مراجعة نهائية وفق الهيكل الوزاري الخطة B

EOT 2023-2024 PHYSICS

Grade 11 Adv

Plan - B

PART 1/2

Chapter 4

(1) IDENTIFY THAT THE DIRECTION OF THE FORCE DUE TO THE PULL ON THE ROPE ACTS EXACTLY IN THE DIRECTION ALONG THE ROPE.
(2) DESCRIBE HOW THE FORCE WITH WHICH WE PULL ON THE MASSLESS ROPE IS TRANSMITTED THROUGH THE ENTIRE ROPE UNCHANGED, EVEN IF THE ROPE PASSES OVER A PULLEY

EXAMPLE 4.1 Modified Tug-of-War

In a tug-of-war competition, two teams try to pull each other across a line. If neither team is moving, then the two teams exert equal and opposite forces on a rope. This is an immediate consequence of Newton's Third Law. That is, if one team pulls on the rope with a force of magnitude F, the other team necessarily has to pull on the rope with a force of the same magnitude but in the opposite direction.

PROBLEM

Now let's consider the situation where three ropes are tied together at one point, with a team pulling on each rope. Suppose team 1 is pulling due west with a force of 2750 N, and team 2 is pulling due north with a force of 3630 N. Can a third team pull in such a way that the three-team tug-of-war ends at a standstill, that is, no team is able to move the rope? If yes, what is the magnitude and direction of the force needed to accomplish this?

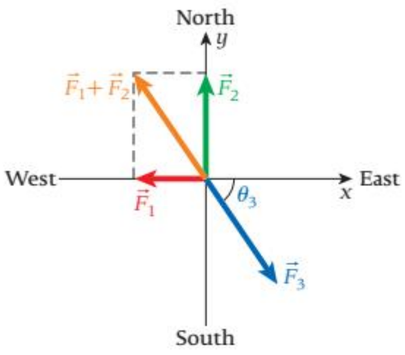


FIGURE 4.9 Addition of force vectors in the three-team tug-of-war.

(1) DERIVE A COMPLETE NEWTON'S SECOND LAW STATEMENT (IN THE APPROPRIATE DIRECTION) FOR AN OBJECT IN VARIOUS PHYSICAL DYNAMIC SITUATIONS, WITHOUT FRICTION (E.G., MASS ON INCLINE, STRINGS/PULLEYS, OR ATWOOD MACHINES).
(2) CALCULATE A VALUE FOR AN UNKNOWN FORCE ACTING ON AN OBJECT ACCELERATING (WITHOUT FRICTION) IN A DYNAMIC SITUATION (E.G., INCLINES, ATWOOD MACHINES, PULLEY SYSTEMS, ETC.)

EXAMPLE 4.3 Two Books on a Table

We have considered the simple situation of one object (a laptop computer) supported from below and held at rest. Now let's look at two objects at rest: two books on a table (Figure 4.14a).

PROBLEM

What is the magnitude of the force that the table exerts on the lower book?

كتابي

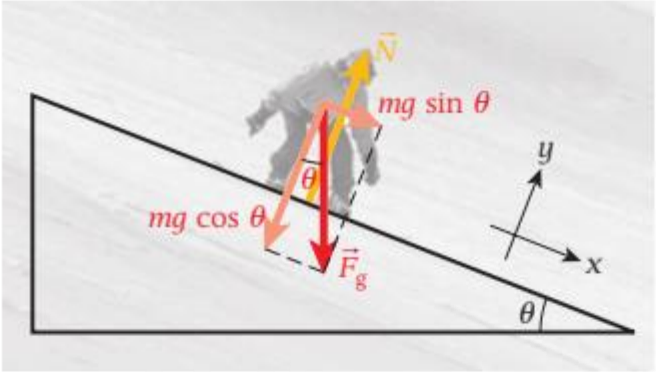
(1) RELATE THE MAGNITUDE OF STATIC OR DYNAMIC FRICTIONAL FORCES TO THE MAGNITUDE OF THE NORMAL FORCE THROUGH THE COEFFICIENT OF STATIC OR KINETIC FRICTION.
(2) DISTINGUISH BETWEEN FRICTION IN A STATIC SITUATION AND A KINETIC SITUATION.

(1) DRAW FREE-BODY DIAGRAMS AND APPLY NEWTON'S SECOND LAW FOR OBJECTS ON HORIZONTAL, VERTICAL, OR INCLINED PLANES IN SITUATIONS INVOLVING FRICTION.
(2) APPLY NEWTON'S SECOND LAW TO A FREE-BODY DIAGRAM OF AN OBJECT THAT MOVES VERTICALLY OR ON A HORIZONTAL OR INCLINED PLANE (WITHOUT FRICTION/WITH FRICTION).

SOLVED PROBLEM 4.1 Snowboarding

PROBLEM

A snowboarder (mass 72.9 kg, height 1.79 m) glides down a slope with an angle of 22° with respect to the horizontal (Figure 4.15a). If we can neglect friction, what is his acceleration?



كتابي

(1) RELATE THE MAGNITUDE OF STATIC OR DYNAMIC FRICTIONAL FORCES TO THE MAGNITUDE OF THE NORMAL FORCE THROUGH THE COEFFICIENT OF STATIC OR KINETIC FRICTION.
(2) DISTINGUISH BETWEEN FRICTION IN A STATIC SITUATION AND A KINETIC SITUATION.

EXAMPLE 4.6 Realistic Snowboarding

Let's reconsider the snowboarding situation from Solved Problem 4.1, but now include friction. A snowboarder moves down a slope for which $\theta = 22°$. Suppose the coefficient of kinetic friction between his board and the snow is 0.21, and his velocity, which is along the direction of the slope, is measured as 8.3 m/s at a given instant.

PROBLEM 1
Assuming a constant slope, what will be the speed of the snowboarder along the direction of the slope when he is 100 m farther down the slope?

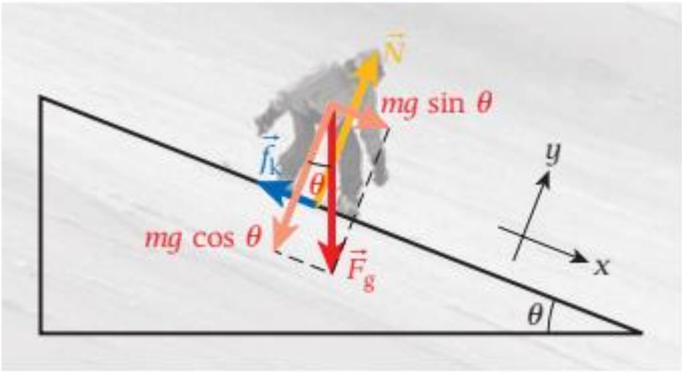


FIGURE 4.19 Free-body diagram of a snowboarder, including the friction force.

PROBLEM 2
How long does it take the snowboarder to reach this speed?

PROBLEM 3
Given the same coefficient of friction, what would the angle of the slope have to be for the snowboarder to glide with constant velocity?

•**4.47** A large ice block of mass $M = 80.0$ kg is held stationary on a frictionless ramp. The ramp is at an angle of $\theta = 36.9°$ above the horizontal.

a) If the ice block is held in place by a tangential force along the surface of the ramp (at angle θ above the horizontal), find the magnitude of this force.

b) If, instead, the ice block is held in place by a horizontal force, directed horizontally toward the center of the ice block, find the magnitude of this force.

4.53 A large cubical block of ice of mass $M = 64.0$ kg and sides of length $L = 0.400$ m is held stationary on a frictionless ramp. The ramp is at an angle of $\theta = 26.0°$ above the horizontal. The ice cube is held in place by a rope of negligible mass and length $l = 1.60$ m. The rope is attached to the surface of the ramp and to the upper edge of the ice cube, a distance L above the surface of the ramp. Find the tension in the rope.

