Chapter four
Motion in One Dimension

You will learn the physics aspect of:

1. Distance
2. Displacement
3. Speed
4. Velocity
5. Acceleration
6. Free fall

Laws of Motion

- Newton's Laws of Motion- classical mechanics

- ***First Law***: Newton's first law: the law of inertia, Newton's first law states that if a body is at rest or moving at a constant speed in a straight line, it will remain at rest or keep moving in a straight line at constant speed unless it is acted upon by a force.
- ***Second Law***: If an object has a certain mass, greater the mass of this object, greater will the force required be to accelerate the object. It is represented by the equation F = ma, where 'F' is the force on the object, 'm' is the mass of the object and 'a' is the acceleration of the object.
- ***Third Law***: For every action, there is an equal and opposite reaction.

Motion

- What is Motion in Physics?

In physics, the **motion is the change in position of an object with respect to its surroundings in a given interval of time**. The motion of an object with some mass can be described in terms of the following:

- Distance
- Displacement
- Speed
- Velocity
- Time
- Acceleration

Main types of motion

1. Translatory motion (linear motion)
2. Rotatory motion
3. Vibrational motion

TRANSLATORY MOTION	ROTATORY MOTION	VIBRATORY MOTION
Motion along a straight or curved path.	Motion along a circumference of a circle.	Back and forth to and fro motion of a body.

- Translatory motion (linear motion)

In linear motion, the particles move from one point to another in either a straight line or a curved path. The linear motion depending on the path of motion is further divided as follows,

Rectilinear Motion – The path of the motion is a straight line.

Curvilinear Motion – The path of the motion is curved.

A few examples of linear motion are the motion of the train, football, the motion of a car on the road, etc.

- Rotatory Motion

Rotatory motion is the motion that occurs when a body rotates on its own axis. A few examples of the rotatory motion are as follows:

The motion of the earth about its own axis around the sun is an example of rotary motion.

While driving a car, the motion of wheels and the steering wheel about its own axis is an example of rotatory motion.

- Oscillatory Motion (vibrational motion)

Oscillatory motion is the motion of a body about its mean position. A few examples of oscillatory motion are;

When a child on a swing is pushed, the swing moves to and fro about its mean position.

The pendulum of a clock exhibits oscillatory motion as it moves to and fro about its mean position.

The string of the guitar when strummed moves to and fro by its mean position resulting in an oscillatory motion.

1. Translatory motion

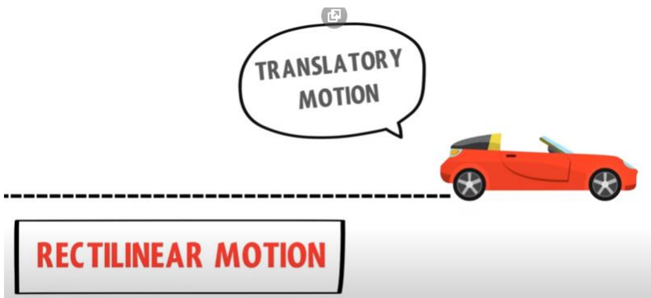
- Motion from one point to another without any rotation.
- The motion can be in a straight line or curved.
- Examples: moving car on a straight line.

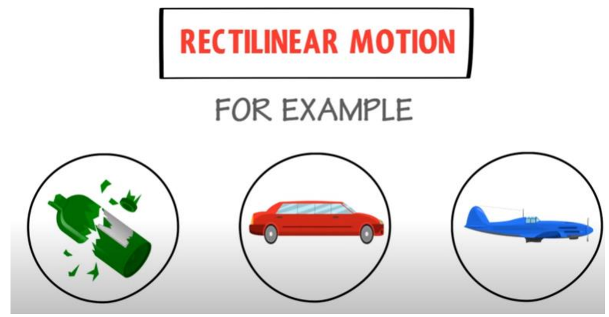
Types of Translatory motion:

1) RECTILINEAR MOTION
2) CURVILINEAR MOTION
3) RANDOM MOTION

Rectilinear motion:

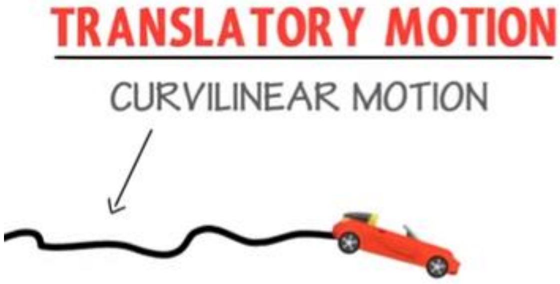
- Motion on a straight line





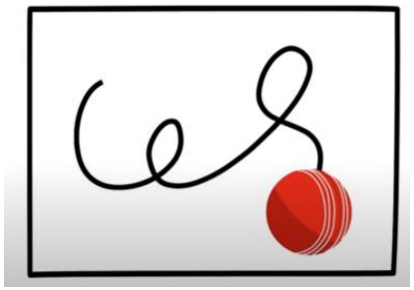
Curvilinear motion

- Motion on a curve path without rotation.



