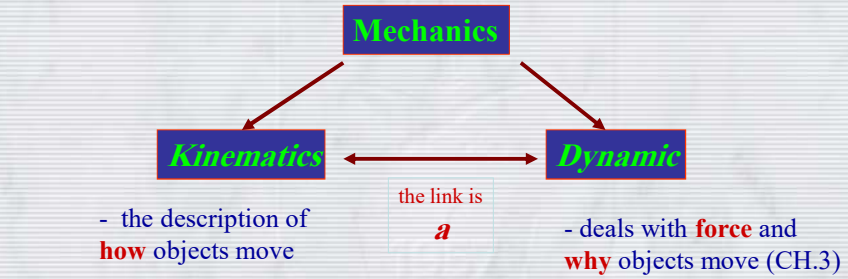
Introduction to Mechanics

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**.



- the description of **how** objects move

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

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***.

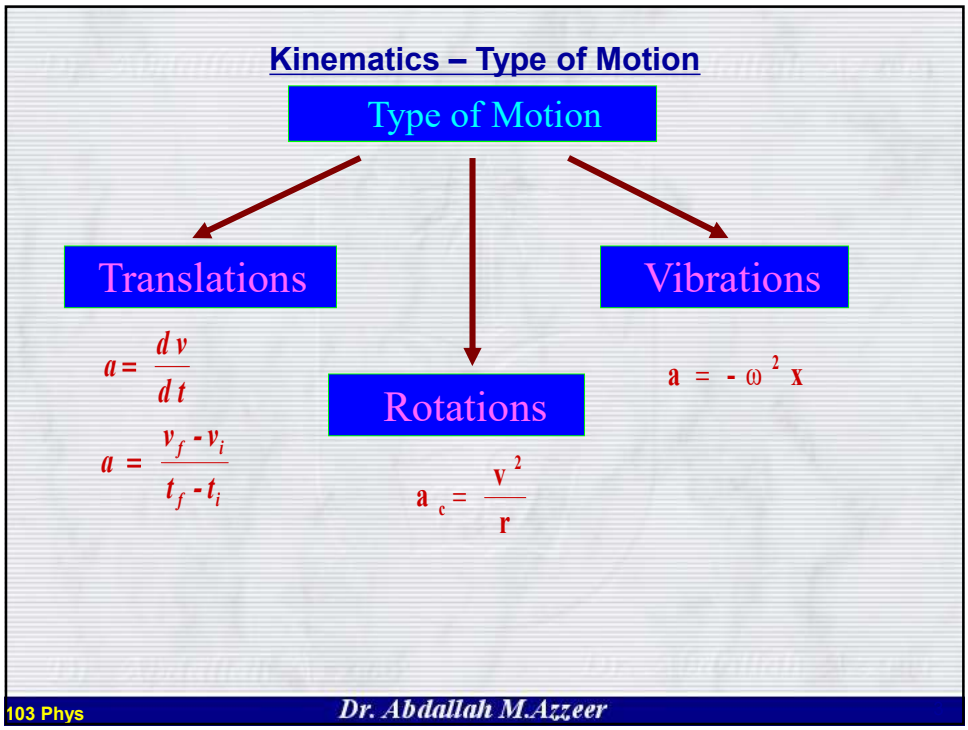
➔ Kinematics in two dimensions : the description of the motion of objects that ***move in paths in two (or three) dimensions***.

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.