•**4.63** A skier starts with a speed of 2.00 m/s and skis straight down a slope with an angle of 15.0° relative to the horizontal. The coefficient of kinetic friction between his skis and the snow is 0.100. What is his speed after 10.0 s?

كتابي

•**4.80** A 2.00-kg block is on a plane inclined at 20.0° with respect to the horizontal. The coefficient of static friction between the block and the plane is 0.600.

a) How many forces are acting on the block?

b) What is the normal force?

c) Is this block moving? Explain.

APPLY NEWTON'S LAWS TO SYSTEMS WITH STRINGS AND PULLEY SYSTEMS.

EXAMPLE 4.4 **Atwood Machine**

The Atwood machine consists of two hanging weights (with masses m_1 and m_2) connected via a rope running over a pulley. For now, we consider a friction-free case, where the pulley does not move, and the rope glides over it. (In Chapter 10 on rotation, we will return to this problem and solve it with friction present, which causes the pulley to rotate.) We also assume

that $m_1 > m_2$. In this case, the acceleration is as shown in Figure 4.17a. (The formula derived in the following is correct for any case. If $m_1 < m_2$, then the value of the acceleration, a, will have a negative sign, which will mean that the acceleration direction is opposite to what we have assumed in working the problem.)

IDENTIFY THAT THE FRICTION FORCE IS A FORCE PARALLEL TO THE SURFACE THAT APPEARS WHEN THE OBJECT SLIDES OR ATTEMPTS TO SLIDE ALONG THE SURFACE.

So far, we have neglected the force of friction and considered only frictionless approximations. However, in general, we have to include friction in most of our calculations when we want to describe physically realistic situations.

We could conduct a series of very simple experiments to learn about the basic characteristics of friction. Here are the findings we would obtain:

- If an object is at rest, it takes an external force with a certain threshold magnitude and acting parallel to the contact surface between the object and the surface to overcome the friction force and make the object move.
- The friction force that has to be overcome to make an object at rest move is larger than the friction force that has to be overcome to keep the object moving at a constant velocity.
- The magnitude of the friction force acting on a moving object is proportional to the magnitude of the normal force.
- The friction force is independent of the size of the contact area between object and surface.
- The friction force depends on the roughness of the surfaces; that is, a smoother interface generally provides less friction force than a rougher one.
- The friction force is independent of the velocity of the object.

These statements about friction are not principles in the same way as Newton's laws. Instead, they are general observations based on experiments. For example, you might think that the contact of two extremely smooth surfaces would yield very low friction. However, in some cases, extremely smooth surfaces actually fuse together as a cold weld. Investigations into the nature and causes of friction continue, as we discuss later in this section.

From these findings, it is clear that we need to distinguish between the case where an object is at rest relative to its supporting surface (static friction) and the case where an object is moving across the surface (kinetic friction). The case in which an object is moving across a surface is easier to treat, and so we consider kinetic friction first.

Kinetic Friction

The above general observations can be summarized in the following approximate formula for the magnitude of the kinetic friction force, f_k:

$$f_k = \mu_k N. \tag{4.10}$$

Here N is the magnitude of the normal force and μ_k is the **coefficient of kinetic friction.** This coefficient is always equal to or greater than zero. (The case where $\mu_k = 0$ corresponds to a frictionless approximation. In practice, however, it can never be reached perfectly.) In almost all cases, μ_k is also less than 1. (Some special tire surfaces used for car racing, though, have a coefficient of friction with the road that can significantly exceed 1.) Some representative coefficients of kinetic friction are shown in Table 4.1.

The direction of the kinetic friction force is *always opposite to the direction of motion* of the object relative to the surface it moves on.

If you push an object with an external force parallel to the contact surface, and the force has a magnitude exactly equal to that of the force of kinetic friction on the object, then the total net external force is zero, because the external force and the friction force cancel each other. In that case, according to Newton's First Law, the object will continue to slide across the surface with constant velocity.

Static Friction

If an object is at rest, it takes a certain threshold amount of external force to set it in motion. For example, if you push lightly against a refrigerator, it will not move. As you push harder and harder, you reach a point where the refrigerator finally slides across the kitchen floor.

For any external force acting on an object that remains at rest, the friction force is exactly equal in magnitude and opposite in direction to the component of that external force that acts along the contact surface between the object and its supporting surface. However, the magnitude of the static friction force has a maximum value: $f_s \le f_{s,max}$. This maximum magnitude of the static friction force is proportional to the normal force, but with a different proportionality constant than the coefficient of kinetic friction: $f_{s,max} = \mu_s N$. For the magnitude of the force of static friction, we can write

$$f_s \le \mu_s N = f_{s,\max}, \tag{4.11}$$

IDENTIFY THAT THE FRICTION FORCE IS A FORCE PARALLEL TO THE SURFACE THAT APPEARS WHEN THE OBJECT SLIDES OR ATTEMPTS TO SLIDE ALONG THE SURFACE.

where μ_s is called the **coefficient of static friction.** Some typical coefficients of static friction are shown in Table 4.1. In general, for any object on any supporting surface, the maximum static friction force is greater than the force of kinetic friction. You may have experienced this when trying to slide a heavy object across a surface: As soon as the object starts moving, a lot less force is required to keep it in constant sliding motion. We can express this finding as a mathematical inequality between the two coefficients:

$$\mu_s > \mu_k. \tag{4.12}$$

Figure 4.18 presents a graph showing how the friction force depends on an external force, F_{ext}, applied to an object. If the object is initially at rest, a small external force results in a small force of friction, rising linearly with the external force until it reaches a value of $\mu_s N$. Then it drops rather quickly to a value of $\mu_k N$ when the object is set in motion. At this point, the external force has a value of $F_{ext} = \mu_s N$, resulting in a sudden acceleration of the object. This dependence of the friction force on the external force is shown in Figure 4.18 as a red line.

On the other hand, if we start with a large external force and the object is already in motion, then we can reduce the external force below a value of $\mu_s N$, but still above $\mu_k N$, and the object will keep moving and accelerating. Thus, the friction coefficient retains a value of μ_k until the external force is reduced to a value of $\mu_k N$. At this point (and only at this point!), the object will move with a constant velocity, because the external force and the friction force are equal in magnitude. If we reduce the external force further, the object decelerates (horizontal segment of the blue line left of the red diagonal in Figure 4.18), because the kinetic friction force is bigger than the external force. Eventually, the object comes to rest because of the kinetic friction, and the external force is not sufficient to move it anymore. Then static friction takes over, and the friction force is reduced proportionally to the external force until both reach zero. The blue line in Figure 4.18 illustrates this dependence of the friction force on the external force. Where the blue line and the red line overlap, this is indicated by alternating blue and red dashes. The most interesting feature of Figure 4.18 is that the blue and red lines do not coincide between $\mu_k N$ and $\mu_s N$.

Let's return to the attempt to move a refrigerator across the kitchen floor. Initially, the refrigerator sits on the floor, and the static friction force resists your effort to move it. Once you push hard enough, the refrigerator jars into motion. In this process, the friction force follows the red path in Figure 4.18. Once the refrigerator moves, you can push less hard and still keep it moving. If you push with less force so that it moves with constant velocity, the external force you apply follows the blue path in Figure 4.18 until it is reduced to $F_{ext} = \mu_k N$. Then the friction force and the force you apply to the fridge add up to zero, and there is no net force acting on the refrigerator, allowing it to move with constant velocity.

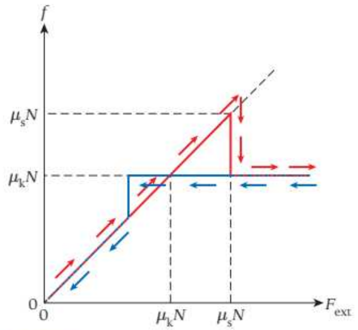


FIGURE 4.18 Magnitudes of the forces of friction as a function of the magnitude of an external force. The red line represents the forces for an object initially at rest, with the external force increasing from zero. The blue line represents the forces for an object initially in motion under the influence of an external force that is larger than the friction force but is then gradually reduced.

