

Chapter 2

1

Motion in one dimension

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Kinematics

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- Describes motion while ignoring the external agents that might have caused or modified the motion.
- Describes motion in terms of: time, position, velocity and acceleration.
- Motion represents a continual change in an object's position.
- For now, will consider motion in one dimension. (Along a straight line)

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Types of Motion

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| | | |
|--|---|---|
| <div style="background-color: #444; color: white; padding: 10px; margin-bottom: 5px;">Translational</div> <div style="border: 1px dashed gray; padding: 10px; margin-top: 10px;">An example is a car traveling on a highway.</div> | <div style="background-color: #444; color: white; padding: 10px; margin-bottom: 5px;">Rotational</div> <div style="border: 1px dashed gray; padding: 10px; margin-top: 10px;">An example is the Earth's spin on its axis.</div> | <div style="background-color: #444; color: white; padding: 10px; margin-bottom: 5px;">Vibrational</div> <div style="border: 1px dashed gray; padding: 10px; margin-top: 10px;">An example is the back-and-forth movement of a pendulum.</div> |
|--|---|---|

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Position, Distance and Displacement

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Position: the location of an object with respect to a reference point.

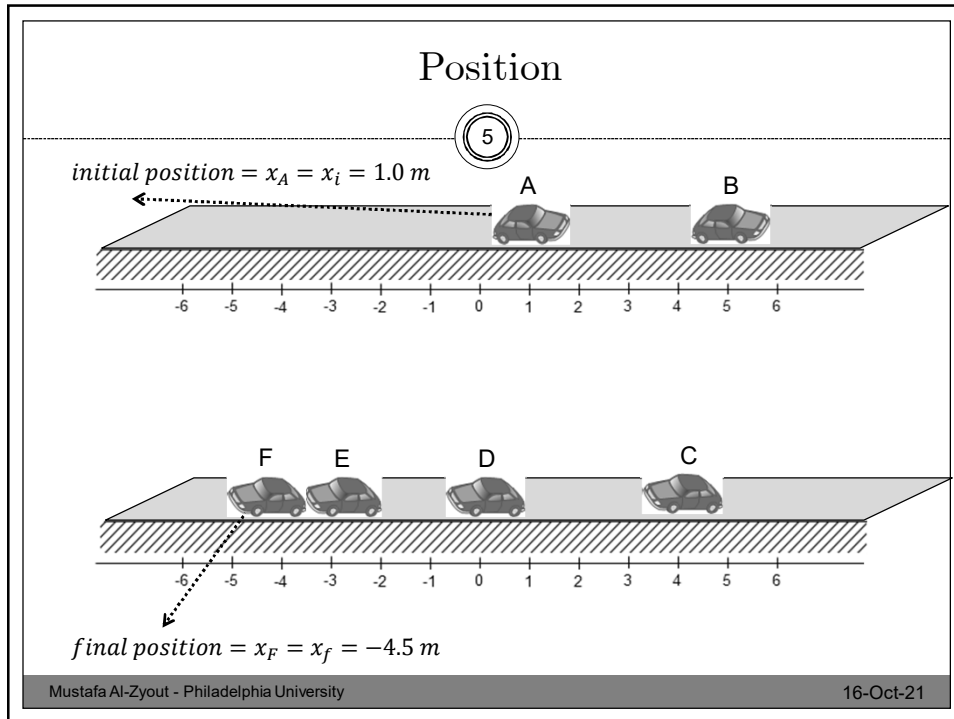
Data Table

- The table gives the actual data collected during the motion of a car.
- Once every 1 s we note the car's position.