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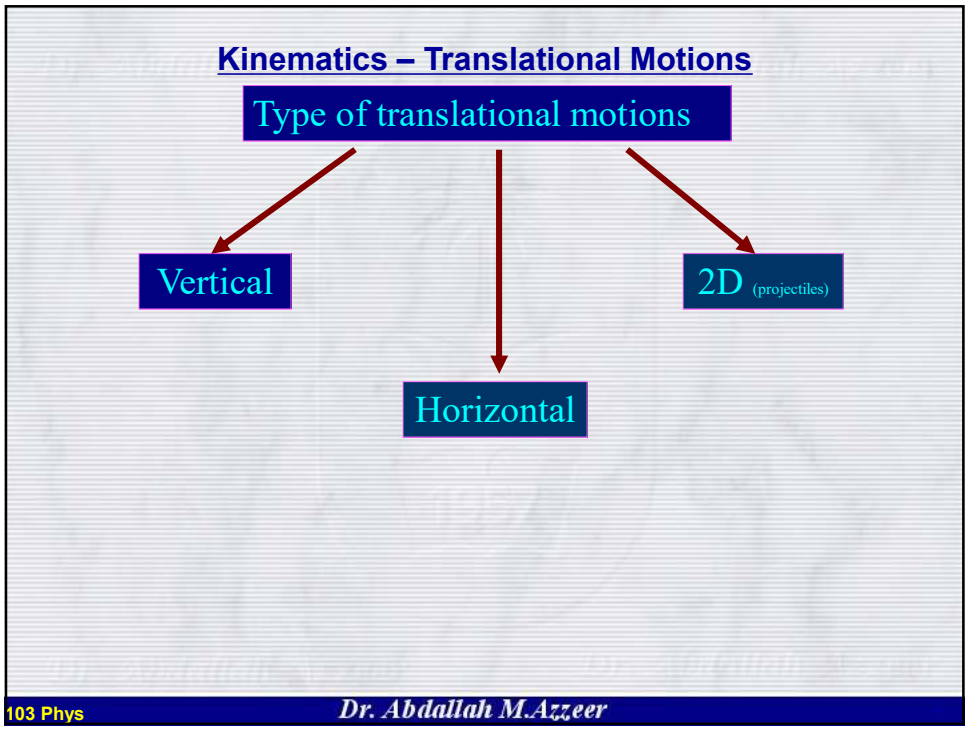
Kinematics – Translational Motions
Type of translational motions
Vertical
Horizontal
2D (projectiles)
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Kinematics – Terms and Concepts

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.

اختبار فصلي واحد فقط حضوريا من 21:30 الى23:30 مساء

	التاريخ			
اليوم	هجري	ميلادي	المقرر	Day
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1443/9/5هـ 2022/4/6 م	فيز 103	9:30 م الى 11:30 م

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أهمية وجهة النظر

إن ما يلاحظه كل منا يعتمد على وجهة نظره

فمثلاً : نفترض عربة قطار تسير بسرعة ثابتة مقدارها 3 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 مســـــــاوية 1 m/s شمالا + 3 m/s شمالا أو 4 m/s بإتجاه الشمال