(1) DRAW FREE- BODY DIAGRAMS AND APPLY NEWTON'S SECOND LAW. (2) SOLVE PROBLEMS RELATED TO OBJECTS ON HORIZONTAL, VERTICAL, OR INCLINED PLANES IN SITUATIONS INVOLVING FRICTION,

SOLVED PROBLEM 4.3 Wedge

A wedge of mass $m = 37.7$ kg is held in place on a fixed plane that is inclined by an wangle $\theta = 20.5°$ with respect to the horizontal. A force $F = 309.3$ N in the horizontal direction pushes on the wedge, as shown in Figure 4.23a. The coefficient of kinetic friction between the wedge and the plane is $\mu_k = 0.171$. Assume that the coefficient of static friction is low enough that the net force will move the wedge.

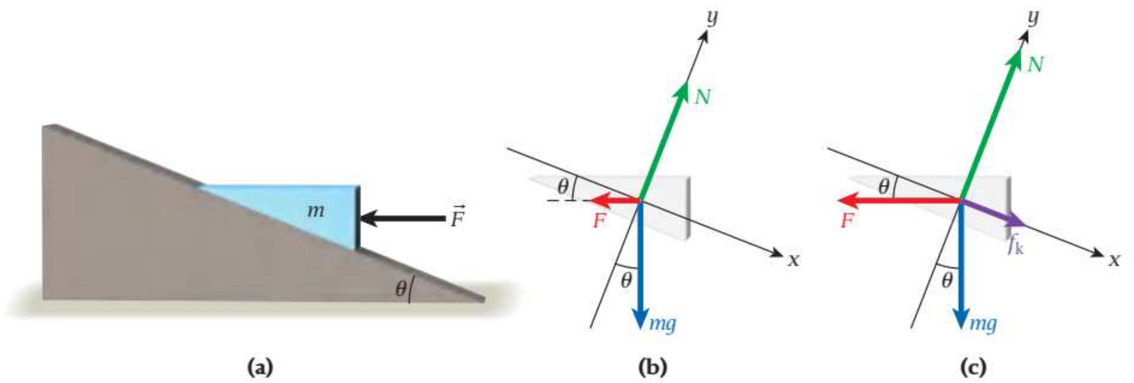


FIGURE 4.23 (a) A wedge-shaped block being pushed on an inclined plane. (b) Free-body diagram of the wedge, including the external force, the force of gravity, and the normal force. (c) Free-body diagram including the external force, the force of gravity, the normal force, and the friction force.

PROBLEM

What is the acceleration of the wedge along the plane when it is released and free to move?

كتابي

DRAW FREE-BODY DIAGRAMS AND APPLY NEWTON'S SECOND LAW FOR OBJECTS ON HORIZONTAL, VERTICAL, OR INCLINED PLANES IN SITUATIONS INVOLVING FRICTION

EXAMPLE 4.9 Pulling a Sled

Suppose you are pulling a sled across a level snow-covered surface by exerting constant force on a rope, at an angle θ relative to the ground.

PROBLEM 1

If the sled, including its load, has a mass of 15.3 kg, the coefficients of friction between the sled and the snow are $\mu_s = 0.076$ and $\mu_k = 0.070$, and you pull with a force of 25.3 N on the rope at an angle of 24.5° relative to the horizontal ground, what is the sled's acceleration?

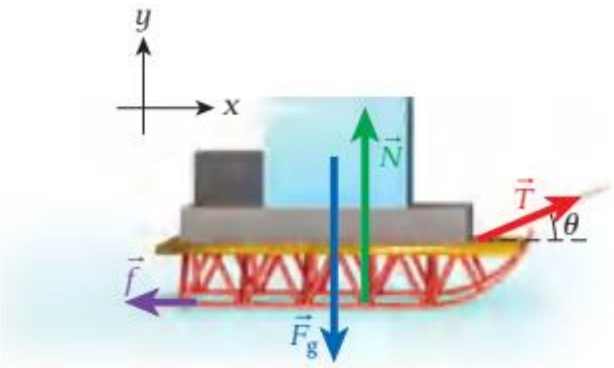


FIGURE 4.25 Free-body diagram of the sled and its load.

4.24 A shipping crate that weighs 340 N is initially stationary on a loading dock. A forklift arrives and lifts the crate with an upward force of 500 N, accelerating the crate upward. What is the magnitude of the force due to gravity acting on the shipping crate while it is accelerating upward?

4.25 A block is sliding on a (near) frictionless slope with an incline of 30.0°. Which force is greater in magnitude, the net force acting on the block or the normal force acting on the block?

APPLY NEWTON'S SECOND LAW TO A FREE-BODY DIAGRAM OF AN OBJECT THAT MOVES VERTICALLY OR ON A HORIZONTAL OR INCLINED PLANE (WITHOUT OR WITHOUT FRICTION).

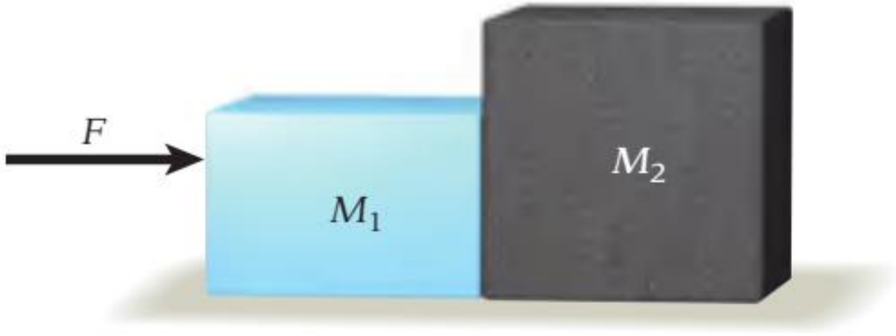
4.28 A 423.5-N force accelerates a go-cart and its driver from 10.4 m/s to 17.9 m/s in 5.00 s. What is the mass of the go-cart plus driver?

4.32 Two blocks are in contact on a frictionless, horizontal tabletop. An external force, $\vec{F}$, is applied to block 1, and the two blocks are moving with a constant acceleration of 2.45 m/s^2. Use $M_1 = 3.20$ kg and $M_2 = 5.70$ kg.

a) What is the magnitude, F, of the applied force?

b) What is the contact force between the blocks?

c) What is the net force acting on block 1?



•**4.34** In a physics laboratory class, three massless ropes are tied together at a point. A pulling force is applied along each rope: $F_1 = 150.$ N at 60.0°, $F_2 = 200.$ N at 100.°, $F_3 = 100.$ N at 190.°. What is the magnitude of a fourth force and the angle at which it acts to keep the point at the center of the system stationary? (All angles are measured from the positive x-axis.)

4.72 What coefficient of friction is required to stop a hockey puck sliding at 12.5 m/s initially over a distance of 60.5 m?

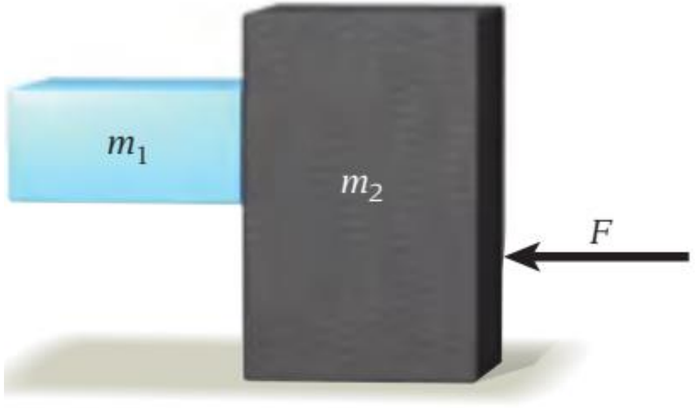
•**4.81** A block of mass 5.00 kg is sliding at a constant velocity down an inclined plane that makes an angle of 37.0° with respect to the horizontal.

a) What is the friction force?

b) What is the coefficient of kinetic friction?

