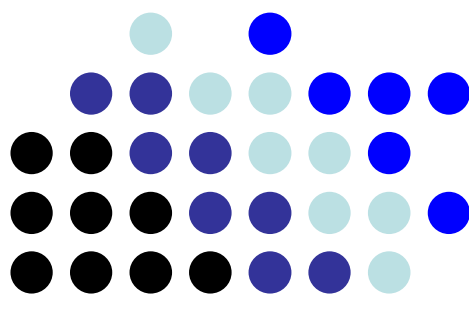


Chapter 2

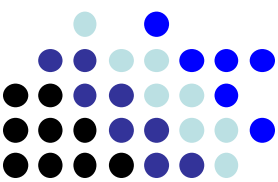
الحركة في بعد واحد

Motion in One Dimension



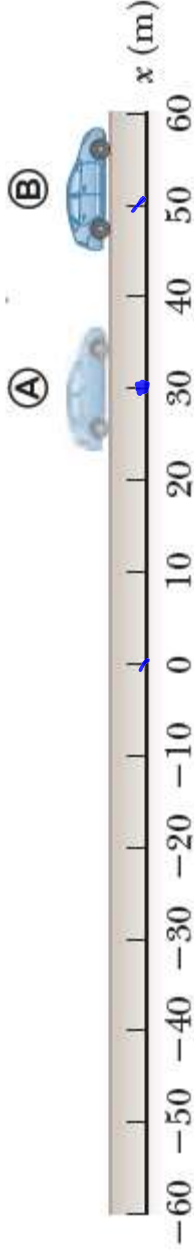
Position

الموقع



The particle's position

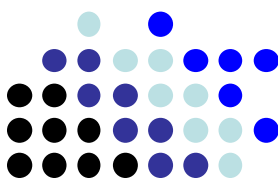
is the location of the particle with respect to a chosen reference point that we can consider to be the origin of a coordinate system.



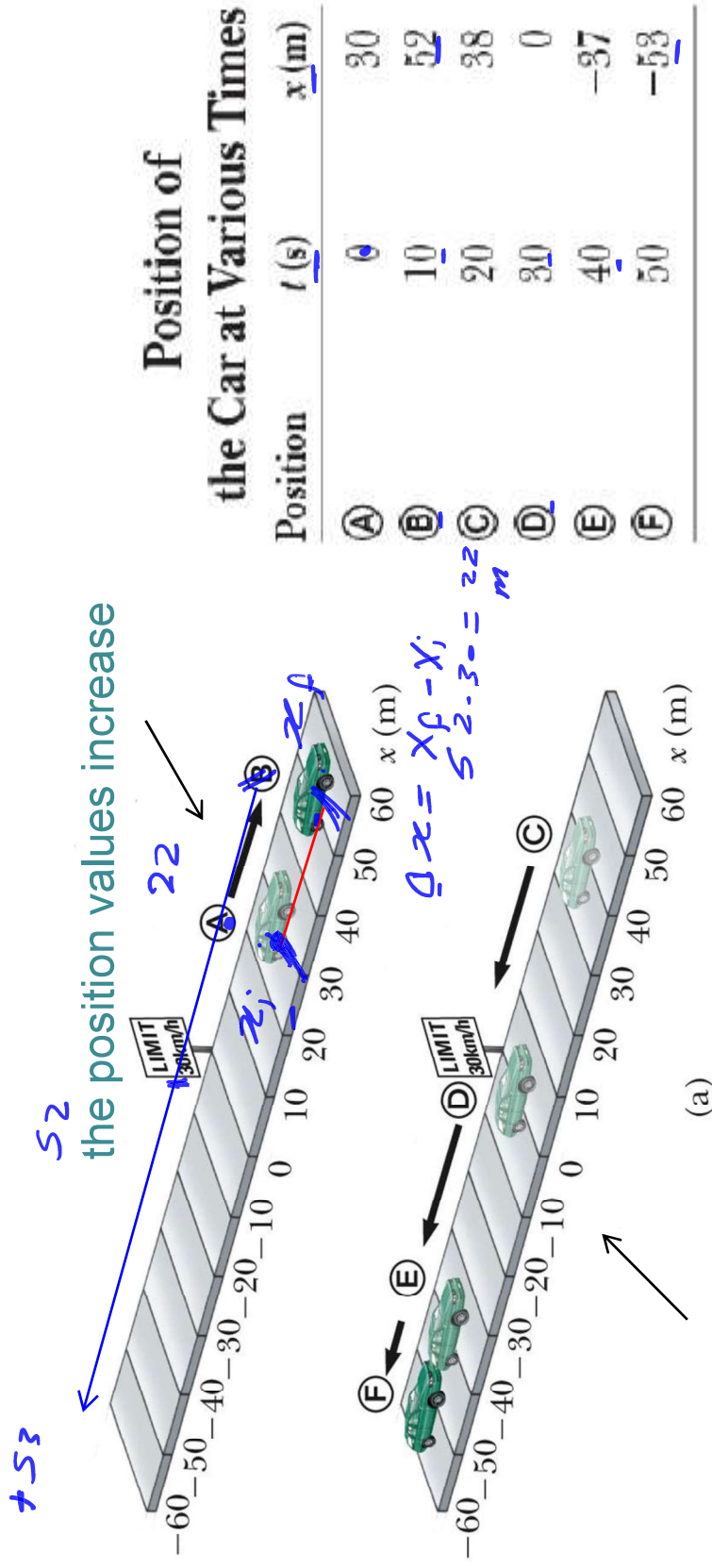
At position A: the car located at 30m from the origin point (0).

At position B: the car located at 52m from the origin point (0).

Position

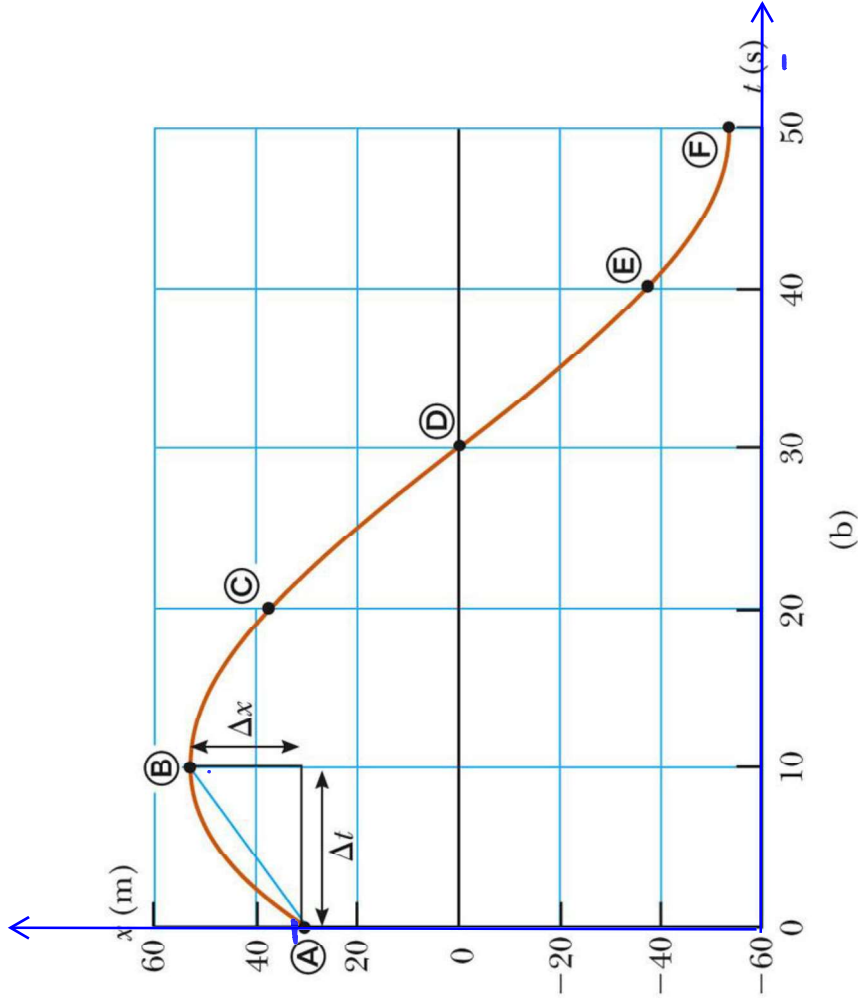


Consider a car moving back and forth along the x axis as in Figure (a). We start our clock and once every 10 s note the car's position from the table

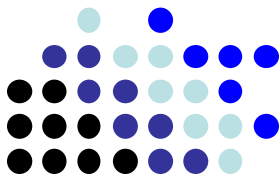


Position-Time Graph

the change in position of the car for various time intervals.



