Department of Biomedical Engineering

Subject : Physics

Grade: 1th Class

Lecture :2 Motion of one and two dimensions

Dr. Haleemah Jaber Mohammed

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Motion

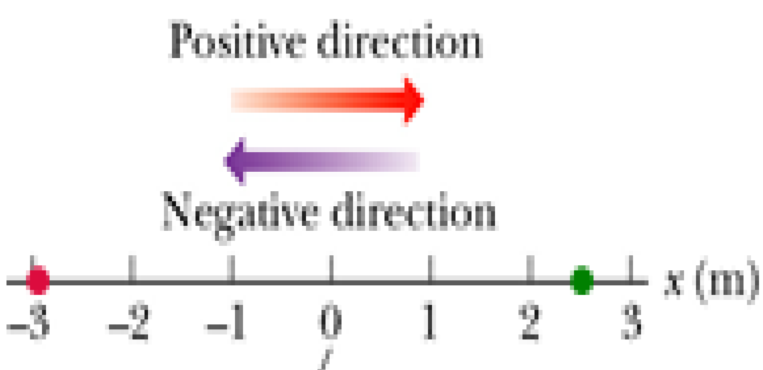
- What is Motion in Physics?

In physics, the **motion is the change in position of an object with respect to its surroundings in a given interval of time.** The motion of an object with some mass can be described in terms of the following:

- **Distance**
- **Displacement**
- **Speed**
- **Velocity**
- **Time**
- **Acceleration**

One Dimensional Position

- Motion can be defined as the change of position over time.
- How can we represent position along a straight line?
- Position definition:
  - Defines a starting point: origin ($x = 0$), x relative to origin
  - Direction: positive (right or up), negative (left or down)
  - It depends on time: $t = 0$ (start clock), $x(t=0)$ does not have to be zero.
- Position has units of [Length]: meters.



$x = +2.5$ m

$x = -3$ m

We use the following variables to describe motion in one dimension: position, displacement, distance, speed, velocity, and acceleration. You'll want to know the meaning of each of these. Knowing how to describe where an object is in space will be essential throughout your study of physics. The first variable we use to understand location is position.

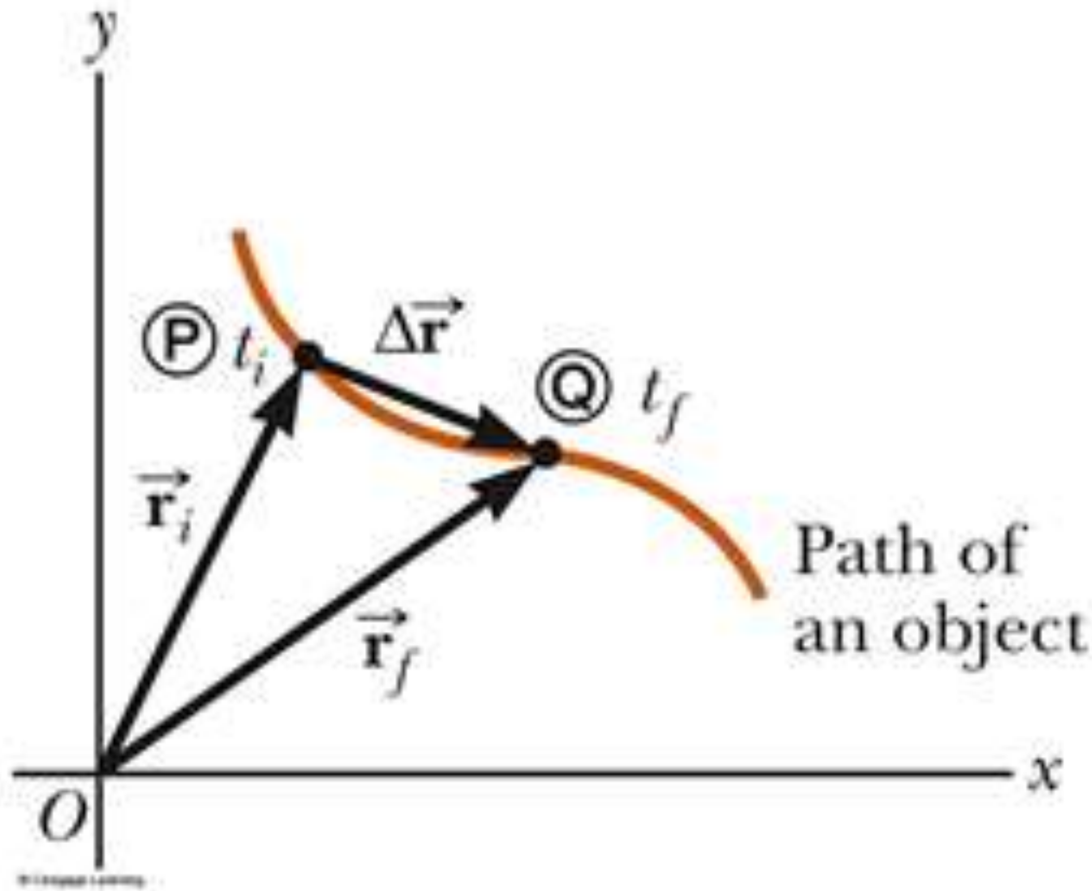
- **Motion:** is any physical movement or change in position or place.
- **Position:** Position refers to the location of an object at a particular time. It is usually measured in meters (m). The position of an object can be positive, negative, or zero depending on the direction of its movement. And it is a vector quantity.
- **Displacement :** It is a vector quantity is the change in position of an object. It is calculated by subtracting the initial position from the final position. Displacement can be positive, negative, or zero depending on the direction of the object's movement. We calculate displacement using the following formula:

Displacement

The position of an object is described by its position vector, $\vec{\mathbf{r}}$

The **displacement** of the object is defined as the ***change in its position***

- $\Delta\vec{\mathbf{r}} = \vec{\mathbf{r}}_f - \vec{\mathbf{r}}_i$



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Displacement	Distance
Displacement is the direct length between any two points when measured along the minimum path between them	The complete length of the path between any two points is called distance
Displacement is a vector quantity as it depends upon both magnitude and direction	Distance is a scalar quantity as it only depends upon the magnitude and not the direction
Displacement can be positive, negative and even zero	Distance can only have positive values

Speed and Velocity

Speed: is defined as. The rate of change of position of an object in any direction. Speed is measured as the ratio of distance to the time in which the distance was covered. Speed is a scalar quantity as it has only direction and no magnitude. and its SI unit is m/s. The speed of the object will never be negative; it will either be positive or zero. Mathematically, we define speed as: $\boldsymbol{s = \frac{d}{t}}$

where (d) is the total distance traveled and (t) is the elapsed time.

Types of Speed: There are four types of speed and they are:

1. Uniform speed
2. Variable speed
3. Average speed
4. Instantaneous speed

Velocity

- The average velocity is the ratio of the displacement to the time interval for the displacement

$$\vec{\mathbf{v}}_{av} \equiv \frac{\Delta \vec{\mathbf{r}}}{\Delta t}$$

- The instantaneous velocity is the limit of the average velocity as Δt approaches zero
  - The direction of the instantaneous velocity is along a line that is tangent to the path of the particle and in the direction of motion

Velocity

- Velocity is the rate of change of position.
- Velocity is a vector quantity.
- Velocity has both magnitude and direction.
- Velocity has a unit of [length/time]: meter/second.
- We will be concerned with three quantities, defined as:
  - Average velocity $v_{avg} = \frac{\Delta x}{\Delta t} = \frac{x_f - x_i}{\Delta t}$
  - Average speed $s_{avg} = \frac{\text{total distance}}{\Delta t}$
  - Instantaneous velocity $v = \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t} = \frac{dx}{dt}$

displacement

distance

displacement

Acceleration

- The average acceleration is defined as the rate at which the velocity changes

$$\vec{\mathbf{a}}_{av} = \frac{\Delta\vec{\mathbf{v}}}{\Delta t}$$

- The instantaneous acceleration is the limit of the average acceleration as Δt approaches zero

