

Physics 2A

Chapter 5 HW Solutions

Chapter 5

Conceptual Question: 2, 7, 9, 20

Problems: 3, 15, 21, 29, 48, 55, 57, 60, 65, 70

Q5.2. Reason: Objects in static equilibrium do not accelerate and remain at rest. Objects in dynamic equilibrium do not accelerate and move with constant velocity.

(a) The girder is moving at constant speed. We assume it's being lifted straight up. If so, it's in dynamic equilibrium.

(b) Since the girder is slowing down it is accelerating, and therefore not in static or dynamic equilibrium.

(c) Since the barbell is not accelerating and remains at rest it is in static equilibrium.

(d) Once the plane has reached its cruising speed and altitude the plane is moving with constant speed and direction. It is in dynamic equilibrium.

(e) A rock in free fall is accelerating due to gravity. It is not in equilibrium.

(f) The box is accelerating since the truck is accelerating and the box is not sliding relative to the truck. The box is not in equilibrium.

Assess: For an object in equilibrium $\vec{F}_{\text{net}} = \vec{0}$.

Q5.7. Reason: If we ignore air resistance as instructed, then the balls are in free fall.

The net force in free fall is simply the force of gravity, which is the mass times g . Therefore, a ranking of the net forces is the same as a ranking of the masses, since g is constant for all four balls.

$$F_{\text{net } 4} > F_{\text{net } 2} = F_{\text{net } 3} > F_{\text{net } 1}$$

Assess: The velocities are irrelevant to the net force.

Note that although all four balls are in free fall (and have the same acceleration), they do not experience the same gravitational force.

Q5.9. Reason: The normal force (by definition) is directed perpendicular to the surface.

(a) If the surface that exerts a force on an object is vertical, then the normal force would be horizontal. An example would be holding a picture on a wall by pushing on it horizontally. The wall would exert a normal force horizontally.

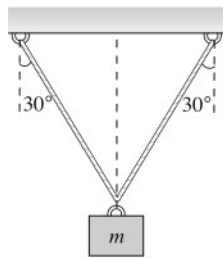
(b) In a similar vein, if the surface that exerts a force on an object is horizontal and above the object, then the normal force would be down. One example would be holding a picture on a ceiling by pushing on it. The ceiling would exert a normal force vertically downward. Another example would be the Newton's third law pair force in the case of you sitting on a chair; the chair exerts a normal force upward on you, so you exert a normal force downward on the chair.

Assess: We see that the normal force can be in any direction; it is always perpendicular to the surface pushing on the object in question.

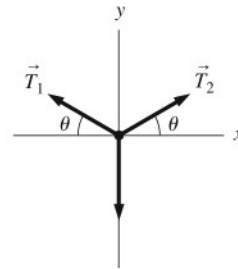
Q5.20. Reason: The kinetic friction acts in a direction to oppose the relative motion, so on block 1 the kinetic friction is to the right and on block 2 it is to the left.

Assess: We would expect them to be opposite since they are a Newton third law pair and the forces in a third law pair are always in opposite directions.

P5.3. Prepare: We assume the speaker is a particle in static equilibrium under the influence of three forces: gravity and the tensions in the two cables. So, all the forces acting on it must cancel to give a zero net force. The forces acting on the speaker are shown on a free-body diagram below. Because each cable makes an angle of 30° with the vertical, $\theta = 60^\circ$.



Known
 $m = 20 \text{ kg}$
 Find
 $T_1 \quad T_2$



Solve: Newton's first law for this situation is

$$(F_{\text{net}})_x = \Sigma F_x = T_{1x} + T_{2x} = 0 \text{ N} \Rightarrow -T_1 \cos \theta + T_2 \cos \theta = 0 \text{ N}$$

$$(F_{\text{net}})_y = \Sigma F_y = T_{1y} + T_{2y} + w_y = 0 \text{ N} \Rightarrow T_1 \sin \theta + T_2 \sin \theta - w = 0 \text{ N}$$

The x -component equation means $T_1 = T_2$. From the y -component equation

$$2T_1 \sin \theta = w \Rightarrow T_1 = \frac{w}{2 \sin \theta} = \frac{mg}{2 \sin \theta} = \frac{(20 \text{ kg})(9.8 \text{ m/s}^2)}{2 \sin 60^\circ} = \frac{196 \text{ N}}{1.732} = 113 \text{ N}$$

Assess: It's to be expected that the two tensions are equal, since the speaker is suspended symmetrically from the two cables. This is 110 N to two significant figures.