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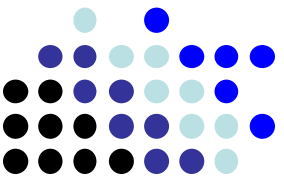


Position of
the Car at Various Times

Position	t (s)	x (m)
(A)	0	30
(B)	10	52
(C)	20	38
(D)	30	0
(E)	40	-37
(F)	50	-53

Displacement

المسافة التي قطعها الجسم



- Defined as the change in position in some time interval

- Represented as Δx

$$\Delta x \equiv x_f - x_i \quad \text{SI units are meters (m)}$$

- x_i initial position
- x_f final position

Δx can be

- Positive $\rightarrow x_f > x_i$
- negative $\rightarrow x_f < x_i$

Example,

Δx

Find the displacement of the car in Figure between

❖ positions A and B.

At positions A $x_i = 30\text{m}$

At positions B $x_f = 52\text{m}$

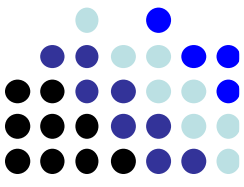
$$\Delta x \equiv x_f - x_i = 52 - 30 = 22\text{ m}$$

❖ positions E and D.

At positions D $x_i = 0\text{ m}$

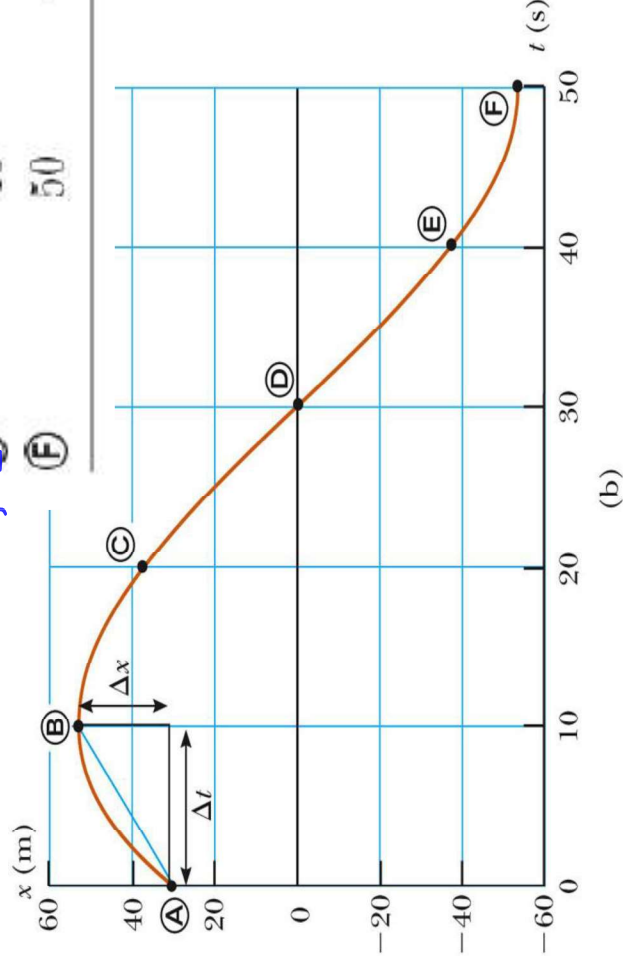
At positions E $x_f = -37\text{m}$

$$\Delta x \equiv x_f - x_i = -37 - 0 = -37\text{ m}$$

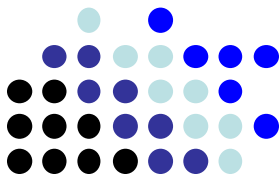


Position of
the Car at Various Times

Position	t (s)	x (m)
(A)	0	30
(B)	10	52
(C)	20	38
(D)	30	0
(E)	40	-37
(F)	50	-53



Distance (x) and Displacement ($\Delta x, \bar{x}$)



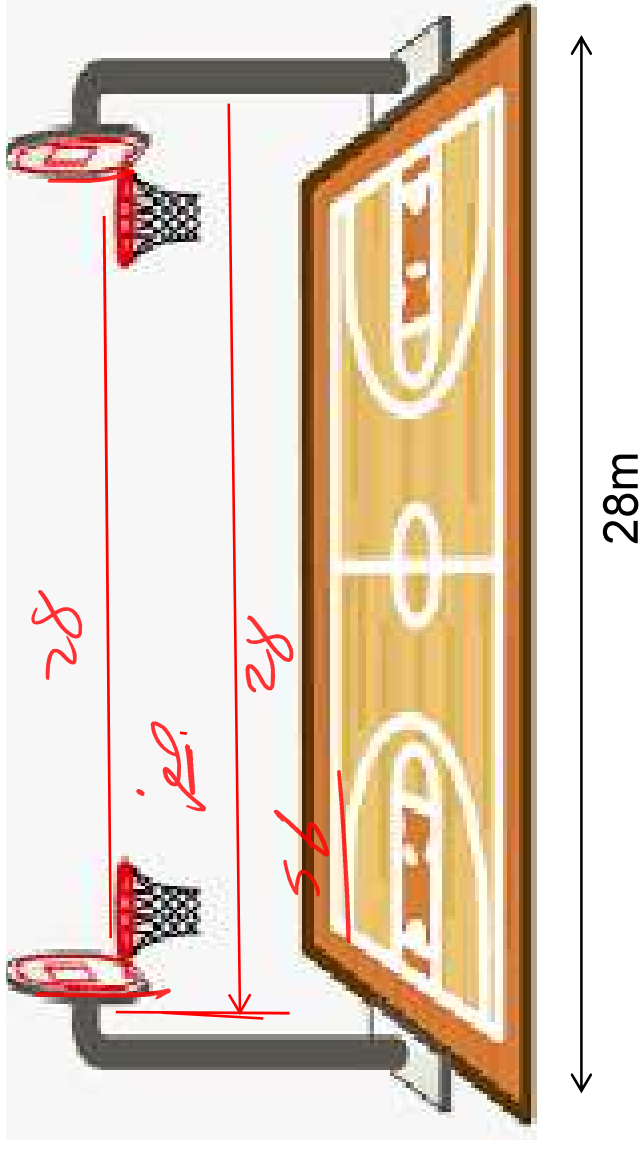
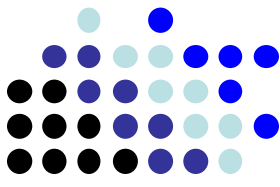
- A scalar quantity
الكمية
- Distance is always a positive number,
المسافة
- A vector quantity
المتجه
- Displacement can be
 - positive $\Delta x > 0$
 - negative $\Delta x < 0$.

▪ Refer to the length of a path followed by a particle.

▪ Refer to the distance between initial position (x_i) to final position (x_f)

- The SI unit of displacement and distance is **meters (m)**.
- Will use + and – signs to indicate vector directions

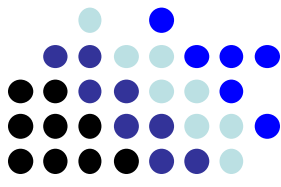
Example,



- The **displacement** from his basket to the opposite basket is **+28 m**,
 - The **displacement** in the reverse direction **-28 m**.
 - The **displacement** of the player during this time interval is **zero**,
 - Each trip represents a **distance** of **28 m**, because distance is a scalar quantity.
 - The **total distance** for the trip down the court and back is **56 m**.
- Distance, therefore, is always represented as a **positive number**, while displacement can be either positive or negative.

السرعة المتوسطة Average Velocity

$$\text{speed} = \frac{\Delta x}{\Delta t}$$



The average velocity $\bar{v}_x$ of a particle is defined as the particle's displacement Δx divided by the time interval Δt during which that displacement occurs:

$$\bar{v}_x = v_{\text{average}} = \frac{\Delta x}{\Delta t} = \frac{x_f - x_i}{t_f - t_i}$$

The x indicates motion along the x-axis

❖ The average velocity depend on the sign of the displacement Δx . It can be

- **Positive** → If the coordinate of the particle increases in time $x_f > x_i$
- **negative** → If the coordinate decreases in time $x_f < x_i$

❖ The time interval Δt is always positive.

the average velocity has dimensions of length divided by time (L/T) meters per second (m/s) in SI units.

