SOLUTION: The ball is in the air for a time $2t_p$. She runs at a constant horizontal speed v_H and travels a distance $l = v_H 2t_p$, where $t_p = -v_i/g$. Hence $l = v_H 2t_p = -v_H 2v_i/g = -(2.0\text{ m/s})2(9.4\text{ m/s})/(-9.81\text{ m/s}^2)$ $l = 3.8$ m.

5. [I] THIS PROBLEM WILL HELP US UNDERSTAND THE ACTION OF FORCES. (a) How much force does the scale on the right exert on the scale on the left? (b) Observing that both scales read 100 N, what is the force on the wall in Fig. P5? (c) What force does the hand pull with?

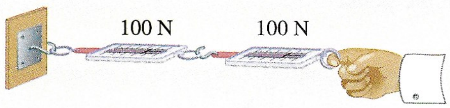

Figure P5

6. [I] THIS PROBLEM WILL HELP US UNDERSTAND THE ACTION OF FORCES. A force of 2.00 kN in the xy-plane acts at 35.0° up from the positive x-axis. (a) Draw a diagram. (b) What is the angle θ between the force and the x-axis? (c) Resolve the force into components in the x- and y-directions.

7. [I] What is the force exerted on the wall by the person in Fig. 4.5a (p. 90)?

8. [I] What is the net force exerted on the scale in Fig. 4.5a?

9. [I] What is the net force exerted on the person on the left by the person on the right in Fig. 4.5d?

10. [I] There are five forces acting on the truck in Fig. P10. What is the net external force on it?

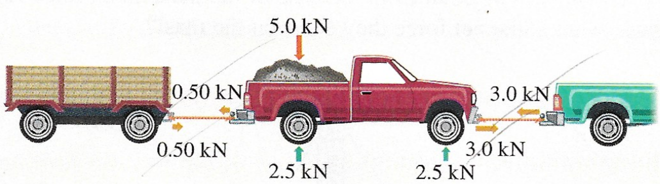

Figure P10

11. [I] The two ropes attached to the hook in Fig. P11 are pulled on with forces of 100 N and 200 N. What size single force acting in what direction would produce the same effect?

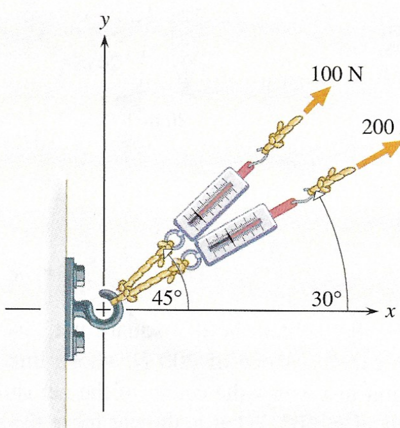

Figure P11

12. [II] The scale in Fig. P12 is being pulled on via three ropes. What net force does the scale read?

TO A

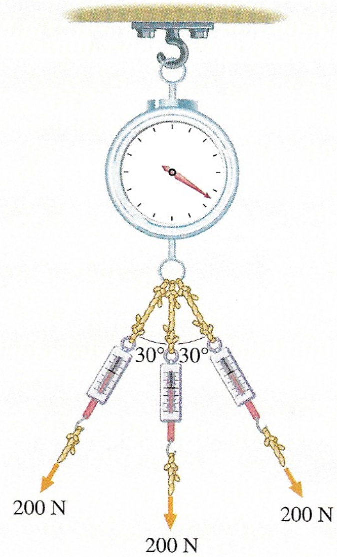

Figure P12

13. [II] What is the net force acting on the ring in Fig. P13?

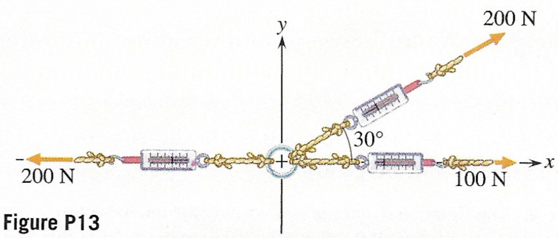

Figure P13

14. [II] What is the net force acting on the ring in Fig. P14?