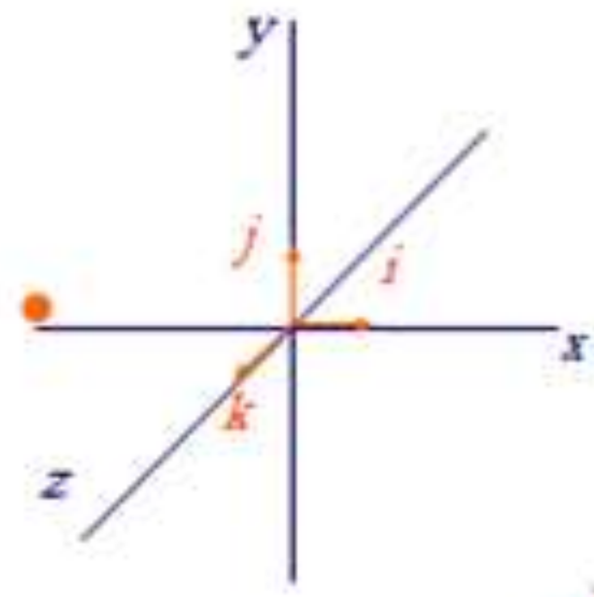
Motion in Two Dimensions

- Using + or – signs is not always sufficient to fully describe motion in more than one dimension
  - Vectors can be used to more fully describe motion
- Still interested in displacement, velocity, and acceleration

Motion in two dimensions

- Kinematic variables in one dimension
  - Position: $x(t)$ m
  - Velocity: $v(t)$ m/s
  - Acceleration: $a(t)$ m/s^2

- Kinematic variables in three dimensions
  - Position: $\vec{r}(t) = x\hat{i} + y\hat{j} + z\hat{k}$ m
  - Velocity: $\vec{v}(t) = v_x\hat{i} + v_y\hat{j} + v_z\hat{k}$ m/s
  - Acceleration: $\vec{a}(t) = a_x\hat{i} + a_y\hat{j} + a_z\hat{k}$ m/s^2



- All are vectors: have direction and magnitudes

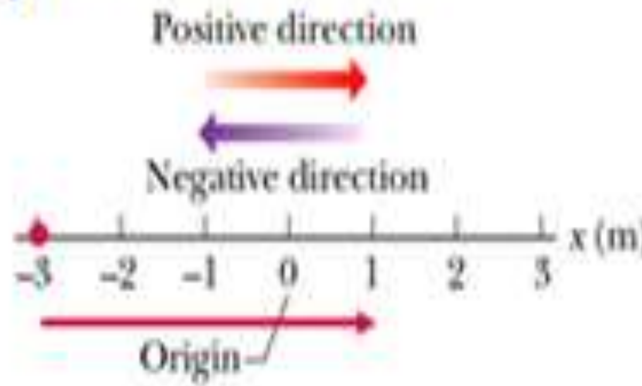
Position and Displacement

- In one dimension

$$\Delta x = x_2(t_2) - x_1(t_1)$$

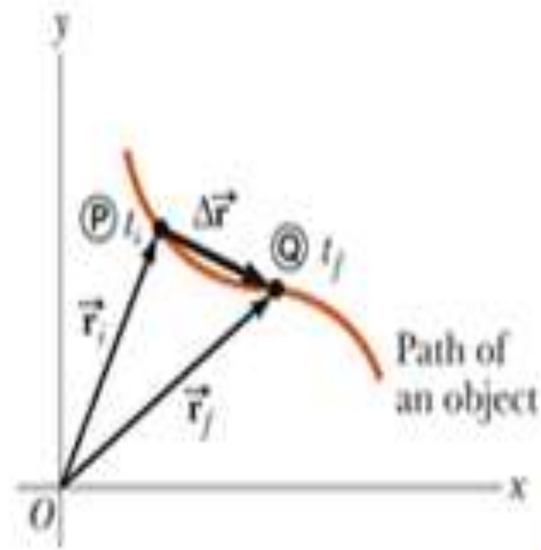
$x_1(t_1) = -3.0$ m, $x_2(t_2) = +1.0$ m