Average velocity geometrically

We can interpret **average velocity** geometrically by drawing a straight line between any two points on the **position–time graph**. This line forms the **hypotenuse** of a right triangle of height Δx and base Δt . The slope of this line is

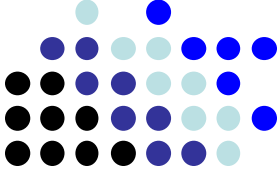
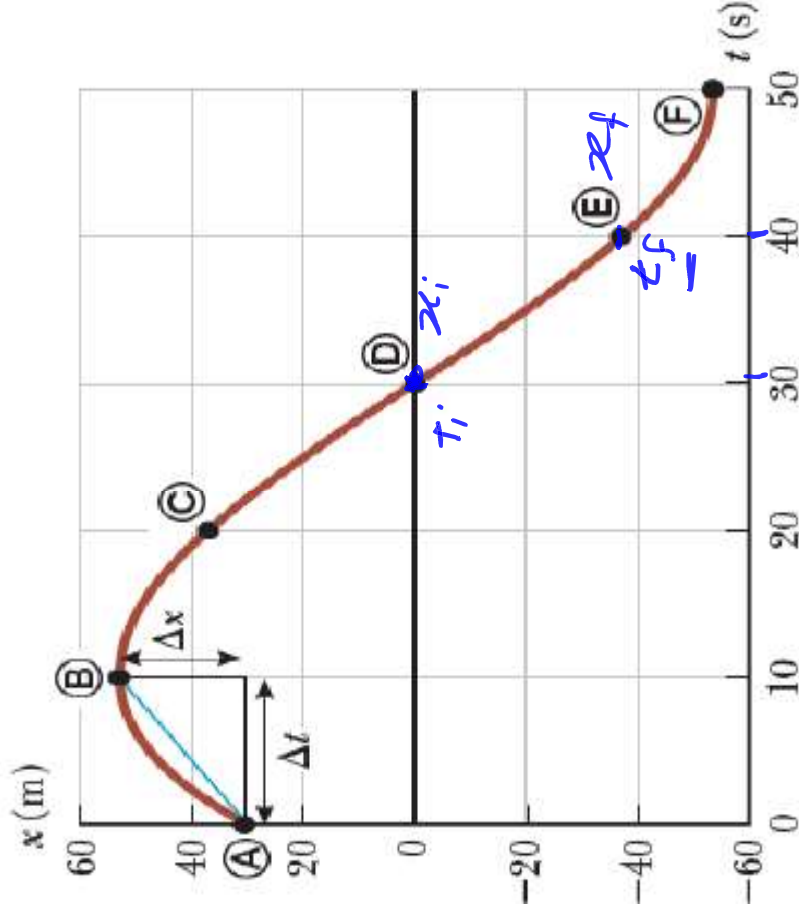
$$\text{slope} = \bar{v}_x = \frac{\Delta x}{\Delta t}$$

Example,
 The line between positions A and B has a slope equal to the average velocity of the car between those two times

$$\text{slope} = \bar{v}_x = \frac{\Delta x}{\Delta t} = \frac{52 - 30}{10 - 0} = 2.2 \text{ m/s}$$

The average velocity between positions D and E equal

$$\text{slope} = \bar{v}_x = \frac{\Delta x}{\Delta t} = \frac{0 - 37}{30 - 40} = -3.7 \text{ m/s}$$



The average speed

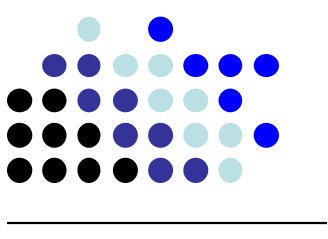
The **average speed** of a particle, a scalar quantity, is defined as the **total distance traveled** divided by the **total time interval** required to travel that distance:

$$\text{Average speed} = \frac{\text{total distance}}{\text{total time}}$$

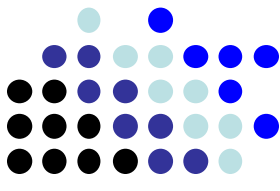
$$v = \frac{d}{t}$$

The SI **unit of average speed** and the average velocity is **meters per second (m/s)**.

Unlike average velocity, however, **average speed** has **no direction** and is always expressed as a **positive number**.



Average velocity and Average speed



- Average **velocity** is the **displacement** divided by the time **interval**,

- has **direction**

- It can be **Positive** or **negative**

- average **speed** is the **distance** divided by the time interval.

- has **no direction**

- it always expressed as a **positive number**.

Find the displacement, average velocity, and average speed of the car in Figure 2.1a between positions A and F.

x_i x_f

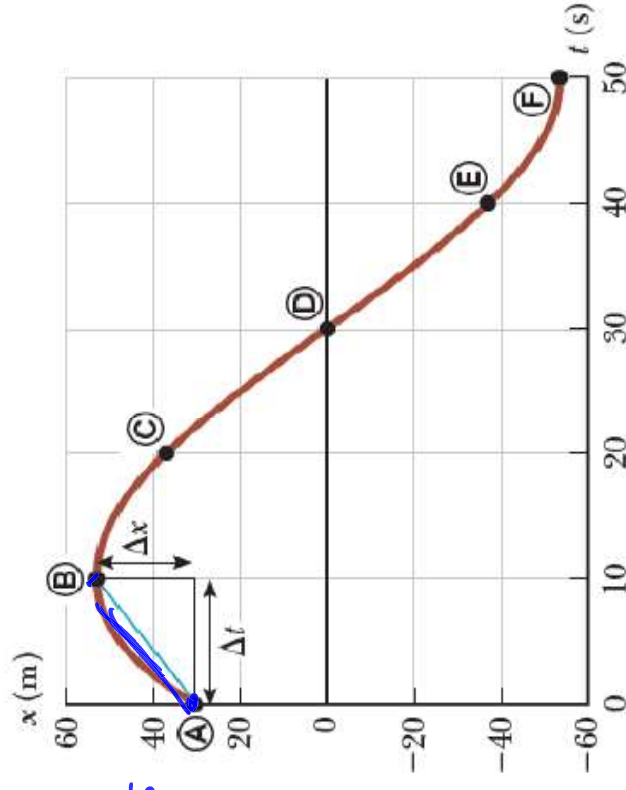
$$\Delta x = x_f - x_i = -53 - 30 = -83 \text{ m}$$

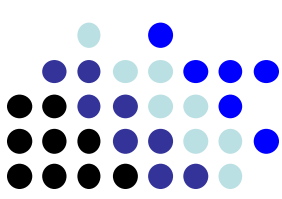
$$\bar{V} = \frac{\Delta x}{\Delta t} = \frac{-83}{50} = -1.7 \text{ m/s}$$

$$\bar{V} = \frac{d}{t} = \frac{127}{50} = 2.5 \text{ m/s}$$

Position of
the Car at Various Times

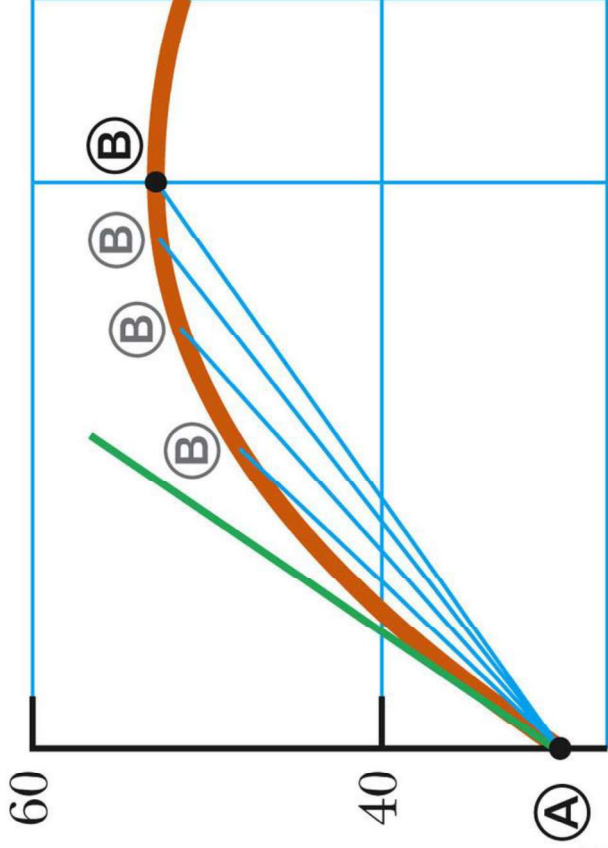
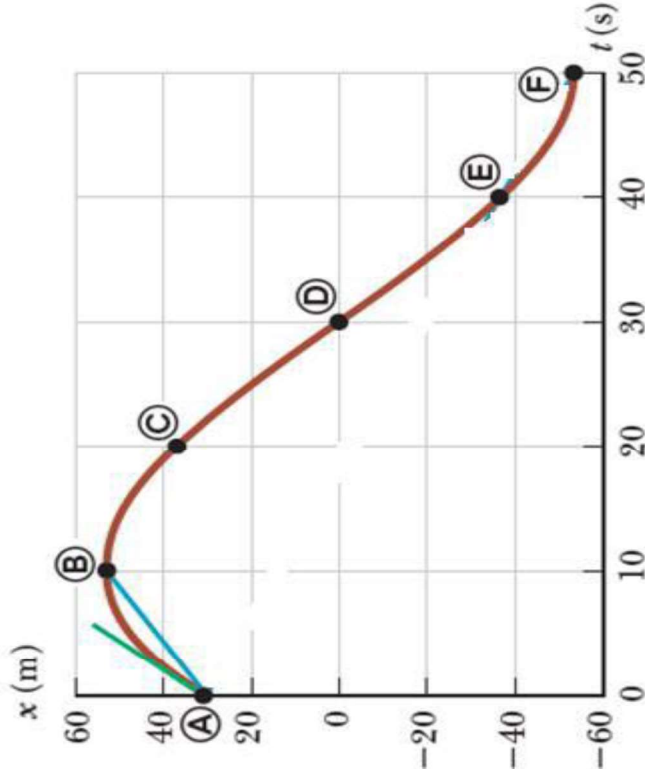
Position	t (s)	x (m)
(A)	0	30
(B)	10	52
(C)	20	38
(D)	30	0
(E)	40	-37
(F)	50	-53