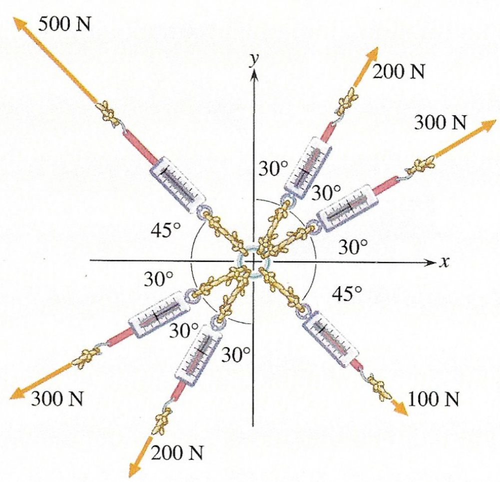

Figure P14

15. [II] Here's a classic: Suppose a conservationist points a dart gun directly at a monkey in a tree. Show that if the monkey drops from its branch just when it sees the gun go off, it will still get hit.

16. [II] Write expressions for the net horizontal and vertical forces due to the hands acting on the block in Fig. P16. The hand on the left pushes downward diagonally.

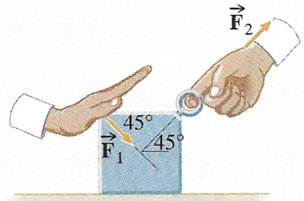

Figure P16

17. [II] What is the net force acting on the ring in Fig. P17? Try to solve this one in an elegant way.

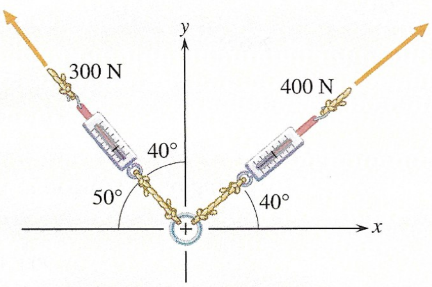

Figure P17

18. [II] Determine the net force acting on the ring in Fig. P18. Again, try to do this one elegantly.

SOLUTION: The situation is symmetrical around the line-of-action of the 200-N force so we resolve all the forces in and perpendicular to that line. Taking up and to the right as positive $\nearrow\sum F = 200\text{ N} - 100\text{ N}\cos 30° - 100\text{ N}\cos 30° = 27\text{ N}$. In the perpendicular direction, the two components arising from the hands pulling cancel $\nwarrow\sum F_{\parallel} = 0$ and the total force is 27 N at 45° upward.

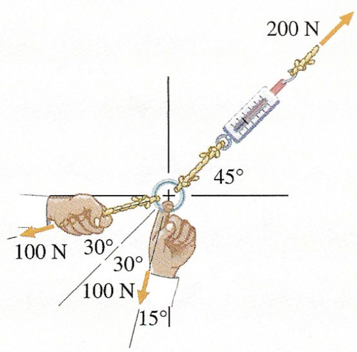

Figure P18

19. [II] THIS PROBLEM ENHANCES THE WAYS WE CAN DEAL WITH FORCES. Two forces, one of which is 60.0 N pointing somewhat north of east and the other is 50.0 N due east, are separated by 50.0°. (a) Draw a diagram. (b) Slide the force vectors parallel to themselves, thereby forming a parallelogram. What is the value of the large angle between the two vectors? (c) Determine the magnitude of the resultant force using the Law of Cosines.

20. [II] THIS PROBLEM PROVIDES PRACTICE IN DEALING WITH FORCES. At the moment of launch, the force exerted by each of the two rubber bands in Fig. P20 is 120 N acting along the band. (a) What are the two force components for each band in the forward direction and perpendicular to it? (b) What is the net force due to the slingshot on the pellet?

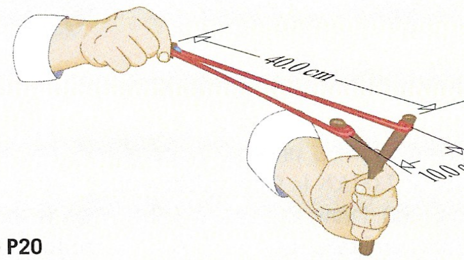

Figure P20

21. [II] A ring is fixed via a harness to a block of stone, and three ropes are attached to the ring. Each rope is to be pulled in the same horizontal plane with a force of 2 kN. How should they be arranged so as to produce a net force due east of 4 kN on the block?

