PHYSICS INDUCTION
An institute of Science & Mathematics

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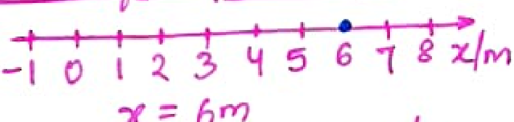
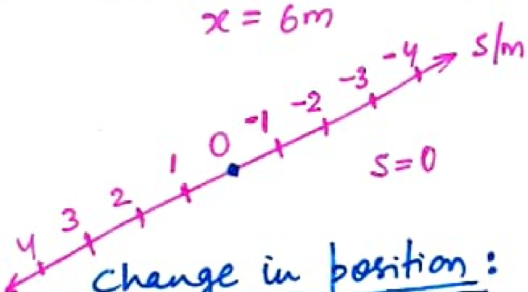
IB PHYSICS (SL) : NOTES : SPACE, TIME AND MOTION : KINEMATICS

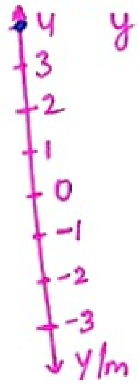
DISTANCE: How far an object travels. It's a scalar quantity. Unit – m.

DISPLACEMENT:– How far the object is, from its starting position, along with its direction. It's the change in position. It's a vector quantity. It describes both the magnitude and direction. Distance $\geq$ Displacement

The position of a particle is determined by the coordinate on the number line:



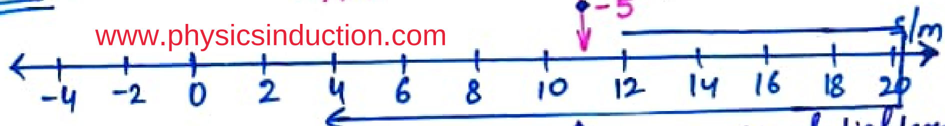




Distance – +ve
Displacement – +ve, –ve, 0
b/w 2 pts, unique value
Single valued fn of time

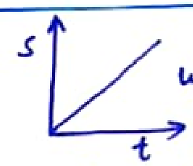
Change in position:

$$\Delta s = s_{final} - s_{initial}$$
$$= 4 - 12 = -8\,m$$



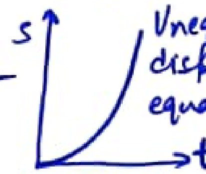
Initial Position	Final Position	Displacement	Direction of Motion
12m	28m	+16m	Towards increasing s
-6m	-14m	-8m	Towards decreasing s
10m	-5m	-15m	Towards decreasing s
-20m	-15m	+5m	Towards increasing s

Uniform Motion



equal displacement in equal intervals of time

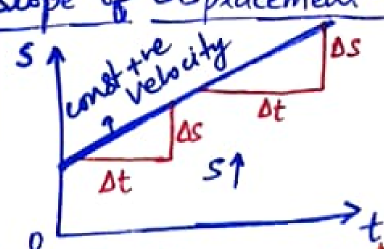
Non-Uniform Motion



Unequal displacement in equal intervals of time.

slope of distance – time graph: speed

slope of displacement – time graph: Velocity



slope : $\frac{\Delta s}{\Delta t}$

$v = \frac{s - s_i}{t}$

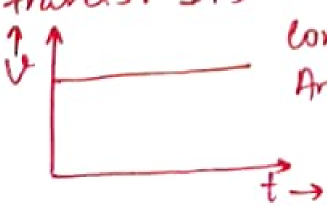
$\Rightarrow \boxed{s = s_i + vt}$

SPEED: how fast an object travels
It's a scalar quantity, Unit – m/s

VELOCITY: how fast an object travels & in which direction it travels. It's a vector quantity. Unit – m/s.

speed – +ve, zero
Velocity – +ve, –ve, 0

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



Constant Velocity
Area under v-t graph: Displacement

VELOCITY = SPEED + DIRECTION

constant Negative Velocity

AVERAGE SPEED :-

(i) $\overset{s}{\underset{t_1 \qquad t_2}{\longrightarrow}}$ $\quad V_{av} = \dfrac{s}{t_2 - t_1}$ $\quad V_{av} = \dfrac{\text{Total distance}}{\text{Total time taken}}$

