2 Mechanics

The major goals of this chapter are to enable you to:

.1Distinguish between a vector and a scalar quantity.
.2Find the components of a vector.
.3Distinguish between speed and velocity.
.4Use vectors to illustrate and solve velocity problems.
.5Distinguish between velocity and acceleration.
.6Utilize vectors to illustrate and solve acceleration problems.
.7Relate force and the law of inertia.
.8Apply the law of acceleration.
.9Identify components of friction.
.10 Analyze forces in one dimension.
.11 Distinguish among weight, mass, and gravity.
.12 Analyze how the law of action and reaction is used.
.13 Distinguish between the common and technical definitions of work.
.14 Analyze how power is used and described in technical applications.
.15 Relate kinetic and potential energy to the law of conservation of mechanical energy.

Scalar

Scalar α a quantity that can be described by ***magnitude*** only

Examples: Speed, Mass, Temperature, Pressure

Vectors

Vector α a quantity that requires both ***magnitude*** and ***direction***

Examples: Velocity, Force, Acceleration

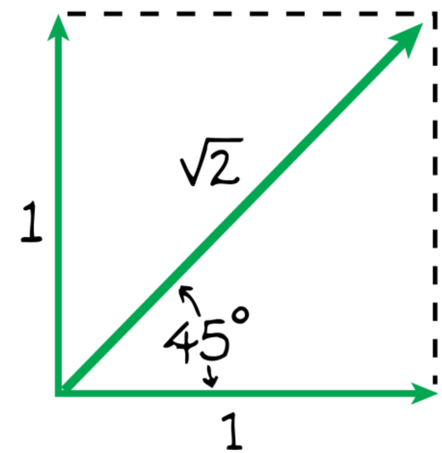
Vectors

Resultant

- **The sum of two or more vectors**
  - For vectors in **the same direction**, **add** arithmetically.
  - For vectors in **opposite directions**, **subtract** arithmetically.
  - Two vectors that **don't act in the same or opposite direction**:
    - **use parallelogram rule**.
  - Two vectors **at right angles** to each other
    - use **Pythagorean Theorem**: $R^2 = V^2 + H^2$.

Parallelogram rule: Finding the resultant geometrically

- Generally applies for **rectangular** and **nonrectangular** vectors
  - The diagonal of a square is $\sqrt{2}$, or 1.414, times the length of one of its sides.



Vector Components

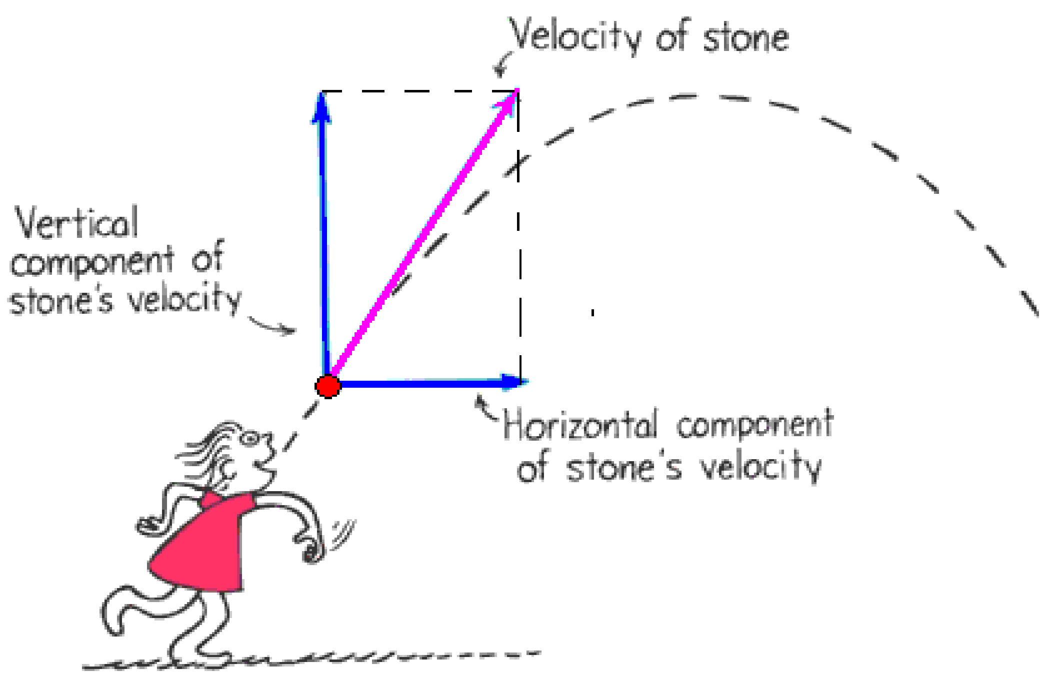
Often we will need to change a single vector into an equivalent set of two *component* vectors at right angles to each other:

- Any vector can be "resolved" into two component vectors at right angles to each other .
- Two vectors at right angles that add up to a given vector are known as the **components** of the given vector .
- The process of determining the components of a vector is called **resolution** .

Vectors

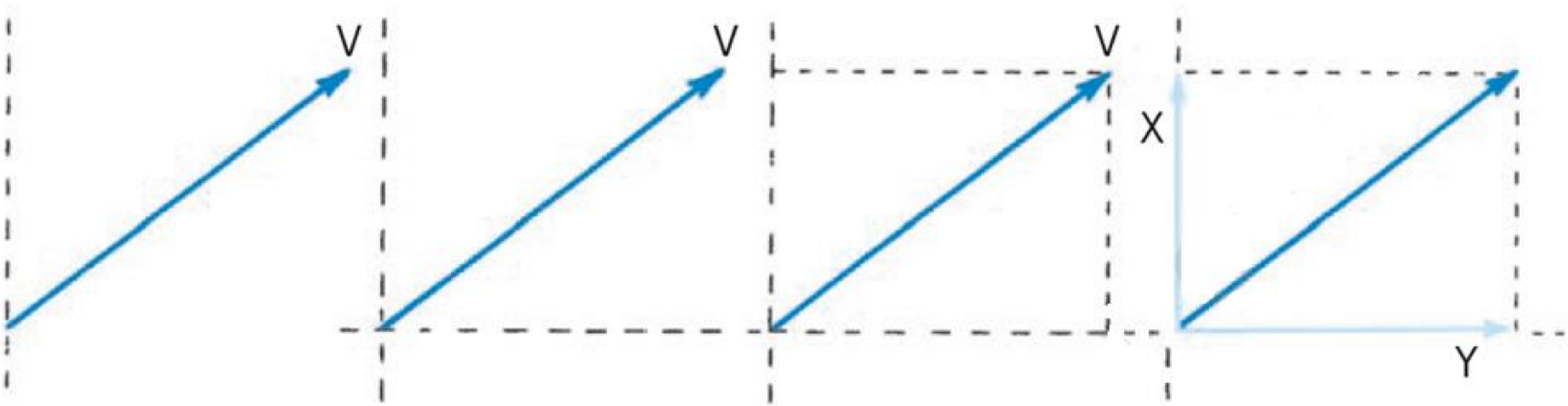
Vector components

- Vertical and horizontal components of a vector are perpendicular to each other
- Determined by **resolution**.



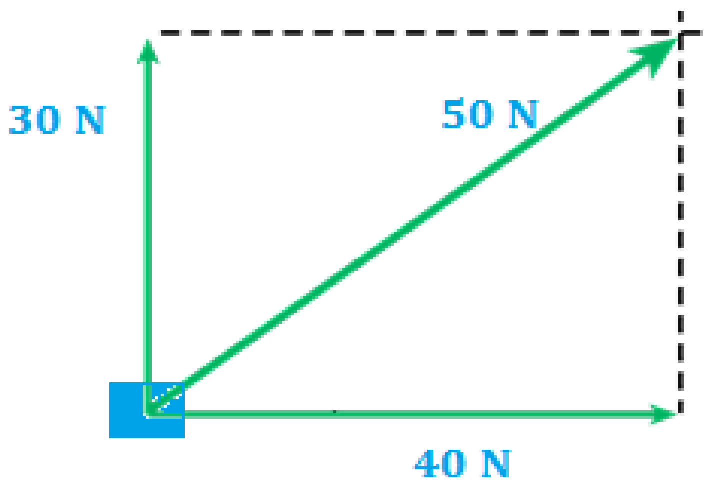
Finding vector components by ***resolution***

Example:



Force vectors

- A pair of forces acting on a box.
- The resultant of the 30-N and 40-N forces is 50-N



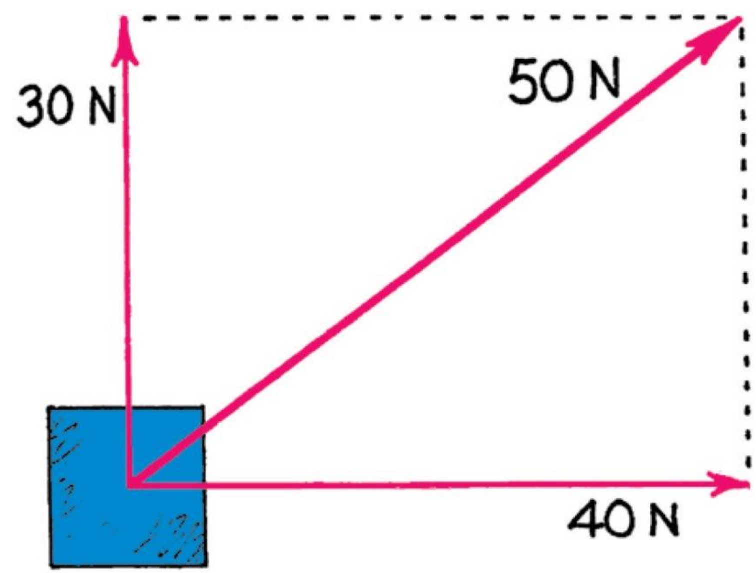
Referring to the figure, which of the following are true statements?

A. 50N is the resultant of the 30- and 40-N vectors.

B. The 30-N vector can be considered a component of the 50-N vector .

C. The 40-N vector can be considered a component of the 50-N vector.

D. All of the above are correct.



Vectors
CHECK YOUR ANSWER

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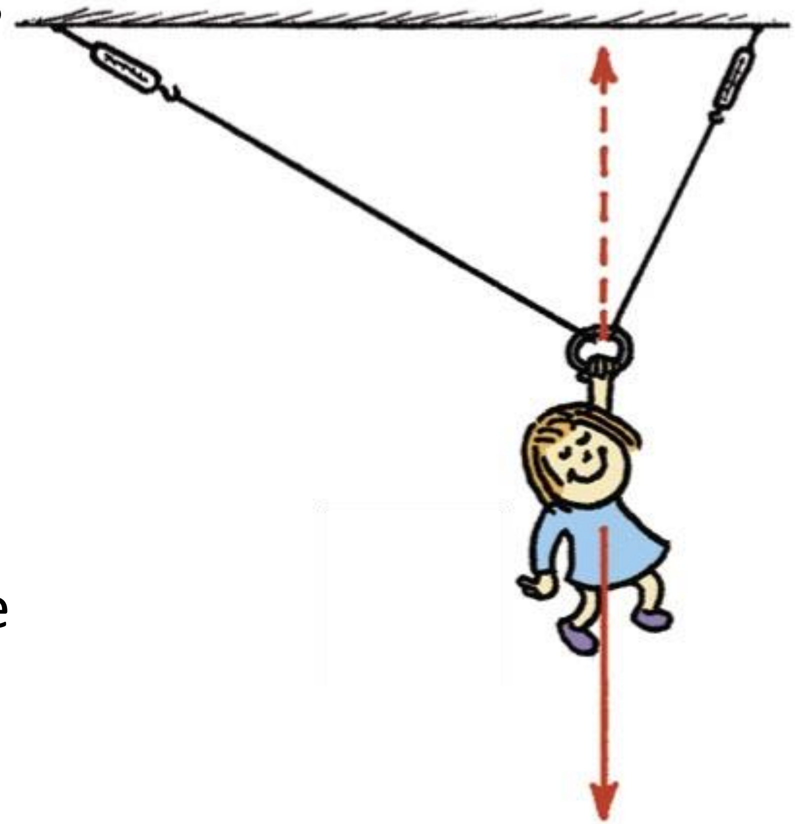
Force Vectors

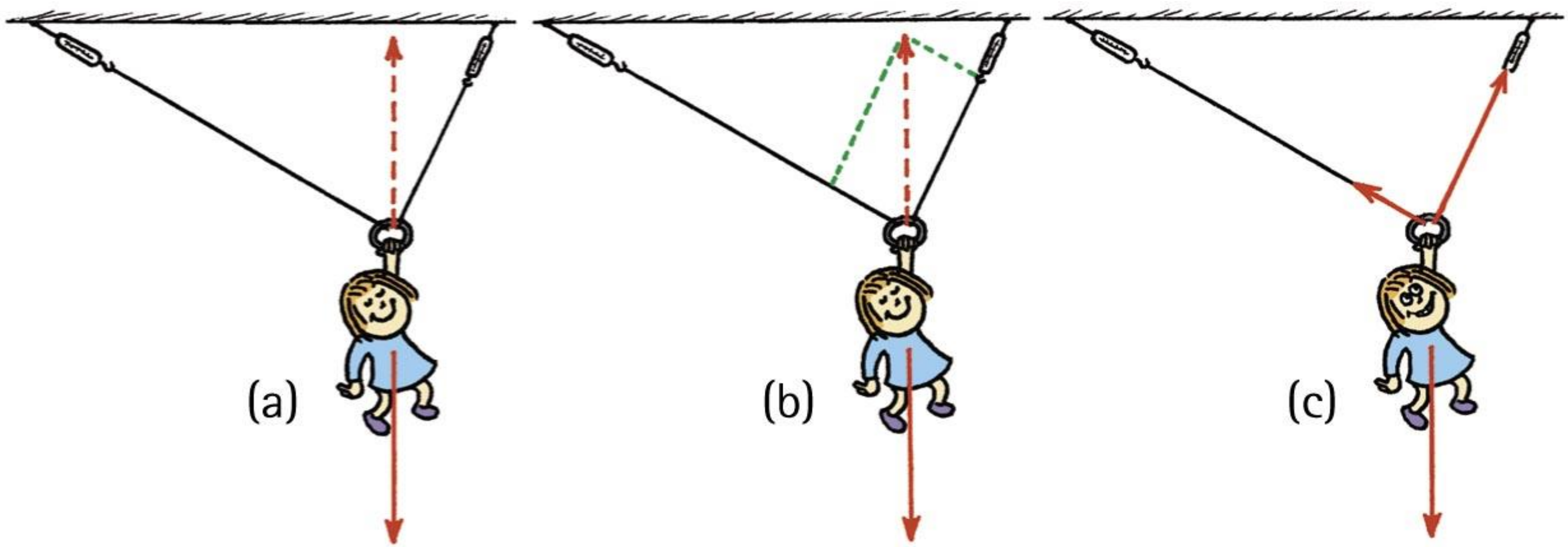
Nellie Newton hangs from a rope as shown.

- Which side has the greater tension ?
- There are three forces acting on Nellie :
  - her weight ,
  - a tension in the left-hand side of the rope ,
  - and a tension in the right-hand side of the rope .



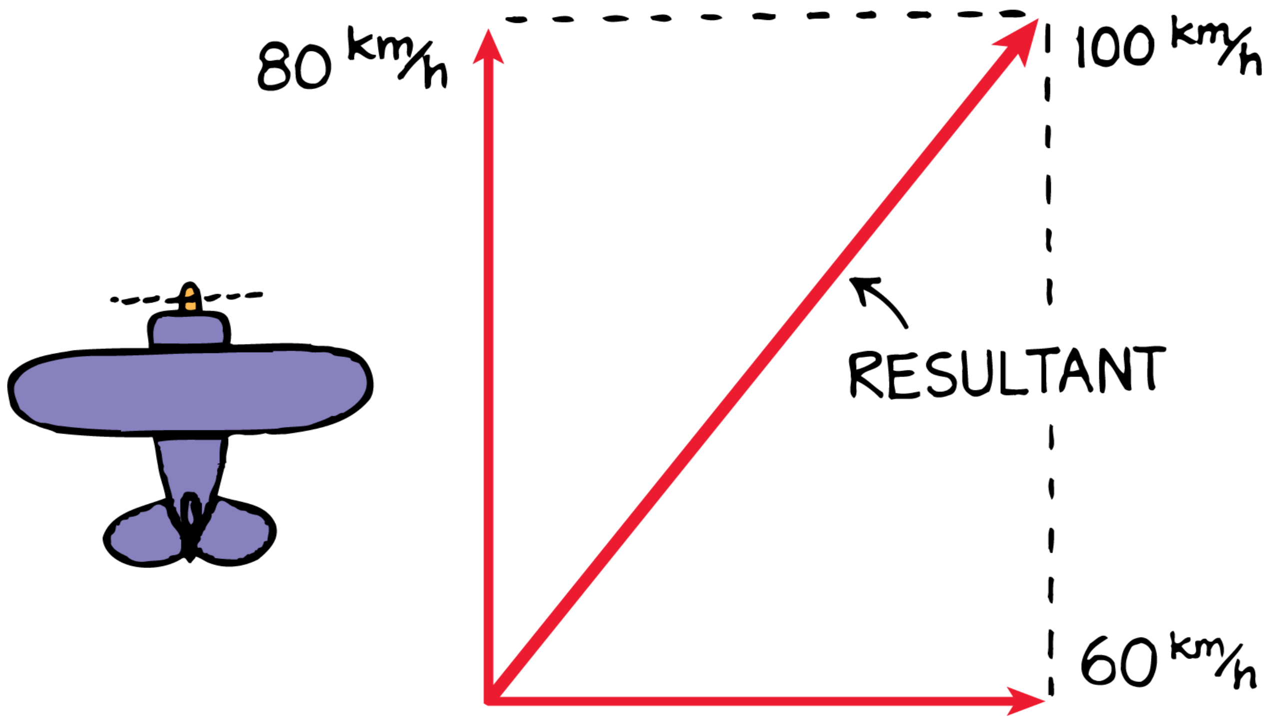
Force Vectors

- Because of the different angles, different rope tensions will occur in each side .
- Nellie hangs in equilibrium, so her weight is supported by two rope tensions, adding vectorially to be equal and opposite to her weight .
- The parallelogram rule shows that the tension in the right-hand rope is greater than the tension in the left-hand rope.