22. [III] Figure P22 shows three people pulling down via ropes, each with 200 N, on the top of a mast 20-m tall. If they stand at equal distances of 20 m from the base of the mast along lines 120° apart, what is the net force they exert on the mast?

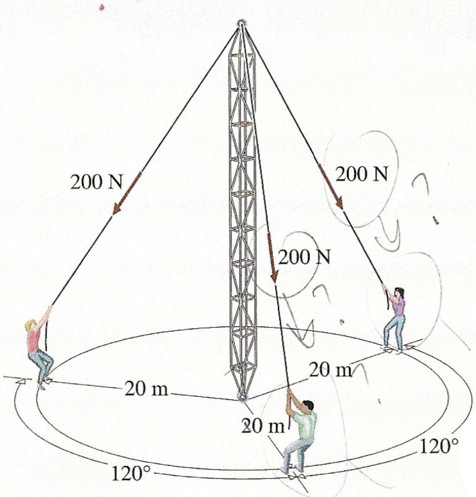

Figure P22

23. [III] Four firefighters hold a square net, one at each corner. Each person exerts a force of 200 N whose line-of-action passes through a point just below the center of the net and makes an angle with the vertical of 60°. What is the net force the firefighters exert on the net?

SECTION 4.3: THE SECOND LAW

SECTION 4.5: THE EFFECTS OF FORCE: NEWTON'S LAWS

24. [I] Draw a free-body diagram of a car rolling frictionlessly down an inclined plane.

25. [I] Draw a free-body diagram of a ball dropped by an astronaut just above the surface of the Moon.

26. [I] By pumping air up through thousands of tiny holes we can make a horizontal air table that will support several pucks so that they can move around on cushions of air with very little friction. Suppose that one such puck, having a mass of 0.25 kg, is pushed along by a 10.0-N force for 10.0 s. Determine its acceleration.

SOLUTION: We have the force and the mass and need the acceleration; the time is irrelevant. $\sum F = ma$, 10.0 N = (0.25 kg)a; a = (10.0 N)/(0.25 kg) = 40 m/s^2.

27. [I] A 60-kg ice skater holds up a large sheet of cardboard that can catch the wind and drive her (frictionlessly) across the ice. While she's moving at 0.5 m/s, a wind that is constant and horizontal for 5.0 s exerts a forward force on the cardboard of 2.0 N. What is the skater's initial acceleration once the wind begins to blow?

28. [I] Two bar magnets of mass 1.0 kg and 2.0 kg have their like poles pressed together so that there is a repulsive interaction between them. In a frictionless environment the two fly apart when released such that the more massive one has an initial acceleration of 10.0 m/s^2 due north. What is the initial acceleration of the other magnet?

29. [I] A person pushes a shopping cart with a force of 100 N acting down at 45°. If the cart travels at a constant speed of 1.0 m/s, what is the value of the combined retarding force acting horizontally on the cart due to friction and air drag? [*Hint: It is the horizontal component of the force that drives the cart forward. The constant speed tells you that* $\sum F_x = ma = 0$.]

30. [I] A rope is tied around a large box of books (of mass m) and someone attaches a spring scale to the rope and pulls up and to the right on it (with a force F). The scale then makes an angle θ with the horizontal. Write expressions for the horizontal and vertical components of the applied force. Write an expression for the normal force exerted on the box by the floor. Once set in motion the box is pulled at a constant speed. If F is then the constant applied force as indicated by the scale, write an expression (in terms of F and θ) for the net frictional retarding force acting horizontally on the box.

31. [I] A kid on an old dirt bike is being pushed along at a constant speed by her father who exerts a constant downward force on the child of 10.0 N at an angle of 30.0° below the horizontal in the forward direction. If the combined mass of the kid and the bike is 30.0 kg, what is the total retarding force (e.g., air friction, friction on the tires, etc.) acting on her and the bike?

32. [I] Studies show that a male lion (170 kg) accelerates toward prey at about 10 m/s^2, which is about the same rate a human sprinter can achieve (compare that to 3.8 m/s^2 for a Porsche). How much force must the lion exert horizontally on the ground during such a charge?