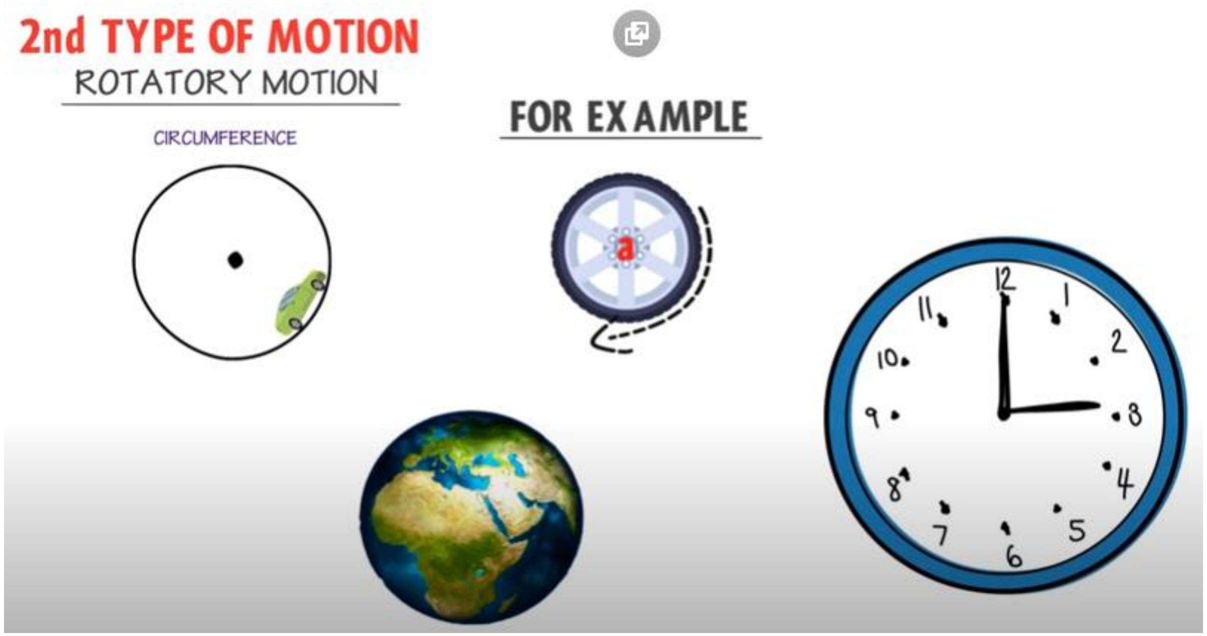
Random motion

- Motion with irregular direction

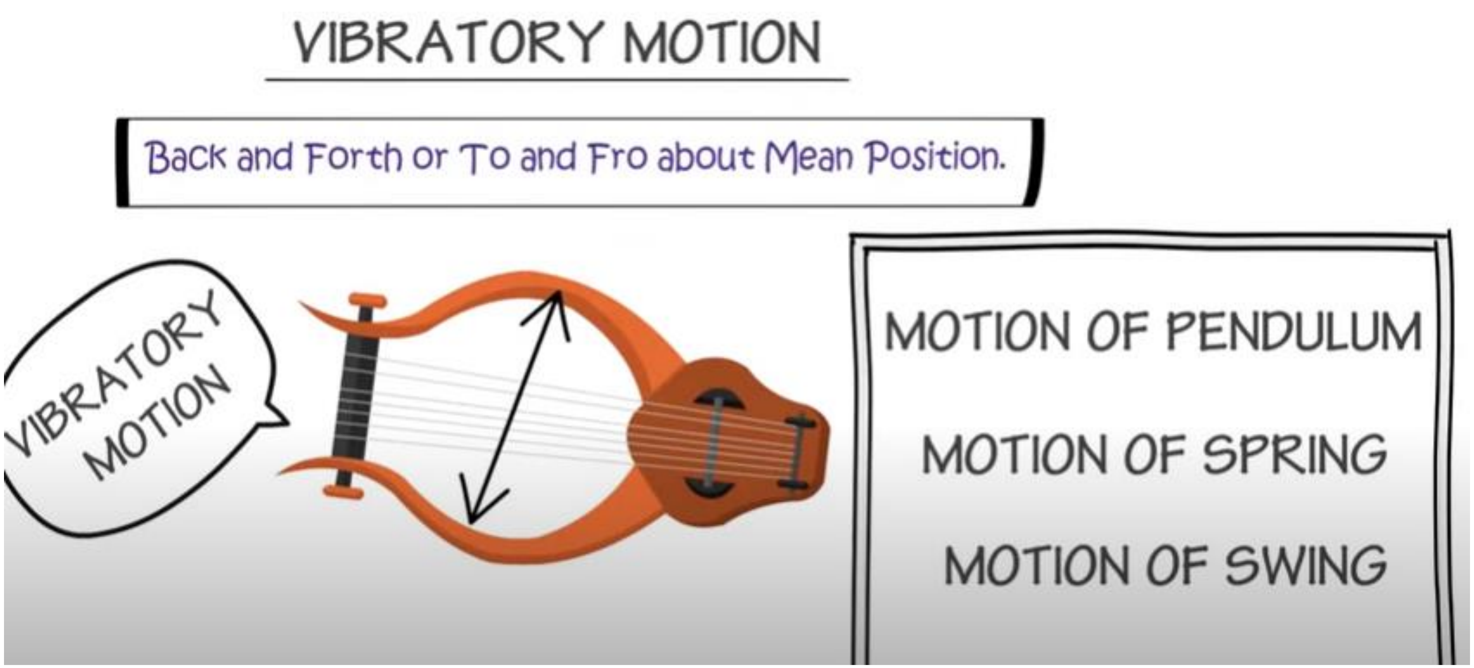


2. Rotatory motion

- Motion of a body around a fixed point
- such as rotating earth around itself.



3. Vibrational motion



Dimensions of motion

- Motion can be along a straight line (**one dimension) or two and three dimensions.**

- Motion along a straight line only does not need the full mathematics of vectors. But using vectors will be essential when we consider motion in two or three dimensions.

- Examples of motion in one dimension:
  - Displacement, velocity, acceleration, free fall, and …. In a straight line.
- An example of motion in two dimension (x and y axis) is projectile motion.
- An example of a three dimensional motion (x, y and z axis) is motion of a bird or an insect since it is flying in space.

Distance And Displacement

Distance And Displacement:

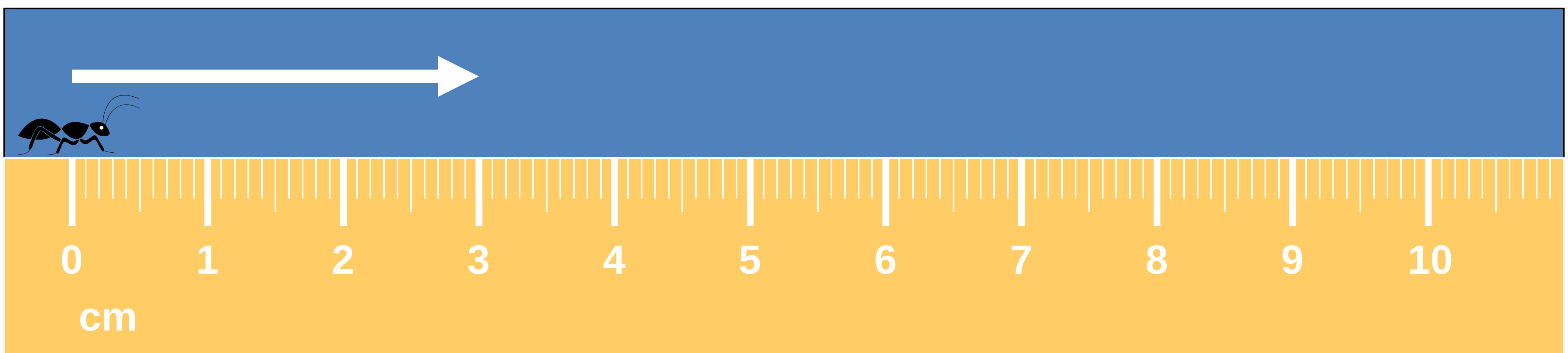
Distance is a scalar quantity refers to "how much ground an object has covered" during its motion.

Displacement is a vector quantity refers to "how far out of place an object is; it is the object's overall change in position.

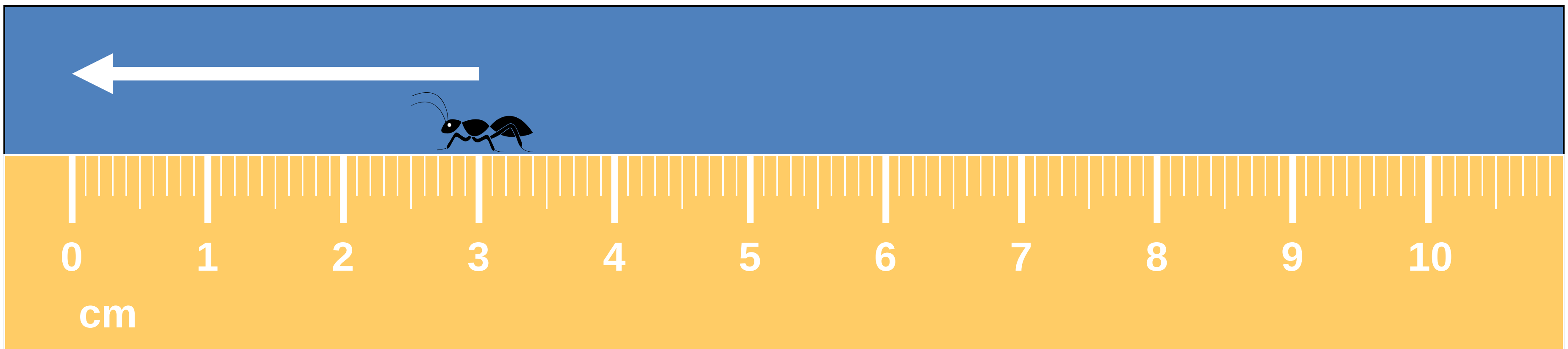
Distance

- Distance (d) – how far an object travels.
  - Does *not* depend on direction.
- Imagine an ant crawling along a ruler.