Velocity Vectors

An 80-km/h airplane flying in a 60-km/h crosswind has a resultant speed of 100 km/h relative to the ground.



Referring to the figure, which of the following are true statements?

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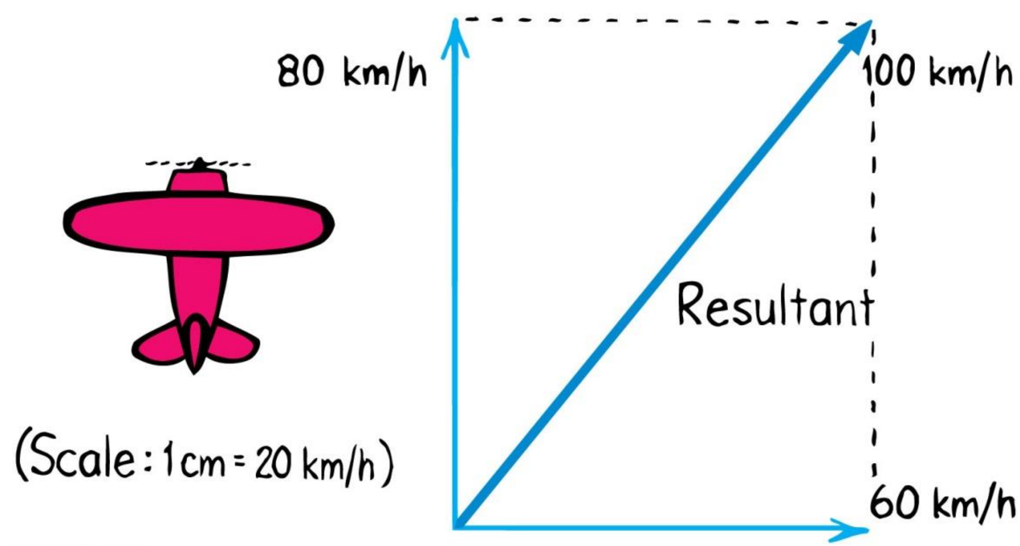
B. The 80-km/h vector can be considered a component of the 100-km/h vector .

C. The 60-km/h vector can be considered a component of the 100-km/h vector.

D. All of the above are correct.



Vectors
CHECK YOUR ANSWER

Referring to the figure, which of the following are true statements?

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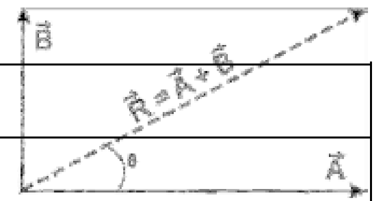
C. The 60-km/h vector can be considered a component of the 100-km/h vector.

D. All of the above are correct.

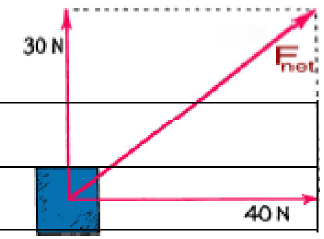
EXAMPLES:

67. Adding two perpendicular vectors ($\vec{A}$) and ($\vec{B}$) gives a resultant ($\vec{R}$) with magnitude:



A	$R = \sqrt{A^2 + B^2}$ ✓	C	$R = \sqrt{A + B}$
B	$R = A^2 + B^2$	D	$R = 1 / \sqrt{A^2 + B^2}$

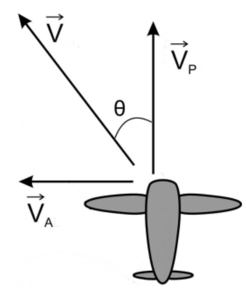
68. Two perpendicular forces, F_1 = 40 N and F_2 = 30 N, act on a brick. The magnitude of the net force (F_{net}) on the brick is:



A	70 N	C	0 N
B	50 N✓	D	10 N

.69If an airplane heading north with speed v_P = 400 km/h faces a westbound wind (ريح نحو الغرب)of speed v_A = 300 km/h, the resultant velocity of the plane is:

A. 500 km/h, north-west ✓ B. 700 km/h, north-east
C. 500 km/h, north-east D. 700 km/h, north-west



Linear Motion

Speed α scalar quantity requiring magnitude only to describe how fast a body is.

$$\text{Speed} = \frac{\text{distance}}{\text{time}}$$

Approximate Speeds in Different Units

12 mi/h =	20 km/h =	6 m/s
25 mi/h =	40 km/h =	11 m/s
37 mi/h =	60 km/h =	17 m/s

Example: A girl runs 6 meters in 1 sec. Her speed is 6 m/s .

INSTANTANEOUS SPEED:

The speed at any instant of time

AVERAGE SPEED

Average speed is defined as

$$\text{Average speed} = \frac{\text{total distance covered}}{\text{time interval}}$$

- doesn’t indicate various instantaneous speeds along the way
- **Example**: drive a distance of 80 km in 1 hour and your

  average speed is 80 km/h
- If we know average speed and travel time, the distance traveled is

  easy to find .

total distance covered = average speed × travel time

EXAMPLE:

29. A horse gallops (يجري) a distance of 10 kilometers in 30 minutes. Its average speed is:

A	15 km/h	C	30 km/h
B	20 km/h✓	D	40 km/h

Constant speed is steady speed, neither speeding up nor slowing down.

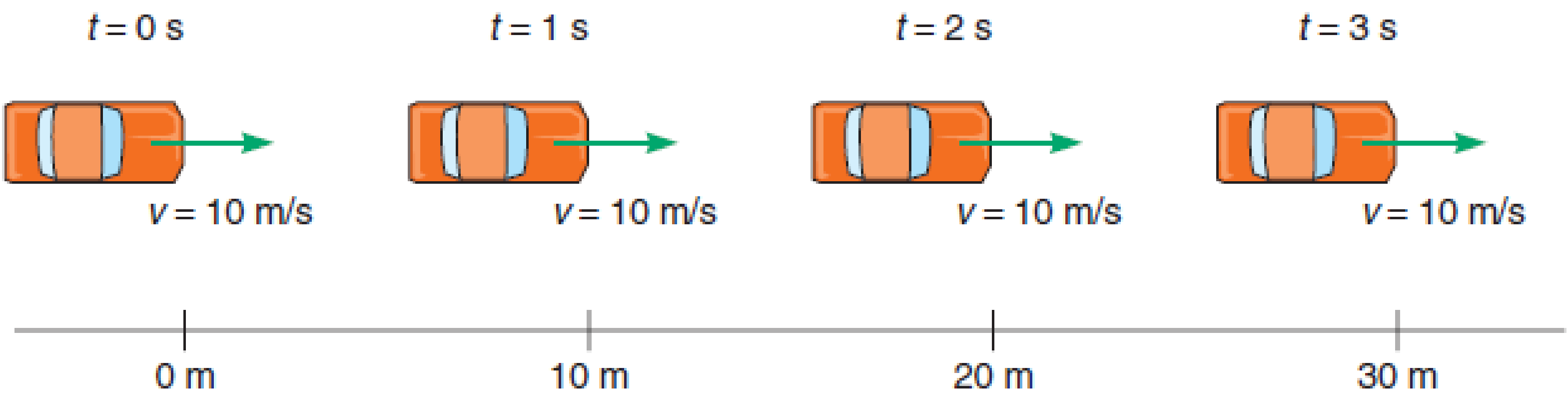
Velocity

Velocity α vector quantity requiring magnitude & direction. It describes *how fast* and in *what direction*.

CONSTANT VELOCITY:

- is constant speed *and* constant direction (straight- line path with no acceleration.(
- Means motion in straight line at a constant speed.

Figure The velocity, displacement, and time for a car traveling at a constant velocity of 10 m/s to the right is shown in 1-s intervals.



Velocity

CHANGING VELOCITY:

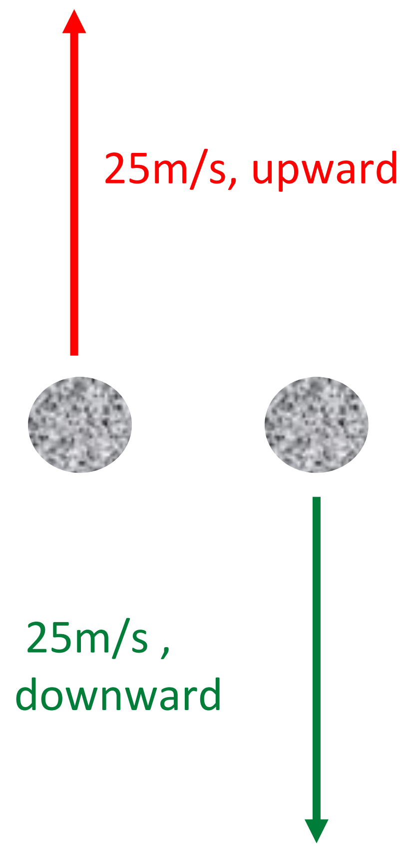
If *either* the speed or the direction (*or both*) changes, then the velocity changes.

- Constant speed and constant velocity are not the same .
- A body may move at constant speed along a curved path but it does not move with constant velocity, because its direction is changing every instant.

Velocity

- <u>**Velocity**</u> is speed *and* direction of object's motion.

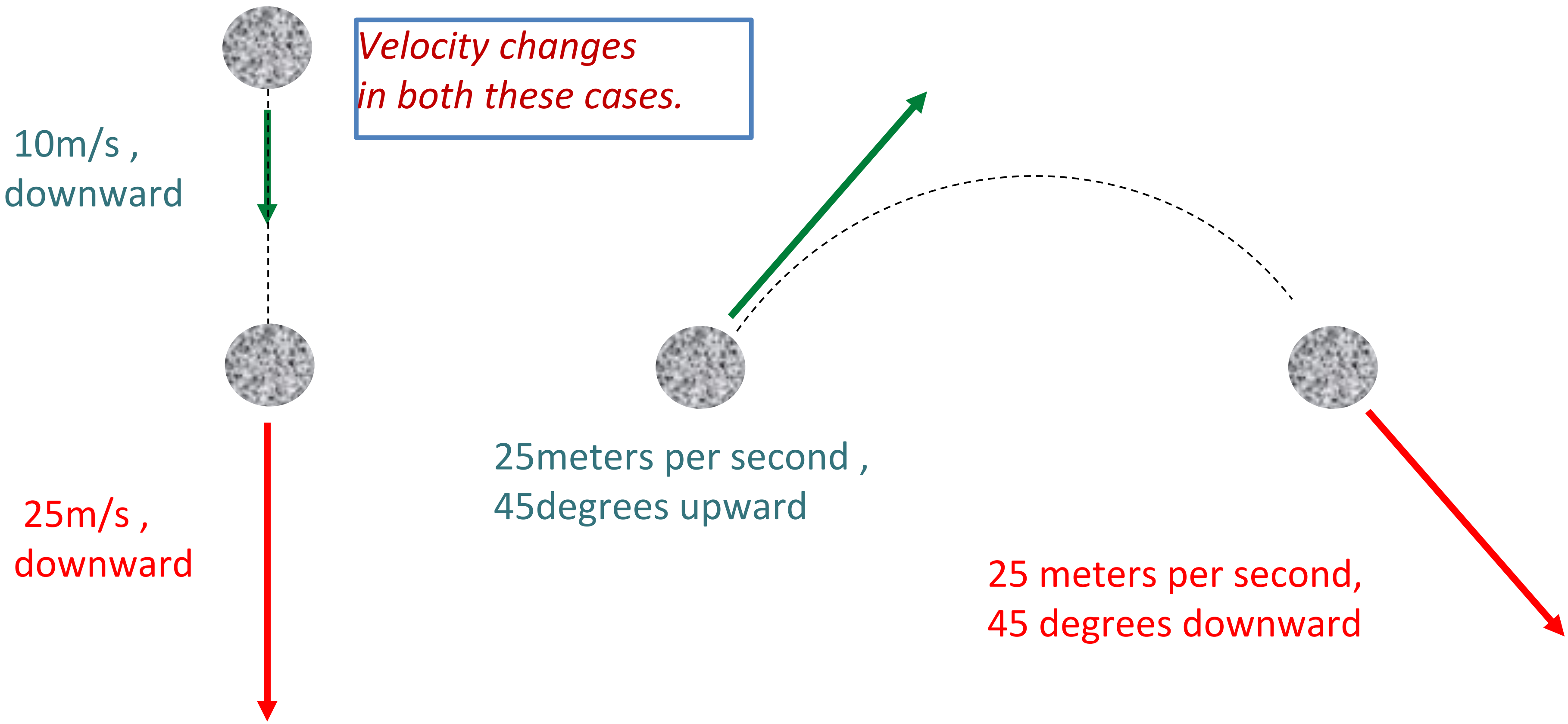
Examples:
- 30miles per hour, Northward
- 25meters per second, Downward
- 300miles per hour, Coming towards you



Same speeds
Different velocities

Changing Velocity

Velocity changes if speed or direction of motion change.



Acceleration

Acceleration α Is the change in velocity per unit time.

$$\text{average acceleration} = \frac{\text{change in velocity (or speed)}}{\text{elapsed time}}$$

$$= \frac{\text{final velocity} - \text{initial velocity}}{\text{time}}$$

$$a = \frac{\Delta v}{t} = \frac{v_f - v_i}{t}$$

$$\Delta v = at$$

Acceleration can mean **speeding up**, **slowing down**, or **changing direction**.

Dimensions: Length/Time^2 ([L]/[T^2]) ; Units: m/s^2, km/h^2, ft/min^2, etc…

EXAMPLE:

A dragster starts from rest (velocity = 0 ft/s) and attains a speed of $15\bar{0}$ ft/s in 10.0 s. Find its acceleration.

Data:

$$\Delta v = 15\bar{0}\text{ ft/s} - 0\text{ ft/s} = 15\bar{0}\text{ ft/s}$$

$$t = 10.0\text{ s}$$

$$a = ?$$

Basic Equation:

$$\Delta v = at$$

Working Equation:

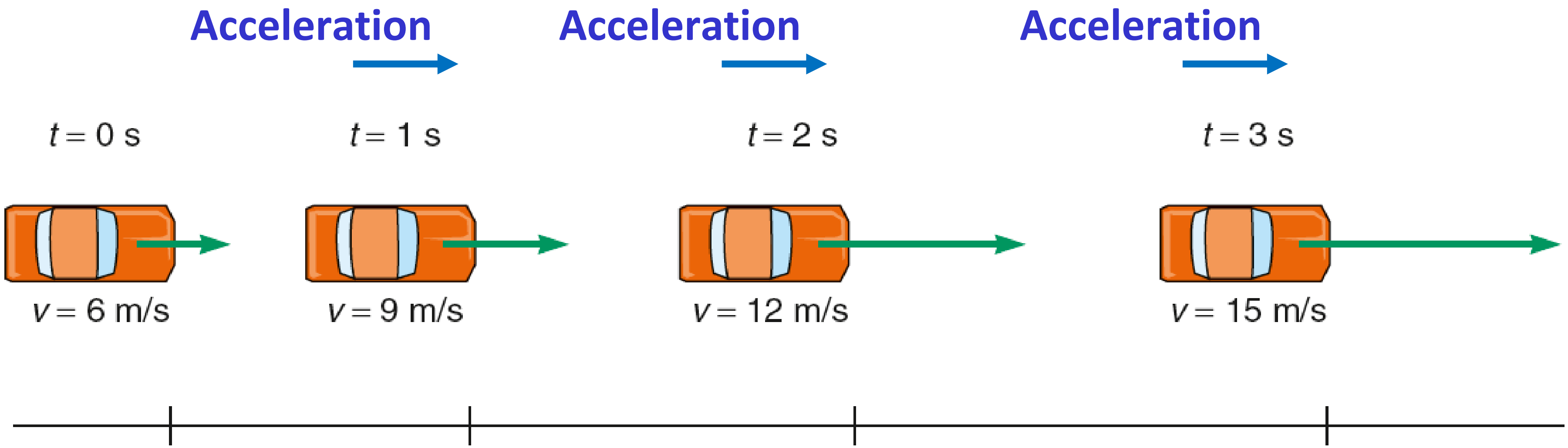
$$a = \frac{\Delta v}{t}$$

Substitution:

$$a = \frac{15\bar{0}\text{ ft/s}}{10.0\text{ s}}$$

$$= 15.0\,\frac{\text{ft/s}}{\text{s}} \quad \text{or } 15.0 \text{ feet per second per second}$$

Acceleration



This car is speeding up with a constant acceleration. Note how the distance covered and the velocity change during each time interval.

EXAMPLE:

A car accelerates from 45 km/h to $8\bar{0}$ km/h in 3.00 s. Find its acceleration (in m/s^2).

Data:

$$\Delta v = 8\bar{0}\ \text{km/h} - 45\ \text{km/h} = 35\ \text{km/h}$$

$$t = 3.00\ \text{s}$$

$$a = ?$$

Basic Equation:

$$\Delta v = at$$

Working Equation:

$$a = \frac{\Delta v}{t}$$

Substitution:

$$a = \frac{35\ \text{km/h}}{3.00\ \text{s}} \times \frac{1000\ \text{m}}{1\ \text{km}} \times \frac{1\ \text{h}}{3600\ \text{s}}$$

$$= 3.2\ \text{m/s}^2$$

Note the use of the conversion factors to change the units km/h/s to m/s^2.

EXAMPLE:

A plane accelerates at 8.5 m/s^2 for 4.5 s. Find its increase in speed (in m/s).