••**4.92** A block of mass $m_1 = 2.30$ kg is placed in front of a block of mass $m_2 = 5.20$ kg, as shown in the figure. The coefficient of static friction between m_1 and m_2 is 0.65, and there is negligible friction between the larger block and the tabletop.

a) What forces are acting on m_1?



كتابي

(1) EXPLAIN THAT A TENSION FORCE IS SAID TO PULL AT BOTH ENDS OF A CORD (OR A CORD-LIKE OBJECT) WHEN THE CORD IS TAUT. (2) APPLY NEWTON'S LAWS TO SYSTEMS WITH STRINGS.

EXAMPLE 4.2 Still Rings

A gymnast of mass 55 kg hangs vertically from a pair of parallel rings (Figure 4.10a).

PROBLEM 1

If the ropes supporting the rings are vertical and attached to the ceiling directly above, what is the tension in each rope?

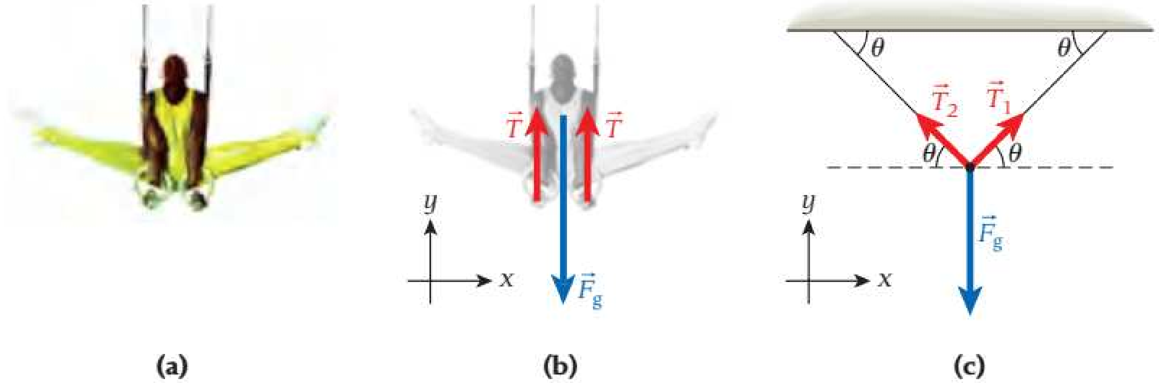


FIGURE 4.10 (a) Still rings in men's gymnastics. (b) Free-body diagram for problem 1. (c) Free-body diagram for problem 2.

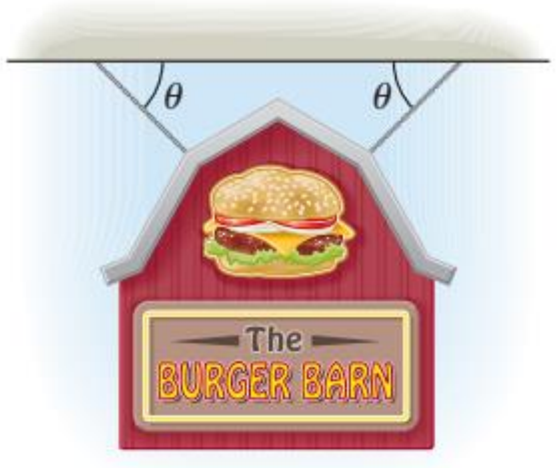
PROBLEM 2

If the ropes are attached so that they make an angle $\theta = 45°$ with the ceiling (Figure 4.10c), what is the tension in each rope?

PROBLEM 3

How does the tension in the ropes change as the angle θ between the ceiling and the ropes becomes smaller and smaller?

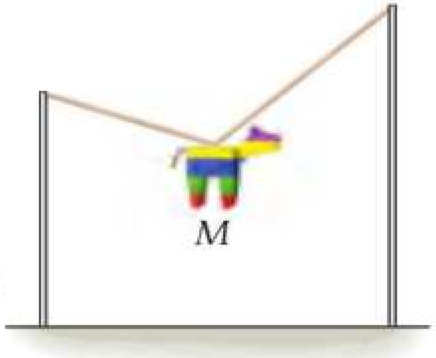
4.44 A store sign of mass 4.25 kg is hung by two wires that each make an angle of $\theta = 42.4°$ with the ceiling. What is the tension in each wire?



كتابي

•4.46 A load of bricks of mass $M = 200.0$ kg is attached to a crane by a cable of negligible mass and length $L = 3.00$ m. Initially, when the cable hangs vertically downward, the bricks are a horizontal distance $D = 1.50$ m from the wall where the bricks are to be placed. What is the magnitude of the horizontal force that must be applied to the load of bricks (without moving the crane) so that the bricks will rest directly above the wall?

•**4.49** A piñata of mass $M = 8.00$ kg is attached to a rope of negligible mass that is strung between the tops of two vertical poles. The horizontal distance between the poles is $D = 2.00$ m, and the top of the right pole is a vertical distance $h = 0.500$ m higher than the top of the left pole.



The piñata is attached to the rope at a horizontal position halfway between the two poles and at a vertical distance $s = 1.00$ m below the top of the left pole. Find the tension in each part of the rope due to the weight of the piñata.

كتابي

(1) DRAW FREE-BODY DIAGRAMS AND APPLY NEWTON’S SECOND LAW FOR OBJECTS ON HORIZONTAL, VERTICAL, OR INCLINED PLANES IN SITUATIONS INVOLVING FRICTION. **(2)** APPLY NEWTON’S SECOND LAW TO A FREE-BODY DIAGRAM OF AN OBJECT THAT MOVES VERTICALLY OR ON A HORIZONTAL OR INCLINED PLANE (WITHOUT FRICTION/WITH FRICTION).

END OF PART 1/2

EOT 2023-2024 PHYSICS

Grade 11 Adv

Plan - B

PART 2
Chapter 5

Identify that electron-volt (eV), is the kinetic energy that an electron gains when accelerated by an electric potential of 1 volt

Some other frequently used energy units are the electron-volt (eV), the food calorie (Cal), and the mega-ton of TNT (Mt):

$$1\ \text{eV} = 1.602 \times 10^{-19}\ \text{J}$$

$$1\ \text{Cal} = 4186\ \text{J}$$

$$1\ \text{Mt} = 4.18 \times 10^{15}\ \text{J}.$$

On the atomic scale, 1 electron-volt (eV) is the kinetic energy that an electron gains when accelerated by an electric potential of 1 volt.

Apply the relationship between a particle's kinetic energy, mass, and speed as $K = \frac{1}{2}mv^2$, measured in joules (j) or N.m or $kg \cdot \frac{m^2}{s^2}$

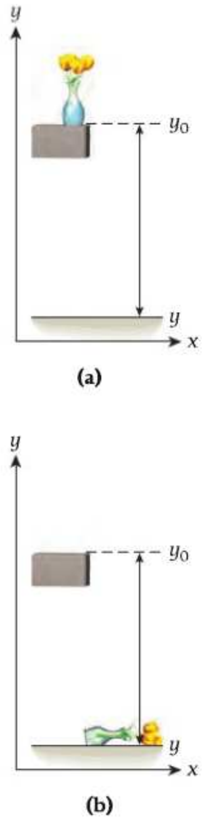


FIGURE 5.7 (a) A vase is released from rest at a height of y_0. (b) The vase falls to the floor, which has a height of y.