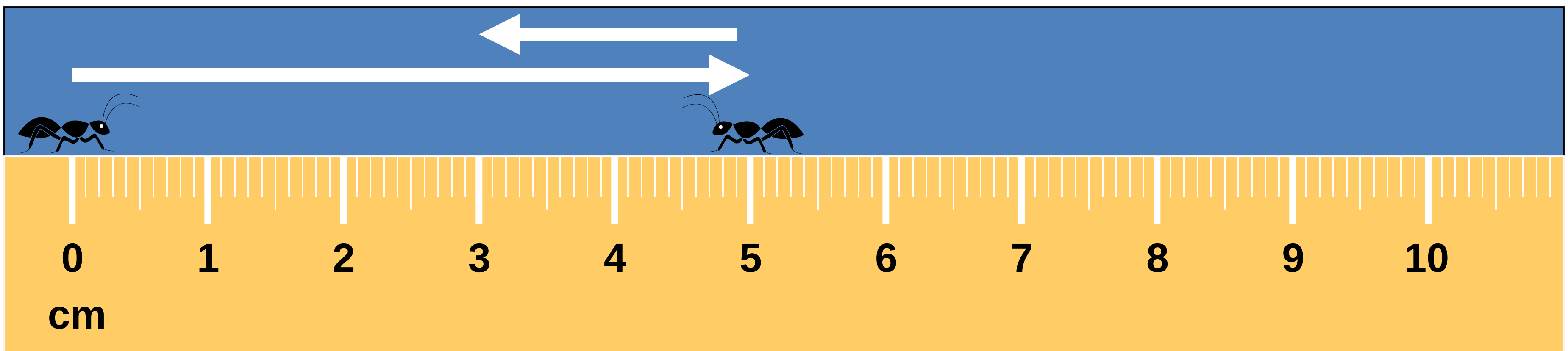
- What *distance* did the ant travel?
  - d = 3 cm



- Distance does not depend on direction.
- Here's our intrepid ant explorer again.
- Now what distance did the ant travel?
  - d = 3 cm
- Does his direction change the answer?



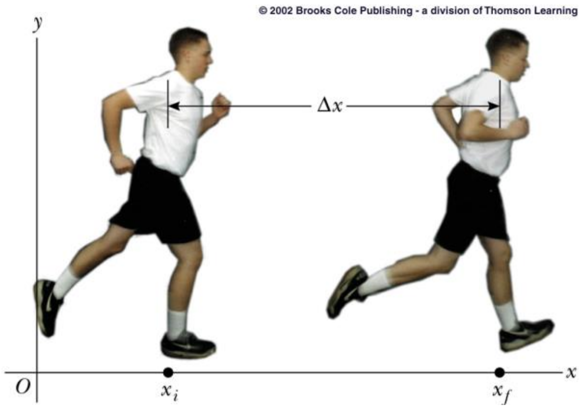
- Distance does not depend on direction.
- Let’s follow the ant again.



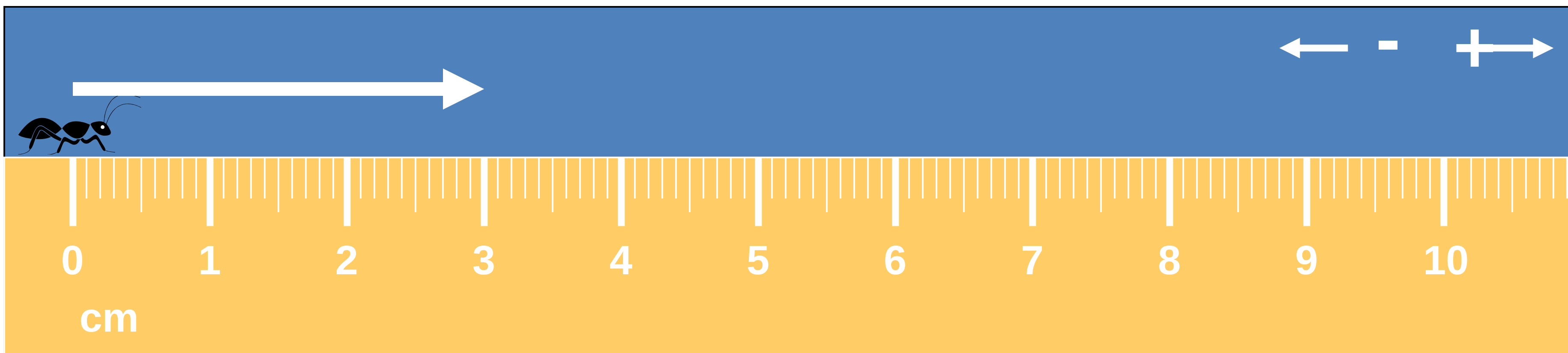
- What distance did the ant walk this time?
- d = 7 cm

Displacement

- Displacement (Δd) – difference between an object's final position and its starting position.
  - *Does* depend on direction.
- Displacement = final position – initial position
- $\Delta x = x_{final} - x_{initial}$
- In order to define displacement, we need directions.
- Examples of directions:
  - + and –
  - N, S, E, W
  - Angles

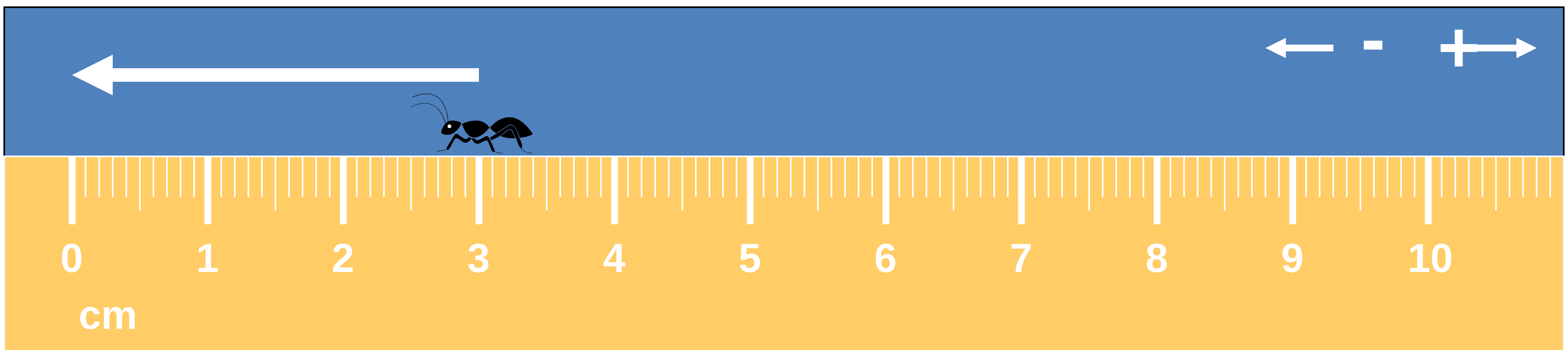


- Let’s revisit our ant, and this time we’ll find his displacement.