Data:

$$a = 8.5\ m/s^2$$
$$t = 4.5\ s$$
$$\Delta v = ?$$

Basic Equation:

$$\Delta v = at$$

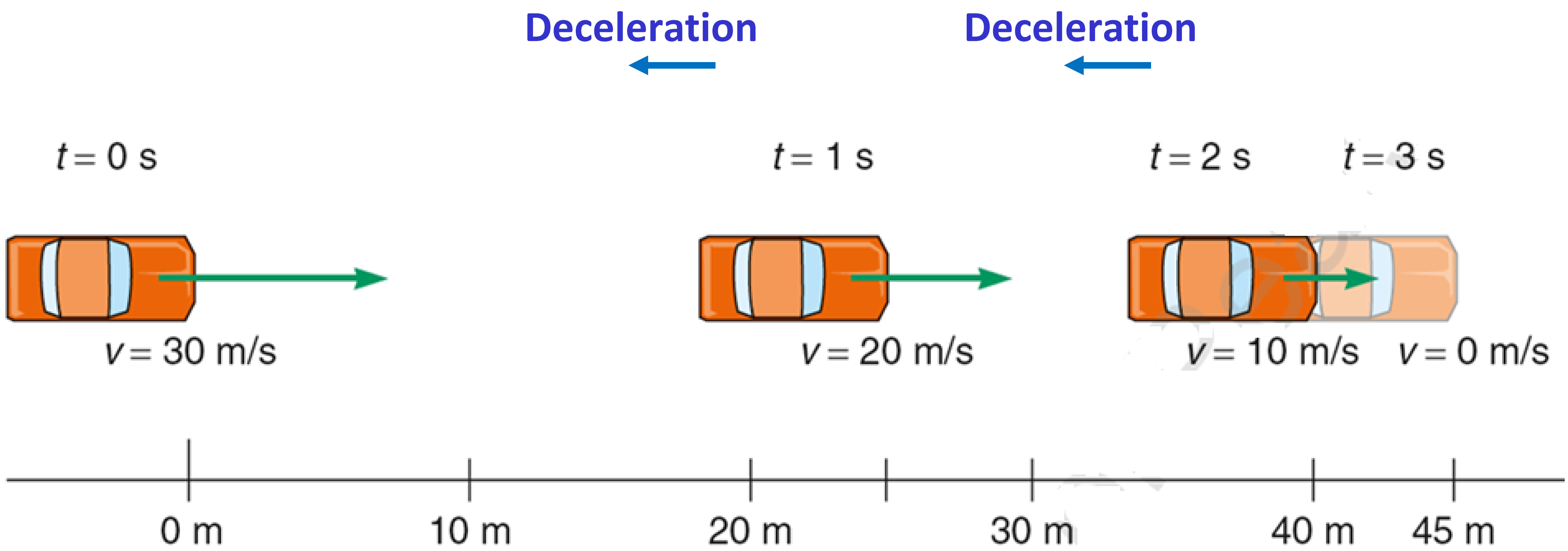
Working Equation: Same

Substitution:

$$\Delta v = (8.5\ m/s^2)(4.5\ s) = 38\ m/s$$

$$\frac{m}{s^2} \times s = \frac{m}{s}$$

Deceleration



This car is slowing down with a constant acceleration of $-10\ m/s^2$. Note how the distance covered and the velocity change during each unit of time interval.

- **Deceleration** is an **acceleration** that usually indicates that an object is **slowing down.**

EXAMPLE:

A driver steps off the gas pedal and coasts at a rate of $-3.00\ \text{m/s}^2$ for 5.00 s. Find the driver's new speed if she was originally traveling at a velocity of 20.0 m/s. (The negative acceleration indicates that the acceleration is in the opposite direction of the velocity; that is, the object is slowing down.)

Data:

$$a = -3.00\ \text{m/s}^2$$
$$t = 5.00\ \text{s}$$
$$v_i = 20.0\ \text{m/s}$$

Basic Equation:

$$\Delta v = at$$
$$v_f - v_i = at$$

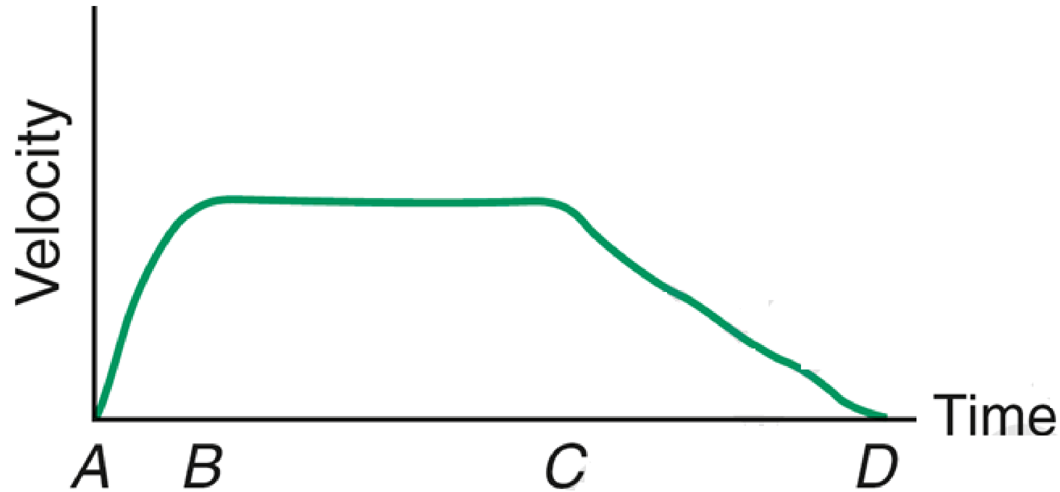
Working Equation:

$$v_f = v_i + at$$

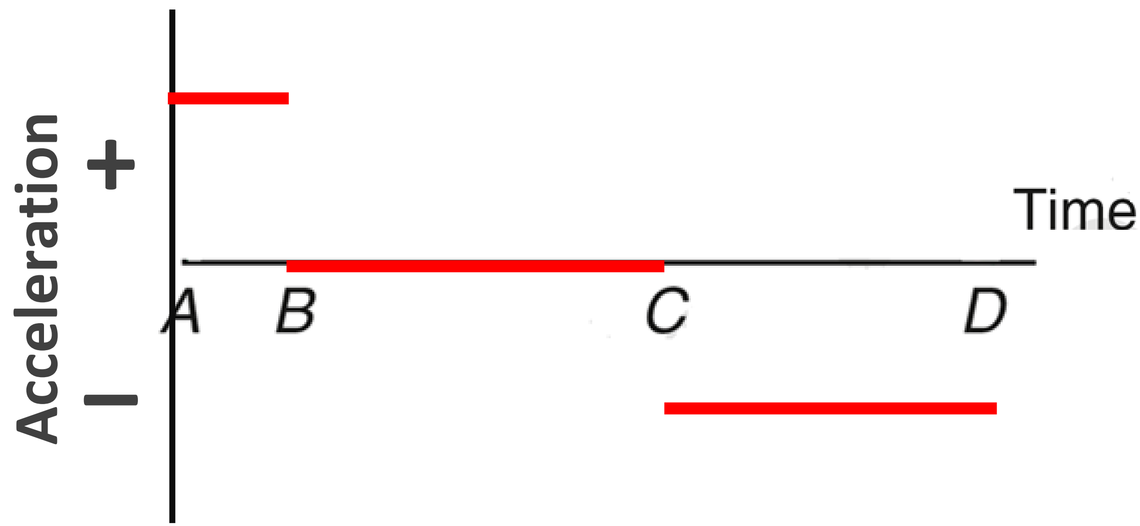
Substitution:

$$v_f = 20.0\ \text{m/s} + (-3.00\ \text{m/s}^2)(5.00\ \text{s})$$
$$= 5.0\ \text{m/s}$$

Acceleration as a vector: *geometrical representation*



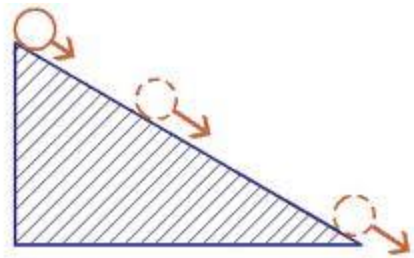
Motion of a high-speed train going from one station to another. When the speed increases, the acceleration is positive. When the speed is constant, the acceleration is zero. When the speed decreases, the acceleration is negative.



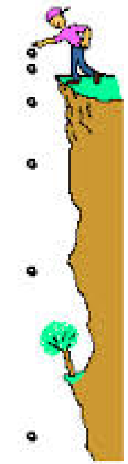
Uniformly accelerated motion and free fall

Characterized by the constant acceleration ®its direction & magnitude are unchanging.

EXAMPLES:



(a) Speed increasing on downward slope



ACCELERATED MOTION:

Equations for motion in straight line with constant acceleration:

1. $v_{avg} = \dfrac{v_f + v_i}{2}$

2. $a = \dfrac{v_f - v_i}{t}$

3. $v_f = v_i + at$

4. $s = v_i t + \dfrac{1}{2} a t^2$

5. $s = \dfrac{1}{2}(v_f + v_i)t$

6. $2as = v_f^2 - v_i^2$

where
s = displacement
v_f = final velocity
v_i = initial velocity
v_{avg} = average velocity
a = constant acceleration
t = time

Displacement is a vector pointing from the initial to the final position and with magnitude equals the shortest distance between the initial and final position

EXAMPLE:

The average velocity of a rolling freight car is 2.00 m/s. How long does it take for the car to roll 15.0 m?

Data:

$$s = 15.0\ \text{m}$$
$$v_{avg} = 2.00\ \text{m/s}$$
$$t = ?$$

Basic Equation:

$$s = v_{avg}\, t$$

Working Equation:

$$t = \frac{s}{v_{avg}}$$

Substitution:

$$t = \frac{15.0\ \text{m}}{2.00\ \text{m/s}} = 7.50\ \text{s}$$

$$\frac{\text{m}}{\text{m/s}} = \text{m} \div \frac{\text{m}}{\text{s}} = \text{m} \cdot \frac{\text{s}}{\text{m}} = \text{s}$$

EXAMPLE:

A dragster starting from rest reaches a final velocity of 318 km/h. Find its average velocity.

Data:

$$v_i = 0$$

$$v_f = 318 \text{ km/h}$$

$$v_{avg} = ?$$

Basic Equation:

$$v_{avg} = \frac{v_f + v_i}{2}$$

Working Equation: Same

Substitution:

$$v_{avg} = \frac{318 \text{ km/h} + 0 \text{ km/h}}{2}$$

$$= 159 \text{ km/h}$$

EXAMPLE:

A train slowing to a stop has an average acceleration of $-3.00\ \text{m/s}^2$. [Note that a minus ($-$) acceleration is commonly called *deceleration*, meaning that the train is slowing down.] If its initial velocity is 30.0 m/s, how far does it travel in 4.00 s?

Data:

$$a = -3.00\ \text{m/s}^2$$
$$v_i = 30.0\ \text{m/s}$$
$$t = 4.00\ \text{s}$$
$$s = ?$$

Basic Equation:

$$s = v_i t + \frac{1}{2}at^2$$

Working Equation: Same

Substitution:

$$s = (30.0\ \text{m/s})(4.00\ \text{s}) + \frac{1}{2}(-3.00\ \text{m/s}^2)(4.00\ \text{s})^2$$
$$= 12\overline{0}\ \text{m} - 24.0\ \text{m}$$
$$= 96\ \text{m}$$

EXAMPLE:

An automobile accelerates from 67.0 km/h to 96.0 km/h in 7.80 s. What is its acceleration (in m/s?(2

Data:

$$v_f = 96.0 \text{ km/h}$$
$$v_i = 67.0 \text{ km/h}$$
$$t = 7.80 \text{ s}$$
$$a = ?$$

Basic Equation:

$$a = \frac{v_f - v_i}{t}$$

Working Equation: Same

Substitution:

$$a = \frac{96.0 \text{ km/h} - 67.0 \text{ km/h}}{7.80 \text{ s}}$$
$$= \frac{29.0 \text{ km/h}}{7.80 \text{ s}}$$
$$= \frac{29.0 \frac{\cancel{\text{km}}}{\cancel{\text{h}}} \times \frac{1000 \text{ m}}{1 \cancel{\text{km}}} \times \frac{1 \cancel{\text{h}}}{3600 \text{ s}}}{7.80 \text{ s}}$$
$$= 1.03 \text{ m/s}^2$$

Free Fall

- Freely falling bodies undergo constant acceleration
- When acceleration $a = g = 9.8\ m/s^2$ **— free fall**
- Acceleration is g when *air resistance is negligible*.
- Acceleration depends on force (weight) and inertia.

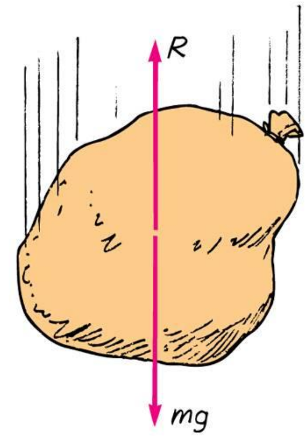
A ball falls with constant acceleration $a = g = 9.82\ \mathrm{m/s^2}$ with the speed and the distance traveled calculated at the given times. Because the ball was dropped, $v_i = 0$ and the formulas for v_f and s are shown simplified. Note how the velocity and the distance traveled increase during each successive time interval.

Time	Distance Traveled	Speed
	$s = \frac{1}{2}at^2$	$v_f = at$
$t = 0$	0 m	0 m/s
$t = 1.00$ s	$s = \frac{1}{2}(9.80\ \mathrm{m/s^2})(1.00\ \mathrm{s})^2$ $s = 4.90$ m	$v_f = (9.80\ \mathrm{m/s^2})(1.00\ \mathrm{s})$ $v_f = 9.80$ m/s
$t = 2.00$ s	$s = \frac{1}{2}(9.80\ \mathrm{m/s^2})(2.00\ \mathrm{s})^2$ $s = 19.6$ m	$v_f = (9.80\ \mathrm{m/s^2})(2.00\ \mathrm{s})$ $v_f = 19.6$ m/s
$t = 3.00$ s	$s = \frac{1}{2}(9.80\ \mathrm{m/s^2})(3.00\ \mathrm{s})^2$ $s = 44.1$ m	$v_f = (9.80\ \mathrm{m/s^2})(3.00\ \mathrm{s})$ $v_f = 29.4$ m/s
$t = 4.00$ s	$s = \frac{1}{2}(9.80\ \mathrm{m/s^2})(4.00\ \mathrm{s})^2$ $s = 78.4$ m	$v_f = (9.80\ \mathrm{m/s^2})(4.00\ \mathrm{s})$ $v_f = 39.2$ m/s

Non-Free Fall

When acceleration of fall is *less than g*, non-free fall

- occurs when air resistance is non-negligible.
- depends on two things :
  - speed and
  - frontal surface area.



Terminal speed

- occurs when acceleration terminates (when air resistance equals weight and net force is zero.(

Terminal velocity

- same as terminal speed, with direction implied or specified.

EXAMPLE:

A rock is thrown straight down from a cliff with an initial velocity of 10.0 ft/s. Its final velocity when it strikes the water below is $31\overline{0}$ ft/s. The acceleration due to gravity is 32.2 ft/s^2. How long is the rock in flight?

Data:

$$v_i = 10.0 \text{ ft/s}$$
$$a = 32.2 \text{ ft/s}^2$$
$$v_f = 31\overline{0} \text{ ft/s}$$
$$t = ?$$

Note the importance of listing all the data as an aid to finding the basic equation.

Basic Equation:

$$v_f = v_i + at \quad \text{or} \quad a = \frac{v_f - v_i}{t} \qquad \text{(two forms of the same equation)}$$

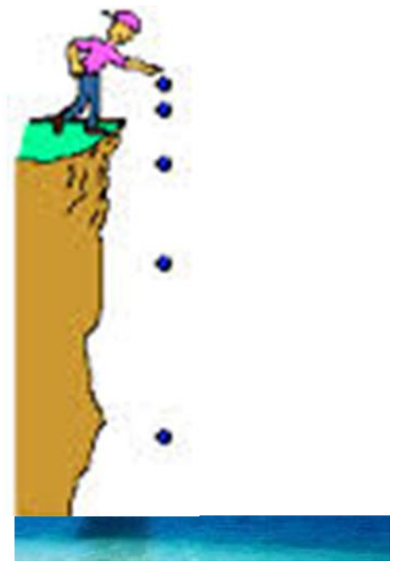
Working Equation:

$$t = \frac{v_f - v_i}{a}$$

Substitution:

$$t = \frac{31\overline{0} \text{ ft/s} - 10.0 \text{ ft/s}}{32.2 \text{ ft/s}^2}$$
$$= \frac{30\overline{0} \text{ ft/s}}{32.2 \text{ ft/s}^2}$$
$$= 9.32 \text{ s}$$

$$\frac{\text{ft/s}}{\text{ft/s}^2} = \frac{\text{ft}}{\text{s}} \div \frac{\text{ft}}{\text{s}^2} = \frac{\text{ft}}{\text{s}} \cdot \frac{\text{s}^2}{\text{ft}} = \text{s}$$



When an object is thrown vertically upward, its speed is uniformly decreased by the force of gravity until it stops for an instant at its peak before falling back to the ground.

EXAMPLE:

A ball is thrown vertically upward with initial speed 1 m/s, determine the time for it to reach the highest altitude.

Data:

$v_i = -1\ \text{m/s}$ (v_i is negative because the initial velocity is directed opposite gravity, g.)

$v_f = 0$ (At the instant of the ball's maximum height, its velocity is zero.)