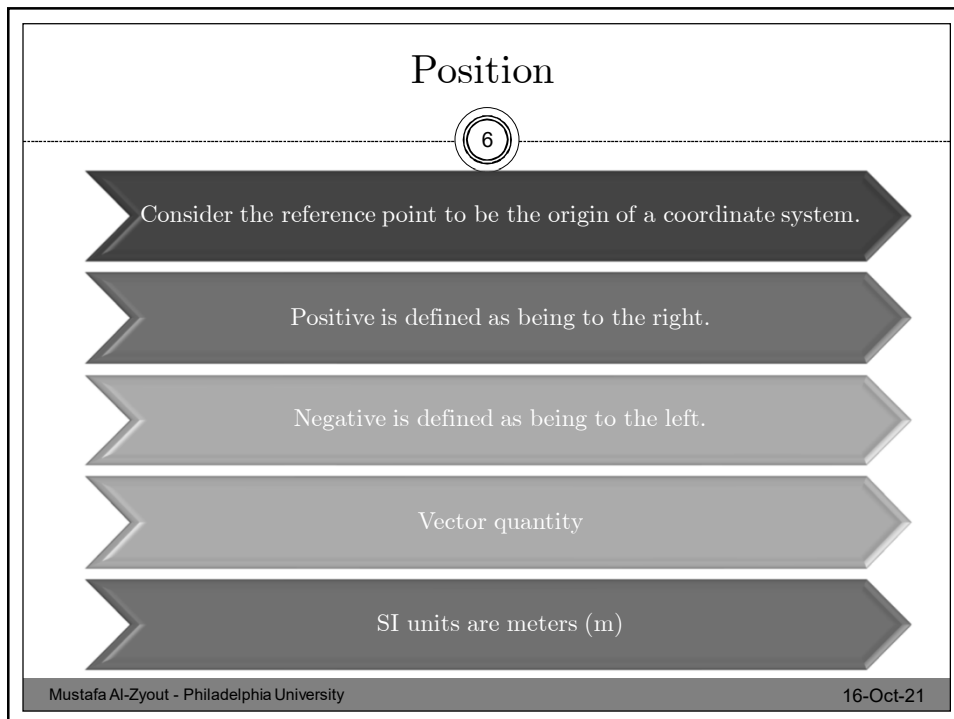
| Position | t (s) | x (m) |
|----------|-------|-------|
| A | 0 | 1.0 |
| B | 1.0 | 5.0 |
| C | 2.0 | 4.0 |
| D | 3.0 | 0.0 |
| E | 4.0 | -3.0 |
| F | 5.0 | -4.5 |

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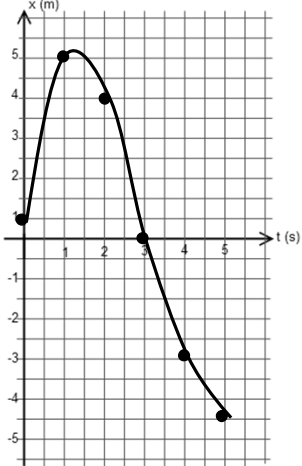


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Position-Time Graph

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•The position-time graph shows the motion of the particle (car).

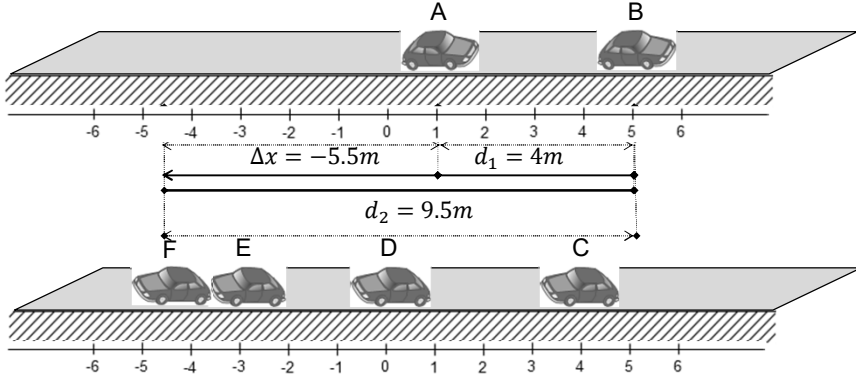


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Displacement and distance

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$Distance = d_1 + d_2 = 4 + 9.5 = 13.5\text{ m}$
 $Displacement = \Delta x = -5.5\text{ m}$

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Displacement and distance

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Displacement is defined as the change in position during some time interval.