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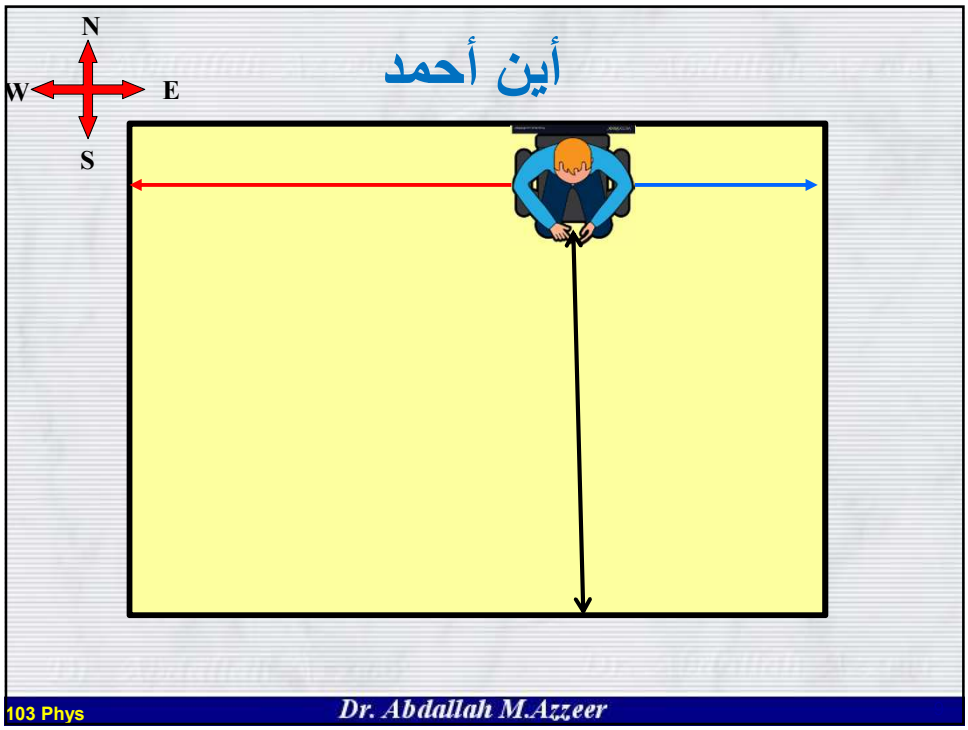
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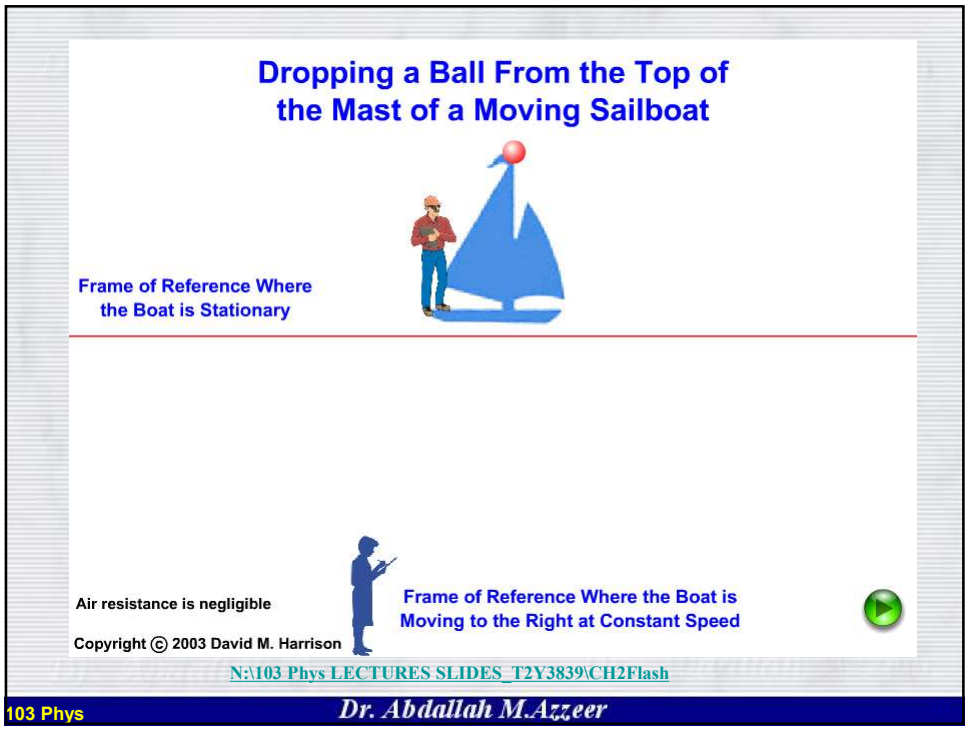
Dropping a Ball From the Top of the Mast of a Moving Sailboat
Frame of Reference Where the Boat is Stationary
Air resistance is negligible
Copyright © 2003 David M. Harrison
Frame of Reference Where the Boat is Moving to the Right at Constant Speed
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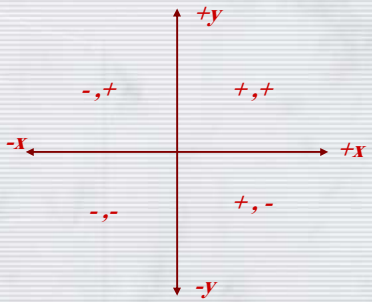
Reference Frames, Coordinate Systems

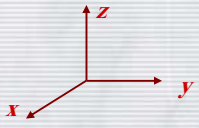
- Every measurement must be made with respect to a **reference frame**.
- Usually, speed is relative to the Earth.
- When specifying speed, always specify the frame of reference unless its obvious ("with respect to the Earth").
- Distances are also measured in a reference frame.
- When specifying speed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

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.

- 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.

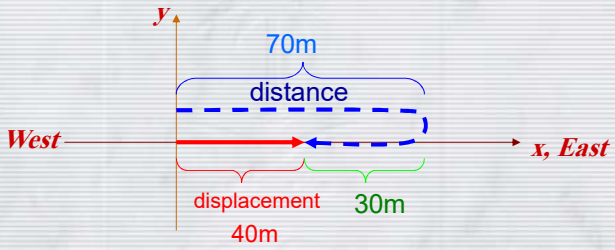
$\Delta x = x_f - x_i$, Δx means the **change in x (position)** which is the displacement.