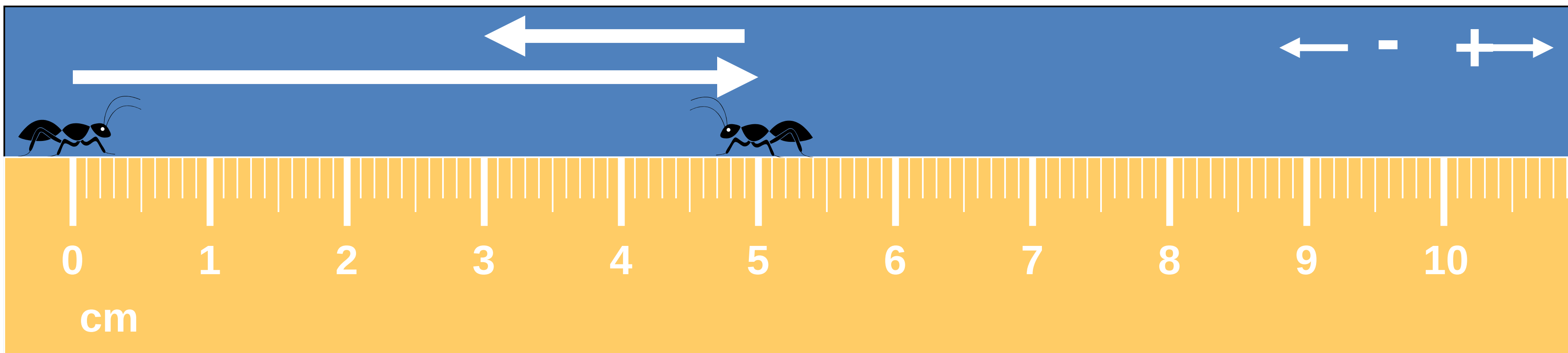
- Distance: 3 cm
- Displacement: +3 cm
  - The positive gives the ant a direction!

- Find the ant’s displacement again.
  - Remember, displacement has direction!



- Distance: 3 cm
- Displacement: -3 cm

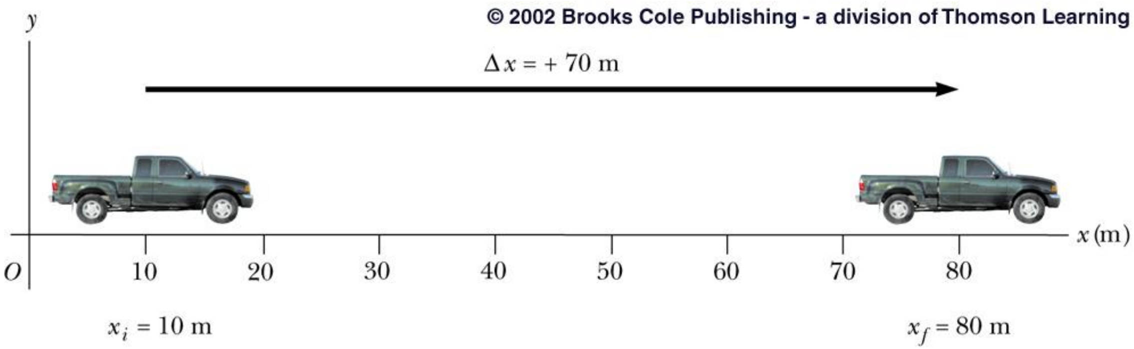
- Find the distance and displacement of the ant.



- Displacement: +3 cm

Example 1:

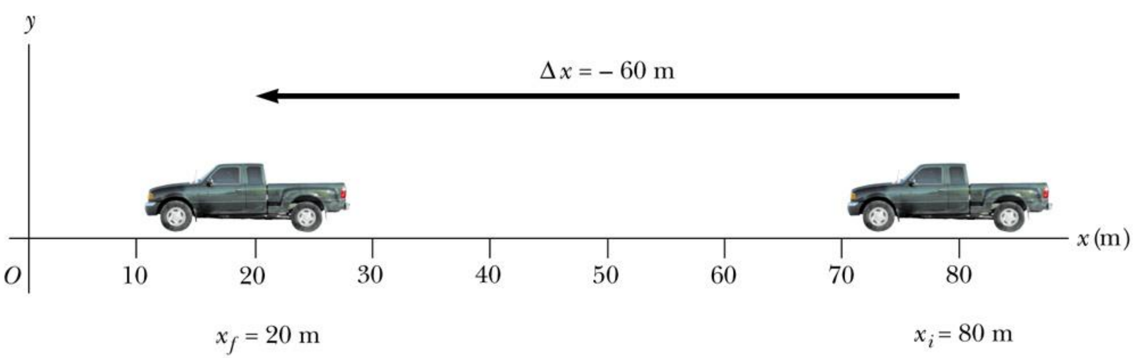
Find the displacement in each case.



(a)

$$\Delta x_1 = x_f - x_i$$
$$= 80\,m - 10\,m$$
$$= \underline{+70\,m}$$

✓



(b)

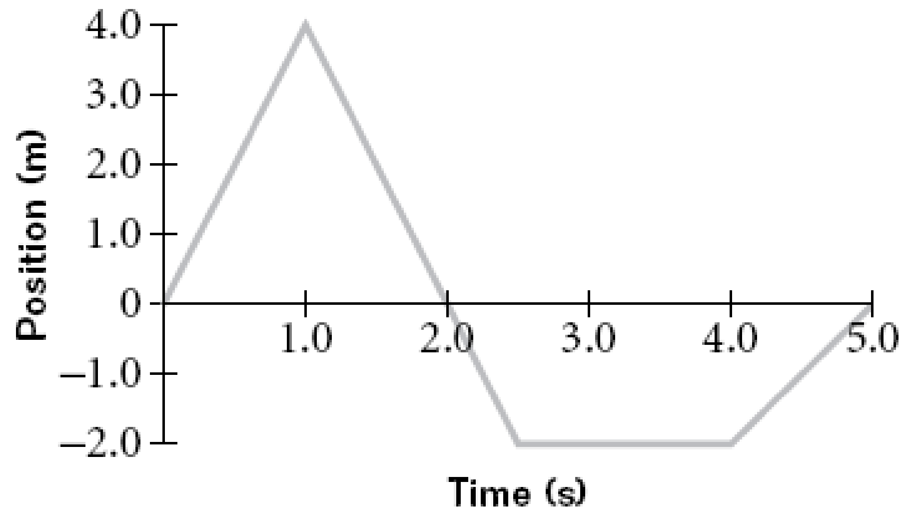
$$\Delta x_2 = x_f - x_i$$
$$= 20\,m - 80\,m$$

✓

$$= \underline{-60\,m}$$

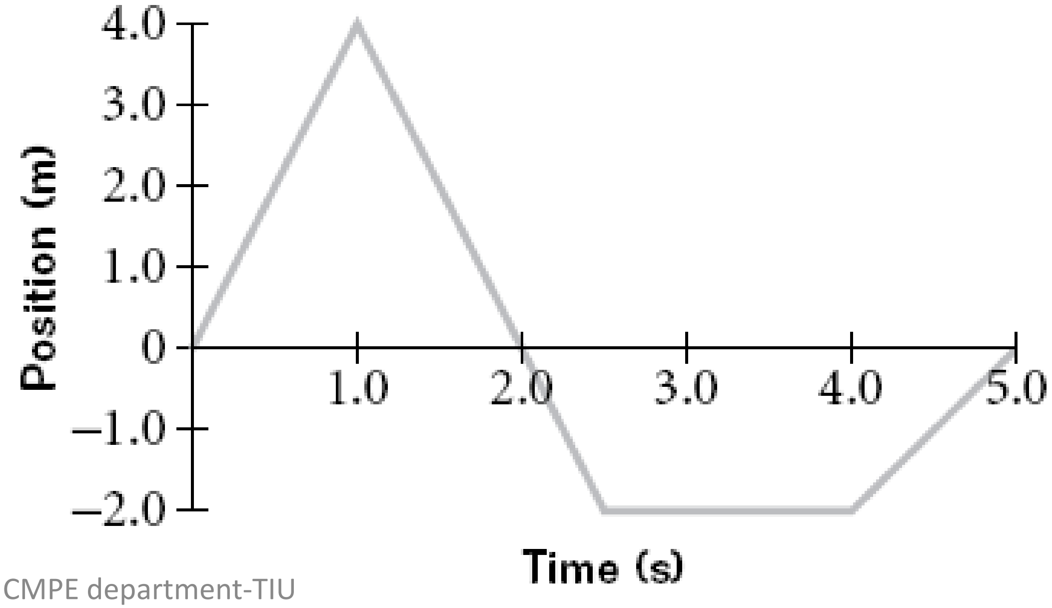
HW 1. What is the squirrel's displacement between 1.0 – 4.0 s?