33. [I] A 100-kg gentleman standing on slippery grass is pulled by his two rather unruly children. One tugs him with 50 N north, toward the ice cream stand, while the other hauls with 120 N toward the bathroom, due east. Overlooking friction, compute Pop's resulting acceleration.

34. [II] The ballistocardiograph is a device used to assess the pumping action of the human heart. A patient lies on a horizontal 2.0-kg platform "frictionlessly" suspended on air-bearings. The rush of blood pumped in one direction will be accompanied by a counterforce on the body and table in the opposite direction. The resulting acceleration of the platform is recorded by an extremely sensitive accelerometer able to measure values as small as 10^{-5} m/s^2. For a young, healthy adult the acceleration over an interval of 0.10 s during the pumping cycle may be as great as 0.06 m/s^2. (a) Compute the force exerted by the heart if the patient has a mass of 70 kg. (b) What is the corresponding change in momentum?

35. [II] A bullet is fired from a handgun with a 24.0-cm-long barrel. Its muzzle speed is 350 m/s and its mass is 6.00 g. Compute the average force exerted on the bullet by the expanding gas in the barrel.

36. [II] Suppose a car stopped on the road is hit from behind by a bus so that it accelerates, in a straight line, up to 4.47 m/s (i.e., 10 mi/h) in 0.10 s. If the driver of the car has a mass of 50 kg and her front-seat passenger has a mass of 80 kg, what average net force must the seat exert on them? (Car seats have been known to collapse under this sort of treatment, though they obviously shouldn't.)

SOLUTION: We know the initial and final speeds, and the time interval over which that change occurred, so we can determine the average acceleration: $a_{av} = \Delta v/\Delta t$ = (4.47 m/s)/(0.10 s) = 44.7 m/s^2. Therefore $\sum F_{av} = ma_{av}$ = (50 kg + 80 kg)(44.7 m/s^2) = 5.8 kN.

37. [II] When a golf club strikes a 0.046-kg ball the latter may attain a speed of 70 m/s during the 0.50-ms collision. Find the average force exerted by the club on the ball.

38. [II] During a particular rocket-powered sled run, Colonel J. P. Stapp of the U.S. Air Force decelerated from a speed of 286.5 m/s (i.e., 940 ft/s) to a dead stop in 1.40 s. Assuming he weighed 175 lb (i.e., has a mass of 79.38 kg), compute the average force, in newtons, exerted on him. Incidentally, the primary dangers in this sort of test are things like blood vessels tearing away from the lungs or the heart, and even retinal detachment, via the First Law.

39. [II] A bullet fired into wet clay will decelerate fairly uniformly. If a 10-g bullet hits a block of clay at 200 m/s and comes to rest in 20 cm, what average force does it exert on the block? [*Hint: From the fact that the bullet goes from* v_i *to 0 in a distance s, you can find* a_{av} *and with that* F_{av}.]

40. [II] Imagine a car involved in a head-on crash. The driver, whose mass is m, is to be brought uniformly to rest within the passenger compartment by compressing an inflated air bag through a distance s_c. Write an expression for the average force exerted on the bag in terms of m, v_i, and s_c. Compute that average force for a 26.8-m/s (i.e., 60-mi/h) collision, where the driver's mass is 60 kg and the allowed stopping distance in the bag is 30 cm. Assume the car deforms only negligibly.

41. [II] A 4265-lb Jaguar XJ12L requires 164 ft of straight runway as a minimum stopping distance from a speed of 60.0 mi/h. Assuming its deceleration is uniform, compute the average stopping force exerted on the car. Sorry about the units, but that's the

way the manufacturer gave the data and we should know how to handle it.

42. [II] Suppose a 6.00-g bullet traveling at 100 m/s strikes a bulletproof vest and comes to rest in about 600 μs. What average force will it impart to the happy wearer?

43. [III] During a parachute exercise over Alaska in 1955, a United States trooper jumped from a C-119 at 1200 ft, but his chute failed to open. He was found flat on his back at the bottom of a $3\frac{1}{2}$-ft-deep crater in the snow, alive and with only an incomplete fracture of the clavicle. Compute the average force that acted on him as he plowed into the snow. Assume the deceleration was constant; take his mass to be 90 kg and his terminal speed to be 120 mi/h.