(ii) $\dfrac{s_1}{v_1}\;\dfrac{s_2}{v_2}\;\dfrac{s_3}{v_3}$ - - - - - -

Total dist $= s_1 + s_2 + s_3 + ----$

$t = \dfrac{s_1}{v_1} + \dfrac{s_2}{v_2} + \dfrac{s_3}{v_3} + ----$

$$\therefore V_{av} = \frac{s_1 + s_2 + s_3 + ------}{\frac{s_1}{v_1} + \frac{s_2}{v_2} + \frac{s_3}{v_3} + -----}$$

(iii) $\dfrac{s}{v_1}\;\dfrac{s}{v_2}$ $\quad V_{av} = \dfrac{2V_1V_2}{V_1 + V_2}$ (Harmonic Mean)

(iv) $\dfrac{V_1}{t_1}\;\dfrac{V_2}{t_2}\;\dfrac{V_3}{t_3}$ - - - - - -

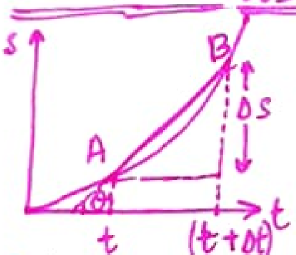
$d = V_1t_1 + V_2t_2 + V_3t_3 + ------$

$V_{av} = \dfrac{V_1t_1 + V_2t_2 + V_3t_3 + -----}{t_1 + t_2 + t_3 + -----}$

If $t_1 = t_2 = --- = t_n = t$

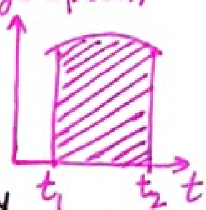
$\therefore V_{av} = \dfrac{V_1 + V_2 + ---}{n}$ (Arithematic Mean)

INSTANTANEOUS SPEED :- $\lim\limits_{\Delta t \to 0} \dfrac{\Delta s}{\Delta t} = \dfrac{ds}{dt}$

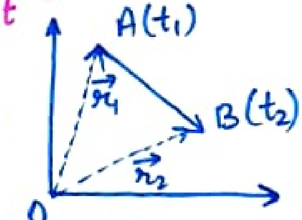


As, $\Delta t \to 0$, chord AB b'comes the tangent & Average speed, $\dfrac{\Delta s}{\Delta t}$ b'comes the slope $\dfrac{ds}{dt}$.

$$s = \int_{t_1}^{t_2} v\,dt$$



AVERAGE VELOCITY :



$\vec{OA} + \vec{AB} = \vec{OB}$

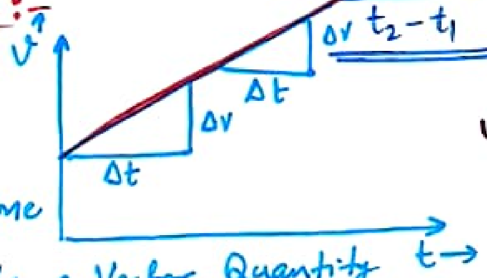
$\vec{V}_{av} = \dfrac{\vec{AB}}{t_2 - t_1} = \dfrac{\vec{r}_2 - \vec{r}_1}{t_2 - t_1}$

Equal change in velocity in equal intervals of time

$v\uparrow \Rightarrow a = +ve$

INSTANTANEOUS VELOCITY :-

$\vec{V} = \lim\limits_{\Delta t \to 0} \dfrac{\Delta \vec{r}}{\Delta t} = \dfrac{d\vec{r}}{dt}$



Unequal change in velocity in equal intervals of time

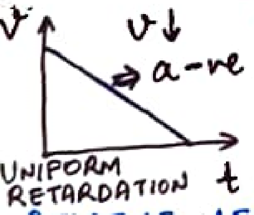
ACCELERATION: Rate of change of velocity with time

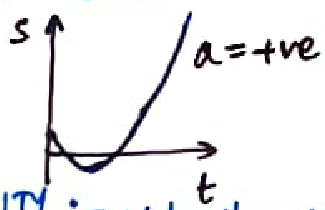
$a = \lim\limits_{\Delta t \to 0} \dfrac{\Delta v}{\Delta t}$ $\qquad$ It's a Vector Quantity

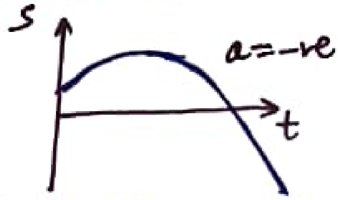
Unit – m/s^2

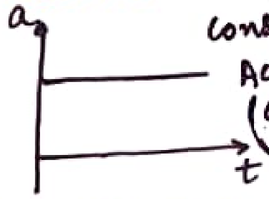
It's the gradient of velocity-against-time graph.