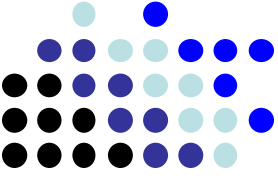


Instantaneous Velocity and speed

we need to know the velocity of a particle at a particular instant in time,



(b)



Instantaneous Velocity

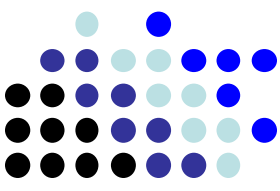
the instantaneous velocity v_x equals the limiting value of the ratio $\Delta x / \Delta t$ as Δt approaches zero

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

The instantaneous velocity can be positive, negative, or zero.

Velocity $\longrightarrow$ instantaneous velocity

Instantaneous Speed



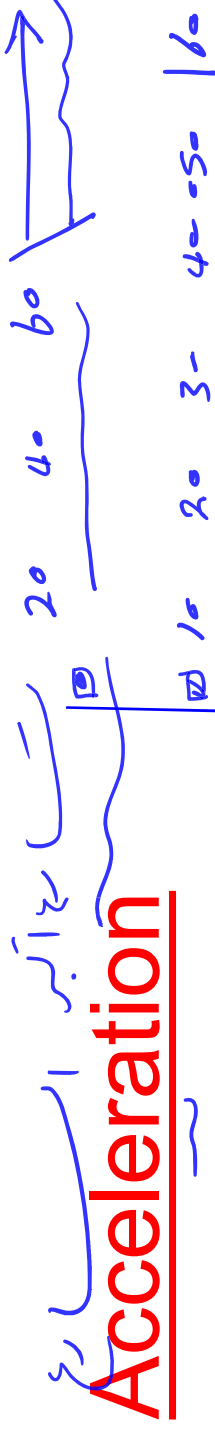
Instantaneous Speed is the magnitude of its instantaneous velocity.

has no direction and no algebraic sign

Example,

if one particle has an **instantaneous velocity** of **+25 m/s** along a given line and another particle has an **instantaneous velocity** of **-25 m/s** along the same line, both have a **speed** of **25 m/s**.

Speed $\longrightarrow$ Instantaneous Speed



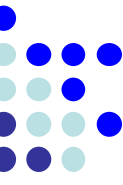
Acceleration

The **average acceleration** $\bar{a}_x$ of the particle is defined as the change in velocity Δv_x divided by the time interval Δt during which that change occurs:

$$a_{x,avg} \equiv \frac{\Delta V_x}{\Delta t} = \frac{V_{xf} - V_{xi}}{t_f - t_i}$$

- we can use **positive and negative** signs to indicate the direction of the acceleration
- The SI unit of acceleration is **meters per second squared (m/s²)**.

Instantaneous Acceleration



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

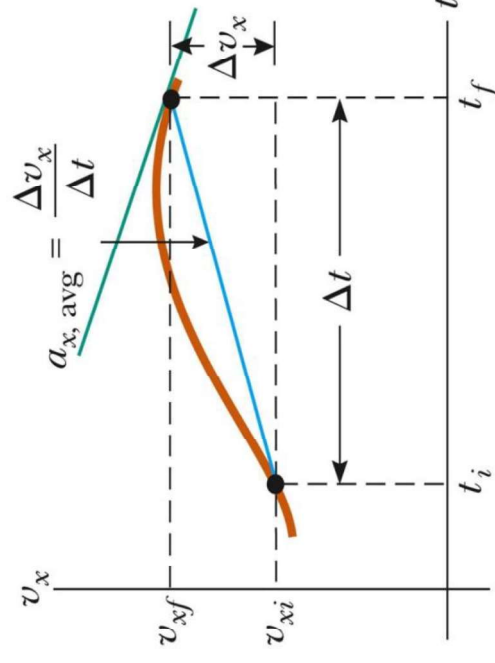
$$\bar{a}_x = \lim_{\Delta t \rightarrow 0} \frac{\Delta v_x}{\Delta t} = \frac{dv_x}{dt}$$

The **instantaneous acceleration** equals the derivative of the velocity with respect to time,

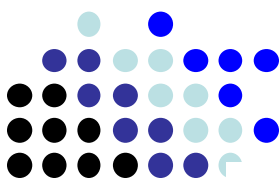
$$\bar{a}_x = \frac{dv_x}{dt} = \frac{d}{dt} \left(\frac{dx}{dt} \right) = \frac{d^2x}{dt^2}$$

The **acceleration** equals the second derivative of x with respect to time.

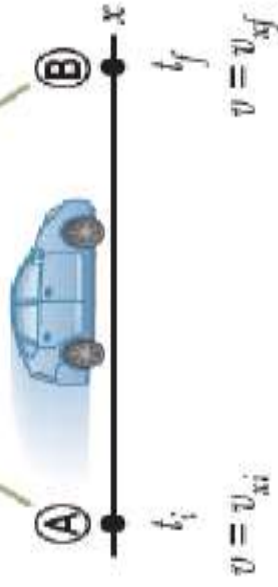
acceleration $\rightarrow$ instantaneous acceleration



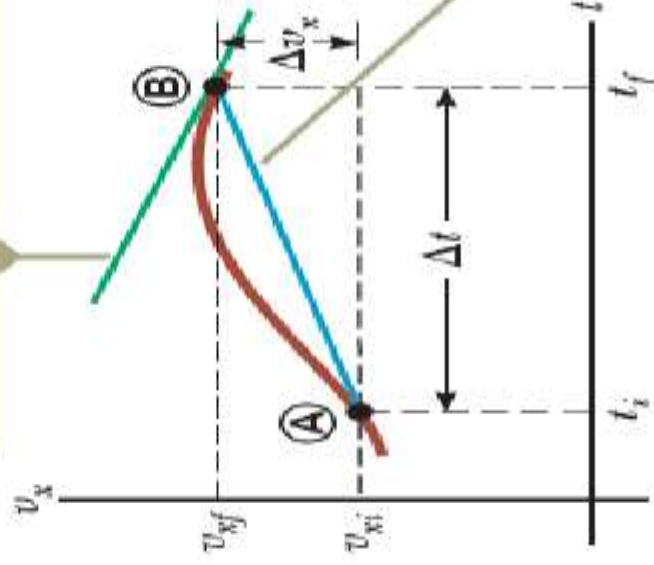
(b)



The car moves with different velocities at points **A** and **B**.

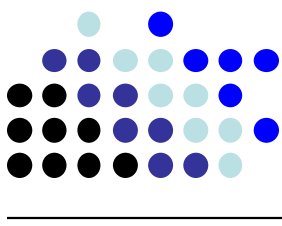


The slope of the green line is the instantaneous acceleration of the car at point **B** (Eq. 2.10).

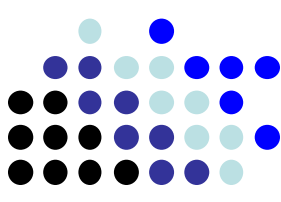


The slope of the blue line connecting **A** and **B** is the average acceleration of the car during the time interval $\Delta t = t_f - t_i$ (Eq. 2.9).

Acceleration



- If a_x is positive, the acceleration is in the positive x direction;
 - if a_x is negative, the acceleration is in the negative x direction.
-
- When the object's velocity and acceleration are in the same direction, the object is speeding up.
 - When the object's velocity and acceleration are in opposite directions, the object is slowing down.



Example 4,5,6

A particle moves along the x axis according to the equation $x = 2.00 + 3.00t - 1.00t^2$, where x is in meters and t is in seconds. At $t = 3.00$ s, **find** (a) the position of the particle, (b) its velocity, (c) its acceleration.

$$x = 2 + 3 \times 3 - 3^2 = 2 \text{ m}$$

$$v = \frac{dx}{dt} = \frac{d}{dt} (2 + 3t - t^2) = 0 + 3 - 2t$$

$$v_{t=3} = 3 - 2 \times 3 = -3 \text{ m/s}$$

$$a = \frac{dv}{dt} = \frac{d}{dt} (3 - 2t) = -2 \text{ m/s}^2$$

force and acceleration

Force is proportional to acceleration

$$F \propto a$$

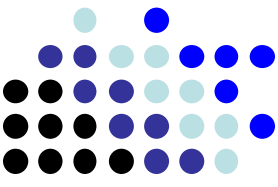
acceleration and force are in

- The same direction. $\longrightarrow$ The object speeds up
- The opposite directions $\longrightarrow$ The object slows down

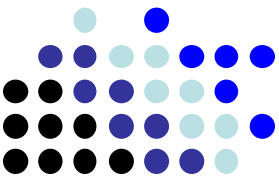
Example

If a car is traveling eastward and slowing down, what is the direction of the force on the car that causes it to slow down?