- Represented as:
 $\Delta x = x_f - x_i$
- SI units are meters (m)
- can be positive, negative or zero
- vector quantity

Distance is the length of a path followed by a particle.

- SI units are meters (m)
- always positive
- scalar quantity

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Average Speed

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Defined as:

$$\text{average speed} = \frac{\text{total distance}}{\text{total time}}$$

- The SI units are m/s
- Speed is a scalar quantity.
- always a positive number.

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Average Velocity

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The average velocity is rate at which the displacement occurs.

$$v_{avg} = \frac{\Delta x}{\Delta t} = \frac{x_f - x_i}{t_f - t_i}$$

- The x indicates motion along the x -axis.
- vector quantity
- The SI units are m/s
- Is also the slope of the line in the position - time graph

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Average Velocity

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Position - time graph

slope of the straight line = v_{avg}

$$= \frac{\Delta x}{\Delta t} = \frac{-4.0 - -1.0}{4.5 - 1.4}$$

$$= \frac{-3.0}{3.1} = -0.97 \text{ m/s}$$

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Average Speed and Average Velocity

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The average speed is not the magnitude of the average velocity.

- For example, a runner ends at her starting point.
- Her displacement is zero.
- Therefore, her velocity is zero.
- However, the distance traveled is not zero, so the speed is not zero.

The average speed equals the average velocity when the object is moving along a straight line and don't change direction.

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Instantaneous Velocity

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It is the velocity at a certain time.

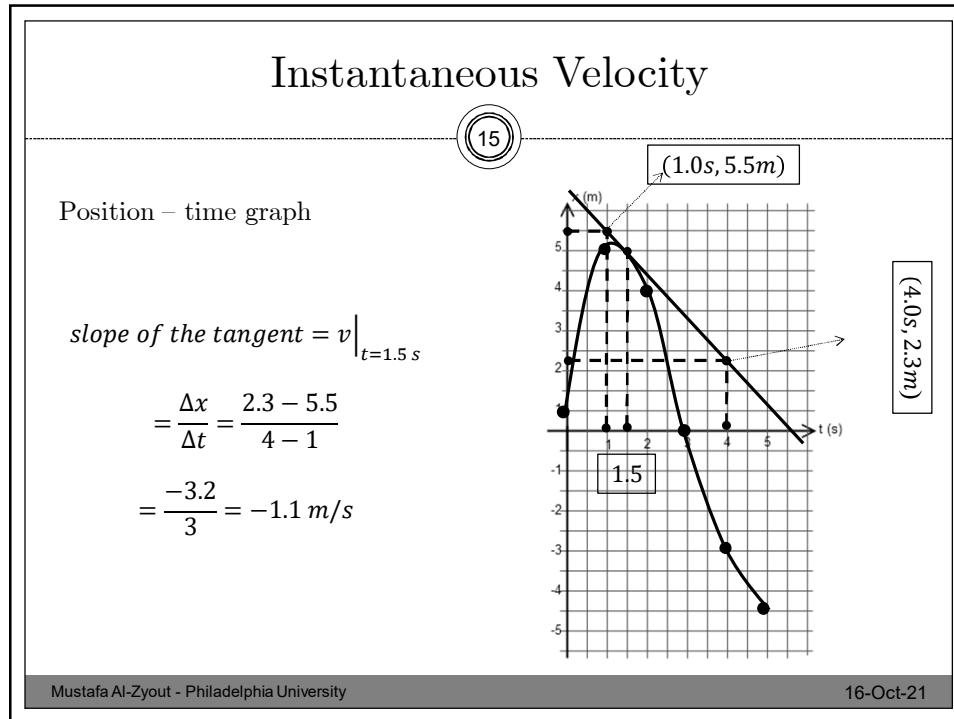
It is the slope of the line tangent to the position – time curve.

The first derivative of the position with respect to time.

$$v = \frac{dx}{dt}$$

The instantaneous velocity can be positive, negative, or zero.

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Instantaneous Speed

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The instantaneous speed is the magnitude of the instantaneous velocity.

The instantaneous speed has no direction associated with it.