$\Delta x = +1.0 \text{ m} + 3.0 \text{ m} = +4.0 \text{ m}$



- In two dimensions
  - Position: the position of an object is described by its position vector $\vec{r}(t)$ --always points to particle from origin.
  - Displacement: $\Delta\vec{r} = \vec{r}_2 - \vec{r}_1$

$$\begin{aligned}\Delta\vec{r} &= (x_2\hat{i} + y_2\hat{j}) - (x_1\hat{i} + y_1\hat{j}) \\ &= (x_2 - x_1)\hat{i} + (y_2 - y_1)\hat{j} \\ &= \Delta x\hat{i} + \Delta y\hat{j}\end{aligned}$$



Average & Instantaneous Velocity

- Average velocity $\vec{v}_{avg} \equiv \dfrac{\Delta \vec{r}}{\Delta t}$

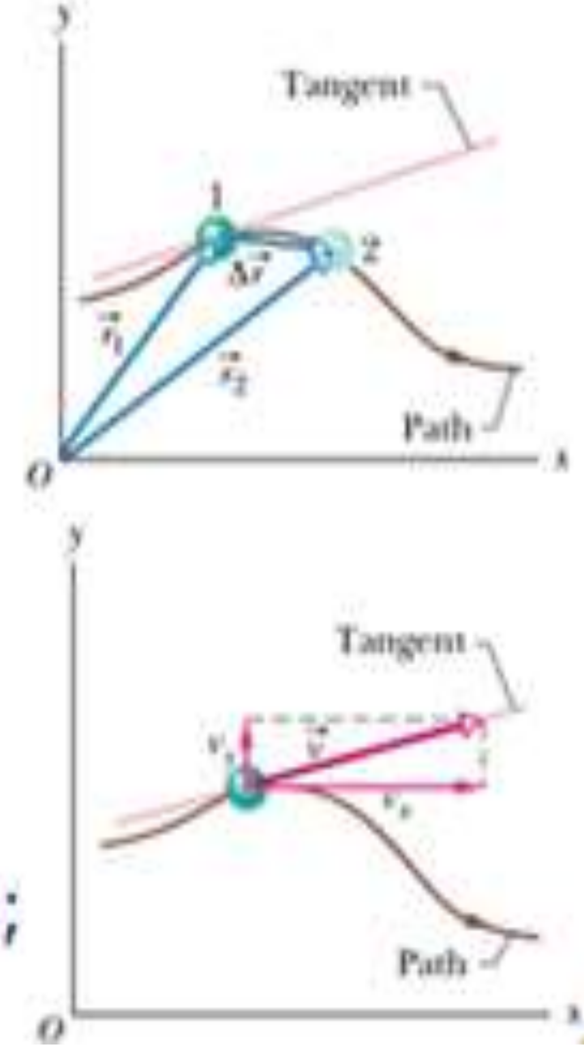
$$\vec{v}_{avg} = \frac{\Delta x}{\Delta t}\hat{i} + \frac{\Delta y}{\Delta t}\hat{j} = v_{avg,x}\hat{i} + v_{avg,y}\hat{j}$$

- Instantaneous velocity

$$\vec{v} \equiv \lim_{t \to 0} \vec{v}_{avg} = \lim_{t \to 0} \frac{\Delta \vec{r}}{\Delta t} = \frac{d\vec{r}}{dt}$$

$$\vec{v} = \frac{d\vec{r}}{dt} = \frac{dx}{dt}\hat{i} + \frac{dy}{dt}\hat{j} = v_x\hat{i} + v_y\hat{j}$$

- $\boldsymbol{v}$ is tangent to the path in x-y graph;