- (a) eastward
- (b) westward
- (c) neither of these.

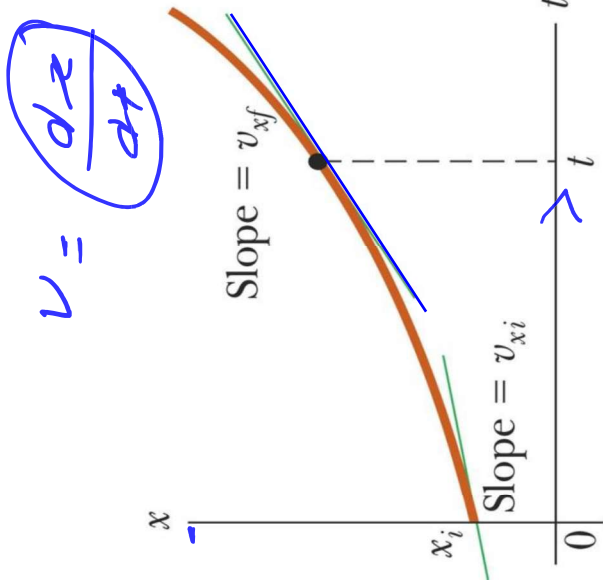


One-Dimensional Motion with Constant Acceleration

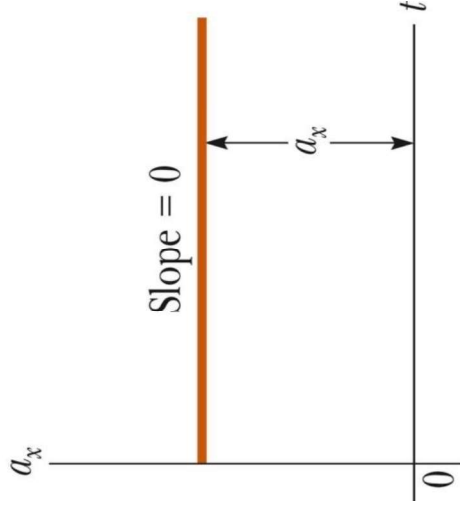
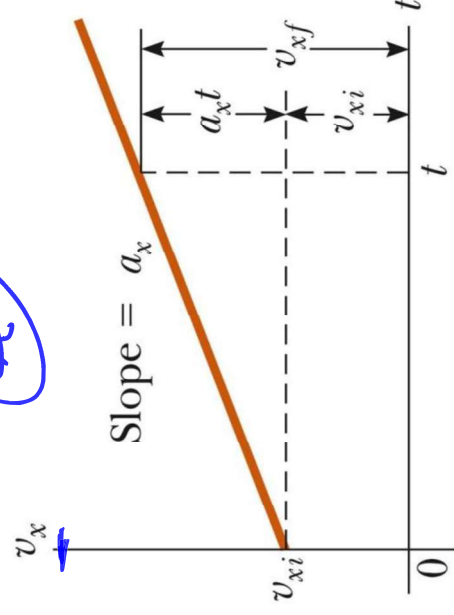


❖ The acceleration of a particle varies in time, its motion can be complex and difficult to analyze. However, a very common and simple type of one-dimensional motion is that in which **the acceleration is constant**.

❖ When **the acceleration is constant**, the graph of acceleration versus time is a straight line having a slope of zero.



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



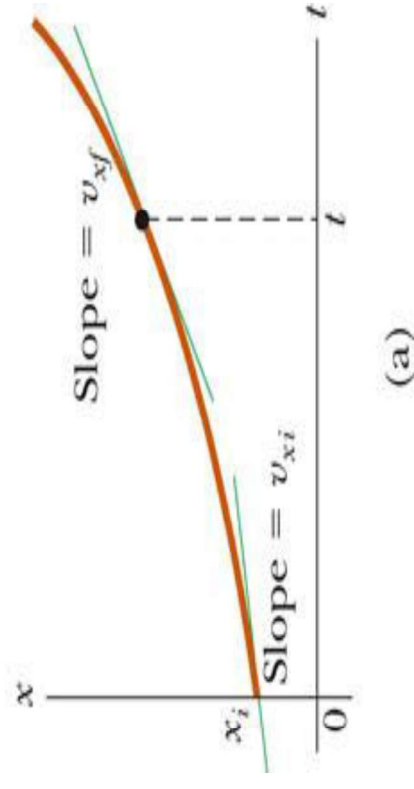
(a)

(b)

(c)

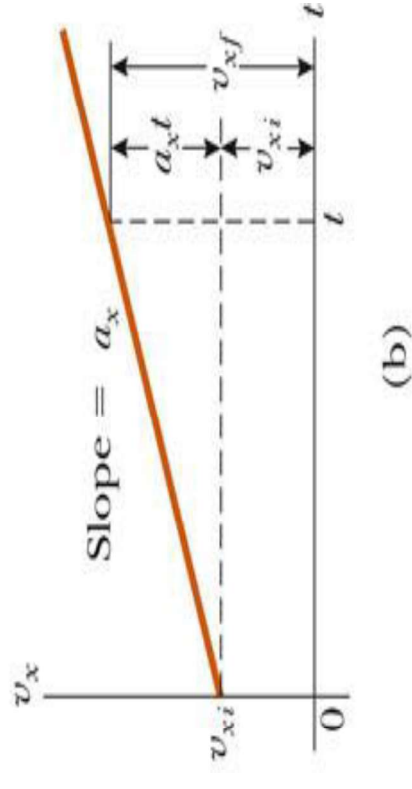
Particle moving along the x axis with constant acceleration a_x ;

The position– time graph,



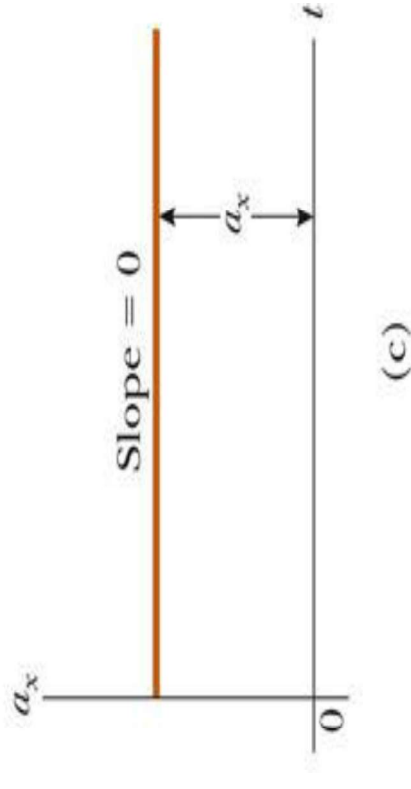
The velocity–time graph,

The velocity at constant acceleration varies linearly in time



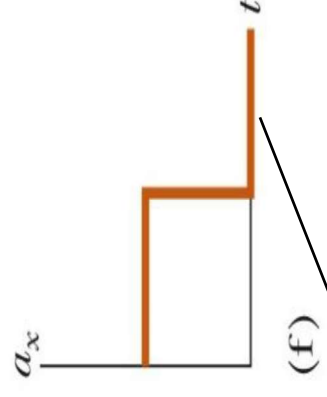
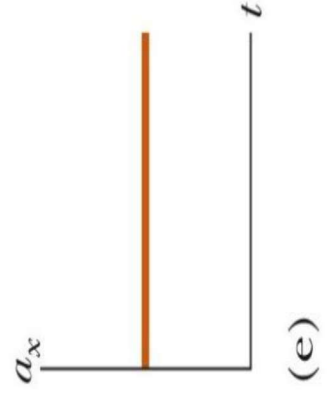
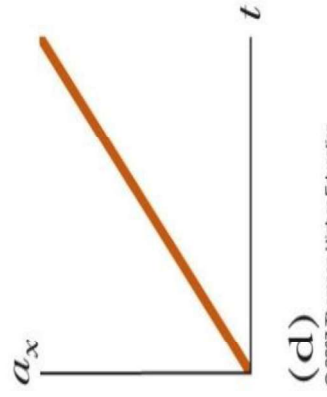
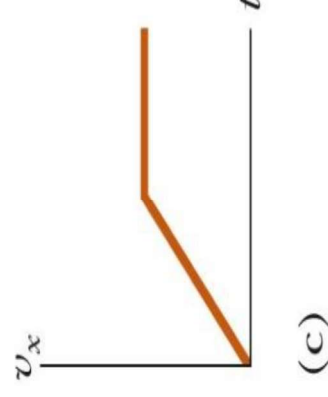
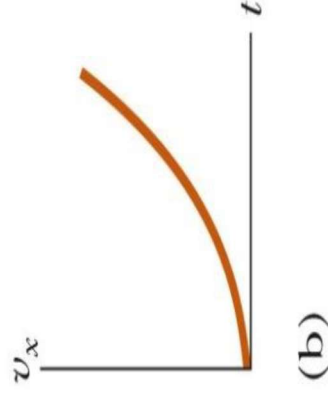
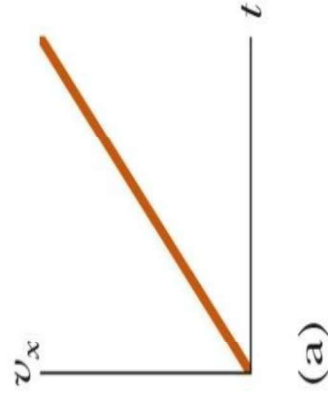
The acceleration–time graph.