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A Particle Under Constant Velocity



Constant velocity indicates that at any instant during a time interval the instantaneous velocity is the same as the average velocity.

$$v = v_{avg}$$

$$v = \frac{x_f - x_i}{t_f - t_i}$$


Common practice is to let $t_i = 0$, $t_f = t$ and the equation becomes:

$x_f = x_i + vt$

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Particle Under Constant Velocity, Graph



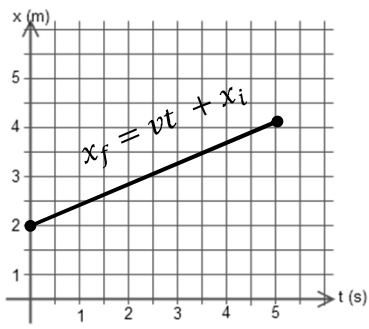
Position – time graph

The graph represents the motion of a particle under constant velocity.
The slope of the graph is the value of the constant velocity;

$$\text{slope} = \frac{\Delta x}{\Delta t} = v$$

$$v = \frac{4 - 2}{5 - 0} = 0.4 \text{ m/s}$$

The y-intercept is x_i
 $x_i = 2 \text{ m}$



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Average Acceleration

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Acceleration is the rate of change of the velocity.

$$a_{avg} = \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{t_f - t_i}$$

SI units are m/s^2

Vector quantity

In one dimension, positive and negative can be used to indicate direction.

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Average Acceleration

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Velocity – time graph

slope of the straight line = a_{avg}

$$= \frac{\Delta v}{\Delta t} = \frac{2.8 - 2.3}{4.5 - 1.5}$$

$$= 0.17 \text{ m/s}^2$$

(1.5s, 2.3m/s) (4.5s, 2.8m/s)

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Instantaneous Acceleration

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It is the acceleration at a certain time.

It is the slope of the line tangent to the *velocity - time* curve.

The first derivative of the velocity with respect to time:

$$a = \frac{dv}{dt}$$

The second derivative of the position with respect to time:

$$a = \frac{d^2x}{dt^2}$$

The instantaneous acceleration can be positive, negative, or zero.

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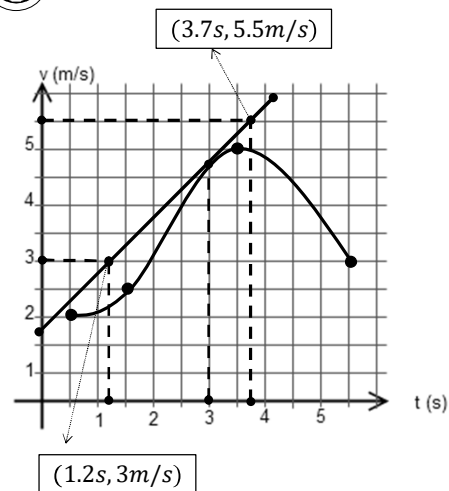
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Instantaneous Acceleration

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Velocity - time graph

$$\begin{aligned} \text{slope of the tangent} &= a \Big|_{t=3s} \\ &= \frac{\Delta v}{\Delta t} = \frac{5.5 - 3}{3.7 - 1.2} \\ &= \frac{2.5}{2} = 1.25 \text{ m/s}^2 \end{aligned}$$



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Integrating velocity \equiv Displacement

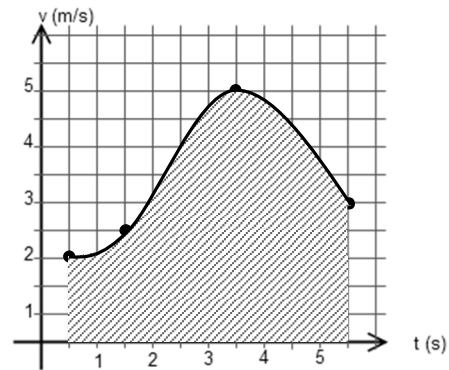
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Velocity – time graph

$$v = \frac{dx}{dt}$$

$$\Delta x = \int_{t_i}^{t_f} v dt$$

$\Delta x = \text{Area under } v - t \text{ graph}$



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Integrating acceleration \equiv Change in velocity

