Introduction to Mechanics

What is Mechanics ?

The study of the motion of objects (through Equations), and the related concepts of force and energy, form the field called mechanics.

Mechanics

Kinematics ↔ *Dynamic*

the link is ***a***

- the description of **how** objects move

- deals with **force** and **why** objects move (CH.3)

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Kinematics

Kinematics : the description of how objects move.

➔ Kinematics in one dimension : describing an object that moves along a straight line path, which is ***one dimensional motion***.

➔ Kinematics in two dimensions : the description of the motion of objects that ***move in paths in two (or three) dimensions***.

Dynamics

Dynamics : deals with force and why objects move as they do.

In this part we will solve the following questions :

➔ What makes an object at rest begin to move ?
➔ What causes a body to accelerate or decelerate ?
➔ What is involved when an object moves in a circle ?

We can answer in each case that a ***FORCE*** is required.

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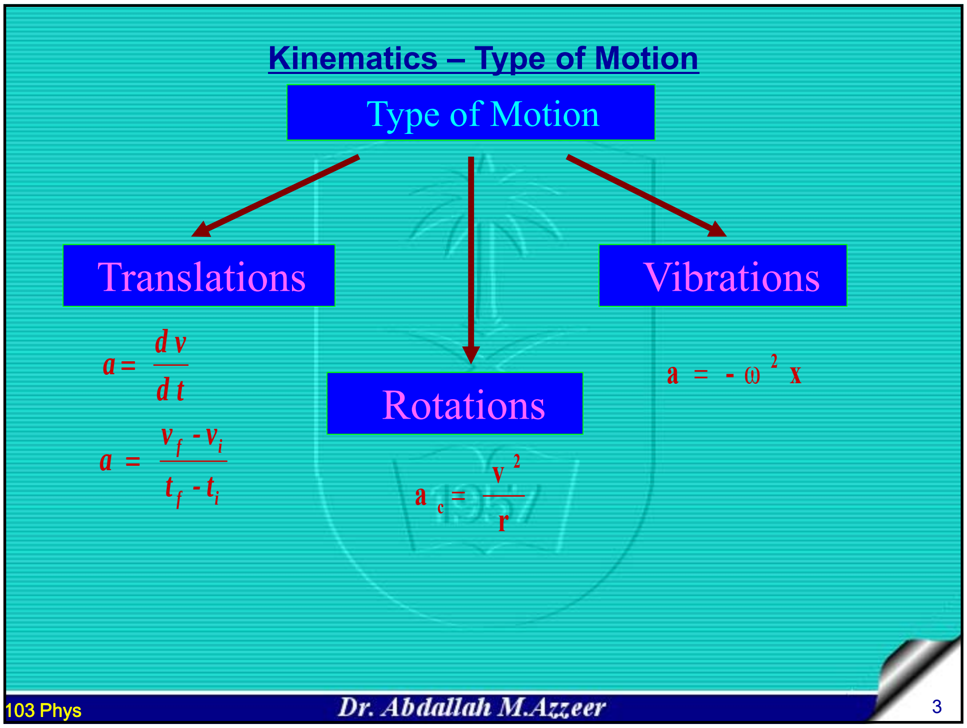
Kinematics – Type of Motion
Type of Motion
Translations
Vibrations
Rotations
$a = \frac{dv}{dt}$
$a = \frac{v_f - v_i}{t_f - t_i}$
$a_c = \frac{v^2}{r}$
$a = -\omega^2 x$
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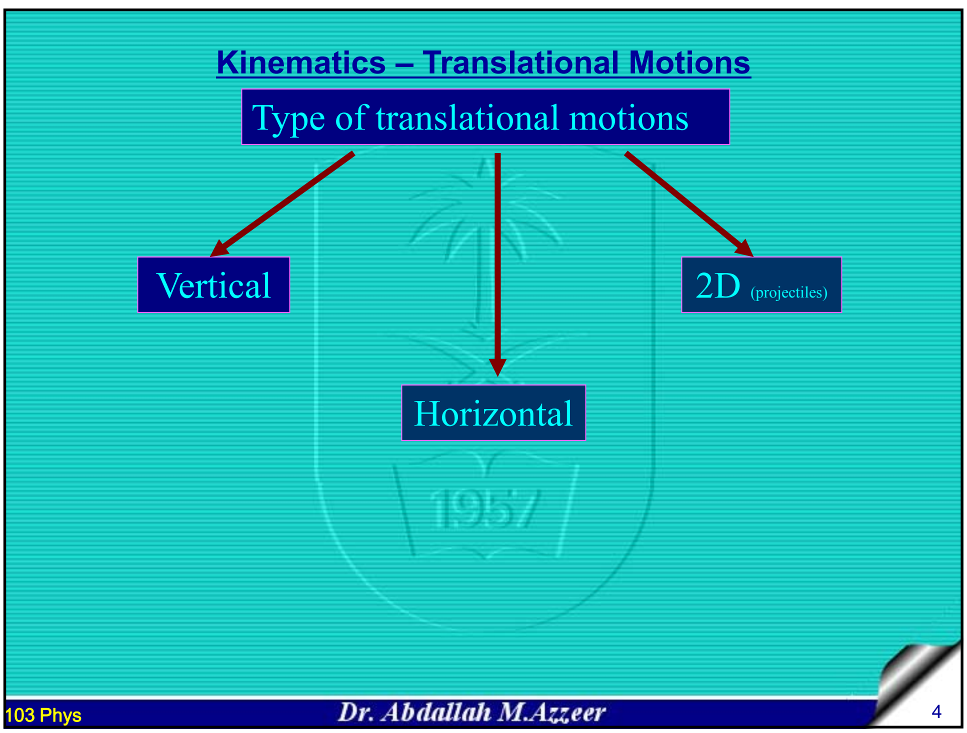
Kinematics – Translational Motions
Type of translational motions
Vertical
2D (projectiles)
Horizontal
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Kinematics – Terms and Concepts