$a = g = 9.80\ \text{m/s}^2$

$t = ?$

Basic Equation:

$$v_f = v_i + at$$

Working Equation:

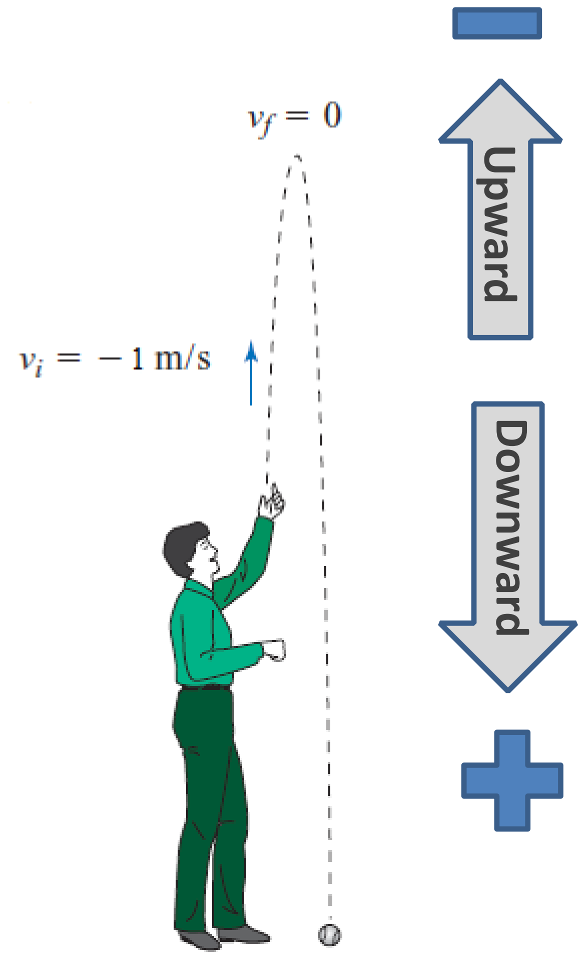
$$t = \frac{v_f - v_i}{a}$$

Substitution:

$$t = \frac{0 - (-1\ \text{m/s})}{9.80\ \text{m/s}^2}$$

$$= 0.1\ \text{s}$$

$$\frac{\text{m/s}}{\text{m/s}^2} = \frac{\text{m}}{\text{s}} \div \frac{\text{m}}{\text{s}^2} = \frac{\cancel{\text{m}}}{\cancel{\text{s}}} \times \frac{\text{s}^{\cancel{2}}}{\cancel{\text{m}}} = \text{s}$$



Force and Law of Inertia

The force:

- Is a vector (has magnitude and direction).
- Is any push or pull.
- Tends to change the state of motion of an object.
- Tends to produce acceleration in the direction of its application.
  - But, for instance, opposite and equal forces cancel each other, resulting in zero acceleration
- SI unit of force is Newton (N)
  - **Conversion factor** SI □ British system:

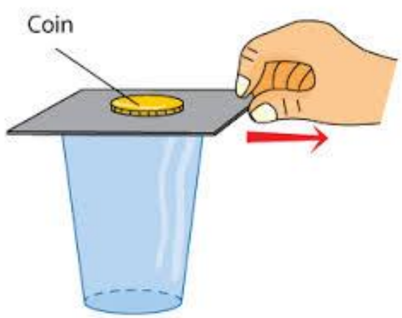
  4.45 N = 1 lb

FIGURE 2.13
The pushing force and the frictional force cancel each other out, resulting in zero acceleration.

Inertia:

- is related to the Newton first law of motion which is also called the *law of inertia:* **a body at state of rest (speed = 0) or motion with *constant velocity* (constant speed in straight line) tends to remain at this state unless acted upon by an unbalanced force.** ®**Inertia** is a property of matter to resist changes in motion.

- depends on the amount of matter in an object (its *mass*.(

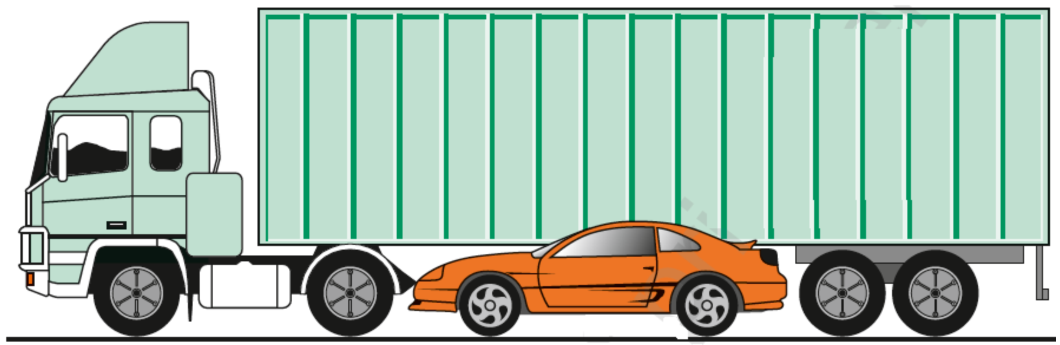


The coin tends to remain at rest.

The car tends to continue moving.

Mass:

- is a measure of the inertia:
  - *The greater the mass of a body the greater is its resistance to motion*



A larger body (in mass) has a greater resistance to a change in its motion than does a smaller one.

- SI unit is: Kilogram (kg :(
  - 1kg = 0.0685 slug

The Equilibrium Rule

Mechanical equilibrium is a state of no change with no net force acting

- When the net force on an object is zero, the object is in mechanical equilibrium-this is known as the **equilibrium rule.**

The equilibrium rule

- the vector sum of forces acting on a non-accelerating object equals zero
- in equation form: ©$F = 0$

١. **Objects at rest are said to be in static equilibrium;**

٢. **objects moving at constant speed in a straight-line path are said to be in dynamic equilibrium .**

Force and the Law of acceleration

Newton second law (the law of acceleration:(

$$F = m\, a$$

F = the total force.

m = mass.

a = acceleration.

® **SI** unit of force = Newton (N)

® From Newton 2^{nd} law: $1\ N = 1\ kg\ m/s^2$

or in **British system**: $1\ lb = 1\ slug\ ft/s^2$.

In other metric system: $1\ dyne = 1\ g\ cm/s^2$.

EXAMPLE:

What force is necessary to produce an acceleration of 6.00 m/s^2 on a mass of 5.00 kg?

Data:

$$m = 5.00 \text{ kg}$$
$$a = 6.00 \text{ m/s}^2$$
$$F = ?$$

Basic Equation:

$$F = ma$$

Working Equation: Same

Substitution:

$$F = (5.00 \text{ kg})(6.00 \text{ m/s}^2)$$
$$= 30.0 \text{ kg m/s}^2$$
$$= 30.0 \text{ N} \quad (1 \text{ N} = 1 \text{ kg m/s}^2)$$

EXAMPLE:

What force is necessary to produce an acceleration of 2.00 ft/s^2 on a mass of 3.00 slugs?

Data:

$$m = 3.00 \text{ slugs}$$
$$a = 2.00 \text{ ft/s}^2$$
$$F = ?$$

Basic Equation:

$$F = ma$$

Working Equation: Same

Substitution:

$$F = (3.00 \text{ slugs})(2.00 \text{ ft/s}^2)$$
$$= 6.00 \text{ slug ft/s}^2$$
$$= 6.00 \text{ lb} \qquad (1 \text{ lb} = 1 \text{ slug ft/s}^2)$$

Find the acceleration produced by a force of $50\bar{0}$ N applied to a mass of 20.0 kg.

Data:

$$F = 50\bar{0} \text{ N}$$
$$m = 20.0 \text{ kg}$$
$$a = ?$$

Basic Equation:

$$F = ma$$

Working Equation:

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

Substitution:

$$\begin{aligned} a &= \frac{50\bar{0} \text{ N}}{20.0 \text{ kg}} \\ &= 25.0 \frac{\text{N}}{\text{kg}} \\ &= 25.0 \frac{\cancel{\text{N}}}{\cancel{\text{kg}}} \times \frac{1 \cancel{\text{kg}} \text{ m/s}^2}{1 \cancel{\text{N}}} \\ &= 25.0 \text{ m/s}^2 \end{aligned}$$

Note: We use a conversion factor to obtain acceleration units.

Gravity and weight

Weight :

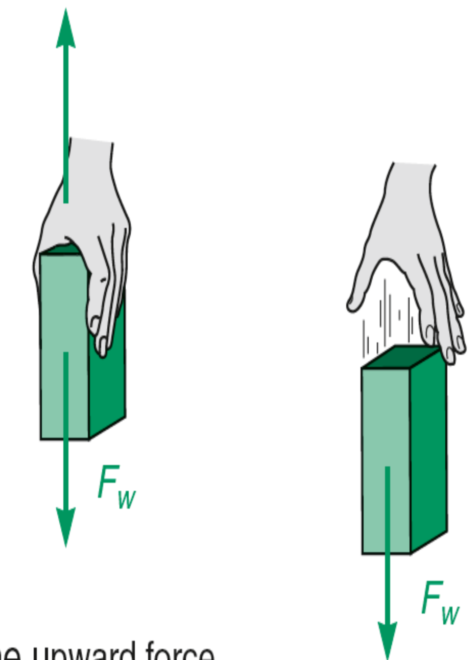
- The force on an object due to gravity
- Scientific unit of force is the newton (N(
- Free fall ®acceleration due to gravity

= g = 9.8 m/s². (g = 32.2 ft/s², British system .(

- Newton second law: $F = m\,a$,
  for free fall, $a = g$, $F = F_w$®

$$F_w = mg$$

where F_w = weight
m = mass
g = acceleration due to gravity
$g = 9.80\ \text{m/s}^2$ (earth, metric)
$g = 32.2\ \text{ft/s}^2$ (earth, U.S.)



(a) The upward force of the hand equals the downward force of the weight.

(b) The downward force of the weight is now greater.

EXAMPLE:

Find the weight of 5.00 kg.

Data:

$$m = 5.00 \text{ kg}$$
$$g = 9.80 \text{ m/s}^2$$
$$F_w = ?$$

Basic Equation:

$$F_w = mg$$

Working Equation: Same

Substitution:

$$F_w = (5.00 \text{ kg})(9.80 \text{ m/s}^2)$$
$$= 49.0 \text{ kg m/s}^2$$
$$= 49.0 \text{ N} \qquad (1 \text{ N} = 1 \text{ kg m/s}^2)$$

EXAMPLE:

Find the weight of 12.0 slugs.

Data:

$$m = 12.0 \text{ slugs}$$
$$g = 32.2 \text{ ft/s}^2$$
$$F_w = ?$$

Basic Equation:

$$F_w = mg$$

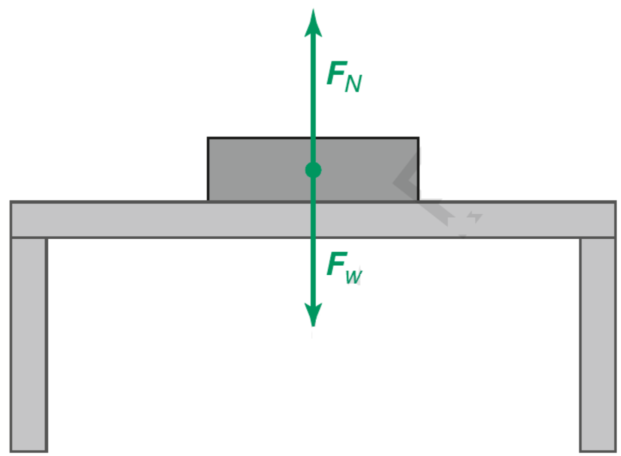
Working Equation: Same

Substitution:

$$F_w = (12.0 \text{ slugs})(32.2 \text{ ft/s}^2)$$
$$= 386 \text{ slug ft/s}^2$$
$$= 386 \text{ lb} \qquad (1 \text{ lb} = 1 \text{ slug ft/s}^2)$$

WEIGHT VERSUS NORMAL FORCE

When an object is in contact with a surface, a force is exerted on that object by the surface. This force, called a **normal force,** *is perpendicular to the contact surface.*



Magnitude of F_N = magnitude of F_w

EXAMPLE:

The normal force on a 2-kg book lying on a level table is:

A	1 N		C	10 N
B	2 N		D	20 N✓

The normal force on a 70-kg student sitting on a level stool is:

A. 7 kg B. 70 kg C. 700 N D. 7 N

MASS VERSUS WEIGHT

EXAMPLE: Astronaut mass = $m = 75.0$ kg

Near the earth's surface:

- The acceleration due to gravity = $g = \mathbf{9.80\ m/s^2}$
- **The weight** =

$$F_w = m\,g = (75.0\text{ kg})\,(9.80\text{ m/s}^2) = \mathbf{735\ N}.$$

Near the moon's surface:

- The acceleration due to gravity = $g = \mathbf{1.63\ m/s^2}$
- **The weight** =

$$F_w = m\,g = (75.0\text{ kg})\,(1.63\text{ m/s}^2) = \mathbf{122\ N}.$$

So mass remains the same, but the weight varies according to the gravitational pull ®mass is a fundamental quantity.

Weight and **mass** are **directly proportional** in a given place

MASS VERSUS VOLUME

Mass:

- The amount of inertia or material in an object.
- Units: **kg**

Volume:

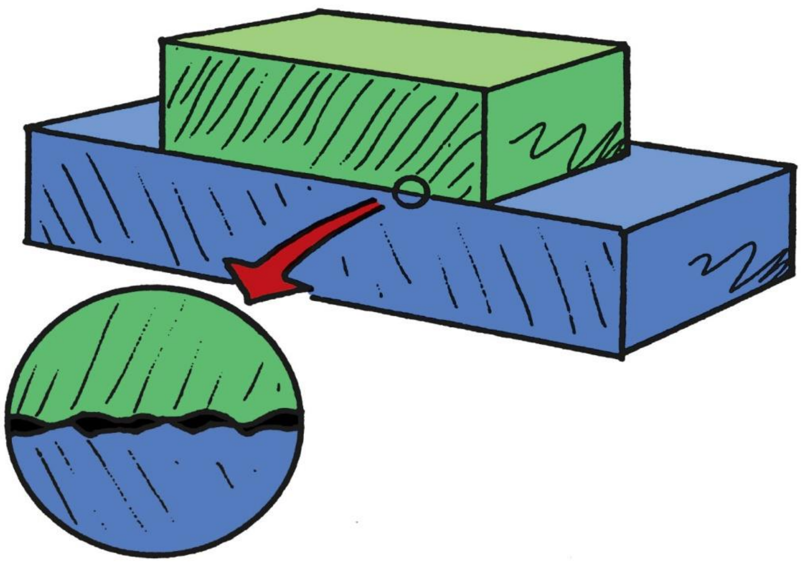
- Measures the space occupied by an object.
- Units: [**Length**]^3 α **m^3, cm^3, Liter (*L*), ft… ,^{3}**

Same *volumes* but different *masses*

The **more mass** contained in an object, the **greater its inertia** and the **more force** it takes **to move** it or **change its motion**.

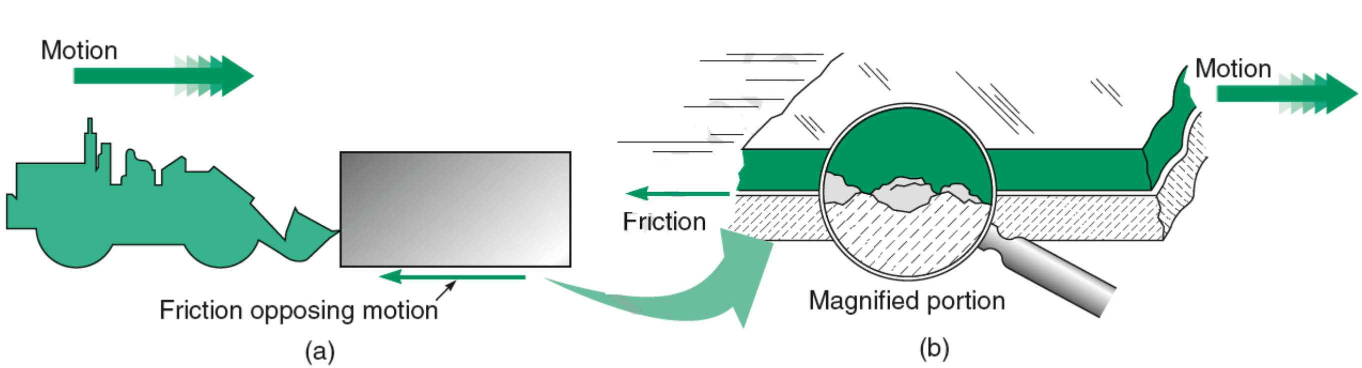
Friction

- is a force that resists the relative motion of two objects in contact
- depends on the kinds of material and how much they are pressed together.
- is due to tiny surface bumps and to "stickiness" of the atoms on a material's surface.

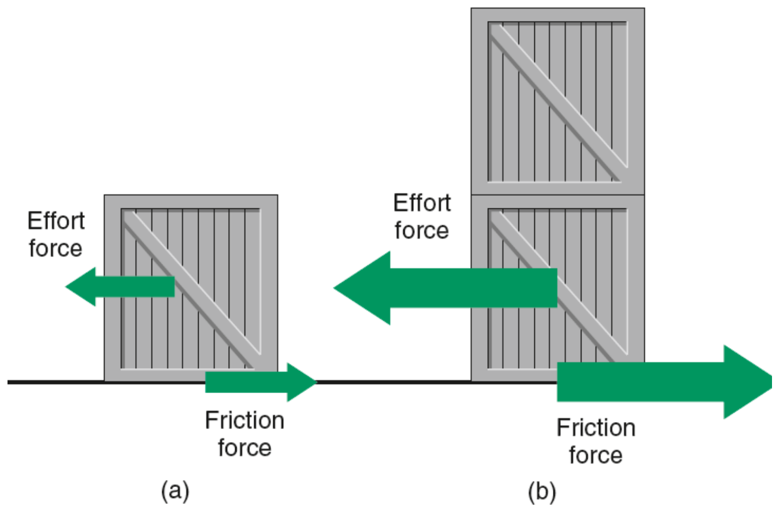


Example: Friction between a crate on a smooth wooden floor is less than that on a rough floor.