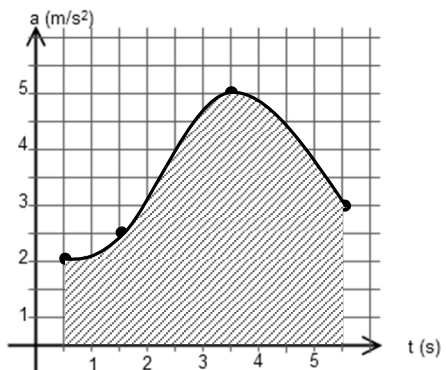
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acceleration – time graph

$$a = \frac{dv}{dt}$$

$$\Delta v = \int_{t_i}^{t_f} a dt$$

$\Delta v = \text{Area under } a - t \text{ graph}$



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Acceleration and Velocity, Directions

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- When an object's velocity and acceleration are in the same direction, the object is speeding up.
- When an object's velocity and acceleration are in opposite directions, the object is slowing down.
- When the object's velocity is constant, the acceleration is zero.
- When the object's acceleration is constant, NOTHING to conclude.
- Force and acceleration are both vectors and directed in the same direction.
- The word deceleration has the connotation of slowing down.

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Notes About Acceleration

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- Negative acceleration does not necessarily mean the object is slowing down.
 - If the acceleration and velocity are both positive, the object is speeding up.
 - If the acceleration and velocity are both negative, the object is speeding up.
 - If the acceleration and velocity are of opposite signs, the object is slowing down.

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Producing An Acceleration

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Various changes in a particle's motion may produce an acceleration.

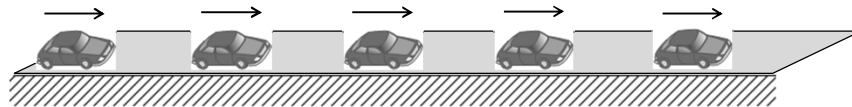
- The magnitude of the velocity vector may change.
- The direction of the velocity vector may change.
- Both may change simultaneously

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Constant Velocity

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- Images are equally spaced.
- The car is moving with constant positive velocity (shown by red arrows maintaining the same size).
- Acceleration equals zero.



→ velocity

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Acceleration and Velocity

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- Images become farther apart as time increases.
- Velocity and acceleration are in the same direction.
- Acceleration is uniform (violet arrows maintain the same length).
- Velocity is increasing (red arrows are getting longer).
- This shows positive acceleration and positive velocity.

→ acceleration
→ velocity

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Acceleration and Velocity

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- Images become closer together as time increases.
- Acceleration and velocity are in opposite directions.
- Acceleration is uniform (violet arrows maintain the same length).
- Velocity is decreasing (red arrows are getting shorter).
- Positive velocity and negative acceleration.

→ acceleration
→ velocity

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A Particle Under Constant Acceleration

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Constant acceleration indicates that at any instant during a time interval the instantaneous acceleration is the same as the average acceleration.

$$a = a_{avg}$$

$$a = \frac{v_f - v_i}{t_f - t_i}$$

Common practice is to let $t_i = 0$, $t_f = t$ and the equation becomes:

$$v_f = v_i + at$$

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Kinematic Equations

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- The kinematic equations can be used with any particle under uniform acceleration.
- The kinematic equations may be used to solve any problem involving one-dimensional motion with a constant acceleration.
- You may need to use two of the equations to solve one problem.
- Many times there is more than one way to solve a problem.

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Kinematic Equations

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| Equations | Missing |
|--------------------------------------|--|
| $v_f = v_i + at$ | Δx : displacement (m) |
| $v_f^2 = v_i^2 + 2a\Delta x$ | t : time (s) |
| $\Delta x = v_i t + \frac{1}{2}at^2$ | v_f : final velocity (m/s) |
| $\Delta x = v_f t - \frac{1}{2}at^2$ | v_i : initial velocity (m/s) |
| $\Delta x = \frac{1}{2}(v_i + v_f)t$ | a : acceleration (m/s ²) |

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When $a = 0$

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When the acceleration is zero,

$$v_f = v_i = v$$

$$x_f = x_i + vt$$

The constant acceleration model reduces to the constant velocity model.