Some important terms which you must know !

- Reference Frames
- Displacement
- Distance
- Speed
- Average Velocity
- Instantaneous Velocity
- Average Acceleration
- Instantaneous Acceleration

1. Reference Frames

Any measurement of position, distance or speed must be made with respect to a frame of reference.

أهمية وجهة النظر

إن ما يلاحظه كل منا يعتمد على وجهة نظره

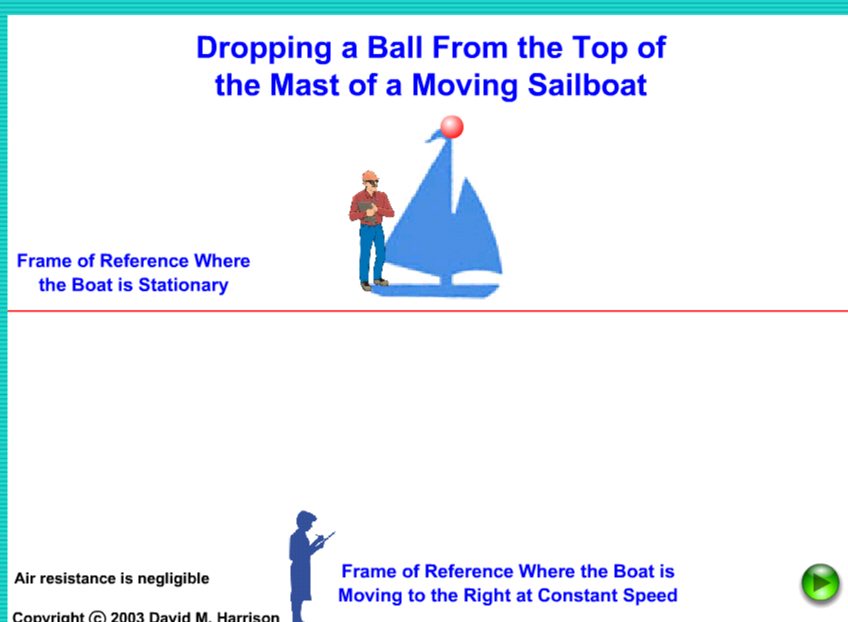
فمثلاً : نفترض عربة قطار تسير بسرعة ثابتة مقدارها 30 m/s في إتجاه الشمال وبداخل هذه العربة رجل يقذف كرة بسرعة ثابتة مقدارها 1 m/s في إتجاه الشمال، ماهي سرعة الكرة ؟

الإجابة على هذا السؤال قد تكون سهلة ولكن ليس هناك إجابة واحدة ...... كيف؟

الإجابة الصحيحة تعتمد على مرجع معين أو راصد..... فهناك إجابتين:

1- بالنسبة الى أرضية العربة (الرجل داخل العربة) تكون سرعة الكرة مساوية لـــ 1 m/s شمالاً

2- بالنسبة الى راصد يقف على الأرض خارج العربة تكون سرعة الكرة مســــــــاوية 1 m/s شمالا + 3 m/s شمالا أو 4 m/s بإتجاه الشمال



Reference Frames, Coordinate Systems

- Every measurement must be made with respect to a reference frame.
- Usually, speed is relative to the Earth.
- When specifying speed, always specify the frame of reference unless its obvious (“with respect to the Earth”).
- Distances are also measured in a reference frame.
- When specifying speed or distance, we also need to specify DIRECTION.

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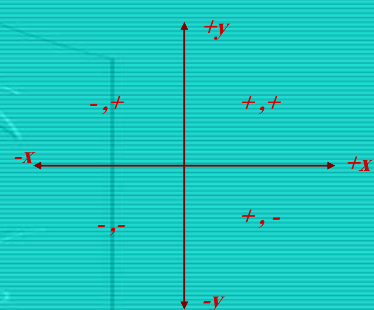
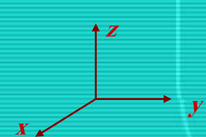
Coordinate Axes

- Define reference frame using a standard coordinate axes.
- 2 Dimensions (x,y)
- Note, if its convenient, could reverse + & - !



- 3 Dimensions (x,y,z)



- Define direction using these.

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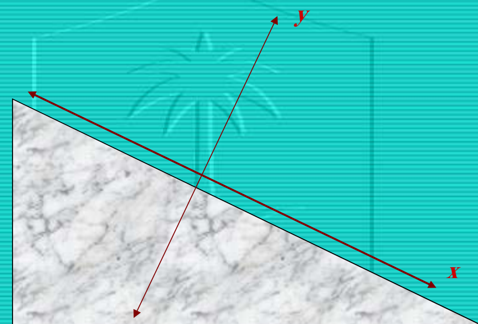
- For inclined plane problems (later), tilted axes will be used (for convenience!):



Distance and Displacement

Distance:

The length of the actual path or total path length

Example,

Jeddah is ~1000 km away from Arriyadh.

Displacement:

The change in position of the object.

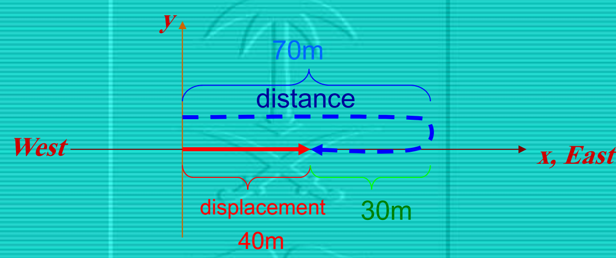
$\Delta x = x_f - x_i$, Δx means the change in x (position) which is the displacement.

A vector quantity

Distance Vs Displacement

Example:

A person walking 70 m to the east and then turning around and walking back (west) a distance of 30 m.



Total distance = 100 m

Displacement = $x_f - x_i = 70\ \text{m} - 30\ \text{m} = 40\ \text{m}$

Average Speed:

Average Speed is defined ***as the distance travelled along its path divided by the time it takes to travel this distance***,

$$average\ \text{speed} = \frac{\text{distance travelled}}{time\ \text{elapsed}}$$

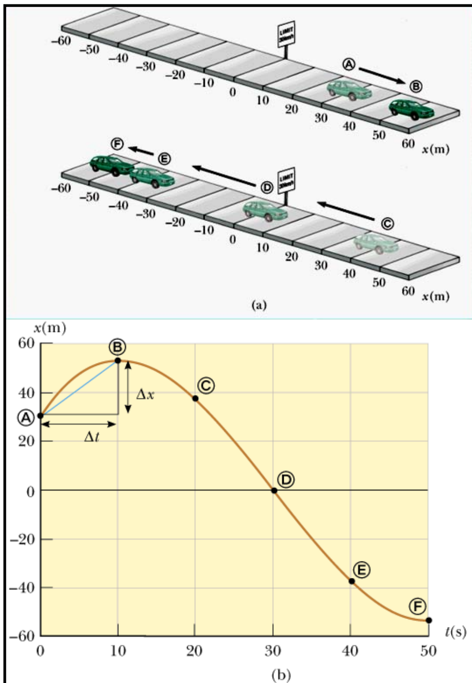
It is a scalar quantity, with unit (ms^{-1})

Average Velocity

Average velocity is defined ***as the displacement divided by the elapsed time***

$$average\ \ velocity\ \bar{v} = \frac{displacement}{time\ \ elapsed} = \frac{\Delta x}{\Delta t} = \frac{x_f - x_i}{t_f - t_i}$$

It is a vector quantity, with unit (ms^{-1})



Example 2.1:

The position of a car is measured every ten seconds relative to zero.