$a = \dfrac{\Delta v}{\Delta t} = \dfrac{v - u}{t - 0} \Rightarrow \boxed{V = u + at}$









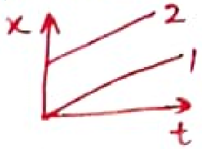
constant Acceleration (a-+ve constant)

RELATIVE VELOCITY :-

Velocity with which one object moves w.r.t. the other object. $\quad V_{12} = V_1 - V_2$, $V_{21} = V_2 - V_1$

If $V_1 = V_2$

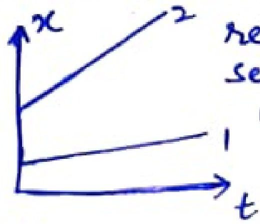
$(V_2 - V_1 = 0)$



constant distance apart

If $V_2 > V_1$

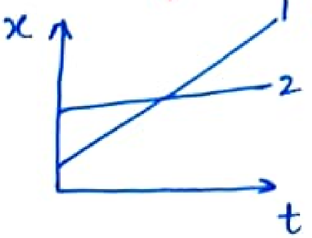
$(V_2 - V_1 = +ve)$



relative separation increases by $(V_2 - V_1)$ after each unit of time

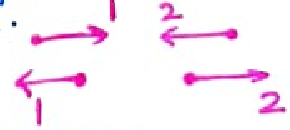
If $V_1 > V_2$

$(V_2 - V_1 = -ve)$



separation will go on decreasing by $(V_1 - V_2)$ after each unit of time.

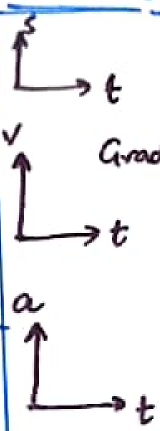
$\vec{V}_{12} = \vec{V}_1 - \vec{V}_2$



$V_{12} = V_1 + V_2$

MEANING OF THE GRADIENT (SLOPE) AND AREA OF DIFFERENT MOTION GRAPHS

	GRADIENT	AREA
Position against time (s-t)	Velocity	–
Velocity against time (v-t)	Acceleration	Change in Position i.e. Displacement
Acceleration against time (a-t)	–	Change in Velocity i.e., Acceleration



Gradient ⇓ Derivative

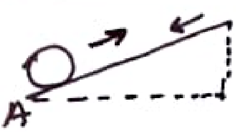
Integral ⇑

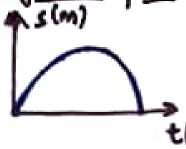
Ex: If you have $v(t)$ and you want to find Acceleration. $a(t) = \frac{dv}{dt}$

Ex: If you start with $v(t)$ & you want displacement $s(t) = \int v(t)dt$

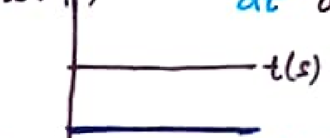
Ex: If you start with $s(t)$, & you want velocity. $v(t) = \frac{ds}{dt}$

Ex: Roll a can of soup up an incline (A→B→A)



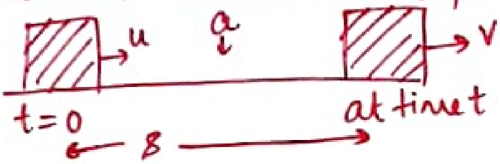


$v(t) = \frac{ds}{dt}$

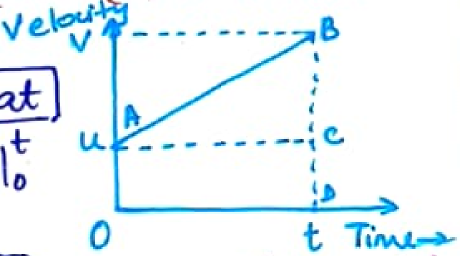


$a(t) = \frac{dv}{dt} = \frac{d^2s}{dt^2}$

EQUATIONS OF KINEMATICS :– used only for motion on a straight line with constant acceleration. (If the initial posⁿ is zero, Δs may be replaced by just s)



