skis and the snow is 0.1, find (a) a skier's acceleration; (b) the velocity reached after 40 m on the ramp.

3-108 If there is no friction, what is the acceleration of the block in Fig. 3.29?

3-109 If the coefficient of sliding friction is 0.2, what is the acceleration of the block in Fig. 3.29?

ANSWERS TO REVIEW QUESTIONS

Q3-1, contact forces; **Q3-2**, gravitational; **Q3-3**, gravitational acceleration; **Q3-4**, volume; **Q3-5**, water at 0°C; **Q3-6**, no net force; **Q3-7**, stable equilibrium; **Q3-8**, an equal but opposite (reaction) force; **Q3-9**, mass; **Q3-10**, $1/r^2$; **Q3-11**, inertial mass; **Q3-12**, mass, weight; **Q3-13**, free fall; **Q3-14**, contact area, normal force; **Q3-15**, start it moving; **Q3-16**, one, kinetic or sliding friction.

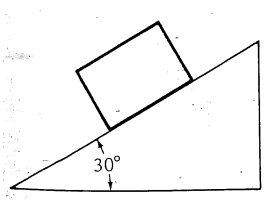

Figure 3.29. Problems 3-108 and 3-109.

Additional Reading

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