A.30 m
B.52 m
C.38 m
D.0 m
E.37 m
F.-53 m

Find the displacement, average velocity and average speed between positions A and F.

Instantaneous Velocity:

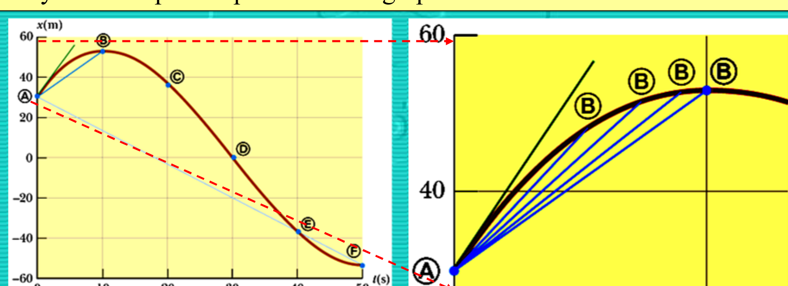
The instantaneous velocity is **the velocity at any instant of time.**

In general the ***instantaneous velocity at any moment is defined as the average velocity over an infinitesimally short time interval.***

$$v_x = \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t} = \frac{dx}{dt}$$

Instantaneous velocity is the derivative of x with respect to t, dx/dt!

Velocity is the slope of a position-time graph!



Example 2.3

A particle moves along the x-axis. Its coordinate varies with time according to the expression

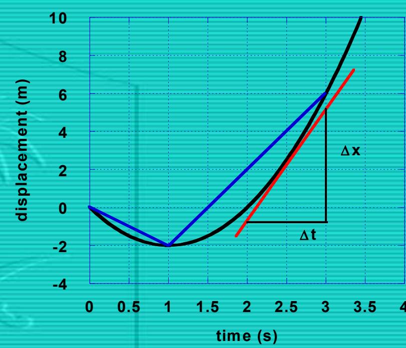
$$x = -(4\ m/s)\cdot t + (2\ m/s)\cdot t^2$$

A. Determine the displacement of the particle in the time intervals t=0 to t=1 s and t=1 s to t=3 s.

B. Calculate the average velocity during these two time interval.

C. Find the instantaneous velocity of the particle at t=2.5 s.

D. What is the instantaneous velocity at 1 s (graph).



Example: Velocity

Assume the earth is in circular orbit about the sun, moving at a constant speed. What are the earth's

i) average velocity

ii) average speed

iii) instantaneous velocity ?

Given that the radius of the earth's orbit is $1.5X10^{11}$m

Solution:

i) average velocity

$$\bar{v} = \frac{displacement}{time\ elapsed} = \frac{\Delta x}{\Delta t} = \frac{x_f - x_i}{t_f - t_i}$$

$$= \frac{0}{T} = 0\ ms^{-1}$$

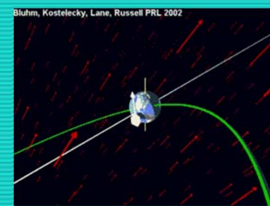
because, in one full cycle, the displacement of earth from original point is zero (earth reaches the initial point again)

ii) Average speed

$$\bar{v}_s = \frac{distance\ travelled}{time\ elapsed}$$

but, $d = 2\pi r = 2\pi\ (1.5\times10^{11}m) = 9.4\times10^{11}m$

$$\bar{v}_s = \frac{9.4\times10^{11}m}{(365.25)(24)(60)(60)} = 2.98\times10^{4}ms^{-1}$$



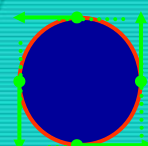
iii) Instantaneous velocity

Because the earth are orbit around the sun at constant speed, and the average speed is given in (ii) above,

thus,

magnitude of v : $2.98 \times 10^4\ ms^{-1}$

direction : tangent to the path at each instant.