Friction



Friction resists motion of objects in contact with each other.



Friction increases as the force between the surfaces increases.

Friction

The characteristics of friction can be described by the following equation:

$$F_f = \mu F_N$$

where F_f = frictional force
F_N = normal force (force perpendicular to the contact surface)
μ = coefficient of friction

Higher μ ®two rough surfaces; lower μ ®two smooth surfaces (*not too smooth*(

- ***Friction is a force that always acts parallel to the surface in contact and opposite to the direction of motion.***

  If there is no motion, friction acts in the direction opposite any force that tends to produce motion. The resistance to motion is the frictional force

- ***Friction increases as the force between the surfaces increases.***

  Friction depends only on the nature of the materials in contact and the force pressing them together.

Friction

Static friction:
The two surfaces are at rest relative to each other
$= \mu_s F_N$

kinetic friction:
The two surfaces are in relative motion
$= \mu_k F_N$

Coefficients of Friction (μ)

Material	Static Friction	Kinetic Friction
Hardwood on hardwood	0.40	0.25
Steel on concrete		0.30
Aluminum on aluminum	1.9	
Rubber on dry concrete	2.0	1.0
Rubber on wet concrete	1.5	0.97

- ®Static friction > Kinetic friction

This is due to inertia.

Friction

In general, to reduce kinetic friction:

.1 Use smoother surfaces.

.2 Use lubrication to provide a thin film between surfaces.

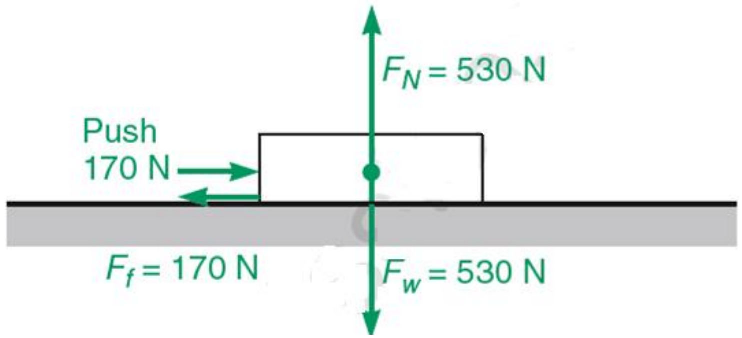
.3 Use Teflon to greatly reduce friction between surfaces when an oil lubricant is not desirable, such as in electric motors.

.4 Substitute rolling friction for sliding friction .

EXAMPLE

A force of 170 N is needed to keep a 530-N wooden box sliding on a wooden floor. What is the coefficient of kinetic friction?

Sketch:



Data:

$$F_f = 170 \text{ N}$$
$$F_N = 530 \text{ N}$$
$$\mu = ?$$

Basic Equation:

$$F_f = \mu F_N$$

Working Equation:

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

Substitution:

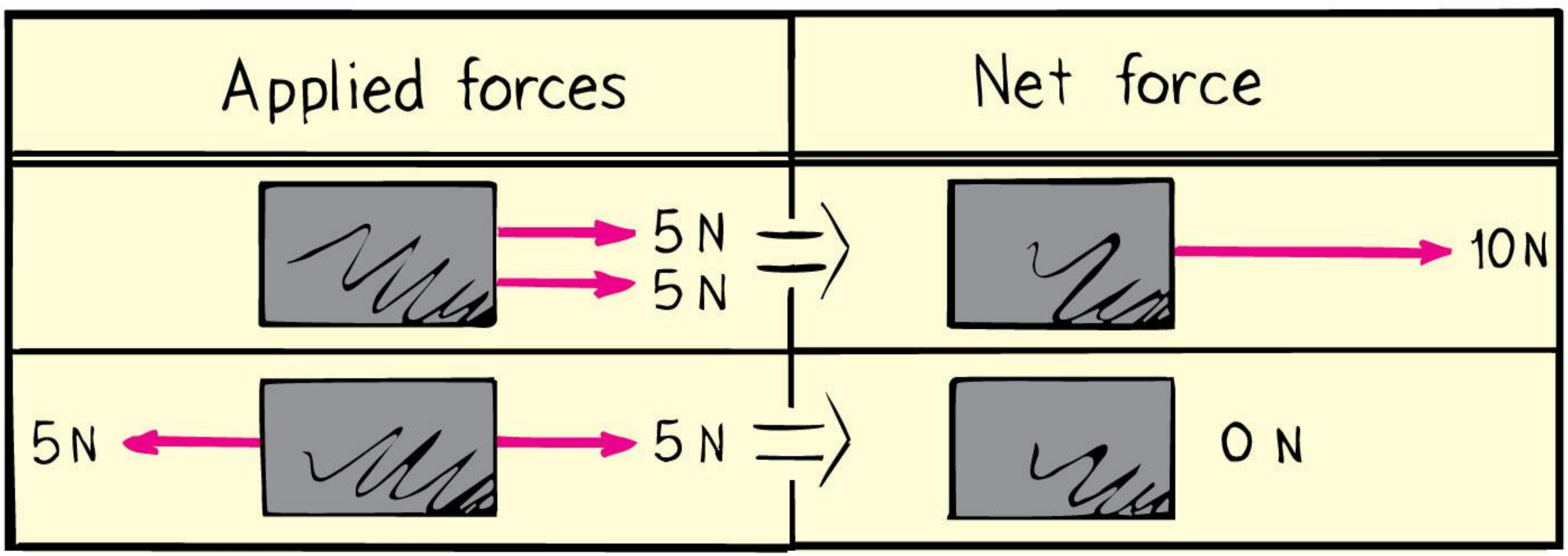
$$\mu = \frac{170 \text{ N}}{530 \text{ N}}$$
$$= 0.32$$

Note that μ does not have a unit because the force units always cancel.

Total Forces in One Dimension

The **total**, or net, **force** acting on an object is the *resultant* of the separate forces.

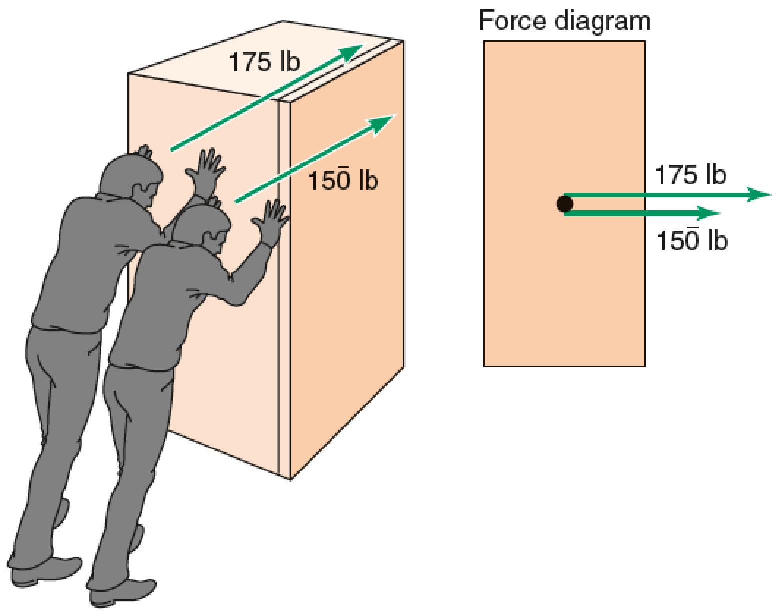
Example: If you pull on a box with 10 N and a friend pulls oppositely with 5 N, the net force is 5 N in the direction you are pulling.



EXAMPLE

Two workers push in the same direction (to the right) on a crate. The force exerted by one worker is $15\bar{0}$ lb. The force exerted by the other is 175 lb. Find the net force exerted.

Sketch:



Both forces act in the same direction, so the total force is the sum of the two.

Note: The Greek letter Σ (sigma) means "sum of."

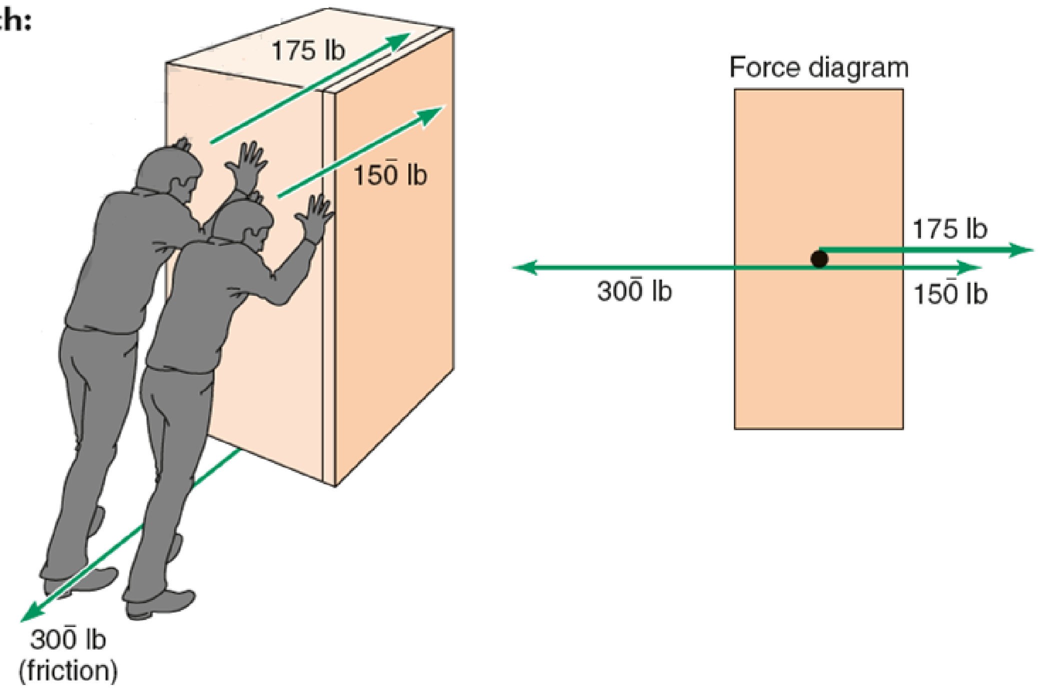
$$\Sigma \mathbf{F} = 175 \text{ lb} + 15\bar{0} \text{ lb}$$

$$= 325 \text{ lb to the right}$$

EXAMPLE:

The same two workers push the crate to the right, and the motion is opposed by a static frictional force of 30$\bar{0}$ lb. Find the net force.

Sketch:



The workers push in one direction and static friction pushes in the opposite direction, so we add the forces exerted by the workers and subtract the frictional force.

$$\sum \mathbf{F} = 175\text{ lb} + 15\bar{0}\text{ lb} - 30\bar{0}\text{ lb}$$

$$= 25\text{ lb to the right}$$

EXAMPLE:

The crate has a mass of 5.00 slugs. What is its acceleration when the workers are pushing against the frictional force?

Data:

$$F = \Sigma \mathbf{F} = 175 \text{ lb} + 15\bar{0} \text{ lb} - 30\bar{0} \text{ lb} = 25 \text{ lb to the right}$$

$$m = 5.00 \text{ slugs}$$

$$a = ?$$

Basic Equation:

$$F = ma$$

Working Equation:

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

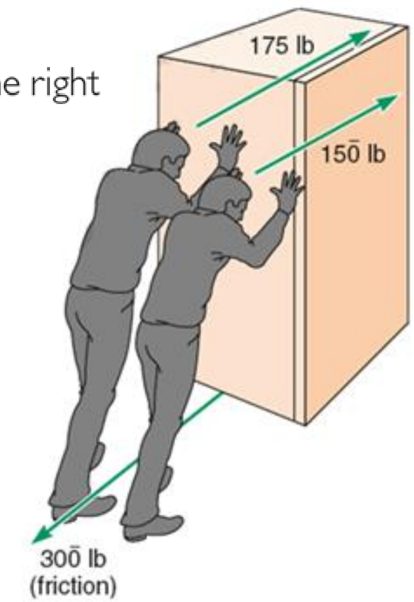
Substitution:

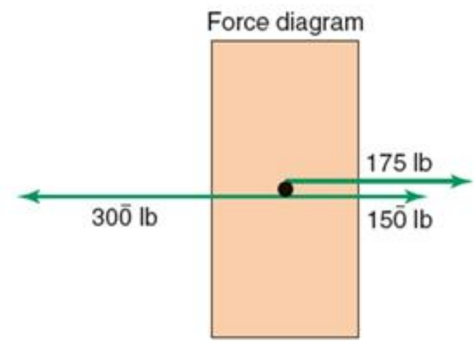
$$a = \frac{25 \text{ lb}}{5.00 \text{ slugs}}$$

$$= 5.0 \frac{\text{lb}}{\text{slugs}} \times \frac{1 \text{ slug ft/s}^2}{1 \text{ lb}}$$

$$= 5.0 \text{ ft/s}^2$$

Note: We use a conversion factor to obtain acceleration units.





EXAMPLE

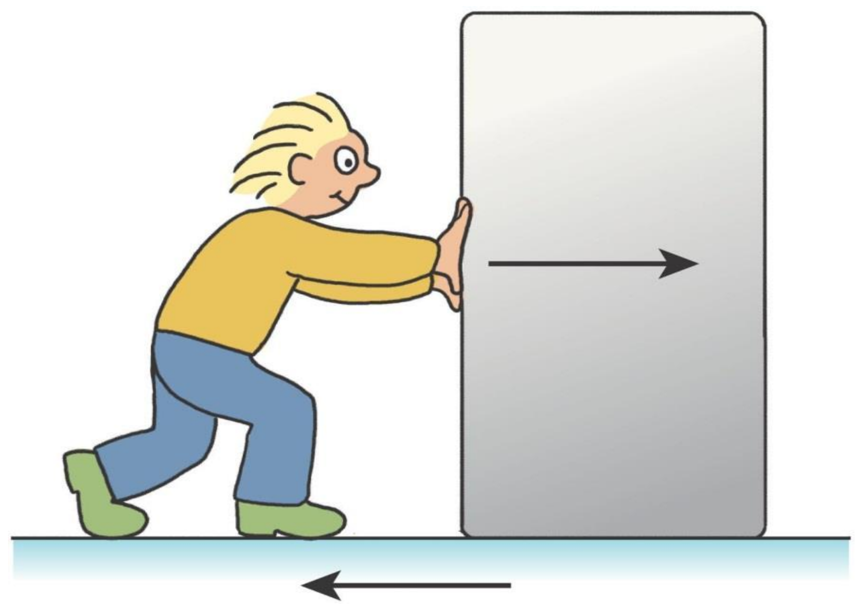
Two workers push in the same direction on a large pallet. The force exerted by one worker is 645 N. The force exerted by the other worker is 755 N. The motion is opposed by a frictional force of 1175 N. Find the net force.

$$\begin{aligned}\Sigma \mathbf{F} &= 645\text{ N} + 755\text{ N} - 1175\text{ N} \\ &= 225\text{ N}\end{aligned}$$

The Force of Friction
CHECK YOUR NEIGHBOR

When Josh pushes a crate across a kitchen floor at a constant speed, the force of friction between the crate and the floor is

A. less than Josh's push.
B. equal to Josh's push .
C. equal and opposite to Josh's push.
D. more than Josh's push.



The Force of Friction
CHECK YOUR ANSWER

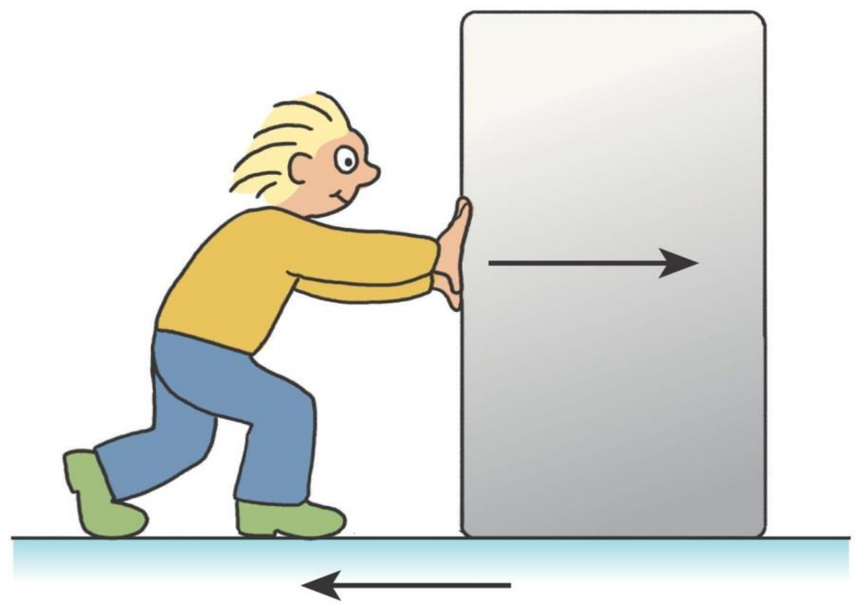
When Josh pushes a crate across a kitchen floor at a constant speed, the force of friction between the crate and the floor is

A. less than Josh’s push.
B. equal to Josh’s push .
C. equal and opposite to Josh’s push.
D. more than Josh’s push.

The Force of Friction
CHECK YOUR NEIGHBOR

When Josh pushes a crate across a kitchen floor at an *increasing speed*, the amount of friction between the crate and the floor is

A. less than Josh's push.
B. equal to Josh's push .
C. equal and opposite to Josh's push.
D. more than Josh's push.



The Force of Friction
CHECK YOUR ANSWER

When Josh pushes a crate across a kitchen floor at an *increasing speed*, the amount of friction between the crate and the floor is

A. less than Josh's push.

B. equal to Josh's push .

C. equal and opposite to Josh's push.

D. more than Josh's push.

Explanation:

The increasing speed indicates a net force greater than zero. The crate is not in equilibrium.