Equations of motion:

$$ta + u = v$$

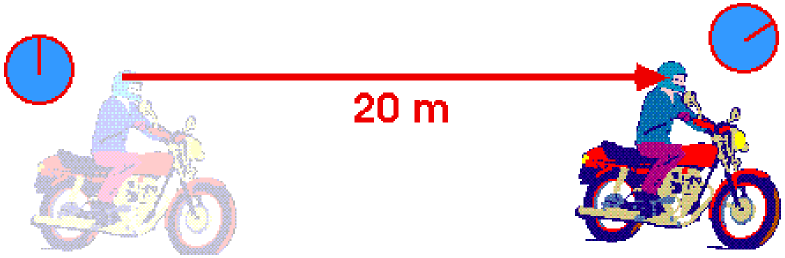
$$= s\left(\frac{v+u}{2}\right)t$$

$$sa2 + {}^{2}u = {}^{2}v$$

$$ta_{2} + tu \overset{1}{=} s^{2}$$

$$s = vt - \frac{1}{2}at^{2}$$

- If a motorcycle travels 20 m in 2 s, then its average velocity is:



$$v_{avg} = \frac{\Delta x}{\Delta t} = \frac{20\ \text{m}}{2\ \text{s}} = 10\ \frac{\text{m}}{\text{s}}$$

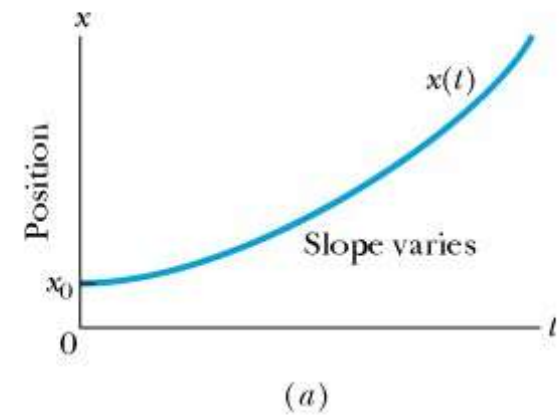
- If an antique car travels 45 km in 3 h, then its average velocity is:

$$v_{avg} = \frac{\Delta x}{\Delta t} = \frac{45\ \text{km}}{3\ \text{h}} = 15\ \frac{\text{km}}{\text{h}}$$

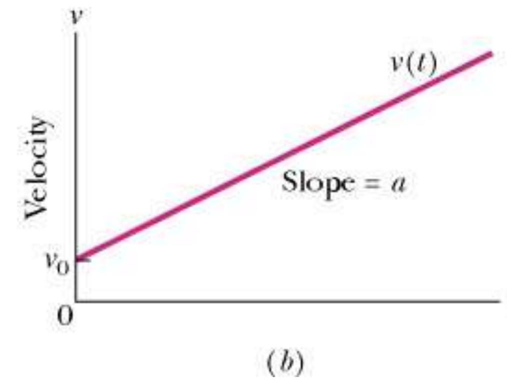
Constant acceleration:

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

$$\rightarrow v = v_0 + \int_{t_0}^{t} a\,dt \rightarrow v = v_0 + a(t - t_0)$$



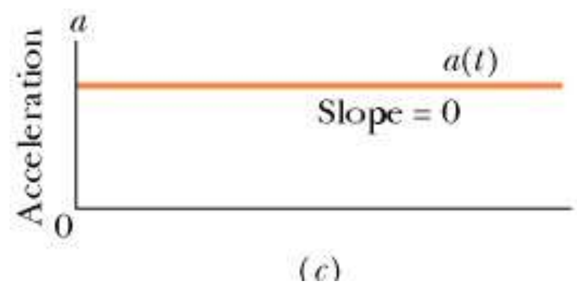
If t_0=0: $\boxed{v = v_0 + at}$ **(1)**



$$v = \frac{dx}{dt} \rightarrow x = x_0 + \int_{t_0}^{t} v\,dt = x_0 + \int_{t_0}^{t} [v_0 + a(t - t_0)]\,dt$$

$$x = x_0 + v_0(t - t_0) + \frac{a(t - t_0)^2}{2}$$

If t_0=0: $\boxed{x = x_0 + v_0 t + \frac{1}{2} a t^2}$ **(2)**



Example: An airplane has a lift-off speed of 30 m/s after a take-off run of 300m, what minimum constant acceleration? What is the corresponding take-off time?