EXAMPLE 5.1 Falling Vase

PROBLEM

A crystal vase (mass = 2.40 kg) is dropped from a height of 1.30 m and falls to the floor, as shown in Figure 5.7. What is its kinetic energy just before impact? (Neglect air resistance for now.)

SOLUTION

Once we know the velocity of the vase just before impact, we can put it into the equation defining kinetic energy. To obtain this velocity, we recall the kinematics of free-falling objects. In this case, it is most straightforward to use the relationship between the initial and final velocities and heights that we derived in Chapter 2 for free-fall motion:

$$v_y^2 = v_{y0}^2 - 2g(y - y_0).$$

(Remember that the y-axis must be pointing up to use this equation.) Because the vase is released from rest, the initial velocity components are $v_{x0} = v_{y0} = 0$. Because there is no acceleration in the x-direction, the x-component of velocity remains zero during the fall of the vase: $v_x = 0$. Therefore, we have

$$v^2 = v_x^2 + v_y^2 = 0 + v_y^2 = v_y^2.$$

We then obtain

$$v^2 = v_y^2 = 2g(y_0 - y).$$

We use this result in equation 5.1:

$$K = \tfrac{1}{2}mv^2 = \tfrac{1}{2}m\left(2g(y_0 - y)\right) = mg(y_0 - y).$$

Inserting the numbers given in the problem statement gives us the answer:

$$K = (2.40 \text{ kg})(9.81 \text{ m/s}^2)(1.30 \text{ m}) = 30.6 \text{ J}.$$

5.1 Which of the following is a correct unit of energy?

a) kg m/s^2

b) kg m^2/s

c) kg m^2/s^2

d) kg^2 m/s^2

e) kg^2 m^2/s^2

5.11 Jack is holding a box that has a mass of m kg. He walks a distance of d m at a constant speed of v m/s. How much work, in joules, has Jack done on the box?

a) mgd

b) $-mgd$

c) $\frac{1}{2}mv^2$

d) $-\frac{1}{2}mv^2$

e) zero

5.19 The damage done by a projectile on impact is correlated with its kinetic energy. Calculate and compare the kinetic energies of these three projectiles:

a) a 10.0 kg stone at 30.0 m/s

b) a 100.0 g baseball at 60.0 m/s

c) a 20.0 g bullet at 300. m/s

Show that the work done on a particle by a force $\boldsymbol{F}$ when the particle undergoes a displacement $\boldsymbol{\Delta r}$, is given by the scalar product: $W = F \cdot \Delta r = F \Delta r \cos\alpha$.

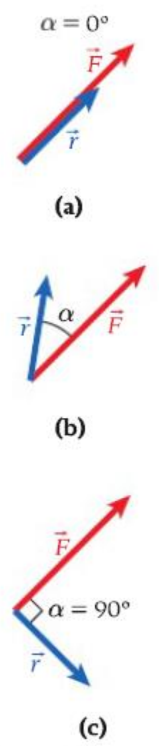
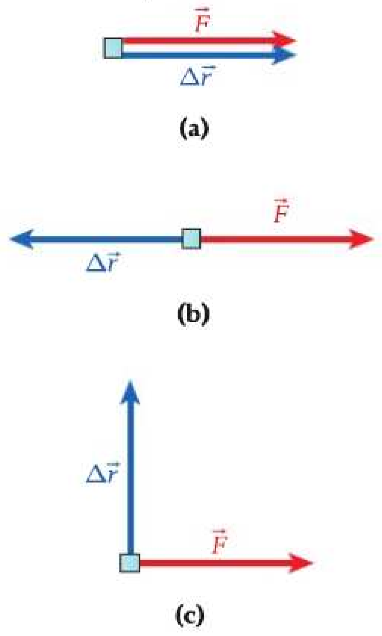


FIGURE 5.9 (a) $\vec{F}$ is parallel to $\vec{r}$ and $W = |\vec{F}||\vec{r}|$. (b) The angle between $\vec{F}$ and $\vec{r}$ is α and $W = |\vec{F}||\vec{r}|\cos\alpha$. (c) $\vec{F}$ is perpendicular to $\vec{r}$ and $W = 0$.

Concept Check 5.1

Consider an object undergoing a displacement $\Delta\vec{r}$ and experiencing a force $\vec{F}$. In which of the three cases shown below is the work done by the force on the object zero?



5.9 A particle moves parallel to the x-axis. The net force on the particle increases with x according to the formula $F_x = (120 \text{ N/m})x$, where the force is in newtons when x is in meters. How much work does this force do on the particle as it moves from $x = 0$ to $x = 0.50$ m?

a) 7.5 J
b) 15 J
c) 30 J
d) 60 J
e) 120 J

5.15 If the net work done on a particle is zero, what can be said about the particle's speed?

5.17 Does the Earth do any work on the Moon as the Moon moves in its orbit?

Show that for a one-dimensional case, the work-kinetic energy theorem is equivalent to newton's second law:

$([(\frac{1}{2}\ mv_x^2)\ -(\frac{1}{2}\ mv_o^2)]\ = ma_x(x - xo\ ) = F_x \cdot\ \Delta x = W)$.

equation 5.7 is equivalent to Newton's Second Law. To see this equivalence, consider a constant force acting in one dimension on an object of mass m. Newton's Second Law is then $F_x = ma_x$, and the (also constant!) acceleration, a_x, of the object is related to the difference in the squares of its initial and final velocities via $v_x^2 - v_{x0}^2 = 2a_x(x - x_0)$, which is one of the five kinematical equations we derived in Chapter 2. Multiplication of both sides of this equation by $\frac{1}{2}m$ yields

$$\frac{1}{2}mv_x^2 - \frac{1}{2}mv_{x0}^2 = ma_x(x - x_0) = F_x\Delta x = W. \quad (5.8)$$

Thus, we see that, for this one-dimensional case, the work-kinetic energy theorem is equivalent to Newton's Second Law.

Because of the equivalence we have just established, if more than one force is acting on an object, we can use the net force to calculate the work done. Alternatively, and more commonly in energy problems, if more than one force is acting on an object, we can calculate the work done by each force, and then W in equation 5.7 represents their sum.

The work-kinetic energy theorem specifies that the change in kinetic energy of an object is equal to the work done on the object by the forces acting on it. We can rewrite equation 5.7 to solve for K or K_0:

$$K = K_0 + W$$

or

$$K_0 = K - W.$$

By definition, the kinetic energy cannot be less than zero; so, if an object has $K_0 = 0$, the work-kinetic energy theorem implies that $K = K_0 + W = W \geq 0$.

While we have only verified the work-kinetic energy theorem for a constant force, it is also valid for variable forces, as we will see below. Is it valid for all kinds of forces? The short answer is no! Friction forces are one kind of force that violate the work-kinetic energy theorem. We will discuss this point further in Chapter 6.

RELATE THE WORK DONE BY THE GRAVITATIONAL FORCE AND THE GRAVITATIONAL POTENTIAL ENERGY FOR AN OBJECT LIFTED FROM REST TO A HEIGHT H AS: $\Delta Ug = -Wg$

Work Done by the Gravitational Force

With the work-kinetic energy theorem at our disposal, we can now take another look at the problem of an object falling under the influence of the gravitational force, as in Example 5.1. On the way down, the work done by the gravitational force on the object is

$$W_g = +mgh, \tag{5.9}$$

where $h = |y - y_0| = |\Delta\vec{r}| > 0$. The displacement $\Delta\vec{r}$ and the force of gravity $\vec{F}_g$ point in the same direction, resulting in a positive scalar product and therefore positive work. This situation is illustrated in Figure 5.10a. Since the work is positive, the gravitational force increases the kinetic energy of the object.