Law of Action and Reaction

Action and reaction forces

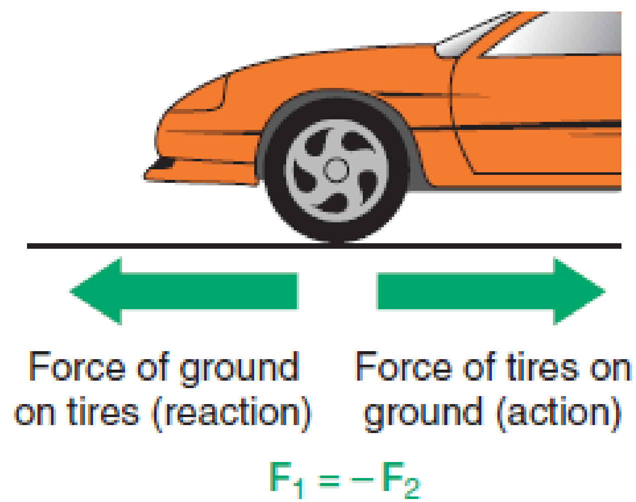
- one force is called the action force; the other force is called the reaction force.
- are co-pairs of a single interaction.
- neither force exists without the other.
- are equal in strength and opposite in direction.
- **always act on *different* objects, i.e., *never*** act on the **same object**

Law of Action and Reaction

The third law of motion, the *law of action and reaction*, can be stated as follows: **To every action there is always an opposed equal reaction.**

For every force applied by object A to object B (action), there is an equal but opposite force exerted by object B to object A (reaction.(

Example: Tires of car push back against the road while the road pushes the tires forward.



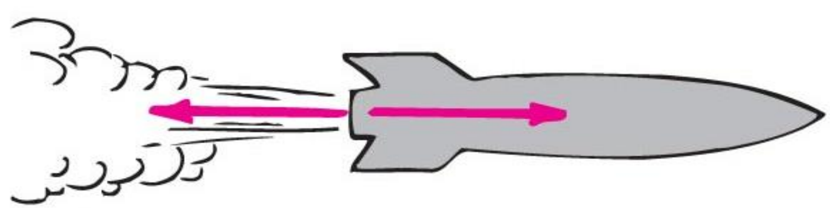
Law of Action and Reaction

Simple rule to identify action and reaction

- Identify the interaction—one thing interacts with another
  - Action: Object A exerts a force on object B.
  - Reaction: Object B exerts a force on object A.

Example: Action—rocket (object A) exerts force on gas (object B.(

Reaction—gas (object B) exerts force on rocket (object A.(



Action: rocket pushes on gas   Reaction: gas pushes on rocket

Work

Work is the product of the force in the direction of the motion and the displacement.

$$W = Fs$$

where W = work
F = force applied *in the direction of the motion*
s = displacement

Work is a transferred energy during the motion (displacement.(

Two things occur whenever work is done:

- application of force
- movement of something by that force
- Work is done when a force acts through a distance

Work
CHECK YOUR NEIGHBOR

If you push against a stationary brick wall for several minutes, you do no work

A. on the wall.

B. at all .

C. Both of the above.

D. None of the above.

Work

CHECK YOUR ANSWER

If you push against a stationary brick wall for several minutes, you do no work

A. on the wall.

B. at all .

C. Both of the above.

D. None of the above.

Explanation:

You may do work on your muscles, but not on the wall.

Work

Work is done *by* the bulldozer *on* the dirt and rocks.

Work

Examples :

- Twice as much work is done in lifting 2 loads 1 story high versus lifting 1 load the same vertical distance.

  Reason: force needed to lift twice the load is twice as much.

- Twice as much work is done in lifting a load 2 stories instead of 1 story.

  Reason: distance is twice as great.

Work

Example:

- a weightlifter raising a barbell from the floor does work on the barbell.

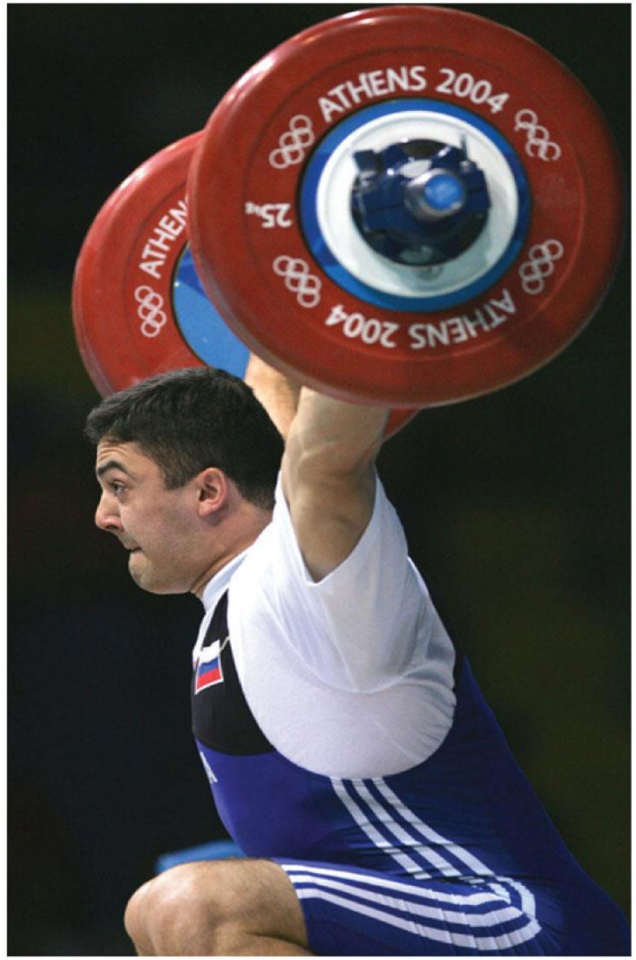
$$\text{work} = \text{force} \times \text{displacement}$$
$$= \text{newton} \times \text{metre} = \text{N m}$$

SI system:

$$1 \text{ N m} = 1 \text{ joule} = 1 \text{ J}$$

British system (or U.S. system(

$$\text{work} = \text{force} \times \text{displacement}$$
$$= \text{pounds} \times \text{feet} = \text{ft lb}$$

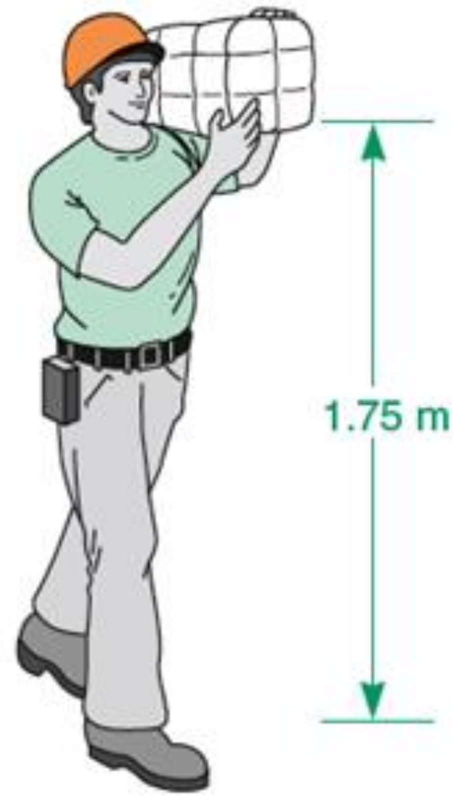


EXAMPLE

Find the amount of work done by a worker lifting 225 N of bricks to a height of 1.75 m as shown in Figure 2.28.

Data:

$$F = 225\ \text{N}$$
$$s = 1.75\ \text{m}$$
$$W = ?$$



Basic Equation:

$$W = Fs$$

Working Equation: Same

Substitution

$$W = (225\ \text{N})(1.75\ \text{m})$$
$$= 394\ \text{N m} \quad \text{or} \quad 394\ \text{J}$$

EXAMPLE

A worker pushes a 350-lb cart a distance of $3\bar{0}$ ft by exerting a constant force of $4\bar{0}$ lb as shown in Figure 2.29. How much work does the person do?

Data:

$$F = 4\bar{0} \text{ lb}$$
$$s = 3\bar{0} \text{ ft}$$
$$W = ?$$

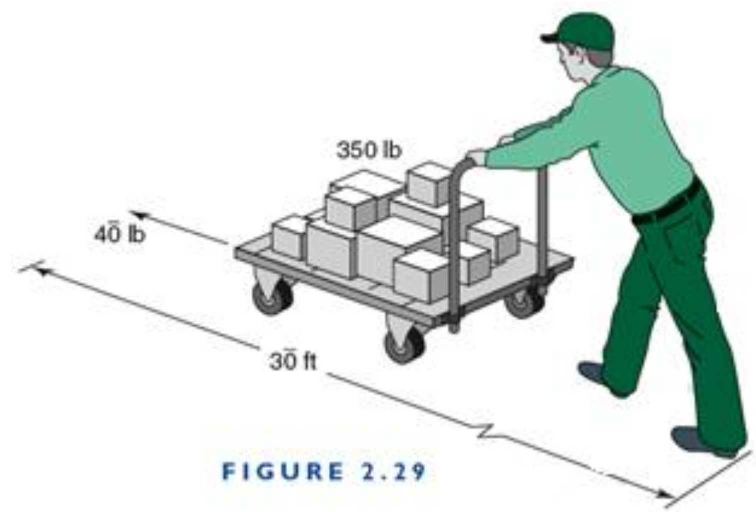


FIGURE 2.29

Basic Equation:

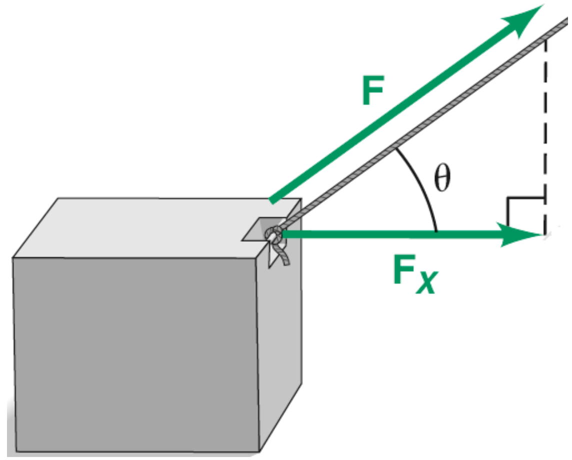
$$W = Fs$$

Working Equation: Same

Substitution:

$$W = (4\bar{0} \text{ lb})(3\bar{0} \text{ ft})$$
$$= 1200 \text{ ft lb}$$

Work done by a force not in the direction of motion



$$\cos\theta = \frac{\text{side adjacent to } \theta}{\text{hypotenuse}} = \frac{|\mathbf{F}_x|}{|\mathbf{F}|}$$

$$W = Fs\cos\theta$$

W = the work done

F = the applied force

s = the displacement

θ = the angle between the applied force and the direction of the motion

Note: Work by force perpendicular (=90^{o}) to the direction of motion is zero. E.g. work by the weight = 0 J in previous example

EXAMPLE

A person pulls a sled along level ground a distance of 15.0 m by exerting a constant force of 215 N at an angle of 30.0° with the ground (Figure 2.31). How much work does he do?

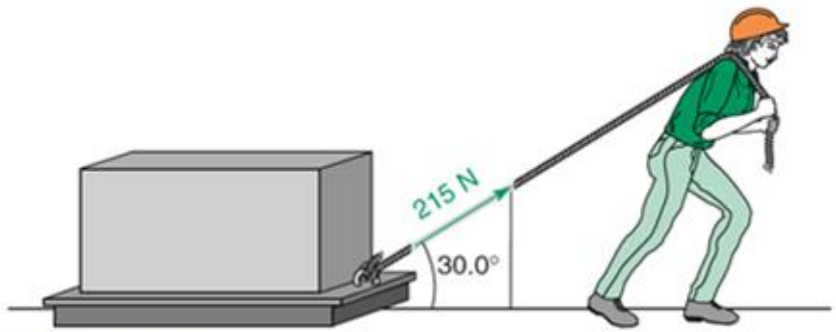


FIGURE 2.31

Data:

$$F = 215 \text{ N}$$
$$s = 15.0 \text{ m}$$
$$\theta = 30.0^\circ$$
$$W = ?$$

Basic Equation:

$$W = Fs\cos\theta$$

Working Equation: Same

Substitution:

$$\begin{aligned} W &= (215 \text{ N})(15.0 \text{ m}) \cos 30.0^\circ \\ &= 2790 \text{ N m} \\ &= 2790 \text{ J} \qquad (1 \text{ N m} = 1 \text{ J}) \end{aligned}$$

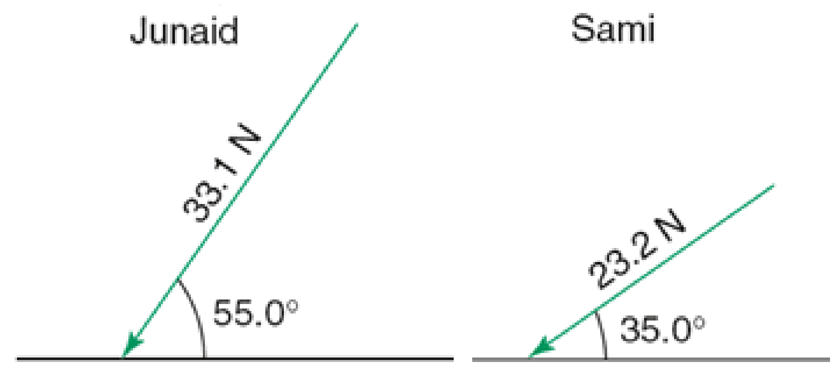
EXAMPLE

Junaid and Sami use a push mower to mow a lawn. Junaid, who is taller, pushes at a constant force of 33.1 N on the handle at an angle of 55.0° with the ground. Sami, who is shorter, pushes at a constant force of 23.2 N on the handle at an angle of 35.0° with the ground. Assume they each push the mower $3\bar{0}00$ m. Who does more work and by how much?

Data:

$F = 33.1\ \text{N}$	$F = 23.2\ \text{N}$
$s = 3\bar{0}00\ \text{m}$	$s = 3\bar{0}00\ \text{m}$
$\theta = 55.0°$	$\theta = 35.0°$
$W = ?$	$W = ?$

Sketch:



Basic Equation:

$W = Fs \cos \theta$ $\qquad$ $W = Fs \cos \theta$

Working Equation: Same $\qquad$ Same

Substitution:

$$W = (33.1\ \text{N})(3\bar{0}00\ \text{m}) \cos 55.0°$$
$$= 57,\bar{0}00\ \text{N m}$$
$$= 57,\bar{0}00\ \text{J} \qquad (1\ \text{N m} = 1\ \text{J})$$

$$W = (23.2\ \text{N})(3\bar{0}00\ \text{m}) \cos 35.0°$$
$$= 57,\bar{0}00\ \text{N m}$$
$$= 57,\bar{0}00\ \text{J}$$

They do the same amount of work. However, Junaid must exert more energy because he pushes into the ground more than Sami, who pushes more in the direction of the motion.

Find the amount of work done in vertically lifting a steel beam (دعامة فولاذية) with mass 750 kg at uniform speed a distance of 45 m.

Here the force is the weight of the beam

Data:

$$F = mg$$
$$m = 750 \text{ kg}$$
$$g = 9.80 \text{ m/s}^2$$
$$s = 45 \text{ m}$$
$$W = ?$$

Basic Equation:

$$W = Fs = mgs$$

Working Equation: Same

Substitution:

$$\begin{aligned} W &= (750 \text{ kg})(9.80 \text{ m/s}^2)(45 \text{ m}) \\ &= 3.3 \times 10^5 \text{ (kg m/s}^2\text{)(m)} \\ &= 3.3 \times 10^5 \text{ N m} \qquad (1 \text{ N} = 1 \text{ kg m/s}^2) \\ &= 3.3 \times 10^5 \text{ J} \qquad (1 \text{ J} = 1 \text{ N m}) \end{aligned}$$

Do you see that 330 kJ would also be an acceptable answer?

Power

Power is *the rate of doing work*;

$$P = \frac{W}{t}$$

$$P = \text{power}$$
$$W = \text{work}$$
$$t = \text{time}$$

Power

The units of power are familiar to most of us. In the metric system, the unit of power is the *watt*:

$$P = \frac{W}{t} = \frac{Fs}{t} = \frac{\text{N m}}{\text{s}} = \frac{\text{J}}{\text{s}} = \text{watt}$$

Power is often expressed in kilowatts and megawatts:

$$1000 \text{ watts (W)} = 1 \text{ kilowatt (kW)}$$
$$1{,}000{,}000 \text{ watts} = 1 \text{ megawatt (MW)}$$

In the U.S. system, the unit of power is either ft lb/s or horsepower:

$$P = \frac{W}{t} = \frac{Fs}{t} = \frac{\text{ft lb}}{\text{s}}$$

Horsepower (hp) is a unit defined by **James Watt**:

$$1 \text{ horsepower (hp)} = 550 \text{ ft lb/s} = 33{,}000 \text{ ft lb/min}$$

- 1hp = ¾ kW = 750 W

EXAMPLE:

A freight elevator with operator weighs $5\bar{0}00$ N. If it is raised to a height of 15.0 m in 10.0 s, how much power is developed?

Data:

$$F = 5\bar{0}00 \text{ N}$$
$$s = 15.0 \text{ m}$$
$$t = 10.0 \text{ s}$$
$$P = ?$$

Basic Equations:

$$P = \frac{W}{t} \quad \text{and} \quad W = Fs$$

Working Equation:

$$P = \frac{Fs}{t}$$

Substitution:

$$P = \frac{(5\bar{0}00 \text{ N})(15.0 \text{ m})}{10.0 \text{ s}}$$
$$= 75\bar{0}0 \text{ N m/s}$$

The power expended in lifting an 825-lb girder (عارضة) to the top of a building 100ft high is 10.0 hp. How much time is required to raise the girder?

