

Chapter 2: Describing Motion Kinematics in One Dimension

Lecture 3
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Average Acceleration $\bar{a} = \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{t_f - t_i}$ acceleration depends on change in velocity
note that \bar{a} is defined over a time interval

Instantaneous Acceleration a
defined at a particular instant of time.

NOTE : average acc. = instantaneous acc.

$$\textcircled{1} \text{ when } \underline{a} \text{ is constant} \Rightarrow \bar{a} = a \\ \Rightarrow \bar{v} = \frac{1}{2}(v_i + v_f) , \bar{v} = \frac{\Delta x}{\Delta t}$$

$$\textcircled{2} \text{ when } \underline{v} \text{ is constant} \Rightarrow \bar{v} = v$$

For constant acceleration, we have five equations of motion :

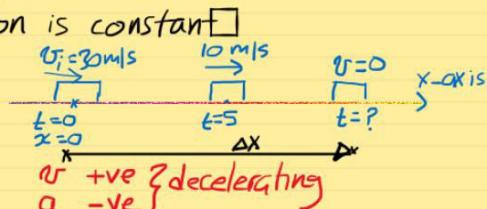
Equation	Missing Variable
$v_f = v_i + at$	x
$x_f - x_i = v_i t + \frac{1}{2}at^2$	v_f
$v_f^2 - v_i^2 = 2a(x_f - x_i)$	t
$x_f - x_i = v_f t - \frac{1}{2}at^2$	v_i
$x_f - x_i = \frac{1}{2}(v_i + v_f)t$	a

Example A car is moving at constant velocity (constant magnitude and direction) of 30 m/s on a horizontal road. Suddenly the driver applies the breaks. The car reaches a velocity of 10 m/s in 5 s. Assume the acceleration is constant.

Find ① its average acceleration.

$$\bar{a} = \frac{\Delta v}{\Delta t} = \frac{10 - 30}{5 - 0} = -4 \text{ m/s}^2$$

NOTE : $a = \bar{a} = -4 \text{ m/s}^2$.



② The time required for the car to stop from the moment the driver applies the breaks.

$$\text{stop: } v_f = 0 \Rightarrow$$

$$0 = 30 + (-4)t \Rightarrow$$

$$t = \frac{30}{4} = 7.5 \text{ s.}$$

$$v_f = v_i + at$$

Alternatively:

$$0 = 10 + (-4)t \Rightarrow t = \frac{10}{4} = 2.5 \text{ s.}$$

required time = $5 + 2.5 = 7.5 \text{ s}$ as before

when it has stopped.

③ The displacement of the car from the moment the driver applied the breaks.

$$v_f^2 - v_i^2 = 2a\Delta x \Rightarrow 0 - (30)^2 = 2(-4)\Delta x \Rightarrow \Delta x = 900/8 \text{ m.}$$

④ The position when it stops

$$\Delta x = x_f - x_i \Rightarrow 900/8 = x_f - 0 \Rightarrow x_f = \Delta x = \frac{900}{8} \text{ m.}$$

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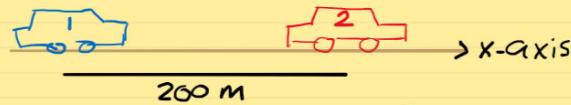
Example

In the figure Car 2 is moving at constant velocity of 30 m/s. Car 1 has an

$$v_i = 20 \text{ m/s}$$

$$a = 4 \text{ m/s}^2$$

$$v = 30 \text{ m/s}$$



initial velocity of 20 m/s when it is 200 m behind car 2. Car 1 accelerates at 4 m/s². How long does car 1 take to overtake car 2?

$$\text{For car 1 } x_f - x_i = v_i t + \frac{1}{2}at^2 \Rightarrow x_{if} - 0 = 20t + 2t^2$$

$$x_{if} = 20t + 2t^2 \quad \text{--- ①}$$

For car 2 $x_{2f} - 200 \leftarrow x_{2i} = 30t + \frac{1}{2}(0)t^2$

$$\therefore x_{2f} = 30t + 200 \quad \textcircled{2}$$

At moment car 1 overtakes car 2

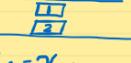
$$x_{1f} = x_{2f} \Rightarrow$$

$$20t + 2t^2 = 30t + 200$$

$$2t^2 - 10t - 200 = 0$$

$$t^2 - 5t - 100 = 0$$

$$a=1, b=-5, c=-100 \Rightarrow t = \frac{5 \pm \sqrt{25-4(1)(-100)}}{2} = \frac{5 \pm \sqrt{425}}{2}$$

looking from top

 $x_{1f} = x_{2f}$

$$\therefore t = \frac{5 + \sqrt{425}}{2} \approx 12.5 \text{ s.}$$

Free Fall

Moving under the effect of the force of gravity ONLY. Motion can be up, or down;

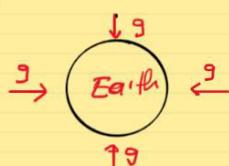
This is an example of motion with constant acceleration in one dimension, along the vertical axis.

Free fall acceleration $g = 9.81 \text{ m/s}^2$ towards the center of the earth.

Instead of x we use y .

How do we deal with direction?

$$\therefore t = \frac{5 + \sqrt{425}}{2} \approx 12.5 \text{ s.}$$



How do we deal with direction?

Conversion 1:

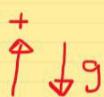
Take upwards as positive



→ any vector that points upwards is positive

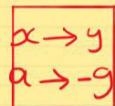
any vector that points downwards is negative

$$g = 9.81 \text{ m/s}^2 \downarrow \Rightarrow \text{use } a = -g$$



Five kinematics equations of motion become:

$$\begin{aligned} v_f &= v_i - gt \\ \Delta y &\quad y_f - y_i = v_i t - \frac{1}{2} g t^2 \\ &\quad v_f^2 - v_i^2 = -2g(y_f - y_i) \\ &\quad y_f - y_i = v_f t + \frac{1}{2} g t^2 \\ &\quad -\frac{1}{2} a t^2 \end{aligned}$$



$$g = 9.81 \text{ m/s}^2$$

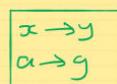
Conversion 2

Take downwards as positive \downarrow $g = 9.81 \text{ m/s}^2 \downarrow$

⇒ $a = g$ since g is vertically downwards towards the center of the earth.

⇒ 5 eqns. of motion become:

$$\begin{aligned} v_f &= v_i + gt \\ \Delta y &\quad y_f - y_i = v_i t + \frac{1}{2} g t^2 \\ v_f^2 - v_i^2 &= 2g(y_f - y_i) \\ y_f - y_i &= v_f t + \frac{1}{2} g t^2 \end{aligned}$$



$$\begin{aligned} v_f &= v_i + a t \\ \Rightarrow v_f &= v_i + g t \end{aligned}$$

Suppose \uparrow $\Rightarrow a = -g$
the positive direction
NOT direction of
acceleration.

v and a have different signs
⇒ deceleration.

$v_f = 0$
 $a = -g$
or $v > 0, a < 0$ and
 $v < 0, a < 0$ both have
negative similar signs
⇒ acc. in -ve direction.

NOTE: gravitation acceleration in this case (\uparrow)
is ALWAYS $a = -g$ at any instant.