A. +4.0 m
B. – 1.0 m
C. 0.0 m
D. – 6.0 m



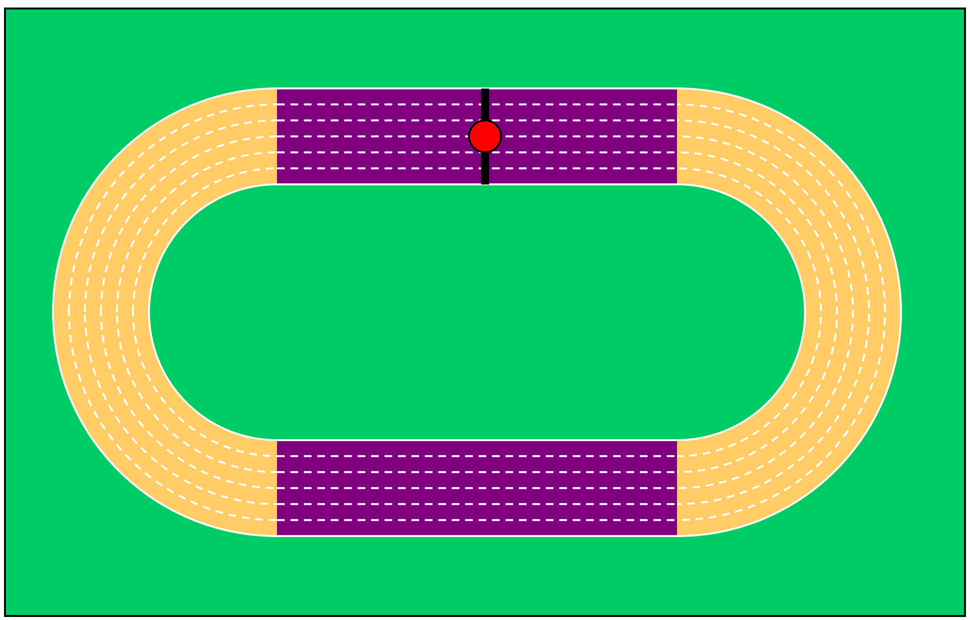
HW 2. What is the distance taken by the squirrel between 0 – 5.0 s?

A. +4.0 m
B. – 1.0 m
C. 0.0 m
D. +12.0 m



Displacement vs. Distance

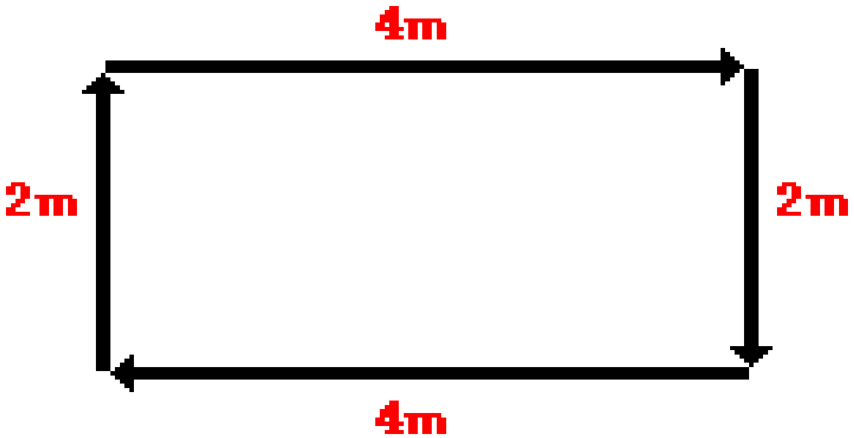
- An athlete runs around a track that is 100 meters long three times, then stops.
  - What is the athlete's distance and displacement?



- Distance = 300 m
- Displacement = 0 m
- Why?

Example 2:

A physics teacher walks 4 meters East, 2 meters South, 4 meters West, and finally 2 meters North.



Distance =4+2+4+2=12 meters
Displacement =4+2-4-2=0 meter

Even though the physics teacher has walked a total distance of 12 meters, her displacement is 0 meters because the initial and the final point are the same.

SPEED AND VELOCITY

Speed is a **scalar quantity** that refers to "how fast an object is moving." Speed can be thought of as the rate at which an object covers distance.

Velocity is a **vector quantity** that refers to "the rate at which an object changes its position.

Notes:

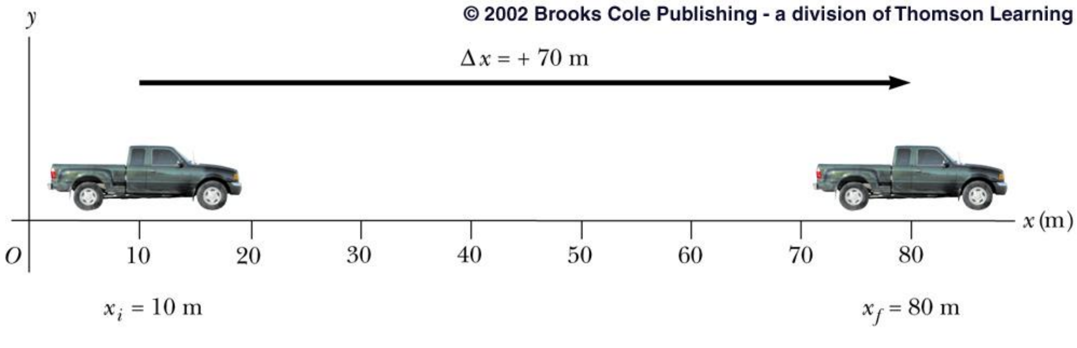
- The direction of the velocity vector is simply the same as the direction that an object is moving.
- The **average velocity** of a particle during a time interval cannot tell us how fast, or in what direction.
- **Instantaneous velocity**, is the velocity at a specific instant of time or specific point along the path.

$$\text{Average Speed} = \frac{\text{Distance Traveled}}{\text{Time of Travel}}$$

$$\text{Average Velocity} = \frac{\Delta\,\text{position}}{\text{time}} = \frac{\text{displacement}}{\text{time}}$$

Example 3:

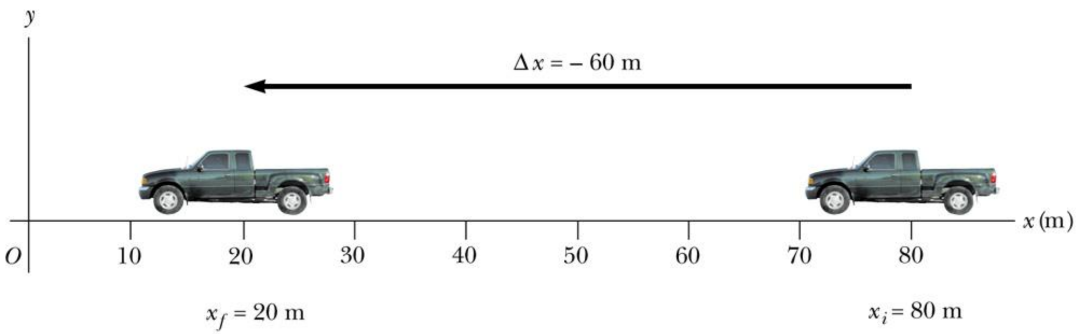
Suppose that in both cases truck covers the distance in 10 seconds, what are their velocities?