SECTION 4.6: WEIGHT: GRAVITATIONAL FORCE

44. [I] What is the smallest force needed to lift a 0.50-kg bullfrog up from the ground, and under what circumstances would that answer be applicable?

45. [I] Using a force platform, it's been found that when people jump straight up as high as they can they exert a net downward force for much of the time equal to about 2.3 times their weight. Approximately what acceleration do they achieve?

46. [I] THIS PROBLEM EXAMINES THE RELATIONSHIP BETWEEN FORCE AND ACCELERATION. An astronaut floating in space next to a 10.0-kg "weightless" beacon wants to push on it so that the beacon accelerates away at 9.81 m/s^2. (a) What force must she apply? (b) Compare that to the beacon's weight on Earth. (c) If she just pushes with her arms, what will happen to her?

47. [I] THIS PROBLEM EXAMINES THE RELATIONSHIP BETWEEN FORCE AND ACCELERATION. The roller in Fig. P47 weighs 5.00 N and the scale reads 3.0 N. (a) What is the tension in the string? (b) What is the mass of the roller? (c) At what rate will the roller accelerate at the moment it is released, assuming it slides frictionlessly? Compare your result with that of Problem 73.

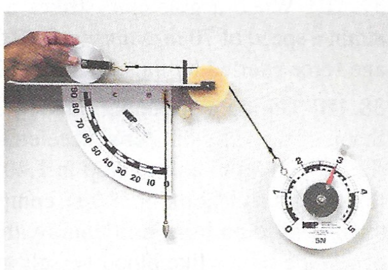

Figure P47

48. [I] The gravitational acceleration on the surface of Mercury is 0.38 times its value on Earth. What is the weight of a 1.0-kg mass on that planet?

SOLUTION: GIVEN $g_M = 0.38g$, the weight will also be 0.38 times smaller: $F_W = mg_M = m0.38g = (1.0\text{ kg})(0.38)(9.81\text{ m/s}^2) = 3.7\text{ N}$.

49. [I] A youngster who weighs 392.4 N on Earth is standing weightless in a space station. She jumps into the air with an average vertical acceleration of 5.00 m/s^2. Determine the average force exerted by the floor on the jumper during the leap. [*Hint: We have the average acceleration and need the propelling force. That can be found from the Second Law. For that you'll need the mass, but you have the weight.*]

50. [I] A maintenance robot 1.70-m tall, weighing 752 N when constructed on Earth, is found floating 400 m from an orbiting power station. The human crew decides to tie a light rope to it and haul it aboard. How much force must be exerted if the robot is to be uniformly accelerated for 1.00 s at 9.81 m/s^2?

51. [I] A rocket that weighed 98.1 N when put together on Earth is attached to a 1.00×10^3-kg signal relay in intergalactic space. The rocket develops a constant thrust (i.e., it pushes with a force) of 10.0 kN. Compute the resulting acceleration.

52. [I] An *F-14* twin-engine supersonic fighter weighs 69 000 lb. Its two Pratt and Whitney TF30-P-412 engines can each deliver a peak thrust (i.e., a forward force), using afterburners, of 20 200 lb. Compute its maximum acceleration (in terms of g) during horizontal flight (neglect air friction). Forgive the units, but this is still the way the data is provided by the military. Clearly it's important to practice unit conversions.

53. [II] Someone of mass 100 kg is standing on top of a steep cliff with only an old rope that he knows will support no more than 500 N. His plan is to slide down the rope using friction to keep from falling freely. At what minimum rate can he accelerate down the rope in order not to break it?

54. [II] A parachutist of mass m lands with legs bent, coming to rest with an upwardly directed average acceleration of $4.0g$. What is the average force exerted on him by the ground? Write your answer in terms of his weight.

SOLUTION: The force needed to bring her to rest is $F_{av} = ma_{av} = m4.0g = 4.0mg = 4.0F_W$, but the ground also supports her weight so the net force is $F_W + 4.0F_W = 5.0F_W$.

55. [II] The all-time champion jumper is the flea. This tiny pest can attain a range of up to 12 in. or about 200 times its own body length. (That's the same as you jumping five city blocks.) Assuming a 45° liftoff angle, a push-off time of 1.0 ms, and a mass of 4.5×10^{-7} kg, compute (a) the initial acceleration of the flea, assuming it to be constant, and (b) the force it exerts on the floor in addition to its weight.