When the acceleration is constant, the graph of acceleration versus time is a straight line having a slope of zero.



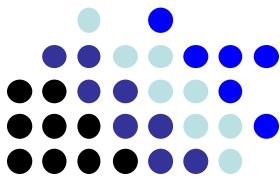
Example

match each $(v_x - t)$ graph on the left with the $(a_x - t)$ graph on the right that best describes the motion.



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The acceleration of a particle is zero, its velocity is constant and its position changes linearly with time



Kinematic Equations

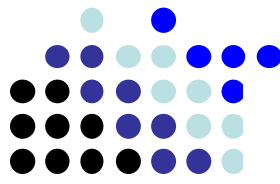


TABLE 2.2

الحركة بتسارع ثابت

Kinematic Equations for Motion of a Particle Under Constant Acceleration

Equation Number	Equation
2.13 <i>key</i>	$v_{xf} = v_{xi} + a_x t$
2.15	$x_f = x_i + \frac{1}{2}(v_{xi} + v_{xf})t$
2.16	$x_f = x_i + v_{xi}t + \frac{1}{2}a_x t^2$
2.17	$v_{xf}^2 = v_{xi}^2 + 2a_x(x_f - x_i)$

}

Note: Motion is along the x axis.

Example 11, 12:

A truck covers 40.0 m in 8.50 s while smoothly slowing down to a final speed of 2.80 m/s. (a) Find its original speed. (b) Find its acceleration.

$$\Delta x = 40 \text{ m}$$

$$\Delta x = x_f - x_i = 40 \text{ m}, \Delta t = 8.5 \text{ s}, v_f = 2.8 \text{ m/s}, v_i = ?$$

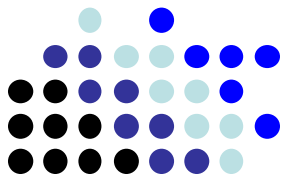
$$(x_f - x_i) = \Delta x = \frac{1}{2} (v_i + v_f) t$$

$$2 \cdot \frac{40}{8.5} = \frac{1}{2} (v_i + 2.8) \times \frac{8.5}{8.5}$$

$$v_i = 6.61 \text{ m/s}$$

$$v_f = v_i + at$$

$$2.8 = 6.61 + a(8.5), \quad a = -0.448 \text{ m/s}^2$$



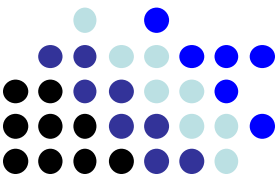
$$v_f = v_i + at$$

$$x_f = x_i + \frac{1}{2}(v_i + v_f)t$$

$$x_f = x_i + v_i t + \frac{1}{2} a t^2$$

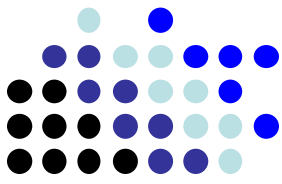
$$v_{xf}^2 = v_{xi}^2 + 2a_x(x_f - x_i)$$

Freely Falling Objects



- It is well known that, in the absence of air resistance, all objects dropped near the Earth's surface fall toward the Earth with the same constant acceleration under the influence of the Earth's gravity.
- A **freely falling object** is any object moving freely under the influence of gravity alone, regardless of its initial motion. Objects thrown upward or downward and those released from rest are all falling freely once they
- We shall denote the magnitude of the free-fall acceleration, also called the acceleration due to gravity, by the symbol g .

Kinematic Equations for Freely Falling Objects



$$g = 9.8 \text{ m/s}^2$$

$$= 10 \text{ m/s}^2$$

$$v_{yf} = v_{yi} + \textcircled{gt}$$

$$y = v_{yi}t + \frac{1}{2}gt^2$$

$$v_{yf}^2 = v_{yi}^2 + 2gy$$

$$y = \frac{1}{2}(v_{yi} + v_{yf})t$$

$$v_{y,avg} = \frac{1}{2}(v_{yi} + v_{yf})$$

$$\uparrow v_{xf} = v_{xi} + \textcircled{a_x t}$$

$$x_f = x_i + \frac{1}{2}(v_{xi} + v_{xf})t$$

$$x_f = x_i + v_{xi}t + \frac{1}{2}a_x t^2$$

$$v_{xf}^2 = v_{xi}^2 + 2a_x \underbrace{(x_f - x_i)}$$

Example 2.10: Describing the Motion of a Tossed Ball

A ball is tossed straight up at 25 m/s. Estimate its velocity at 1-s intervals. ($g = -10 \text{ m/s}^2$)

$$v_f = v_i + gt$$

$$v_f = 25 + (-10)(t)$$

$$a \quad t = 1 \text{ s}$$

$$v_f = 25 - 10(1) = 15 \text{ m/s}$$

$$a \quad t = 2 \text{ s}$$

$$v_f = 25 - 10(2) = 5 \text{ m/s}$$

$$a \quad t = 3 \text{ s}$$

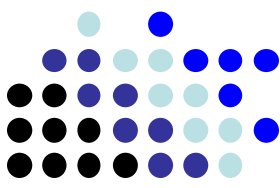
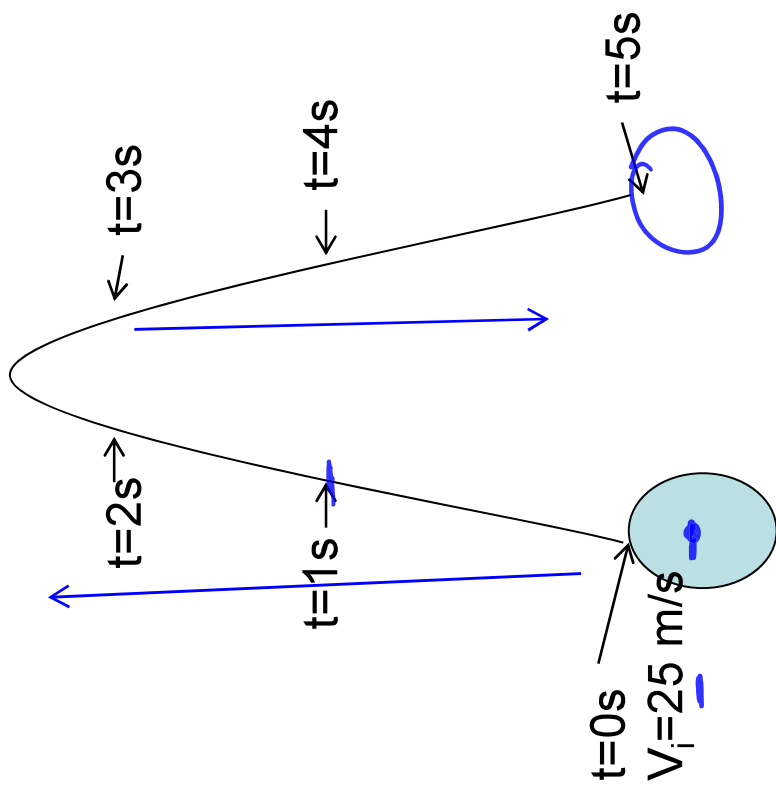
$$v_f = 25 - 10 \times 3 = -5 \text{ m/s}$$

$$a \quad t = 4 \text{ s}$$

$$v_f = 25 - 10(4) = -15 \text{ m/s}$$

$$a \quad t = 5 \text{ s}$$

$$v_f = 25 - 10(5) = -25 \text{ m/s}$$



Example 22:

$$g = -9.81 \approx -10$$

An arrow is shot straight up in the air at an initial speed of 15.0 m/s. After how much time is the arrow moving downward at a speed of 8.00 m/s?