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Freely Falling Objects

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- A freely falling object is any object moving vertically under the influence of gravity alone.
- We will neglect air resistance
- It is a motion in one dimension
- It is a motion with constant acceleration
- It does not depend upon the initial velocity of the object. Including:
 - Dropped (released from rest)
 - Thrown vertically (straight) down
 - Thrown vertically (straight) up

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Acceleration of Freely Falling Object

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- The acceleration of an object in free fall is directed downward, regardless of the initial motion.
- The magnitude of free fall acceleration is

$$g = 9.8 \text{ m/s}^2$$
- Let upward be positive
- Use the kinematic equations and:
 - replace the acceleration (a) with (-g).
 - replace the displacement (Δx) with (Δy)

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Equations – Freely Falling

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

| Equations | Missing |
|--------------------------------------|--------------------------------|
| $v_f = v_i - gt$ | Δy : displacement (m) |
| $v_f^2 = v_i^2 - 2g\Delta y$ | t : time (s) |
| $\Delta y = v_i t - \frac{1}{2}gt^2$ | v_f : final velocity (m/s) |
| $\Delta y = v_f t + \frac{1}{2}gt^2$ | v_i : initial velocity (m/s) |

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Equations – Freely Falling

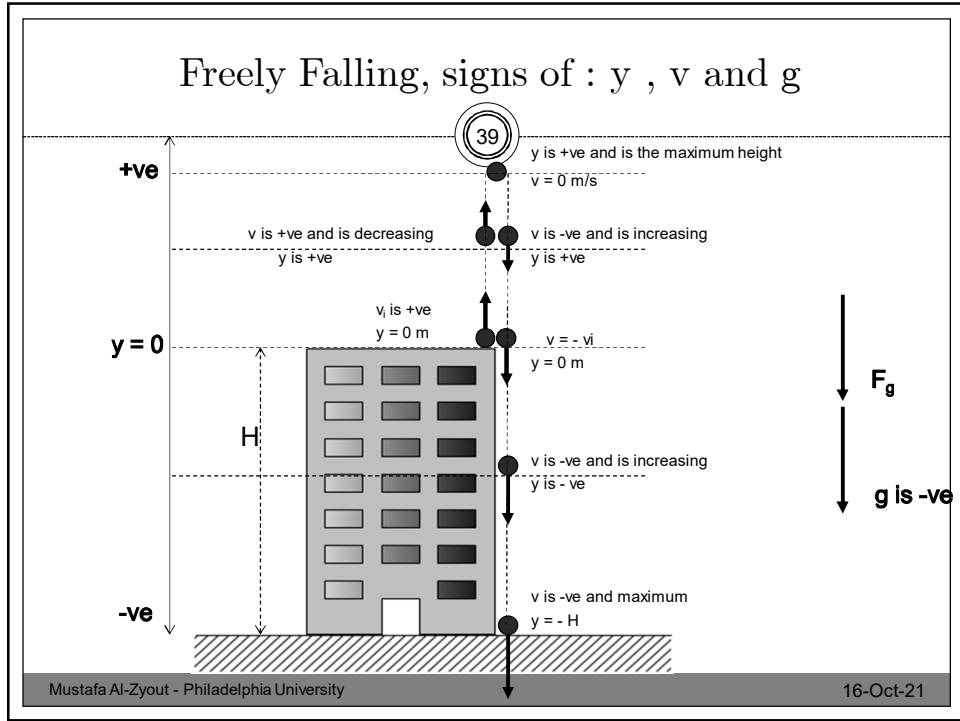
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NOTE : when applying kinematic equations:

- Consider the launching point as our reference point ($y_i = 0$). Therefore; the final position will be:
 - positive when the object above (y_i),
 - and negative when it is below (y_i).
- The velocity is:
 - positive while the object is moving upward,
 - negative while it is moving downward
 - and Zero at its maximum height.

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