Data:

$$F = 825 \text{ lb}$$
$$s = 10\bar{0} \text{ ft}$$
$$P = 10.0 \text{ hp}$$
$$t = ?$$

Basic Equations:

$$P = \frac{W}{t} \quad \text{and} \quad W = Fs$$

Working Equation:

$$t = \frac{W}{P} = \frac{Fs}{P}$$

Substitution:

$$t = \frac{(825 \text{ lb})(10\bar{0} \text{ ft})}{10.0 \text{ hp}}$$
$$= \frac{(825 \text{ lb})(10\bar{0} \text{ ft})}{10.0 \text{ hp}} \times \frac{1 \text{ hp}}{550 \frac{\text{ft lb}}{\text{s}}}$$
$$= 15.0 \text{ s}$$

$$\frac{\text{lb ft}}{\text{hp}} \times \frac{\text{hp}}{\frac{\text{ft lb}}{\text{s}}} = \frac{\text{lb ft}}{\text{hp}} \times \left(\text{hp} \div \frac{\text{ft lb}}{\text{s}}\right) = \frac{\cancel{\text{lb}}\,\cancel{\text{ft}}}{\cancel{\text{hp}}} \times \left(\cancel{\text{hp}} \times \frac{\text{s}}{\cancel{\text{ft}}\,\cancel{\text{lb}}}\right) = \text{s}$$

EXAMPLE 2.28

The mass of a large steel wrecking ball is $20\bar{0}0$ kg. What power is used to raise it to a height of 40.0 m if the work is done in 20.0 s?

Data:

$m = 20\bar{0}0\ \text{kg}$ $s = 40.0\ \text{m}$ $t = 20.0\ \text{s}$ $P = ?$

Basic Equations:

$$P = \frac{W}{t} \quad \text{and} \quad W = Fs$$

Working Equation:

$$P = \frac{Fs}{t}$$

Substitution: Note that we cannot directly substitute into the working equation because our data are given in terms of *mass* and we must find *force* to substitute in $P = Fs/t$. The force is the weight of the ball:

$$F = mg = (20\bar{0}0\ \text{kg})(9.80\ \text{m/s}^2) = 19{,}600\ \text{kg m/s}^2 = 19{,}600\ \text{N}$$

Then

$$P = \frac{Fs}{t} = \frac{(19{,}600\ \text{N})(40.0\ \text{m})}{20.0\ \text{s}}$$

$$= 39{,}200\ \text{N m/s}$$

$$= 39{,}200\ \text{W} \quad \text{or} \quad 39.2\ \text{kW}$$

A machine is designed to perform a given amount of work in a given amount of time. A second machine does the same amount of work in half the time. Find the power of the second machine compared with the first.

Data (for the second machine given in terms of the first):

$$W = W$$

$$t = \tfrac{1}{2}t = \frac{t}{2}$$

$$P = ?$$

Basic Equation:

$$P = \frac{W}{t}$$

Working Equation: Same

Substitution:

$$P = \frac{W}{\frac{t}{2}} = W \div \frac{t}{2} = W \times \frac{2}{t} = 2\left(\frac{W}{t}\right) = 2P$$

Thus, the power is doubled when the time is halved.

A motor is capable of developing 10.0 kW of power. How large a mass can it lift 75.0 m in 20.0 s?

Data:

$$P = 10.0\text{ kW} = 10{,}\bar{0}00\text{ W}$$
$$s = 75.0\text{ m}$$
$$t = 20.0\text{ s}$$
$$F = ?$$

Basic Equations:

$$P = \frac{W}{t} \quad \text{and} \quad W = Fs \quad \text{or} \quad P = \frac{Fs}{t}$$

Working Equation:

$$F = \frac{Pt}{s}$$

Substitution:

$$F = \frac{(10{,}\bar{0}00\text{ W})(20.0\text{ s})}{75.0\text{ m}}$$
$$= 2670\,\frac{\cancel{\text{W}}\,\cancel{\text{s}}}{\cancel{\text{m}}} \times \frac{1\text{ N }\cancel{\text{m}}/\cancel{\text{s}}}{1\,\cancel{\text{W}}} \qquad (1\text{ W} = 1\text{ J/s} = 1\text{ N m/s})$$
$$= 2670\text{ N}$$

$$m = \frac{F}{g} = \frac{2670\,\cancel{\text{N}}}{9.80\,\cancel{\text{m/s}^2}} \times \frac{1\text{ kg }\cancel{\text{m/s}^2}}{1\,\cancel{\text{N}}} = 272\text{ kg}$$

EXAMPLE:

A pump is needed to lift $15\bar{0}0$ L of water per minute a distance of 45.0 m. What power, in kW, must the pump be able to deliver? (1 L of water has a mass of 1 kg.)

Data: $m = 15\bar{0}0 \text{ L} \times \frac{1 \text{ kg}}{1 \text{ L}} = 15\bar{0}0 \text{ kg}$ $\quad s = 45.0 \text{ m}$ $\quad t = 1 \text{ min} = 60.0 \text{ s}$

$g = 9.80 \text{ m/s}^2$ $\quad P = ?$

Basic Equations:

$$P = \frac{W}{t}, \quad W = Fs, \quad \text{and} \quad F = mg, \quad \text{or} \quad P = \frac{mgs}{t}$$

Working Equation:

$$P = \frac{mgs}{t}$$

Substitution:

$$P = \frac{(15\bar{0}0 \text{ kg})(9.80 \text{ m/s}^2)(45.0 \text{ m})}{60.0 \text{ s}}$$

$$= 1.10 \times 10^4 \text{ kg m}^2/\text{s} \quad \left(1 \text{ W} = \frac{1 \text{ J}}{\text{s}} = \frac{1 \text{ N m}}{\text{s}} = \frac{1 \text{ (kg m/s}^2)(\text{m})}{\text{s}} = 1 \text{ kg m}^2/\text{s}\right)$$

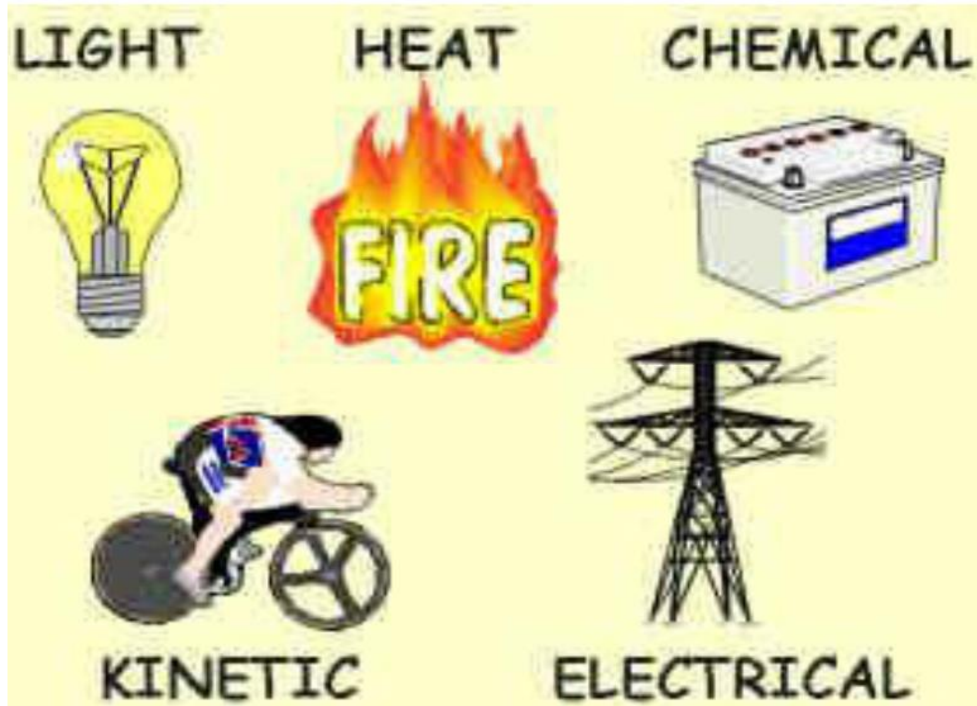
$$= 1.10 \times 10^4 \text{ W} \times \frac{1 \text{ KW}}{10^3 \text{ W}}$$

$$= 11.0 \text{ KW}$$

Energy

Energy is defined as the ability to do work .

Forms of energy:



Units:

SI system: Joule (J(

U.S. system: ft lb

Renewable energies

Solar

Wind

Mechanical Energy

- The mechanical energy of a body or a system is due to its position, its motion, or its internal structure.

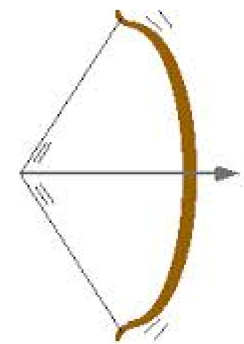
There are two forms of mechanical energy:

- Potential energy
- Kinetic energy

Potential Energy

- **Potential energy** is the stored energy of a body due to its *internal characteristics* or its *position*.

١. **Internal potential energy** is determined by the nature or condition of the substance;



Example :

- A stretched bow has stored energy that can do work on an arrow.
- A stretched rubber band of a slingshot has stored energy and is capable of doing work.

Potential Energy

٢. **Gravitational potential energy** is determined by the position of an object relative to a particular reference level.

Example :

- water in an elevated reservoir
- raised ram of a pile driver

Gravitational potential energy

- Equal to the work done (force required to move it upward × the vertical distance moved against gravity) in lifting it

- In equation form:

$$E_p = m\,g\,h$$

where E_p = potential energy
m = mass
g = 9.80 m/s^2 or 32.2 ft/s^2
h = height above reference level

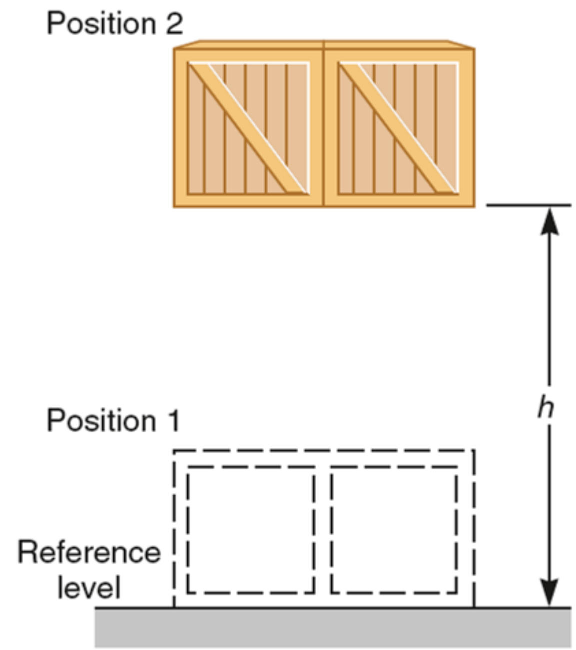


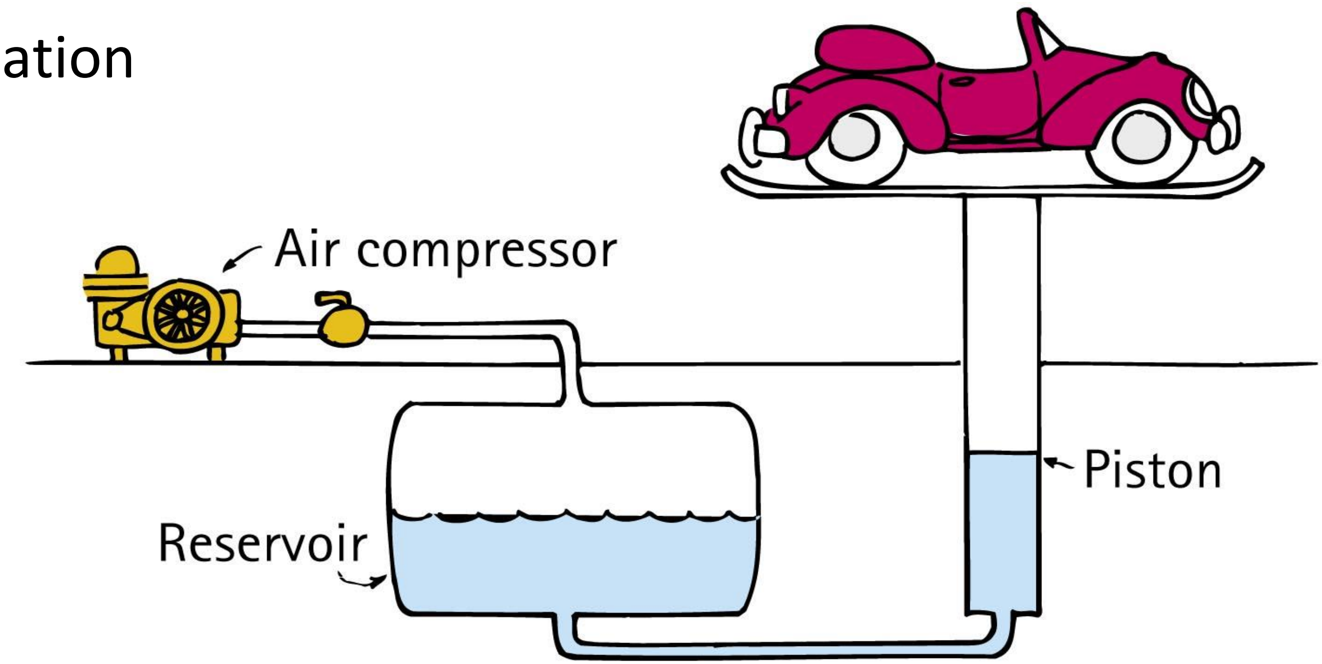
FIGURE 2.33

Work done in raising the crate gives it potential energy.

Potential Energy
CHECK YOUR NEIGHBOR

Does a car hoisted for repairs in a service station have increased potential energy relative to the floor?

A. Yes
B. No
C. Sometimes
D. Not enough information



Potential Energy
CHECK YOUR ANSWER

Does a car hoisted for repairs in a service station have increased potential energy relative to the floor?

A. Yes

B. No

C. Sometimes

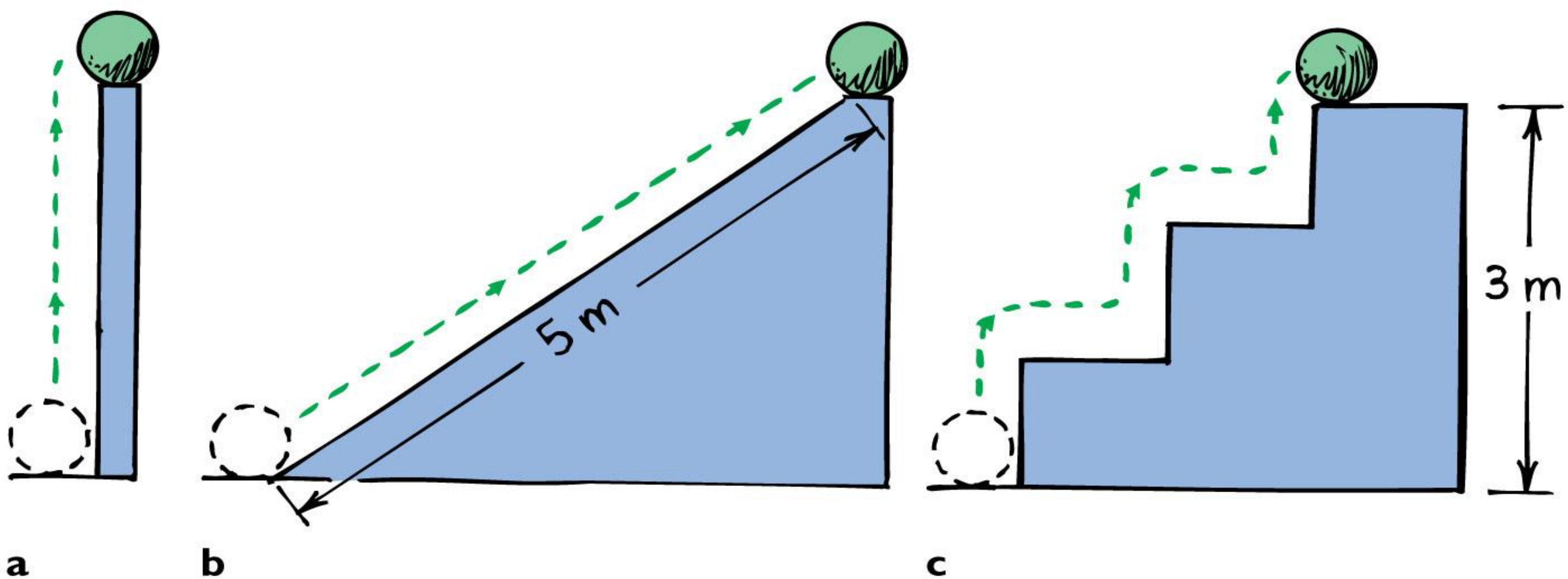
D. Not enough information

Comment:

If the car were twice as heavy, its increase in potential energy would be twice as great.

Potential Energy

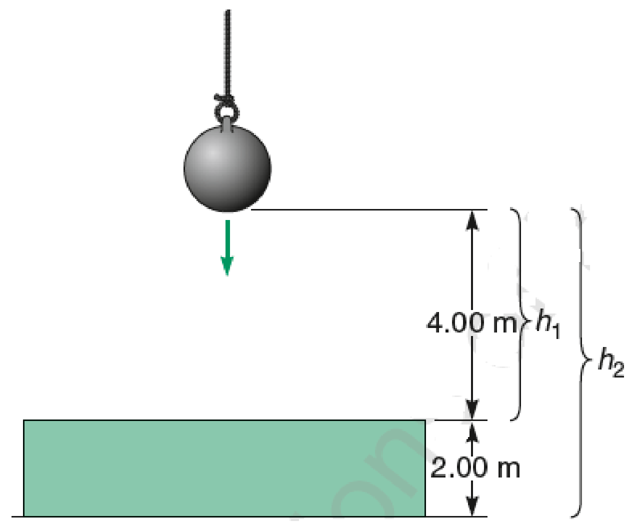
Example: Potential energy of 10-N ball is the same in all 3 cases because work done in elevating it is the same.