- (a) 0.714 s (b) 1.24 s (c) 1.87 s (d) 2.35 s (e) 3.22

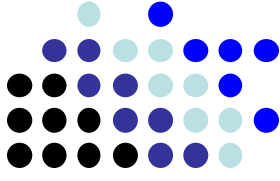
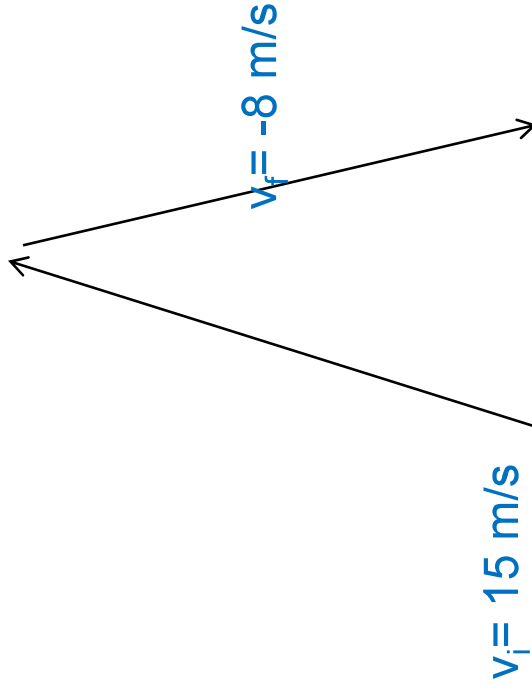
$$v_i = +15 \text{ m/s}, t, v_f = -8 \text{ m/s}$$

$$v_f = v_i + gt$$

$$-8 = 15 - 10t$$

$$\frac{-23}{-10} = \frac{-10t}{-10} \Rightarrow t = 2.3 \text{ s}$$

?



A stone thrown from the top of a building is given an initial velocity of 20.0 m/s straight upward. The building is 50.0 m high,

(A) the **time** at which the stone reaches its **maximum height**,

$$v_f = 0, \quad v_i = 20 \text{ m/s}$$

$$v_f = v_i + gt$$

$$0 = 20 + (9.81)t$$

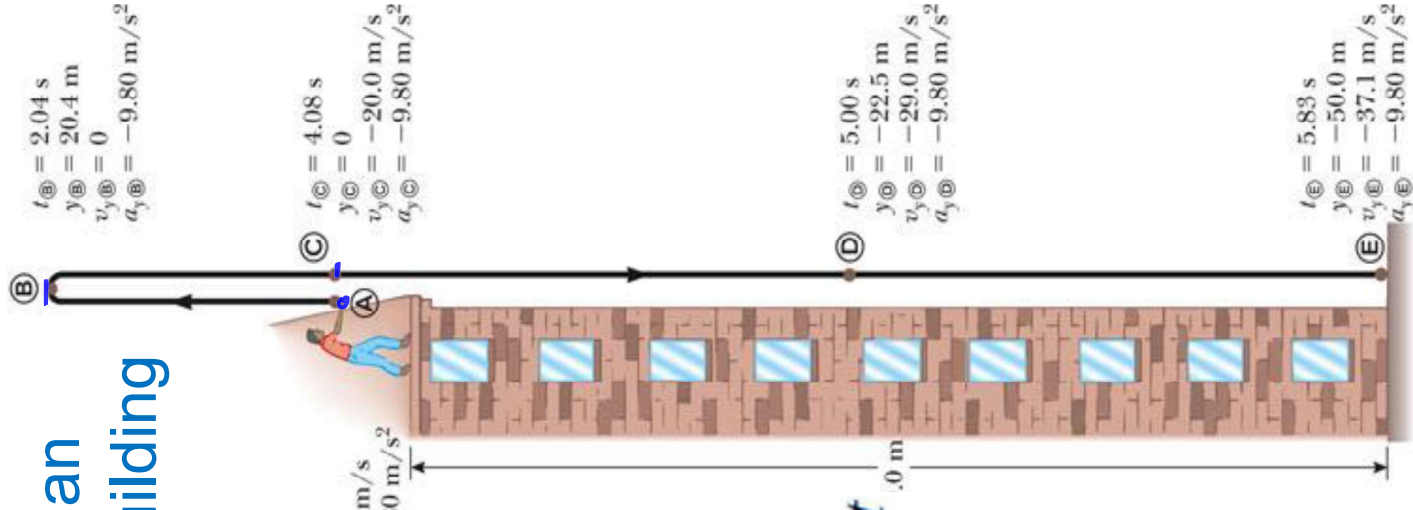
$$t = \frac{20}{9.81} = 2.04 \text{ s}$$

(B) the **maximum height**

$$y = 20 \times 2.04 + \frac{1}{2} (9.81) (2.04)^2$$

$$y = 20.38 \text{ m}$$

$$0 = (20)^2 + 2(-9.81)y$$



$$t = 2.04$$

C) the **time** at which the stone returns to the height from which it was thrown,

$$t = 4.08 \text{ s}$$

(D) the **velocity** of the stone at this instant

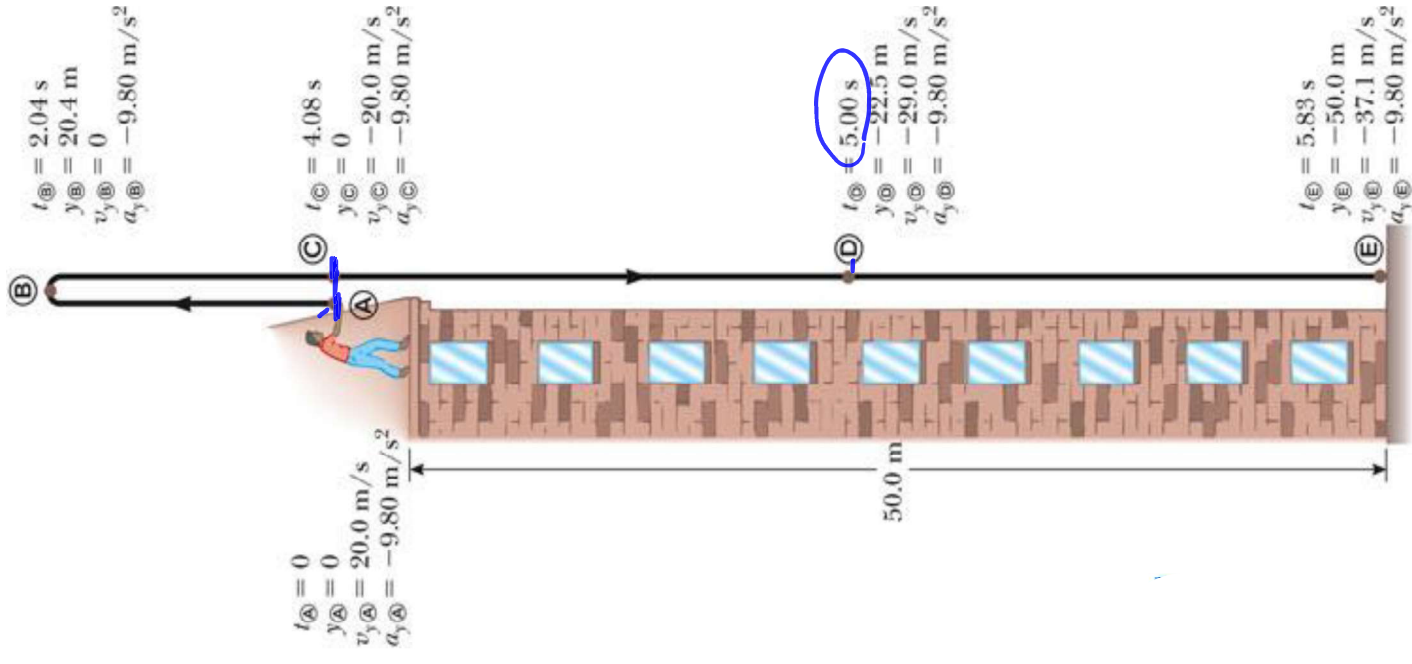
$$v = -20 \text{ m/s}$$

$v_f = v_i + g t = 20 + (-9.81)(4.08) = -20 \text{ m/s}$
E) the velocity and position of the stone at $t = 5 \text{ s}$

$$v_f = v_i + g t$$

$$v_f = 20 + (-9.81)(5) = -29 \text{ m/s}$$

$$y = 20(5) + 0.5(-9.81)(5)^2 = -22.6 \text{ m}$$



At position C

$$y_C = 0, \quad v_C = -20 \text{ m/s}$$

C) the **time** at which the stone returns to the height from which it was thrown,