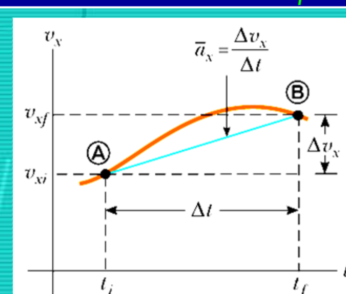
ACCELERATION

Average Acceleration

Acceleration specifies **how rapidly the velocity of an object is changing.** Average acceleration is defined as the change in velocity divided by the time taken to make this change

$$\text{average acceleration } \bar{a}_x = \frac{change\ of\ velocity}{time\ elapsed} = \frac{\Delta v_x}{\Delta t} = \frac{v_{xf} - v_{xi}}{t_f - t_i}$$

(a)

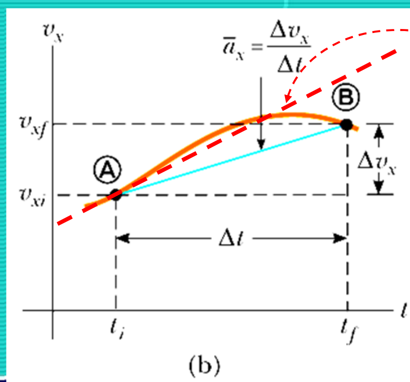


(b)

Instantaneous Acceleration:

The instantaneous acceleration is the acceleration at any instant of time. In general the *instantaneous acceleration at any moment is defined as the average acceleration over an infinitesimally short time interval*

$$\textit{instantaneous acceleration } a_x = \lim_{\Delta t \to 0} \frac{\Delta v_x}{\Delta t} = \frac{dv_x}{dt}$$



$$a_x \equiv \lim_{\Delta t \to 0} \frac{\Delta v_x}{\Delta t} = \frac{dv_x}{dt}$$

Units: m/sec^2

Because $v_x = dx/dt$, the acceleration can also be written as:

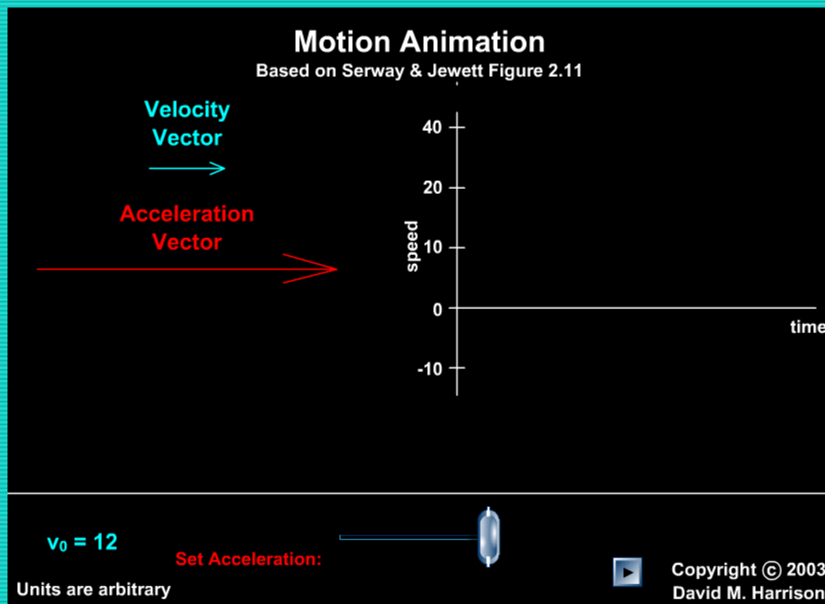
$$a_x \equiv \frac{dv_x}{dt} = \frac{d}{dt}\left(\frac{dx}{dt}\right) = \frac{d^2x}{dt^2}$$

Conceptual Question #1

- Velocity and acceleration are both vectors (they have magnitude & direction).
- *Are the velocity and the acceleration always in the same direction?*

NO!!•

READ EXAMPLES 2.4 & 2.5 in the Textbook



Pervious Final question

A runner runs around a track consisting of two parallel lines 96m long connected at the ends by tow semicircles with a radius of 49m. If he completes one lap in two minutes, then his average speed is:

A. 1.6 m/s
B. 4.2 m/s
C. 2.9 m/s
D. 0 m/s