We can reverse this situation and toss the object vertically upward, making it a projectile and giving it an initial kinetic energy. This kinetic energy will decrease until the projectile reaches the top of its trajectory. During this time, the displacement vector $\Delta\vec{r}$ points up, in the opposite direction to the force of gravity (Figure 5.10b). Thus, the work done by the gravitational force during the object's upward motion is

$$W_g = -mgh. \tag{5.10}$$

Therefore, the work done by the gravitational force reduces the kinetic energy of the object during its upward motion. This conclusion is consistent with the general formula for work done by a constant force, $W = \vec{F} \cdot \Delta\vec{r}$, because the displacement (pointing upward) of the object and the gravitational force (pointing downward) are in opposite directions.

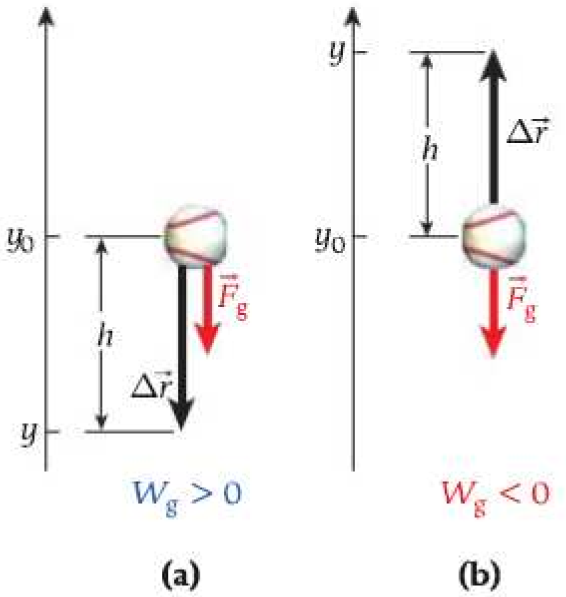


FIGURE 5.10 Work done by the gravitational force. (a) The object during free fall. (b) Tossing an object upward.

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(1) Calculate graphically the work done on an object from an initial to a final position using a force versus position graph.
(2) Solve problems related to work done by a general variable force.
(3) Apply the work–kinetic energy theorem to situations where an object is moved by a variable force.

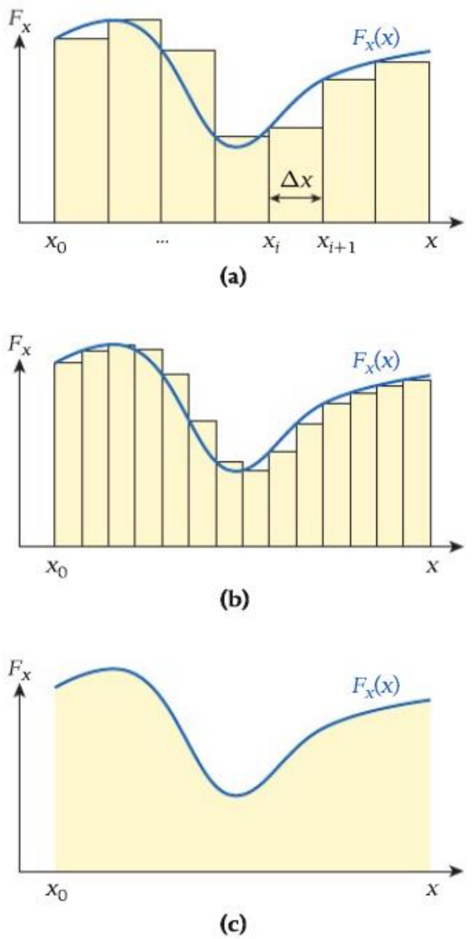
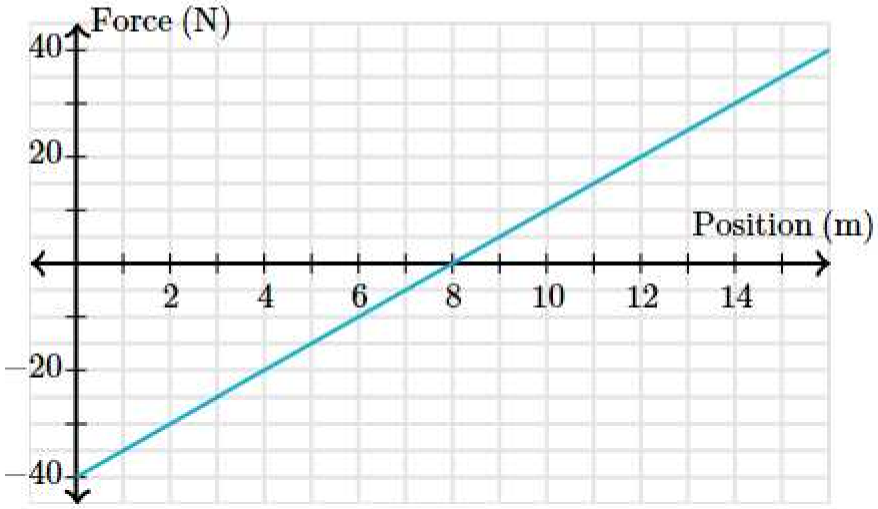


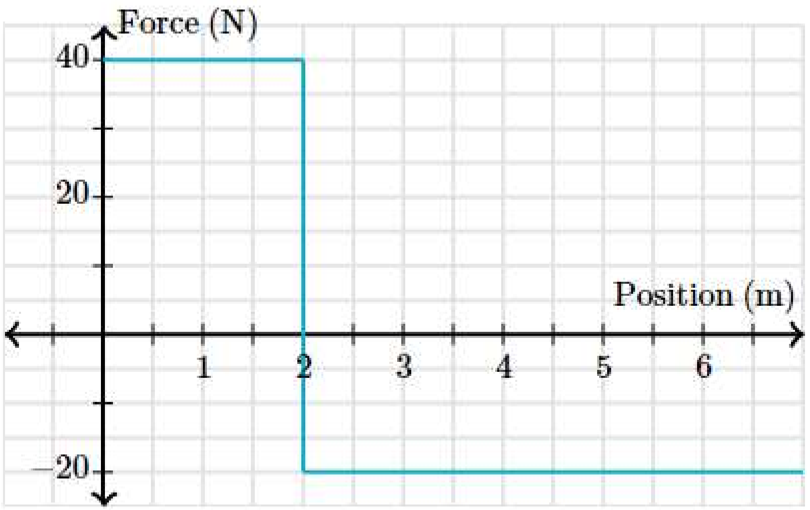
FIGURE 5.13 (a) A series of rectangles approximates the area under the curve obtained by plotting the force as a function of the displacement; (b) a better approximation using rectangles of smaller width; (c) the exact area under the curve.

The net horizontal force on a box F as a function of the horizontal position x is shown below.



What is the work done on the box from $x = 0\,\mathrm{m}$ to $4.0\,\mathrm{m}$?

The net vertical force on a box F as a function of the vertical position y is shown below.