Solution: $v^2 = u^2 + 2as$

v = final velocity (lift-off speed) = 30 m/s

u = initial velocity = 0 (since the airplane starts from rest)

a = acceleration (which we want to find) , s = distance traveled = 300 m

$$30^2 = 0^2 + 2a(300) \rightarrow a = \frac{900}{600}$$

$$\therefore a = 1.5\,\frac{m}{s^2}$$

Now, to find the corresponding take-off time, we can use the following kinematic equation: $v = u + at \rightarrow 30 = 0 + 1.5t$

$$\therefore t = \frac{30}{1.5} \rightarrow t = 20 second$$

- **Example :** A toy car accelerates from 3m/s to 5m/s in 5 s. What is its acceleration?

- **Solution:**
Given: Initial Velocity v_0 = 3m/s,
Final Velocity v_f = 5m/s,
Time taken t = 5s.

$$\boxed{= v_o + atv_f} \qquad a = (v_f - v_o)/2 = 5 - 3/5 = 0.4m/s\text{^}2$$

Example . A ball initially at rest rolls down a hill and has an acceleration of 3.3 m/s^2. If it accelerates for 7.5 s, how far will it move during this time?

F. 12 m
G. 93 m
H. 120 m
J. 190 m

Example 8. A car moving eastward along a straight road increases its speed uniformly from 16 m/s to 32 m/s in 10.0 s.

a. What is the car's average acceleration?

b. What is the car's average velocity?

c. How far did the car move while accelerating?

Answers: a. 1.6 m/s^2 eastward

b. 24 m/s
c. 240 m

Example

If a car with a velocity of 4.0 m/s accelerates at a rate of 4.0 m/s^2 for 2.5 s, what is the final velocity?

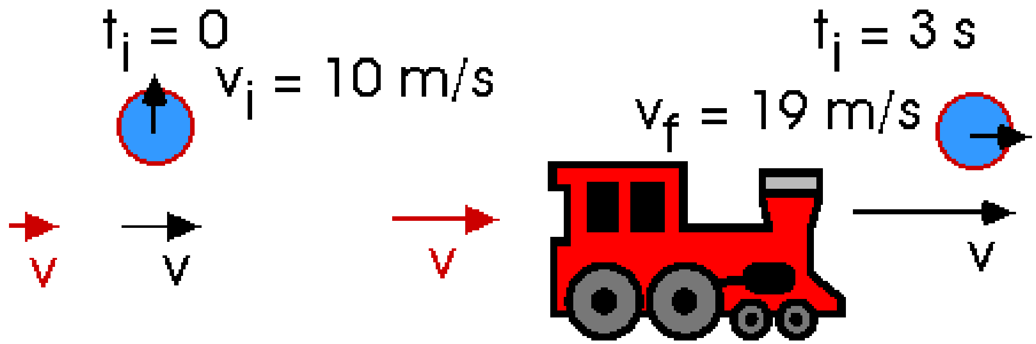
$v_f = v_i + at$ $=4.0+(4.0)(2.5)=4.0+10=14$ m/s

Example

If a cart slows from 22.0 m/s with an acceleration of -2.0 m/s^2, how long does it require to get to 4 m/s? (t=?)

$t=(v_f-v_i)/a=(-18)/-2.0)=9.0$ s

- **Acceleration**



$$a = \frac{\Delta v}{\Delta t} = \frac{(19 - 10)\,m/s}{3\ s} = \frac{9\ m/s}{3\ s} = 3\ \frac{m/s}{s}$$

$$a = 3\ m/s/s = 3\ m/s^2$$

H.W

- If an object has zero acceleration, does that mean it has zero velocity? Give an example.
- If an object has zero velocity, does that mean it has zero acceleration? Give an example.
- If the acceleration of a motorboat is 4.0 m/s^2, and the motorboat starts from rest, what is its velocity after 6.0 s?
- The friction of the water on a boat produces an acceleration of -10. m/s^2. If the boat is traveling at 30. m/s and the motor is shut off, how long does it take the boat to slow down to 5.0 m/s?