EXAMPLE 2.32

A wrecking ball of mass $20\bar{0}$ kg is poised 4.00 m above a concrete platform whose top is 2.00 m above the ground. (a) With respect to the platform, what is the potential energy of the ball? (b) With respect to the ground, what is the potential energy of the ball?

Sketch:



Data:

$m = 20\bar{0}$ kg $h_1 = 4.00$ m $h_2 = 6.00$ m $E_p = ?$

Basic Equation:

$$E_p = mgh$$

Working Equation: Same

(a) Substitution:

$$E_p = (20\bar{0}\ \text{kg})(9.80\ \text{m/s}^2)(4.00\ \text{m})$$

$$= 7840 \frac{\cancel{\text{kg}}\ \cancel{\text{m}^2}}{\cancel{\text{s}^2}} \times \frac{1\ \text{J}}{\cancel{\text{kg}}\ \cancel{\text{m}^2/\text{s}^2}} \qquad [1\ \text{J} = 1\ \text{N m} = 1\ (\text{kg m/s}^2)(\text{m}) = 1\ \text{kg m}^2/\text{s}^2]$$

$= 7840$ J (which also indicates the amount of work done by gravity on a falling object)

(b) Substitution:

$$E_p = (20\bar{0}\ \text{kg})(9.80\ \text{m/s}^2)(6.00\ \text{m}) = 11{,}800 \frac{\cancel{\text{kg}}\ \cancel{\text{m}^2}}{\cancel{\text{s}^2}} \times \frac{1\ \text{J}}{\cancel{\text{kg}}\ \cancel{\text{m}^2/\text{s}^2}} = 11{,}800\ \text{J}$$

Kinetic Energy

- Energy of motion
- Kinetic energy is due to the mass and the velocity of a moving object
- is given by the formula:

$$E_k = \frac{1}{2} m v^2$$

where E_k = kinetic energy
m = mass of moving object
v = velocity of moving object

- If object speed is doubled $\Rightarrow$ kinetic energy is quadrupled.

Kinetic Energy

- **Kinetic energy and work of a moving object**
  - Equal to the work required to bring it from rest to that speed, or the work the object can do while being brought to rest.
  - *In other words*, if all the work is transferred into kinetic energy then:

Total work = net force $\times$ displacement $=$ kinetic energy,

or

$$F \times s = \frac{1}{2} m v^2$$

EXAMPLE 2.33

A pile driver with mass $10,\bar{0}00$ kg strikes a pile with velocity 10.0 m/s. (a) What is the kinetic energy of the driver as it strikes the pile? (b) If the pile is driven 20.0 cm into the ground, what force is applied to the pile by the driver as it strikes the pile? Assume that all the kinetic energy of the driver is converted to work.

Data: $m = 1.00 \times 10^4$ kg $v = 10.0$ m/s
$s = 20.0$ cm $= 0.200$ m $F = ?$

(a) Basic Equation:

$$E_k = \frac{1}{2}mv^2$$

Working Equation: Same

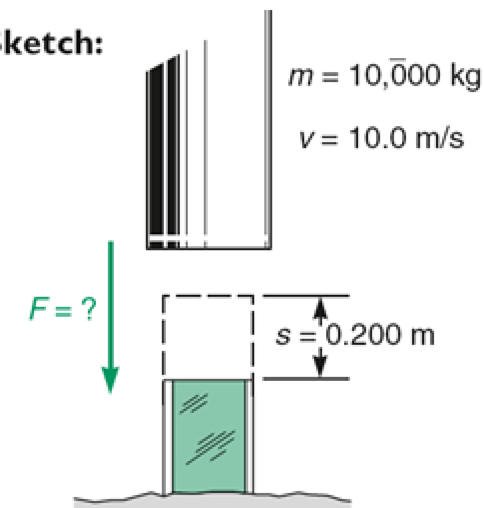
Substitution:

$$E_k = \frac{1}{2}(1.00 \times 10^4 \text{ kg})(10.0 \text{ m/s})^2$$
$$= 5.00 \times 10^5 \frac{\text{kg m}^2}{\text{s}^2} \times \frac{1 \text{ J}}{\text{kg m}^2/\text{s}^2}$$

$[1 \text{ J} = 1 \text{ N m} = 1 (\text{kg m/s}^2)(\text{m}) = 1 \text{ kg m}^2/\text{s}^2]$

$$= 5.00 \times 10^5 \text{ J} \quad \text{or} \quad 5\bar{0}0 \text{ kJ}$$

Sketch:



(b) Basic Equation:

$$E_k = W = Fs$$

Working Equation:

$$F = \frac{E_k}{s}$$

[Use E_k from part (a).]

Substitution:

$$F = \frac{5.00 \times 10^5 \text{ J}}{0.200 \text{ m}} \times \frac{1 \text{ N m}}{1 \text{ J}}$$

$(1 \text{ J} = 1 \text{ N m})$

$$= 2.50 \times 10^6 \text{ N}$$

EXAMPLE 2.34

A 60.0-g bullet is fired from a gun with 3150 J of kinetic energy. Find its velocity.

Data:

$$E_k = 3150 \text{ J}$$
$$m = 60.0 \text{ g} = 0.0600 \text{ kg}$$
$$v = ?$$

Basic Equation:

$$E_k = \frac{1}{2} m v^2$$

Working Equation:

$$v = \sqrt{\frac{2E_k}{m}}$$

Substitution:

$$v = \sqrt{\frac{2(3150 \cancel{\text{J}})}{0.0600 \cancel{\text{kg}}} \times \frac{1 \cancel{\text{kg}} \text{ m}^2/\text{s}^2}{1 \cancel{\text{J}}}} \qquad [1 \text{ J} = 1 \text{ N m} = 1 \text{ (kg m/s}^2)(\text{m}) = 1 \text{ kg m}^2/\text{s}^2]$$

$$= 324 \text{ m/s}$$

Conservation of Energy

Law of conservation of energy

- Energy cannot be created or destroyed; it may be transformed from one form into another, but the total amount of energy never changes.

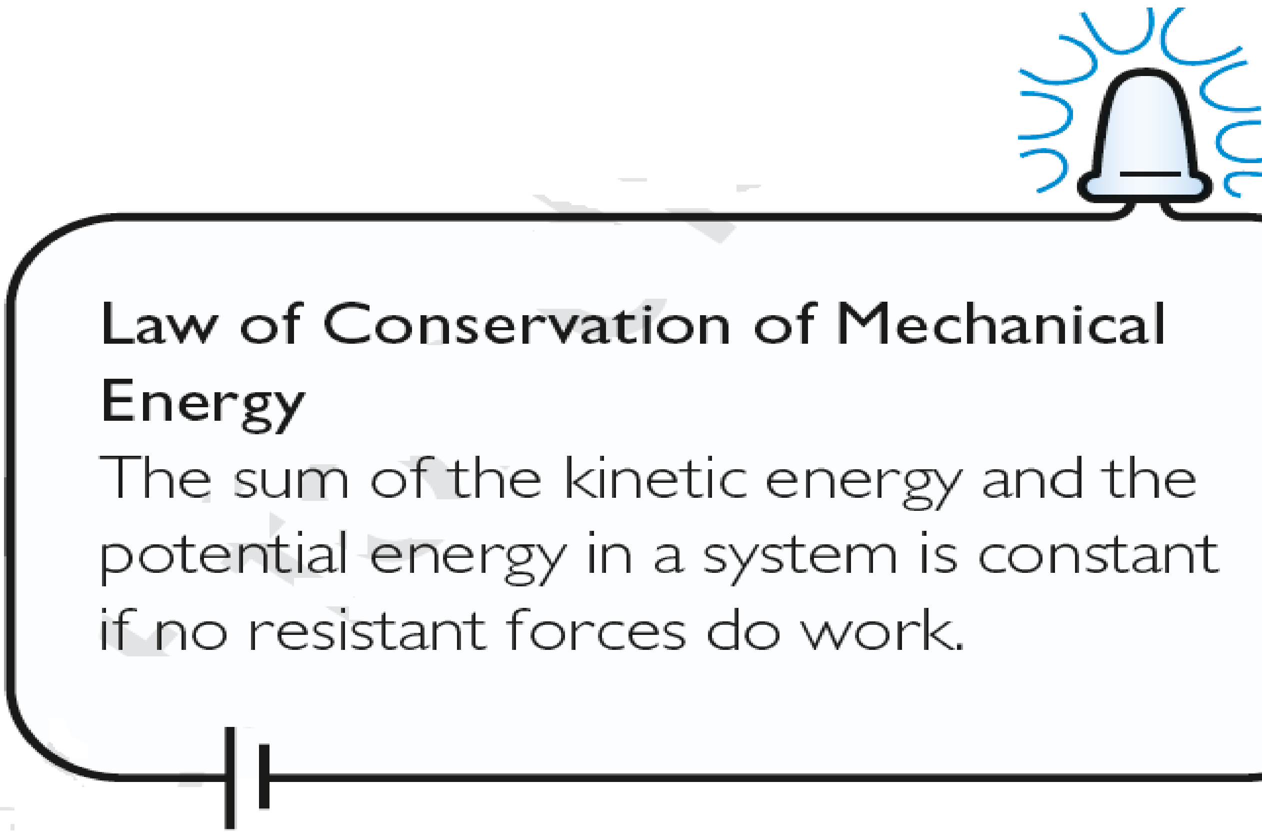
Conservation of Energy

A situation to ponder…

Consider the system of a bow and arrow. In drawing the bow, we do work on the system and give it potential energy. When the bowstring is released, most of the potential energy is transferred to the arrow as kinetic energy and some as heat to the bow.

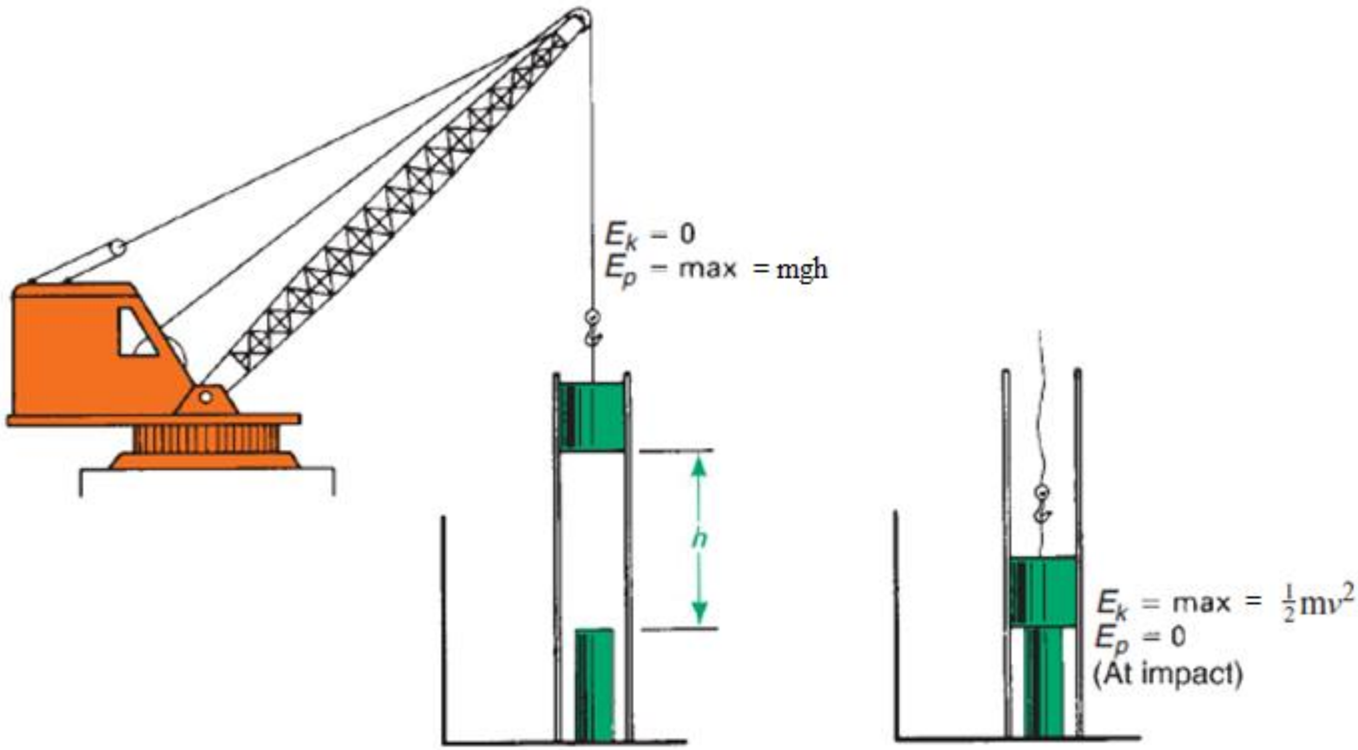
Conservation of Mechanical Energy

Mechanical Energy = Potential Energy + Kinetic Energy



Conservation of Mechanical Energy

Example: Energy transforms without net loss or net gain in the operation of a pile driver.



- **conservation of mechanical energy** $\Rightarrow$ $\max E_p = \max E_k$

$$mgh = \tfrac{1}{2}mv^2$$

- **Solving for the velocity** $\Rightarrow$ $v = \sqrt{2\,g\,h}$

EXAMPLE 2.35

A pile driver falls freely from a height of 3.50 m above a pile. What is its velocity as it hits the pile?

Data:

$$h = 3.50 \text{ m}$$
$$g = 9.80 \text{ m/s}^2$$
$$v = ?$$

Basic Equation:

$$v = \sqrt{2gh}$$

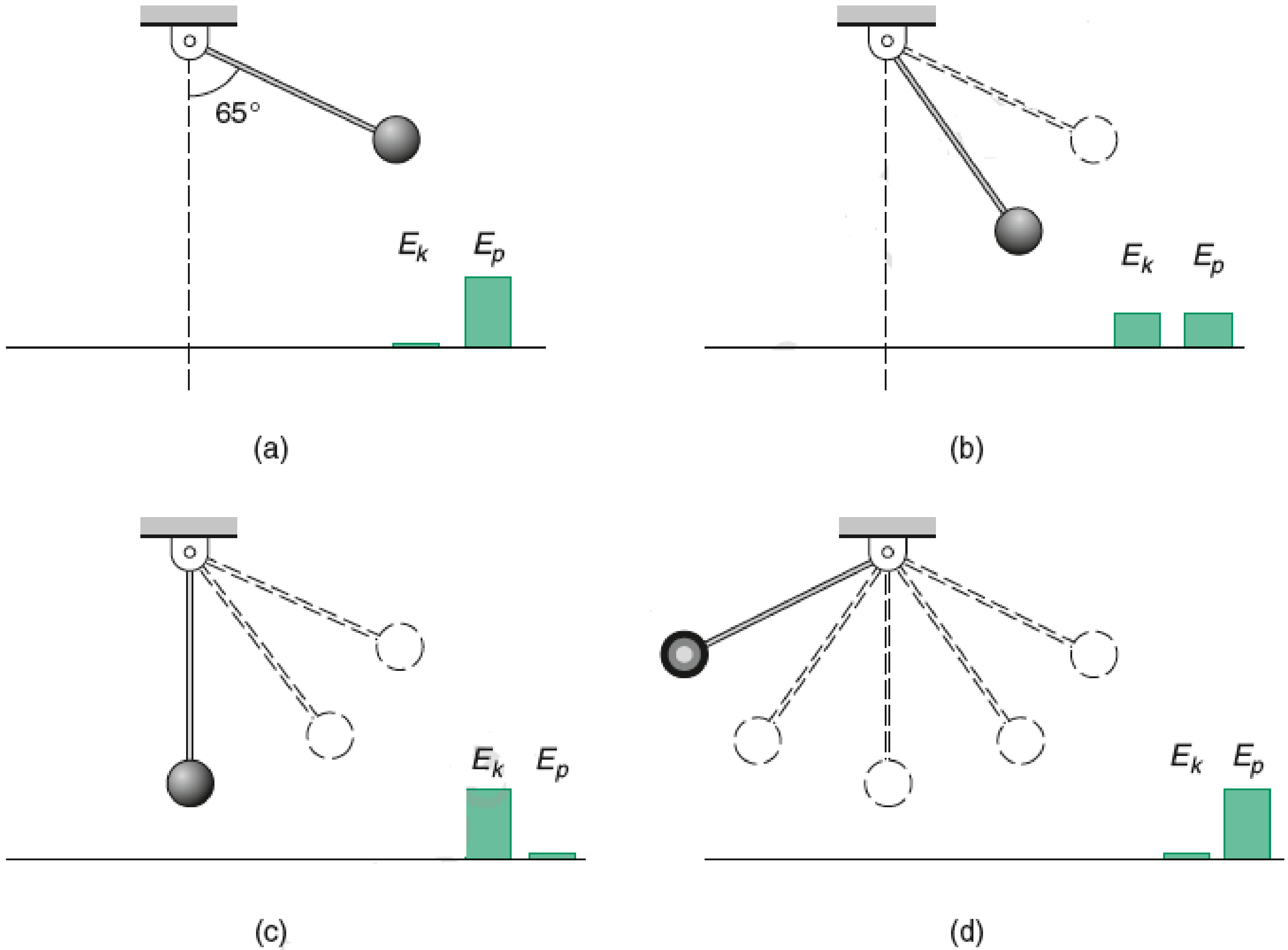
Working Equation: Same

Substitution:

$$v = \sqrt{2(9.80 \text{ m/s}^2)(3.50 \text{ m})}$$
$$= 8.28 \text{ m/s}$$

$$\boxed{\sqrt{\text{m}^2/\text{s}^2} = \text{m/s}}$$

Conservation of Mechanical Energy



Kinetic and potential energy changes in a pendulum