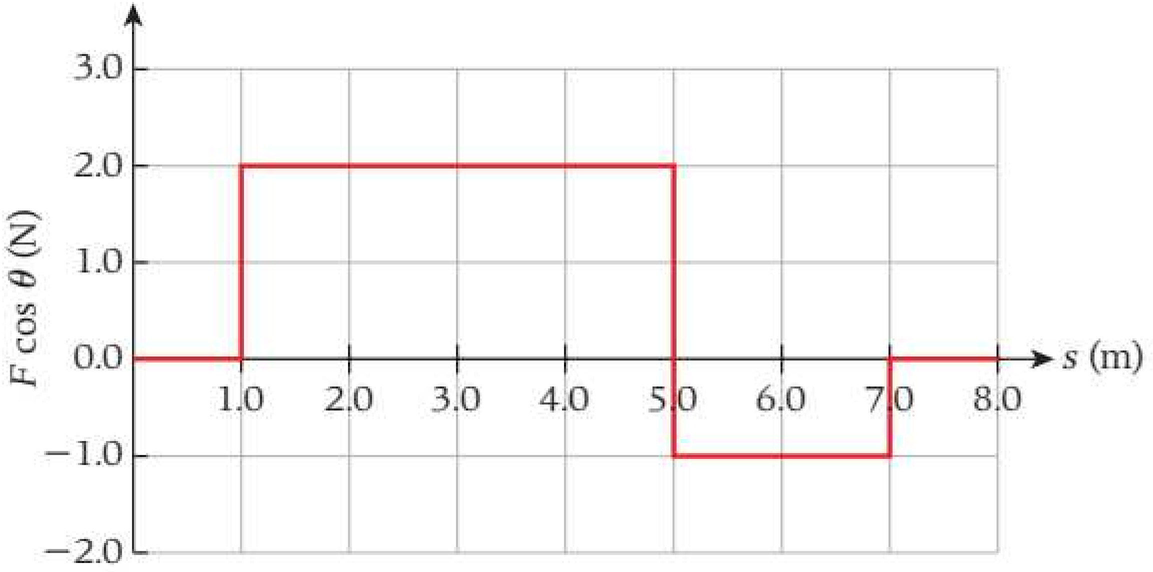
What is the work done on the box from $y = 0\,\mathrm{m}$ to $7.0\,\mathrm{m}$?

كتابي

6.78 The graph shows the component ($F \cos \theta$) of the net force that acts on a 2.00 kg block as it moves along a flat horizontal surface. Find

a) the net work done on the block;

b) the final speed of the block if it starts from rest at $s = 0$.



APPLY HOOK'S LAW TO CALCULATE THE SPRING FORCE, THE SPRING CONSTANT, OR THE DISPLACEMENT OF THE END OF THE SPRING KNOWING THE OTHER TWO QUANTITIES.

EXAMPLE 5.3 Spring Constant

PROBLEM 1

A spring has a length of 15.4 cm and is hanging vertically from a support point above it (Figure 5.15a). A weight with a mass of 0.200 kg is attached to the spring, causing it to extend to a length of 28.6 cm (Figure 5.15b). What is the value of the spring constant?

SOLUTION 1

We place the origin of our coordinate system at the top of the spring, with the positive direction upward, as is customary. Then, $x_0 = -15.4$ cm and $x = -28.6$ cm. According to Hooke's Law, the spring force is

$$F_s = -k(x - x_0).$$

Also, we know the force exerted on the spring was provided by the weight of the 0.200-kg mass: $F = -mg = -(0.200\text{ kg})(9.81\text{ m/s}^2) = -1.962$ N. Again, the negative sign indicates the direction. Now we can solve the force equation for the spring constant:

$$k = -\frac{F_s}{x - x_0} = -\frac{1.962\text{ N}}{(-0.286\text{ m}) - (-0.154\text{ m})} = 14.9\text{ N/m}.$$

Note that we would have obtained exactly the same result if we had put the origin of the coordinate system at another point or if we had elected to designate the downward direction as positive.

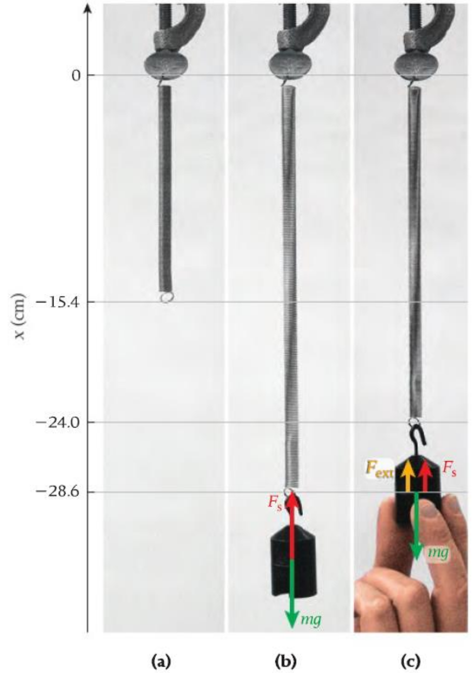


FIGURE 5.15 Mass on a spring. (a) The spring without any mass attached. (b) The spring with the mass hanging freely. (c) The mass pushed upward by an external force.

APPLY HOOK'S LAW TO CALCULATE THE SPRING FORCE, THE SPRING CONSTANT, OR THE DISPLACEMENT OF THE END OF THE SPRING KNOWING THE OTHER TWO QUANTITIES.

EXAMPLE 5.3 Spring Constant

PROBLEM 2

How much force is needed to hold the weight at a position 4.6 cm above −28.6 cm (Figure 5.15c)?

SOLUTION 2

At first sight, this problem might appear to require a complicated calculation. However, remember that the mass has stretched the spring to a new equilibrium position. To move the mass from that position takes an external force. If the external force moves the mass up 4.6 cm, then it has to be exactly equal in magnitude and opposite in direction to the spring force resulting from a displacement of 4.6 cm. Thus, all we have to do to find the external force is to use Hooke's Law for the spring force (choosing new equilibrium position to be at $x_0 = 0$):

$$F_{ext} + F_s = 0 \Rightarrow F_{ext} = -F_s = kx = (0.046\ \text{m})(14.9\ \text{N/m}) = 0.68\ \text{N}.$$

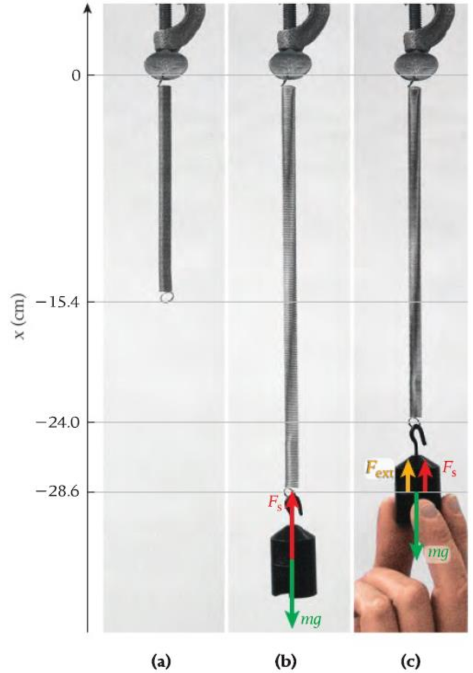


FIGURE 5.15 Mass on a spring. (a) The spring without any mass attached. (b) The spring with the mass hanging freely. (c) The mass pushed upward by an external force.

APPLY HOOK'S LAW TO CALCULATE THE SPRING FORCE, THE SPRING CONSTANT, OR THE DISPLACEMENT OF THE END OF THE SPRING KNOWING THE OTHER TWO QUANTITIES.

SOLVED PROBLEM 5.2 **Compressing a Spring**

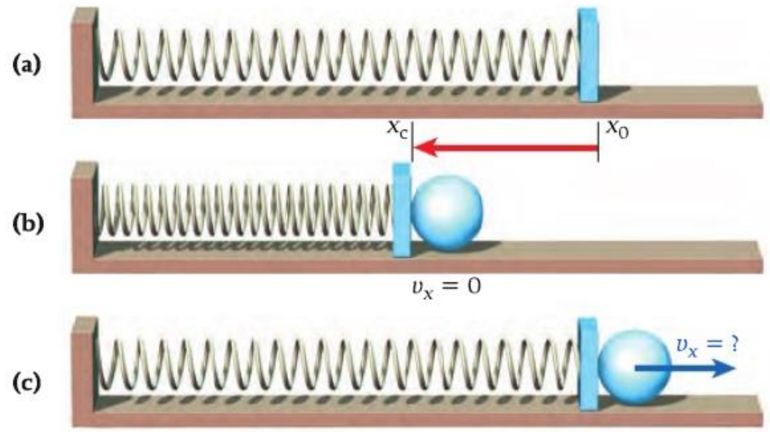


FIGURE 5.16 (a) Spring in its equilibrium position; (b) compressing the spring; (c) relaxing the compression and accelerating the steel ball.