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 = $x_f - x_i = 70\ m - 30\ m = 40\ m$

Average Speed:

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

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

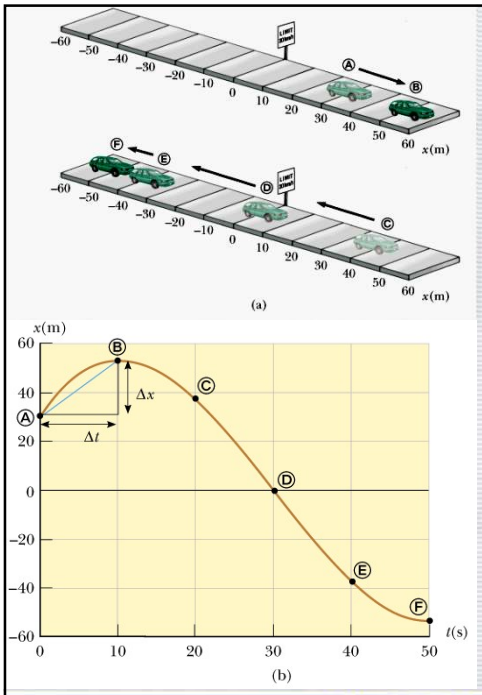
It is a scalar quantity, with unit (ms^{-1})

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.

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Instantaneous Velocity:

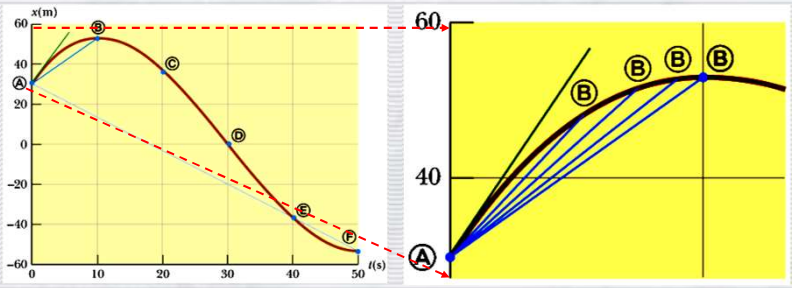
The instantaneous velocity is **the velocity at any instant of time**.

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!



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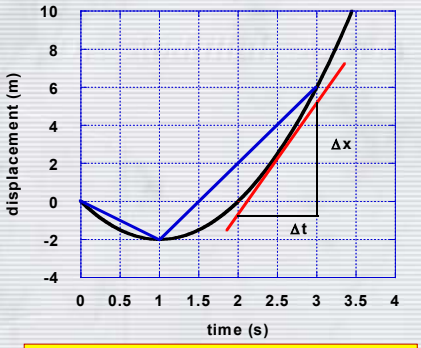
Example 2.3

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).



(a) x(t=0)=0
x(t=1)=-4+2= -2 m
$\Delta x = x_2 - x_1$ = -2 – 0 = -2 m
x(t=3) = -4×3 + 2×9 =6 m
$\Delta x = x_2 - x_1$ = 6-(-2)= 8 m
(b) $\overline{v} = \Delta x/\Delta t$= -2/1= -2 m/s
$\overline{v} = \Delta x/\Delta t$=8/2=4 m/s
(c) v(t)=dx/dt= -4 + 2(2) t
for t = 2.5 s v= 6 m/s
(d) v(t)=dx/dt= -4 + 2(2) t
v(t=1) = 0 m/s

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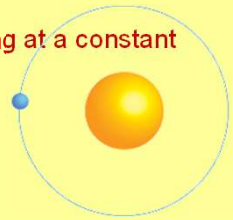
Example: Velocity

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

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

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

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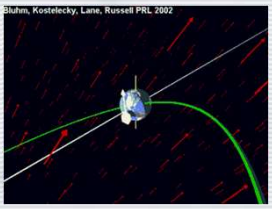
ii) Average speed



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

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

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

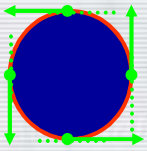
iii) Instantaneous velocity

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.