(a)

$$\vec{v}_{1\,average} = \frac{\Delta\vec{x}_1}{\Delta t} = \frac{+70m}{10s}$$

$$= \underline{+7\,m/s}$$



(b)

$$\vec{v}_{2\,average} = \frac{\Delta\vec{x}_2}{\Delta t} = \frac{-60m}{10s}$$

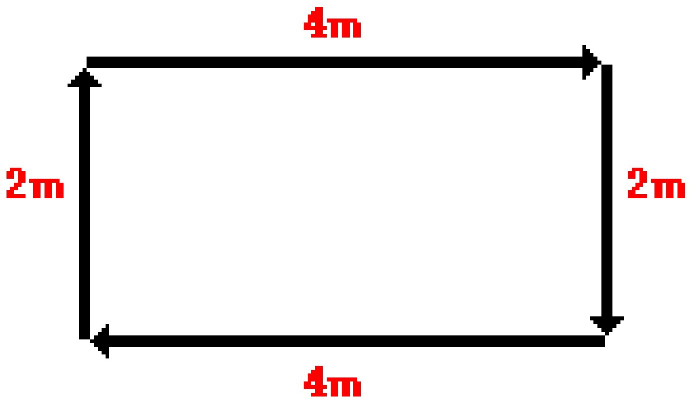
$$= \underline{-6\,m/s}$$

Example 4: While on vacation, Lisa Carr travelled a total distance of 440 miles. Her trip took 8 hours. What was her average speed?

$$v = \frac{d}{t} = \frac{440\ \text{mi}}{8\ \text{hr}} = 55\ \text{mi/hr}$$

Instantaneous Speed - the speed at any given instant in time.
Average Speed - the average of all instantaneous speeds; found simply by a distance/time ratio.

Example 5:
The physics teacher walked a distance of 12 meters in 24 seconds; find average speed and velocity.



Ans. average speed = 0.50 m/s., since Average velocity =0 m/s.

Velocity VS Speed	
SPEED	VELOCITY
Speed is the quantitative measure of how quickly something is moving.	Velocity defines the direction of the movement of the body or the object.
Speed is primarily a scalar quantity	Velocity is essentially a vector quantity
It is the rate of change of distance	It is the rate of change of displacement
Speed of an object moving can never be negative	The velocity of a moving object can be zero.
Speed is a prime indicator of the rapidity of the object.	Velocity is the prime indicator of the position as well as the rapidity of the object.
It can be defined as the distance covered by an object in unit time.	Velocity can be defined as the displacement of the object in unit time.

Example of Velocity

To understand the concept of instantaneous velocity and average velocity, let's take this example. Jewel goes to school in her dad's car every morning. Her school is 8 km from her home, and she takes 15 mins to travel, but when she looks at the speedometer on the dashboard of the car, it shows a different reading all the time. So, now how would she know her velocity?

For convenience, we have considered the car to move in a straight line, and we will convert all the units of time to hours. Therefore, 15 mins = 1560 = 0.25 hours.

Average velocity, $v = \Delta x / \Delta t$

v = 8 km/0.25 hrs

v = 32 km/h

Acceleration

YOU WILL LEARN:

1. Principle of acceleration
2. Average and instantaneous acceleration

Average and instantaneous acceleration

- Acceleration describes the rate of change of velocity with time.
- Acceleration is a vector quantity.
- Acceleration in straight-line motion can refer to either speeding up or slowing down.
- The **average acceleration** of the particle as it moves from a point of (p_1) to (p_2) be a vector quantity whose *x*-component $a_{av.-x}$ (called the **average *x*-acceleration**) equals Δv_x, the change in the *x*-component of velocity, divided by the time interval,

$$\boxed{\vec{a}_{average} = \frac{\Delta \vec{v}}{\Delta t} = \frac{\vec{v}_f - \vec{v}_i}{\Delta t}}$$

- The unit of acceleration is $\frac{m}{s^2}$ *in SI unit system*

Average and instantaneous acceleration

- When the sign of the velocity and the acceleration are the same (either positive or negative), then the speed is increasing
- When the sign of the velocity and the acceleration are opposite, the speed is decreasing.
- **The instantaneous acceleration** is the limit of the average acceleration as the time interval approaches zero. In the language of calculus, instantaneous acceleration equals the derivative of velocity with time. Thus

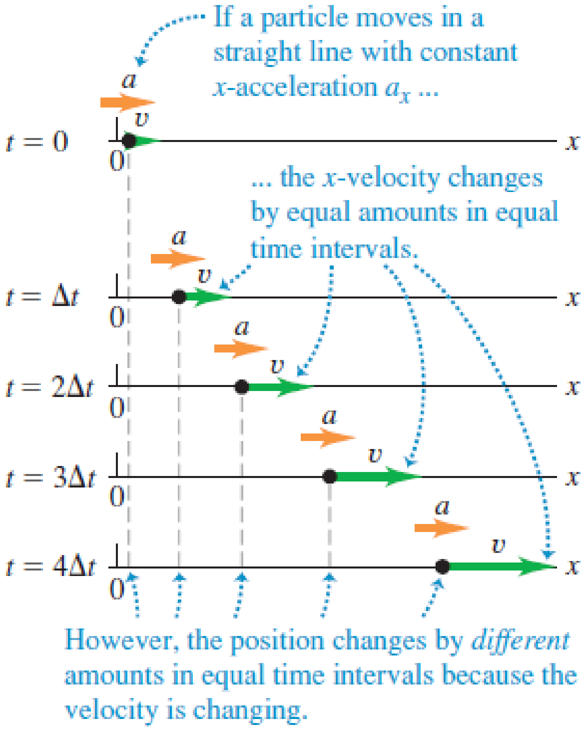
$$a_x = \lim_{\Delta t \to 0} \frac{\Delta v_x}{\Delta t} = \frac{dv_x}{dt} \qquad \text{(instantaneous } x\text{-acceleration, straight-line motion)}$$

Motion with Constant Acceleration

- The simplest kind of accelerated motion is straight-line **motion with *constant* acceleration**.

- In this case the **velocity changes at the same rate** throughout the motion.

- Examples: a falling body has a constant acceleration if the effects of the air are not important. The same is true for a **body sliding on an incline or along a rough horizontal** surface, or for an airplane being catapulted from the deck of an aircraft carrier.



Motion with Constant Acceleration

- When the x-acceleration a_x is constant, the average x-acceleration $a_{av.-x}$ for any time interval is the same as a_x,

$$a_x = \frac{v_{2x} - v_{1x}}{t_2 - t_1}$$

- Now we let $t_1 = 0$ and t_2 let be any later time t. We use the symbol v_{0x} for the x-velocity at the initial time t=0; the x-velocity at the later time t is v_x,

$$a_x = \frac{v_x - v_{0x}}{t - 0} \qquad \text{or}$$

$$v_x = v_{0x} + a_x t \qquad \text{(constant } x\text{-acceleration only)}$$

$$v_{\text{av-}x} = \frac{v_{0x} + v_x}{2} \qquad \text{(constant } x\text{-acceleration only)}$$

Motion with Constant Acceleration: Formula

$$v_x = v_{0x} + a_x t \Rightarrow \boxed{v_f = v_o + at}$$

$$v_x^2 = v_{0x}^2 + 2a_x(x - x_0) \Rightarrow v_f^2 = v_o^2 + 2a\Delta x$$

$$x - x_0 = v_{0x}t + \frac{1}{2}a_x t^2 \Rightarrow \Delta x = V_0.t + \frac{1}{2} a.t^2$$

$$\boxed{V_{avarage} = \frac{V_0 + V_f}{2}}$$

Where,
vf = Final Velocity,
vo = Initial velocity,
a = acceleration,
t = time taken,
x= distance travelled

- **Example 6:** A toy car accelerates from 3m/s to 5m/s in 5 s. What is its acceleration?