P5.15. Prepare: We assume that the seat belt supplies all the force necessary to decelerate the driver (that is, $F_{\text{seatbelt}} = F_{\text{net}}$), and that the deceleration is constant over the time interval of 0.10 s. Set up a coordinate system with the car traveling to the right along the x -axis.

We use the kinematics equations from Chapter 2 to solve for the constant acceleration, and then $F_{\text{net}} = ma$ (with $m = 70 \text{ kg}$) to solve for the force exerted by the seat belt.

Solve: The definition of acceleration says

$$a_x = \frac{\Delta v_x}{\Delta t} = \frac{0.0 \text{ m/s} - 14 \text{ m/s}}{0.10 \text{ s}} = -140 \text{ m/s}^2$$

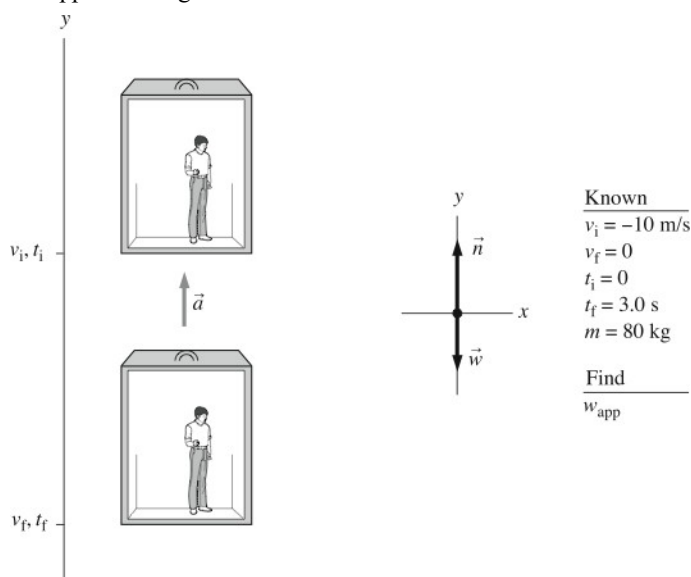
where the negative sign indicates that the car (which is traveling to the right) is slowing down.

$$F_{\text{seatbelt}} = F_{\text{net}} = ma_x = (70 \text{ kg})(-140 \text{ m/s}^2) = -9800 \text{ N}$$

where the negative sign shows the force acting in the negative x -direction (the same direction as the acceleration).

Assess: 9800 N is quite a bit of force, but so it is in a head-on collision at a significant speed. You can see from the equations above that if the crash had taken more time the force would not be so severe; save that thought for a future chapter.

P5.21. Prepare: We'll assume Zach is a particle moving under the effect of two forces acting in a single vertical line: gravity and the supporting force of the elevator. These forces are shown in Figure 5.12 in a free-body diagram. We will use Equation 5.8 to find the apparent weight.



Solve: (a) Before the elevator starts braking, Zach is not accelerating. His apparent weight (see Equation 5.8) is

$$w_{\text{app}} = w \left(1 + \frac{a}{g} \right) = w \left(1 + \frac{0 \text{ m/s}^2}{g} \right) = mg = (80 \text{ kg})(9.8 \text{ m/s}^2) = 784 \text{ N} \approx 780 \text{ N}$$

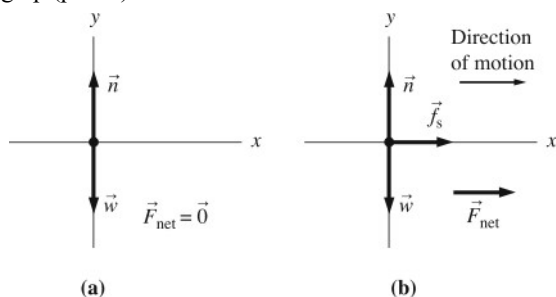
(b) Using the definition of acceleration,

$$a = \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{t_f - t_i} = \frac{0 - (-10) \text{ m/s}}{3.0 \text{ s}} = 3.33 \text{ m/s}^2$$

$$\Rightarrow w_{\text{app}} = w \left(1 + \frac{a}{g} \right) = (80 \text{ kg})(9.8 \text{ m/s}^2) \left(1 + \frac{3.33 \text{ m/s}^2}{9.8 \text{ m/s}^2} \right) = (784 \text{ N})(1 + 0.340) = 1100 \text{ N}$$

Assess: While the elevator is braking, it not only must support Zach's weight but must also push upward on him to decelerate him, so the apparent weight is greater than his normal weight.