(i) $v = u + at$ (ii) $s = ut + \frac{1}{2}at^2$ (iii) $v^2 - u^2 = 2as$



First Eqⁿ of Motion :–

$a = \frac{dv}{dt} = \frac{v-u}{t-0} \Rightarrow \boxed{v = u + at}$

OR $\int_u^v dv = \int_0^t a\,dt \Rightarrow v\Big|_u^v = a\,t\Big|_0^t$

$\Rightarrow v - u = at$

$\Rightarrow \boxed{v = u + at}$

Second Eqⁿ of Motion:

s = Area Under Curve

$\Rightarrow s = ar(ABCDOA)$

$= ar(ACDO) + ar(\Delta ABC)$

$= OA \times OD + \frac{1}{2} \times AC \times BC$

$\Rightarrow s = ut + \frac{1}{2}.t(v-u)$ $(\because v - u = at)$

$\Rightarrow \boxed{s = ut + \frac{1}{2}at^2}$

OR

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

$\Rightarrow ds = v\,dt = (u + at)\,dt$

$\int_0^s ds = \int_0^t (u+at)\,dt$

$\Rightarrow [s]_0^s = u[t]_0^t + \frac{1}{2}a[t^2]_0^t$

$\Rightarrow \boxed{s = ut + \frac{1}{2}at^2}$

Third Eqⁿ of Motion

$s = ar(\text{trapezium } ABDO)$

$s = \frac{1}{2}(OA + BD) \times AC$

$\Rightarrow s = \frac{1}{2}(u+v).t$ $\left\{ \because v = u + at \Rightarrow t = \frac{v-u}{a} \right\}$

$\Rightarrow s = \frac{1}{2}(v+u)\left(\frac{v-u}{a}\right)$

$\Rightarrow 2as = v^2 - u^2 \Rightarrow \boxed{v^2 - u^2 = 2as}$

OR

$a = \frac{dv}{dt} = \frac{dv}{ds} \times \frac{ds}{dt} = \frac{dv}{ds} \times v$

$\Rightarrow a\,ds = v\,dv$

$\Rightarrow a\int_0^s ds = \int_u^v v\,dv$

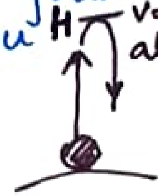
$\Rightarrow a[s]_0^s = \left[\frac{v^2}{2}\right]_u^v$

$\Rightarrow a(s-0) = \frac{1}{2}(v^2 - u^2)$

$\Rightarrow \boxed{v^2 - u^2 = 2as}$

$\vec{v}.\vec{v} = \vec{u}.\vec{u} + 2\vec{a}.\vec{s}$

$u = 0$ object falls from a height



$v = 0$ at H

ACCELERATION OF FREE FALL : Acceleration due to gravity : A special acceleration: g

$a = g = 9.8\,m/s^2$ (directⁿ → Vertically downwards)

$\approx 10\,m/s^2$

↑ $g = -ve$ upward

↓ $g = +ve$ downward

$s = h$ $v = u + gt$

$h = ut + \frac{1}{2}gt^2$, $v^2 - u^2 = 2gh$

FLUID RESISTANCE :- Whenever a body moves through a fluid (g or l) it experiences a fluid resistance force that is directed opposite to the velocity.

$F = kv$, for low speeds

$F = kv^2$, for high speeds

F increases with increasing speed.

* The faster an object moves, the greater the no. of collisions with air molecules. This increases friction, and the air molecules bouncing off gain even more kinetic energy.

As $v\uparrow$, $F\uparrow$ eventually, F = weight

$\Rightarrow a = 0 \Rightarrow v$ = constant $\rightarrow$ Terminal speed, v_T

$\therefore \; mg = kv_T \Rightarrow \boxed{v_T = \frac{mg}{k}}$