- **Solution:**
  Given: Initial Velocity v_0 = 3m/s,
  Final Velocity v_f = 5m/s,
  Time taken t = 5s.

$$\boxed{v_f = v_o + at} \qquad a = (v_f - v_o)/2 = 5 - 3/5 = 0.4m/s\text{^}2$$

Example 7. A ball initially at rest rolls down a hill and has an acceleration of 3.3 m/s^2. If it accelerates for 7.5 s, how far will it move during this time?

F. 12 m

G. 93 m

H. 120 m

J. 190 m

Example 8. A car moving eastward along a straight road increases its speed uniformly from 16 m/s to 32 m/s in 10.0 s.

a. What is the car's average acceleration?

b. What is the car's average velocity?

c. How far did the car move while accelerating?

Answers: a. 1.6 m/s^2 eastward
b. 24 m/s
c. 240 m

Example 9

If a car with a velocity of 4.0 m/s accelerates at a rate of 4.0 m/s^2 for 2.5 s, what is the final velocity?

vf=vi+at =4.0+(4.0)(2.5)=4.0 +10 =14 m/s

Example 10

If a cart slows from 22.0 m/s with an acceleration of -2.0 m/s^2, how long does it require to get to 4 m/s? (t=?)

t=(vf−vi) / a= (−18)/−2.0) =9.0 s

H.W

- If an object has zero acceleration, does that mean it has zero velocity? Give an example.
- If an object has zero velocity, does that mean it has zero acceleration? Give an example.
- If the acceleration of a motorboat is 4.0 m/s^2, and the motorboat starts from rest, what is its velocity after 6.0 s?
- The friction of the water on a boat produces an acceleration of -10. m/s^2. If the boat is traveling at 30. m/s and the motor is shut off, how long does it take the boat to slow down to 5.0 m/s?

Example 11

Suppose a planner is designing an airport for small airplanes. Such planes must reach a speed of 56 m/s before takeoff and can accelerate at 12.0 m/s^2. What is the minimum length for the runway of this airport?

The acceleration in this problem is constant and the initial velocity of the airplane is zero. Therefore, we can use the equation ${v_f}^2 = 2ad$ and solve for d.

$$d = \frac{{v_f}^2}{2a} = \frac{(56\ \mathrm{m/s})^2}{(2)(12.0\ \mathrm{m/s^2})} = 130\ \mathrm{m}$$

Example 12

How long does it take a car to travel 30.0 m if it accelerates from rest at a rate of 2.00 m/s^2?

The acceleration in this problem is constant and the initial velocity is zero, therefore, we can use $d = \frac{1}{2}at^2$ solved for t.

$$t = \sqrt{\frac{2d}{a}} = \sqrt{\frac{(2)(30.0\ \mathrm{m})}{2.00\ \mathrm{m/s^2}}} = 5.48\ \mathrm{s}$$

Example 13

A baseball pitcher throws a fastball with a speed of 30.0 m/s. Assume the acceleration is uniform and the distance through which the ball is accelerated is 3.50 m. What is the acceleration?

Since the acceleration is uniform and the initial velocity is zero, we can use ${v_f}^2 = 2ad$ solve for a.

$$a = \frac{v_f^2}{2d} = \frac{(30.0\ \mathrm{m/s})^2}{(2)(3.50\ \mathrm{m})} = \frac{900.\ \mathrm{m^2/s^2}}{7.00\ \mathrm{m}} = 129\ \mathrm{m/s^2}$$

Summary

- There are three equations we can use when acceleration is constant to relate displacement to two of the other three quantities we use to describe motion – time, velocity, and acceleration:
  - $d = \left(\frac{1}{2}\right)(v_f + v_i)(t)$ (Equation 1)
  - $d = v_i t + \frac{1}{2}at^2$ (Equation 2)
  - ${v_f}^2 = {v_i}^2 + 2ad$ (Equation 3)
- When the initial velocity of the object is zero, these three equations become:
  - $d = \left(\frac{1}{2}\right)(v_f)(t)$ (Equation 1')

  - $d = \frac{1}{2}at^2$ (Equation 2')
  - ${v_f}^2 = 2ad$ (Equation 3')
- The slope of a velocity versus time graph is the acceleration of the object.
- The area under the curve of a velocity versus time graph is the displacement that occurs during the given time interval.

Free Fall

You will learn

- **The Principle of Free Fall Objects.**
- **Gravitational Force In Both Up And Down Direction.**

Free Fall

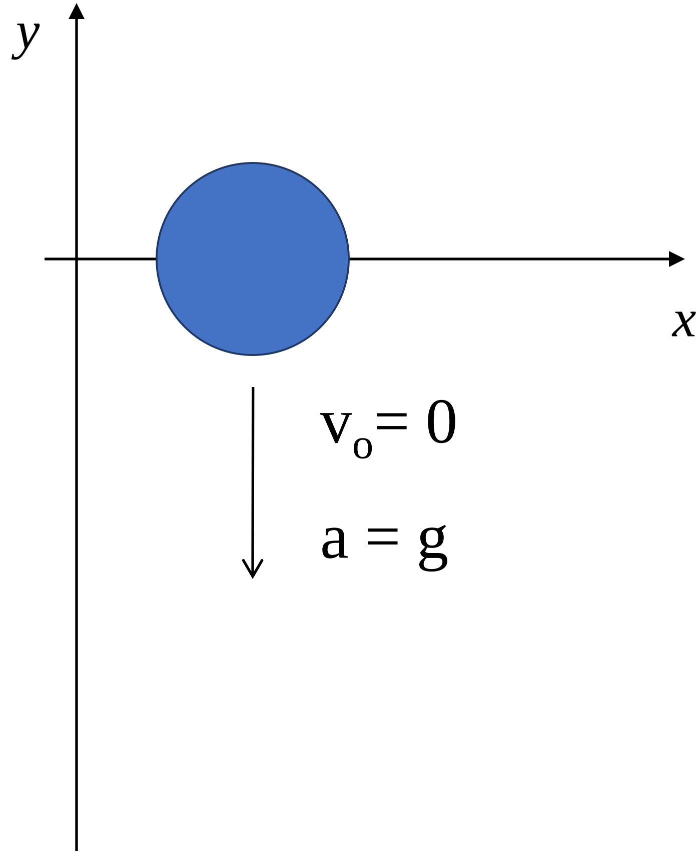
- ►All objects moving under the influence of only gravity are said to be in free fall.
- ►All objects falling near the earth’s surface, falling with a constant acceleration.
- ►This acceleration is called the acceleration due to gravity, and indicated by ‘‘g’’.
- ►***We will frequently*** use the approximate value of g *at or near the earth’s surface.*

Acceleration due to Gravity

- It is Symbolized by g.
- $g = -9.8\ m/s^2$ always (because it is always directed downward).
- $g = -10\ m/s^2$ can also be used for estimates.
- g is always directed downward.
  - toward the center of the earth
- Once released, only gravity pulls on the object, just like in up-and-down motion.
- Since gravity pulls on the object downwards:
  - ✓ Vertical acceleration downwards
  - ✓ NO acceleration will be in horizontal direction

Free Fall
Case 1- an Object Dropped

- ▶ **Initial velocity is zero**.
- ▶ **Velocity and displacement are negative after time , t, from initial point**.
- ▶ Frame: let up be positive.
- ▶ Use the kinematic equations.
  - Generally use y instead of x since vertical.