P5.29. Prepare: We show below the free-body diagrams of the crate when the conveyer belt runs at constant speed (part a) and the belt is speeding up (part b).



Solve: (a) When the belt runs at constant speed, the crate has an acceleration $\vec{a} = \vec{0} \text{ m/s}^2$ and is in dynamic equilibrium. Thus $\vec{F}_{\text{net}} = \vec{0}$. It is tempting to think that the belt exerts a friction force on the crate. But if it did, there would be a *net* force because there are no other possible horizontal forces to balance a friction force. Because there is no net force, there cannot be a friction force. The only forces are the upward normal force and the crate's weight. (A friction force would have been needed to get the crate moving initially, but no horizontal force is needed to keep it moving once it is moving with the same constant speed as the belt.)

(b) If the belt accelerates gently, the crate speeds up without slipping on the belt. Because it is accelerating, the crate must have a net horizontal force. So *now* there is a friction force, and the force points in the direction of the crate's motion. Is it static friction or kinetic friction? Although the crate is moving, there is *no* motion of the crate relative to the belt. Thus, it is a *static* friction force that accelerates the crate so that it moves without slipping on the belt.

(c) The static friction force has a maximum possible value $(f_s)_{\max} = \mu_s n$. The maximum possible acceleration of the crate is

$$a_{\max} = \frac{(f_s)_{\max}}{m} = \frac{\mu_s n}{m}$$

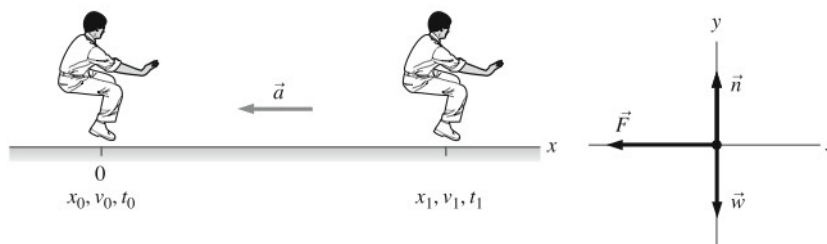
If the belt accelerates more rapidly than this, the crate will not be able to keep up and will slip. It is clear from the free-body diagram that $n = w = mg$. Thus,

$$a_{\max} = \mu_s g = (0.50)(9.8 \text{ m/s}^2) = 4.9 \text{ m/s}^2$$

(d) The acceleration of the crate will be $a = \mu_k g = (0.30)(9.8 \text{ m/s}^2) = 2.9 \text{ m/s}^2$.

P5.48. Prepare: We can assume the person is moving in a straight line under the influence of the combined decelerating forces of the air bag and seat belt or, in the absence of restraints, the dashboard or windshield. The following is an overview of the situation in a pictorial representation and the occupant's free-body diagram is shown below. Note that the occupant is brought to rest over a distance of 1 m in the former case, but only over 5 mm in the latter.

Known
$m = 60 \text{ kg}$
$x_0 = 0 \text{ m}$
$v_0 = 15 \text{ m/s}$
$v_f = 0 \text{ m/s}$
(a) $x_f = 1 \text{ m}$
(b) $x_f = 0.005 \text{ m}$
Find
F



Solve: (a) In order to use Newton's second law for the passenger, we'll need the acceleration. Since we don't have the stopping time,

$$v_f^2 = v_i^2 + 2a(x_f - x_i) \Rightarrow a = \frac{v_f^2 - v_i^2}{2(x_f - x_i)} = \frac{0 \text{ m}^2/\text{s}^2 - (15 \text{ m/s})^2}{2(1 \text{ m} - 0 \text{ m})} = -112.5 \text{ m/s}^2$$

$$\Rightarrow F_{\text{net}} = F = ma = (60 \text{ kg})(-112.5 \text{ m/s}^2) = -6750 \text{ N}$$

The net force is 6800 N to the left.