56. [II] On its first flight in 1981, the *Columbia* spaceship was part of a 4.5×10^6-lb (i.e., 20 MN) 18-story-high launch assembly that developed a total thrust of about 6.4×10^6 lb (i.e., 28.5 MN). (a) What was its initial acceleration at full power? (b) According to newspaper reports, it was traveling at 33.5 m/s (i.e., 75 mi/h) 6.0 s after blastoff when it cleared the 347-ft (i.e., 105.8-m) support tower. Are these observations consistent? To what average acceleration does that correspond? (c) Compare these values of acceleration and explain any differences.

57. [II] A 2000-kg car in neutral at the top of a 20° inclined 20-m-long driveway slips its parking brake and rolls downward. At what speed will it hit the garage door at the bottom of the incline? Neglect all retarding forces.

58. [II] A rescue helicopter lifts two people from the sea on an essentially weightless rope. Jamey (100 kg) hangs 15 m below Amy (50.0 kg), who is 5.0 m below the aircraft. What is the tension (a) on the topmost end of the rope and (b) at its middle while the helicopter hovers? (c) Compute those answers again, this time with the aircraft accelerating upward at 9.8 m/s^2.

59. [II] A pink pom-pom of mass m hangs on a chain from the rearview mirror of a Corvette L82. That machine can go from rest to 26.8 m/s (60 mi/h) in 6.8 s. The pom-pom serves as a pendulum accelerometer. Assuming a constant maximum acceleration, compute the angle the pom-pom makes with the vertical.

60. [II] It's known from laboratory studies (Problem 45) that when people jump straight up as high as they can, they exert a net downward force for much of the time equal to about 2.3 times their weight. Starting with the knees bent, the vertical distance over

which the force is applied is about 0.4 m. At approximately what speed will they leave the ground and how high will they rise?

61. [II] Suppose that a person of mass m steps off a ladder at a height s_h and lands on the ground without bouncing. If the total compression of the body and the soil during impact is s_c, and if the deceleration is assumed constant, show that the force exerted by the ground is given by

$$F_{av} = mg\ (s_h/s_c)$$

Notice that bending the knees extends s_c considerably, decreasing F_{av} accordingly.

62. [II] When a person jumps and lands stiff-legged on the heels of the feet, a considerable force can be exerted on the long leg bones. The greatest stress occurs in the tibia, or shin bone, a bit above the ankle where the bone has its smallest cross section. If a force in excess of about 50 000 N is applied upward on the heel, the tibia will probably fracture. Keeping in mind the results of Problem 61, what is the minimum height of a fall above which a 60-kg person is likely to suffer a tibial fracture? Assume the body decelerates uniformly through a distance of 1.0 cm and the landing occurs squarely on both feet.

63. [II] In Problem 36, how much force must the driver's neck exert to keep her head in line with her body during the collision if her head weighs 44.5 N (10 lb)? Think about "whiplash."

64. [III] Navy jets are hurled off the deck of a modern carrier by a combination of catapult and engine thrust. The catapult (e.g., the C-7) has a 250-ft stroke (that is, runway) and will yank a 70 000-lb F-14A jet, with its engines developing a net average thrust of 16 000 lb, from rest to a speed of 200 ft/s in just 2.4 s. (a) Compute the average force exerted by the catapult. (b) Is the acceleration of the plane uniform? [*Hint: Try several of the equations for constant a.*]

SECTION 4.7: COUPLED MOTIONS

65. [I] Referring to Fig 4.22*b*, suppose m_2 equals 2.00 kg and it's on a frictionless surface. If m_1 = 10.0 kg, someone holds m_2 at rest, what will be the tension in the string?

66. [I] The pulley in Fig. 4.22*a* is essentially weightless and frictionless. If m_1 = 10.0 kg, the m_2 weighs 300 N, and someone holds on to m_2 so that the system is motionless, what is the tension in the rope and the acceleration of m_1?

67. [I] The pulley in Fig. 4.22*a* is essentially weightless and frictionless. If m_1 weighs 100 N and the m_2 weighs 300 N, and someone holds on to m_1 so that the system is motionless, what is the tension in the rope and the acceleration of m_1? How much force must the person exert and in what direction?