$$\Delta y = \frac{1}{2} a t^2$$

$$a = -9.8\, m/s^2$$

$$thus: g = -9.8 \text{m/s}^2$$

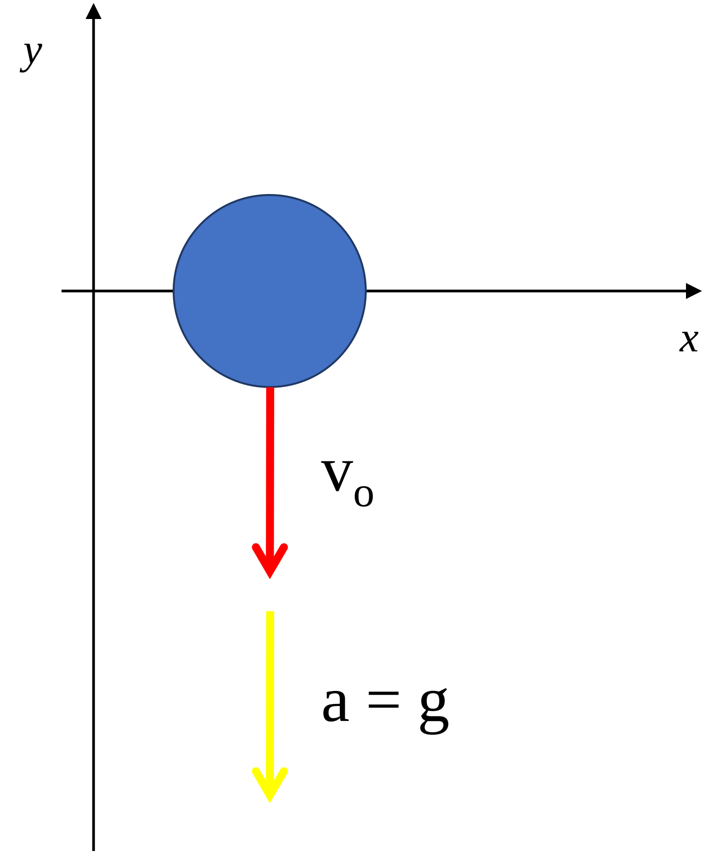
Free Fall

Case 2- an Object Thrown Downward

- ► **a = g**
  - **With downward , y, acceleration will be negative,**

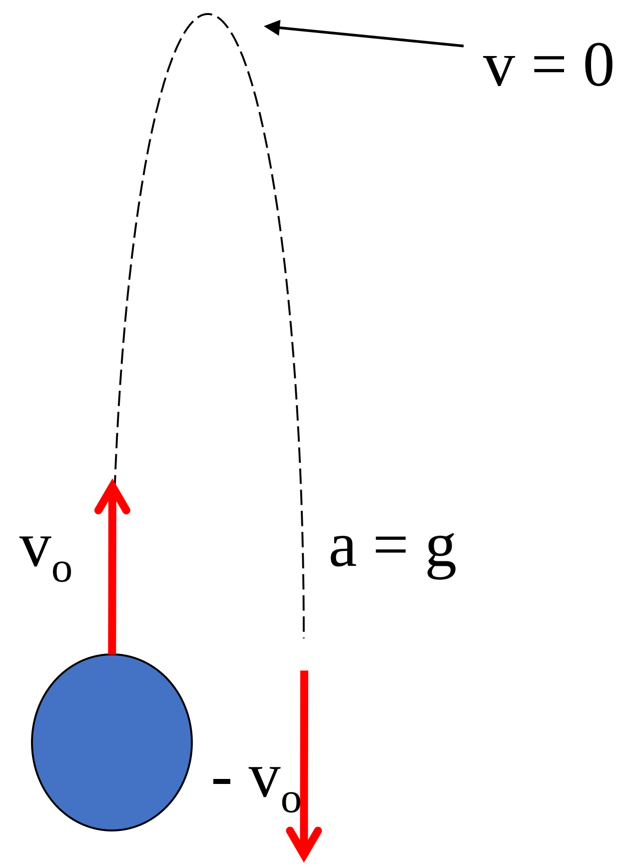
  thus: g = - 9.8 m/s²
- ► **Initial velocity ≠ 0**

- ► **initial velocity will be negative.**
- ► **Velocity and displacement are negative after time , t, from initial point.**



Free Fall
Case 3- object thrown upward

- Initial velocity is upward, so it is toward positive y axis.
- **The instantaneous velocity at the maximum height is zero**
- **Velocity and displacement are positive after time , t, from initial point**.
- a = g everywhere in the motion and **g = - 9.8 m/s²**
  - g is always downward, negative



Free fall formula

kinematic equations

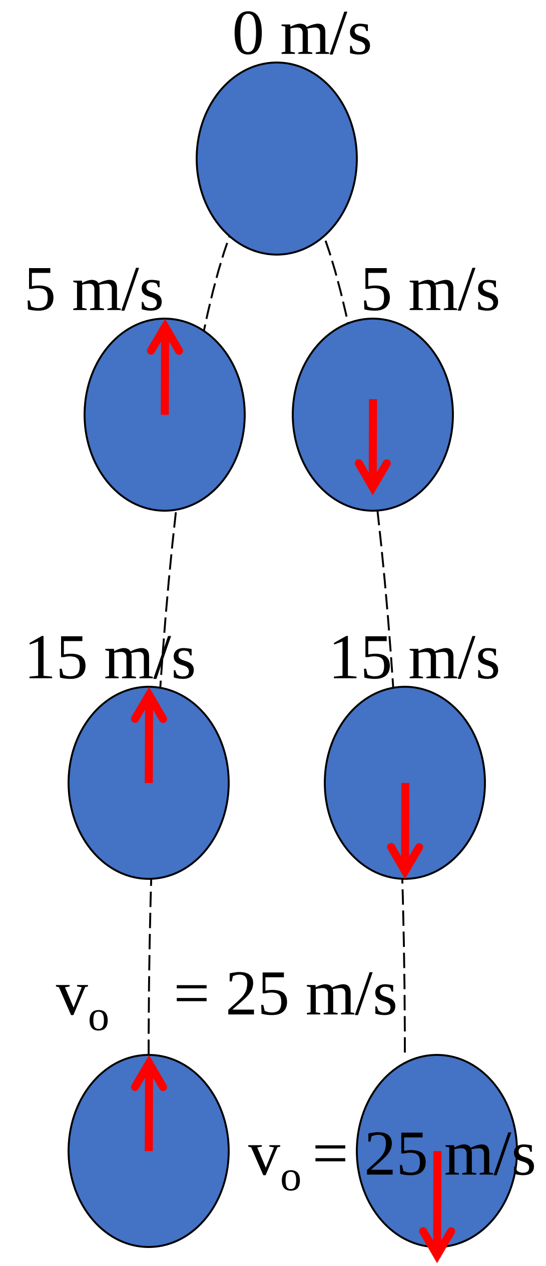
$$1)\ v_f^2 = v_i^2 + 2g\Delta s$$

$$2)\ \Delta x = v_i \Delta t + \frac{1}{2} g\Delta t^2$$

$$3)\ v_f = v_i + g\Delta t$$

$$4)\ \bar{v} = \frac{v_i + v_f}{2}$$

Solution Let us choose the upward direction to be positive. Regardless of whether the ball is moving upward or downward, its vertical velocity changes by approximately −10 m/s for every second it remains in the air. It starts out at 25 m/s. After 1 s has elapsed, it is still moving upward but at 15 m/s because its acceleration is downward (downward acceleration causes its velocity to decrease). After another second, its upward velocity has dropped to 5 m/s. Now comes the tricky part—after another half second, its velocity is zero. The ball has gone as high as it will go. After the last half of this 1-s interval, the ball is moving at −5 m/s. (The negative sign tells us that the ball is now moving in the negative direction, that is, *downward*. Its velocity has changed from +5 m/s to −5 m/s during that 1-s interval. The change in velocity is still −5 m/s − (+5 m/s) = −10 m/s in that second.) It continues downward, and after another 1 s has elapsed, it is falling at a velocity of −15 m/s. Finally, after another 1 s, it has reached its original starting point and is moving downward at −25 m/s.



End of chapter four