(b) Using the same approach as in part (a),

$$F = ma = m \frac{v_f^2 - v_i^2}{2(x_f - x_i)} = (60 \text{ kg}) \frac{0 \text{ m}^2/\text{s}^2 - (15 \text{ m/s})^2}{2(0.005 \text{ m})} = -1,350,000 \text{ N}$$

The net force is $1.4 \times 10^6 \text{ N}$ to the left.

(c) The passenger's weight is $mg = (60 \text{ kg})(9.8 \text{ m/s}^2) = 590 \text{ N}$. The force in part (a) is 11.5 times the passenger's weight. The force in part (b) is 2300 times the passenger's weight.

Assess: An acceleration of 11.5g is well within the capability of the human body to withstand. A force of 2300 times the passenger's weight, on the other hand, would surely be catastrophic.

P5.55. Prepare: The length of the hill is $\Delta x = h / \sin \theta$. The acceleration is $g \sin \theta$.

Solve: First use the kinematic equation, with $v_i = 0 \text{ m/s}$ at the top of the hill, to determine the speed at the bottom of the hill.

$$(v_f)_1^2 = (v_i)_1^2 + 2a\Delta x \Rightarrow (v_f)_1^2 = 2(g \sin \theta)(h / \sin \theta) = 2gh$$

Now apply the same kinematic equation to the horizontal patch of snow, only this time we want Δx . To connect the two parts $(v_f)_1 = (v_i)_2$. The final speed is zero: $(v_f)_2 = 0$.

$$(v_f)_2^2 = (v_i)_2^2 + 2a\Delta x = (v_f)_1^2 + 2a\Delta x = 2gh + 2a\Delta x = 0$$

The friction force is the net force, so $a = -f_k / m$. Note $f_k = \mu_k n = \mu_k mg$. Solve for Δx .

$$\Delta x = \frac{-2gh}{2a} = \frac{-gh}{-f_k / m} = \frac{gh}{\mu_k mg / m} = \frac{h}{\mu_k} = \frac{3.0 \text{ m}}{0.05} = 60 \text{ m}$$

Assess: It seems reasonable to glide 60 m with such a low coefficient of friction. It is interesting that we did not need to know the angle of the (frictionless) slope; this will become clear in the chapter on energy. The answer is also independent of Josh's mass.

P5.57. Prepare: The force plate reads the normal force n of the plate on the woman. The other force on the woman is her weight (the gravitational force of the earth down on her). The net force will be the sum of these two and will be different at different times as the normal force of the force plate changes according to the graph. Since the graph is piecewise constant, the acceleration will be constant during (within) each phase of the jump.

We can do a preliminary calculation to find the woman's mass. During the standing still phases, the force plate reads 500 N. During these equilibrium phases the force plate reads the same magnitude as her weight (so $w = 500$ N); hence her mass must be $m = w/g = (500 \text{ N})/(9.8 \text{ m/s}^2) = 51 \text{ kg}$.

We will assume air resistance is negligible during all portions of the problem.

Solve: (a) We now know m and the normal force during push-off (1000 N). Apply the second law:

$$\begin{aligned}\Sigma F_y &= n - w = ma_y \\ a_y &= \frac{n - w}{m} = \frac{1000 \text{ N} - 500 \text{ N}}{51 \text{ kg}} = \frac{500 \text{ N}}{51 \text{ kg}} = 9.8 \text{ m/s}^2\end{aligned}$$

This result looks familiar, but it is not the acceleration of an object in free fall for two reasons: (1) she is not in free fall, and (2) this acceleration is up while objects in free fall accelerate down.

(b) After she leaves the force plate she is in free fall, so her acceleration is $a = -g$ or, in other words, 9.8 m/s^2 , down.

(c) During the landing phase the normal force of the plate on her is 1500 N while her weight is still 500 N. Apply the second law:

$$\begin{aligned}\Sigma F_y &= n - w = ma_y \\ a_y &= \frac{n - w}{m} = \frac{1500 \text{ N} - 500 \text{ N}}{51 \text{ kg}} = \frac{1000 \text{ N}}{51 \text{ kg}} = 20 \text{ m/s}^2\end{aligned}$$

This acceleration is positive, or up (opposite the direction of motion, as she is slowing down).