68. [I] Referring to Fig 4.22*b* suppose m_2, which weighs 300 N, rests on a frictionless surface. If the tension in the string is measured to be 100 N, what is the acceleration of m_1?

69. [I] The pulley in Fig. 4.22*a* is essentially weightless and frictionless. If m_1 = 10.0 kg and the second mass m_2 weighs 98.1 N, what is the tension in the rope and the acceleration of m_1?

70. [I] The two masses in Fig. 4.22*c* are m_1 = 10.0 kg and m_2 = 20.0 kg. What must be the tension in the rope on the right if the two blocks accelerate at 0.50 m/s^2 in a straight line over a frictionless surface?

71. [I] The pulley in Fig. 4.22*a* is essentially weightless and frictionless. Suppose that someone holds onto m_2 = 10.0 kg and accelerates it upward at 4.905 m/s^2. What will then be the tension in the rope given that m_1 = 10.0 kg?

72. [I] Suppose that the blocks in Fig 4.22*b* are m_1 = 10.0 kg and m_2 = 20.0 kg and the surfaces are frictionless. (a) If someone holds on to m_1 and pulls it down with an acceleration of 9.81 m/s^2, what is the tension in the rope? (b) What is the value of the force (F_A) applied to m_1 by the person?

SOLUTION: (a) The mass m_2 experiences a net horizontal force such that $\sum F_H = F_T = m_2 a$ = (20.0 kg)(9.81 m/s^2) = 196 N; that's the tension. (b) The mass m_1 experiences a net force such that $\sum F = m_1 a$ = (10.0 kg)(9.81 m/s^2); moreover, taking down as positive $\sum F = F_W + F_A - F_T = m_1 a = m_1 g$ = 98.1 N; hence F_A = 98.1 N − F_W + F_T = 98.1 N − 98.1 N + F_T and $F_A = F_T$ = 196 N.

73. [I] THIS PROBLEM WILL HELP US LEARN ABOUT FORCES AND ACCELERATION. In Fig. P73 the cylindrical roller weighs 5.0 N and each of the hanging masses weighs 1.0 N. Assume the pulley is weightless and frictionless, and the roller slides freely. (a) What is the tension in the rope when everything is at rest? (b) After the roller is released, describe the motion of the system. (c) Is the tension now the same as it was before? (d) Draw a free-body diagram of both the roller and the hanging mass. (e) When released, at what rate will the cylinder accelerate? (f) Compare your result with that of Problem 47 and make sure you understand the difference.

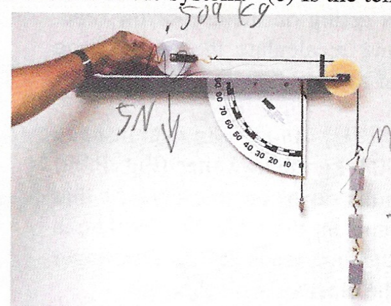

Figure P73

74. [II] THIS PROBLEM WILL HELP US LEARN ABOUT FORCES AND ACCELERATION. Figure P74 depicts four identical 20.0-kg cartons being pushed forward by a 80.0-N force on a frictionless horizontal plane. (a) What is the total mass being accelerated? (b) Determine the acceleration of each block. (c) What is the net force exerted on each block? (d) What force does the block second from the left exert on the block third from the left?

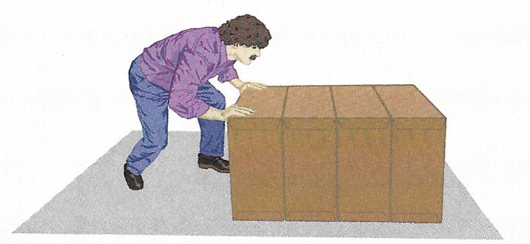

Figure P74

75. [II] A tug pulls two small barges (of mass $m_1 = 4.00 \times 10^3$ kg and $m_2 = 3.50 \times 10^3$ kg) tied together, one behind the other. The tug exerts 1.00 kN on the line to the first barge (m_1) and accelerates at 0.100 m/s^2. Compute the tension in the two ropes and, knowing that friction opposes the motion, determine the friction on each barge, assuming it's the same for both. [*Hint: There are two unknowns, the tension in the connecting rope and the friction. Take the sum of the forces on the first barge and the sum of the forces on the second barge, and solve the two equations simultaneously.*]