A massless spring located on a smooth horizontal surface is compressed by a force of 63.5 N, which results in a displacement of 4.35 cm from the initial equilibrium position. As shown in Figure 5.16, a steel ball of mass 0.075 kg is then placed in front of the spring and the spring is released.

PROBLEM

What is the speed of the steel ball when it is shot off by the spring, that is, right after it loses contact with the spring? (Assume there is no friction between the surface and the steel ball; the steel ball will then simply slide across the surface and will not roll.)

5.42 An ideal spring has the spring constant $k = 440$ N/m. Calculate the distance this spring must be stretched from its equilibrium position for 25.0 J of work to be done.

5.43 A spring is stretched 5.00 cm from its equilibrium position. If this stretching requires 30.0 J of work, what is the spring constant?

5.44 A spring with spring constant k is initially compressed a distance x_0 from its equilibrium length. After returning to its equilibrium position, the spring is then stretched a distance x_0 from that position. What is the ratio of the work that needs to be done on the spring in the stretching to the work done in the compressing?

•**5.45** A spring with a spring constant of 238.5 N/m is compressed by 0.231 m. Then a steel ball bearing of mass 0.0413 kg is put against the end of the spring, and the spring is released. What is the speed of the ball bearing right after it loses contact with the spring? (The ball bearing will come off the spring exactly as the spring returns to its equilibrium position. Assume that the mass of the spring can be neglected.)

DEFINE POWER AS THE RATE AT WHICH WORK IS DONE OR ENERGY IS TRANSFERRED.

Power is the rate at which work is done. Mathematically, this means that the power, P, is the time derivative of the work, W:

$$P = \frac{dW}{dt}. \tag{5.18}$$

It is also useful to define the average power, $\bar{P}$ as

$$\bar{P} = \frac{W}{\Delta t}. \tag{5.19}$$

The SI unit of power is the **watt** (W). [Beware of confusing the symbol for work, W *(italicized)*, and the abbreviation for the unit of power, W (nonitalicized).]

$$1\ \mathrm{W} = 1\ \mathrm{J/s} = 1\ \mathrm{kg\ m^2/s^3}. \tag{5.20}$$

Conversely, one joule is also one watt times one second. This relationship is reflected in a very common unit of energy (not power!), the **kilowatt-hour** (kWh):

$$1\ \mathrm{kWh} = (1000\ \mathrm{W})(3600\ \mathrm{s}) = 3.6 \times 10^6\ \mathrm{J} = 3.6\ \mathrm{MJ}.$$

APPLY THE RELATIONSHIP BETWEEN AVERAGE POWER, THE WORK DONE BY A FORCE OR THE ASSOCIATED ENERGY TRANSFER, AND THE TIME INTERVAL IN WHICH THAT WORK IS DONE, OR ENERGY IS TRANSFERRED ($Pave=W/\Delta t$).

$$\overline{P} = \frac{W}{\Delta t} = \frac{\Delta K}{\Delta t} = \frac{\frac{1}{2} mv^2}{\Delta t} = \frac{mv^2}{2\Delta t}.$$

$$P = \frac{dW}{dt} = \frac{\vec{F} \bullet d\vec{r}}{dt} = \vec{F} \bullet \vec{v} = Fv \cos \alpha,$$

APPLY THE RELATIONSHIP BETWEEN AVERAGE POWER, THE WORK DONE BY A FORCE OR THE ASSOCIATED ENERGY TRANSFER, AND THE TIME INTERVAL IN WHICH THAT WORK IS DONE, OR ENERGY IS TRANSFERRED ($Pave = W/\Delta t$).

EXAMPLE 5.4 Accelerating a Car

PROBLEM

Returning to the example of an accelerating car, let's assume that the car, of mass 1550 kg, can reach a speed of 60 mph (26.8 m/s) in 7.1 s. What is the average power needed to accomplish this?

APPLY THE RELATIONSHIP BETWEEN AVERAGE POWER, THE WORK DONE BY A FORCE OR THE ASSOCIATED ENERGY TRANSFER, AND THE TIME INTERVAL IN WHICH THAT WORK IS DONE, OR ENERGY IS TRANSFERRED ($Pave=W/\Delta t$).

SOLVED PROBLEM 5.4 **Riding a Bicycle**

PROBLEM

A bicyclist coasts down a 4.2° slope at a steady speed of 5.1 m/s. Assuming a total mass of 82.2 kg (bicycle plus rider), what power output must the cyclist expend to pedal up the same slope at the same speed?

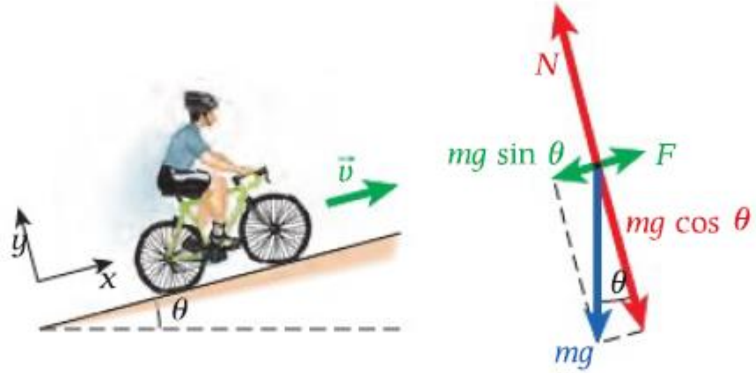


FIGURE 5.24 Sketch of the bicycle moving up the slope (left) and the free-body diagram (right).

5.46 A horse draws a sled horizontally across a snow-covered field. The coefficient of friction between the sled and the snow is 0.195, and the mass of the sled, including the load, is 202.3 kg. If the horse moves the sled at a constant speed of 1.785 m/s, what is the power needed to accomplish this?

5.48 While a boat is being towed at a speed of 12.0 m/s, the tension in the towline is 6.00 kN. What is the power supplied to the boat through the towline?

5.49 A car of mass 1214.5 kg is moving at a speed of 27.9 m/s when it misses a curve in the road and hits a bridge piling. If the car comes to rest in 0.236 s, how much average power (in watts) is expended in this interval?

(1) APPLY THE EQUATION ($W=F\cdot\Delta r=F\Delta r\cos\alpha$) TO CALCULATE THE WORK DONE ON AN OBJECT BY A CONSTANT FORCE BY TAKING THE DOT PRODUCT OF THE FORCE VECTOR F AND THE DISPLACEMENT VECTOR ΔR.

(2) APPLY THE RELATIONSHIP BETWEEN AVERAGE POWER, THE WORK DONE BY A FORCE OR THE ASSOCIATED ENERGY TRANSFER, AND THE TIME INTERVAL IN WHICH THAT WORK IS DONE, OR ENERGY IS TRANSFERRED ($Pavg=W\Delta t$).

كتابي

5.26 A force of 5.00 N acts over a distance of 12.0 m in the direction of the force. Find the work done.

5.30 You push your couch a distance of 4.00 m across the living room floor with a horizontal force of 200.0 N. The force of friction is 150.0 N. What is the work done by you, by the friction force, by gravity, and by the net force?

•**5.32** A father pulls his son, whose mass is 25.0 kg and who is sitting on a swing with ropes of length 3.00 m, backward until the ropes make an angle of 33.6° with respect to the vertical. He then releases his son from rest. What is the speed of the son at the bottom of the swinging motion?

•**5.33** A constant force, $\vec{F} = (4.79, -3.79, 2.09)$ N, acts on an object of mass 18.0 kg, causing a displacement of that object by $\vec{r} = (4.25, 3.69, -2.45)$ m. What is the total work done by this force?

END OF PART 2/2

BEST OF LUCK!

Ms. Asmaa Alhameed
Telg: @Asmaa_Alhameed