(d) We'll assume she accelerates from rest. We are given that the push-off phase lasts $\Delta t = 0.25$ s. We'll use the answer from part (a) for a_y .

$$(v_y)_f = (v_y)_i + a_y \Delta t = 0.0 \text{ m/s} + (9.8 \text{ m/s}^2)(0.25 \text{ s}) = 2.45 \text{ m/s} \approx 2.5 \text{ m/s}$$

(e) After she leaves the force table she is in free fall (see part (b)). What was the final velocity in part (d) becomes the initial velocity now. Use Equation 2.13 with $(v_y)_f = 0.0$ m/s.

$$(v_y)_f^2 = (v_y)_i^2 + 2a_y \Delta x$$

Solve for Δy :

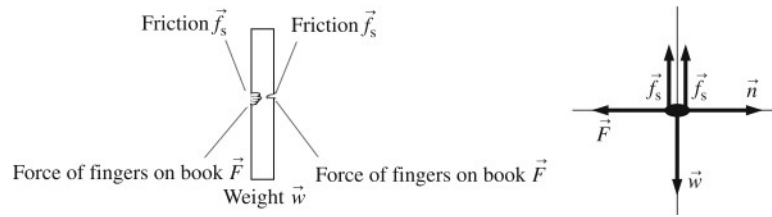
$$\Delta y = \frac{-(v_y)_i^2}{2a_y} = \frac{-(2.45 \text{ m/s})^2}{2(-9.8 \text{ m/s}^2)} = 0.31 \text{ m}$$

Assess: All of these results appear reasonable. The accelerations are within the expectations of daily life experience. The result of part (d) is used in part (e), so we kept a third significant figure to use in the last calculation, but still reported the answers to two significant figures. The last answer is kind of a check on the previous ones, and it is quite reasonable: 31 cm is just over one foot.

Also review each calculation to verify that the units work out.

P5.60. Prepare: The book is in static equilibrium so Equation 5.1 can be applied. The maximum static frictional force the person can exert will determine the heaviest book he can hold.

Solve: Consider the free-body diagram below. The force of the fingers on the book is the reaction force to the normal force of the book on the fingers, so is exactly equal and opposite the normal force on the fingers.



The maximal static friction force will be equal to $f_{s \max} = \mu_s n = (0.80)(6.0 \text{ N}) = 4.8 \text{ N}$. The frictional force is exerted on both sides of the book. Considering the forces in the y -direction, we have that the weight supported by the maximal frictional force is

$$w = f_{s \max} + f_{s \max} = 2f_{s \max} = 9.6 \text{ N}$$

Assess: Note that the force on both sides of the book are exactly equal also because the book is in equilibrium.

P5.65. Prepare: With no friction, the only forces along the incline are the tension T and a component of the weight, $mg \sin \theta$. Since the blocks aren't accelerating then $T = mg \sin \theta$.

Solve: For tension 1:

$$T_1 = (5 \text{ kg})(9.8 \text{ m/s}^2) \sin 20^\circ = 16.76 \text{ N} \approx 17 \text{ N}$$

For tension 2 the mass is the sum of both blocks:

$$T_2 = (5 \text{ kg} + 3 \text{ kg})(9.8 \text{ m/s}^2) \sin 20^\circ = 26.81 \text{ N} \approx 27 \text{ N}$$

Assess: We would expect $T_2 > T_1$.

P5.70. Prepare: Call the 2.0 kg block m_2 and the 1.0 kg block m_1 . Assume the pulley is massless and frictionless.

Solve: On block 2 $f_k = \mu_k n = \mu_k m_2 g$.

$$\Sigma F_x = T - \mu_k n = T - \mu_k m_2 g = m_2 a_2$$

Block 1 is also accelerating.

$$\Sigma F_y = T - m_1 g = m_1 a_1$$

The acceleration constraint is $(a_2)_x = -(a_1)_y = a$. Solve for T in the second equation and insert in the first. $T = m_1(g - a)$.

$$m_1(g - a) - \mu_k m_2 g = m_2 a$$

$$m_1 g - \mu_k m_2 g = m_2 a + m_1 a$$

$$a = \frac{g(m_1 - \mu_k m_2)}{m_1 + m_2} = \frac{(9.8 \text{ m/s}^2)(1.0 \text{ kg} - (0.20)(2.0 \text{ kg}))}{1.0 \text{ kg} + 2.0 \text{ kg}} = 1.96 \text{ m/s}^2 \approx 2.0 \text{ m/s}^2$$

Assess: The answer seems reasonable.