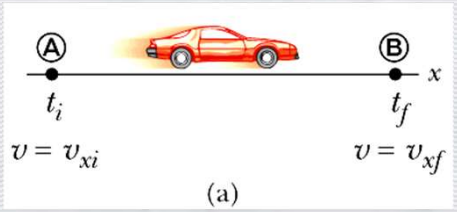


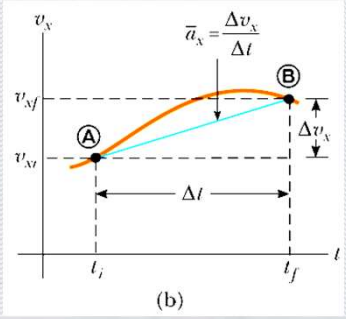
ACCELERATION

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

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

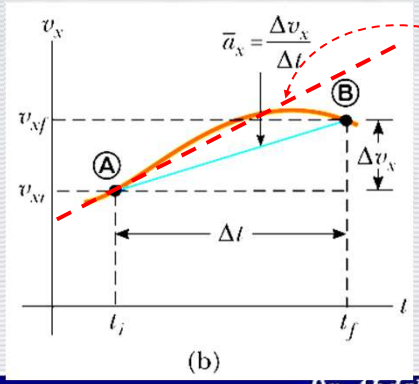




Instantaneous Acceleration:

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***

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



$$a_x \equiv \lim_{\Delta t \to 0} \frac{\Delta v_x}{\Delta t} = \frac{dv_x}{dt}$$ Units: m/sec^2

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

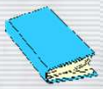
$$a_x \equiv \frac{dv_x}{dt} = \frac{d}{dt}\left(\frac{dx}{dt}\right) = \frac{d^2x}{dt^2}$$

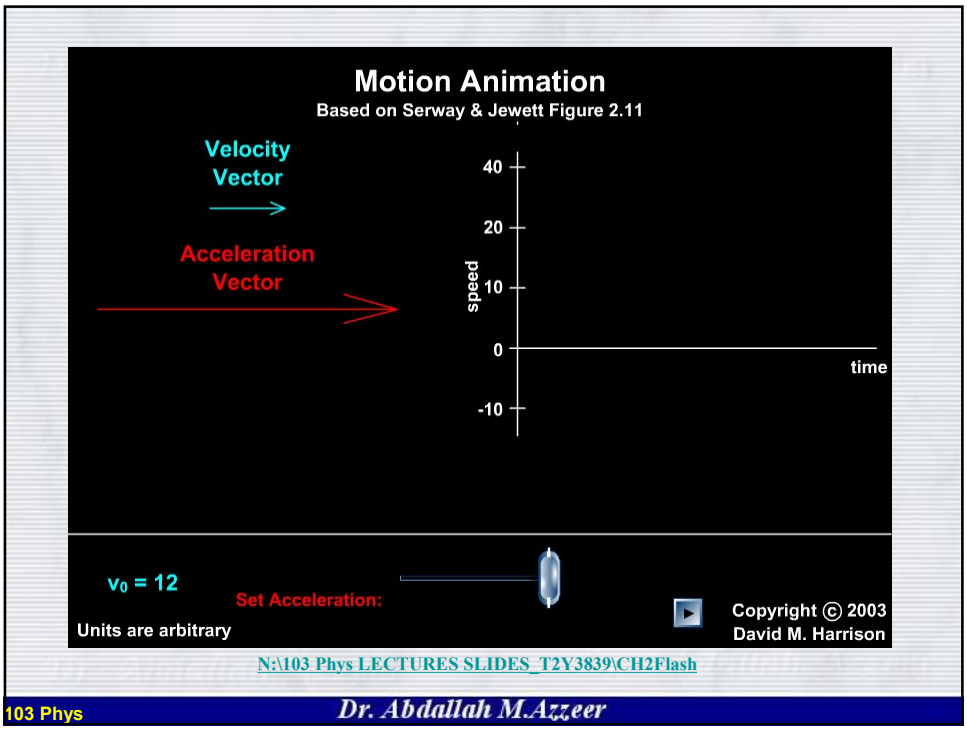
Conceptual Question #1

- 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

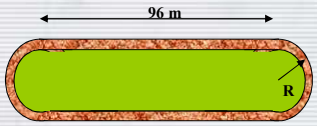




Pervious Final question

A runner runs around a track consisting of two parallel lines 96 m long connected at the ends by two semicircles with a radius of 49 m. 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



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