$$y_f = y_i + v_i t + \frac{1}{2} g t^2$$

$$0 = 0 + (20)t + \frac{1}{2}(-9.8)t^2$$

$$t(20 - 4.9t) = 0$$

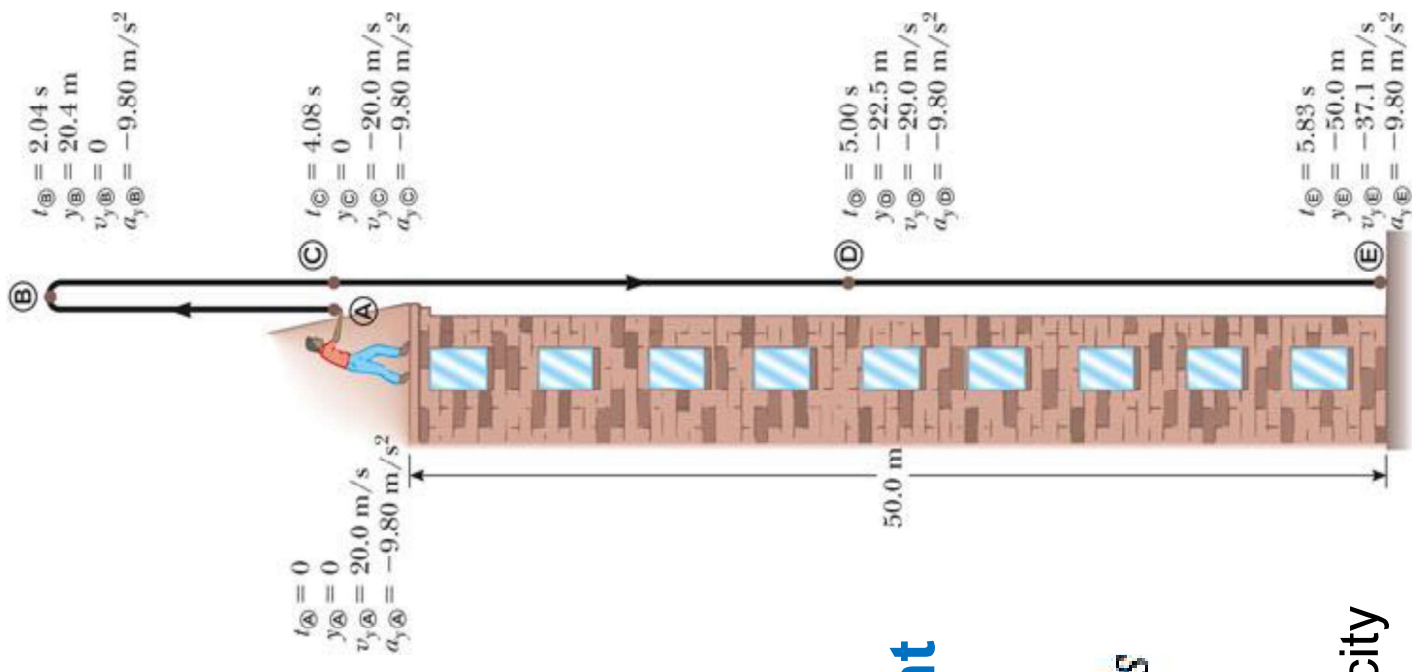
$$t = 0 \text{ or } 20 - 4.9t = 0 \longrightarrow t = 4.08 \text{ s}$$

(D) the **velocity** of the stone at this instant

$$v_f = v_i + at$$

$$v_f = 20 + (-9.8)(4.08) \longrightarrow v_f = -20 \text{ m/s}$$

The velocity of the stone when it arrives back at its original height is equal in magnitude to its initial velocity but opposite in direction.



At position D

E) the velocity and position of the stone at $t = 5\text{ s}$

The initial position A

$$v_f = v_i + at$$

$$v_f = 20 + (-9.8)(5)$$

$$v_f = -29\text{ m/s}$$

From the initial position c

$$y_f = y_i + v_i t + \frac{1}{2}gt^2$$

$$y_f = 0 + (-20)(5 - 4.08) + \frac{1}{2}(-9.8)(5 - 4.08)^2$$

$$y_f = -22.5\text{ m}$$

The initial position B

$$v_f = v_i + at$$

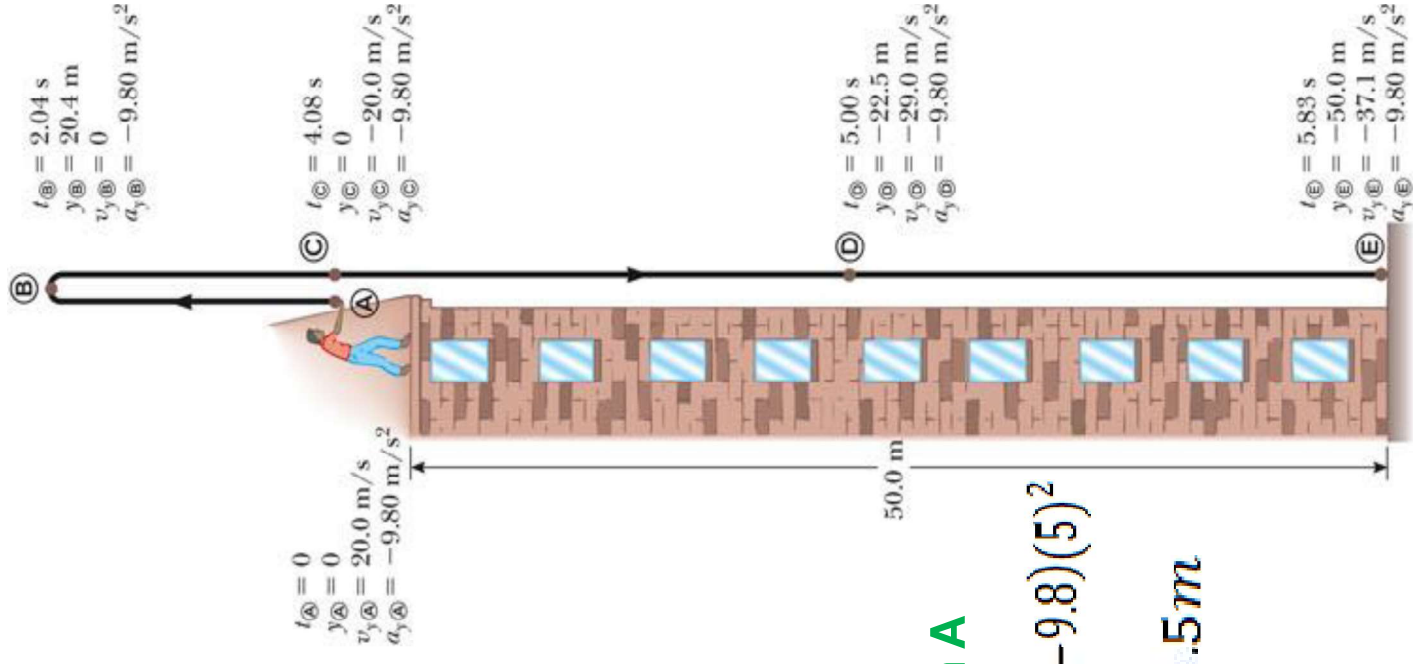
$$v_f = 0 + (-9.8)(5 - 2.04)$$

$$v_f = -29\text{ m/s}$$

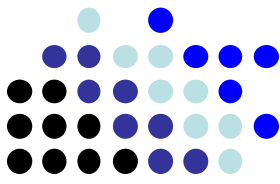
The initial position A

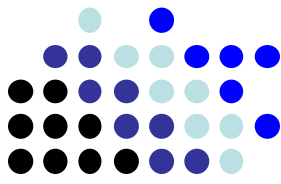
$$y_f = 0 + (20)(5) + \frac{1}{2}(-9.8)(5)^2$$

$$y_f = -22.5\text{ m}$$



At position E





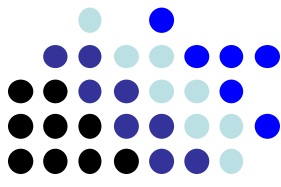
Example 2-1

The position of an object is 35 meters when the time was 2 seconds and then the position changes to 87 meters at 15 seconds.

Calculate the average velocity of the object?

Solution

$$\begin{aligned}U_{avo} &= \frac{\Delta x}{\Delta t} = \frac{x_f - x_i}{t_f - t_i} \\&= \frac{87 - 35}{15 - 2} = \frac{52}{13} = 4 \text{ m/s}\end{aligned}$$



Example 2-2

A Car travels 10 km at velocity of 90 km/h, and then the car stopped because the car run out of the fuel. This is causing the driver to walk a distance of 5 km to reach the nearest petrol station for half an hour.

What is the average velocity for the driver?

Solution

The distance x_1 equal to zero because the driver was still at home, x_2 is the distance covered by car until the fuel run out, and x_3 is the distance that the driver walked to the petrol station.

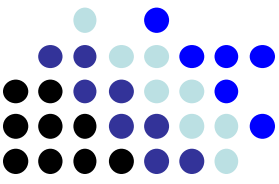
Convert the distance from kilometers to meters, and convert the units of other velocity from km/h to m/s as follows

$$x_f = x_2 + x_3 = 10 \times 10^3 + 5 \times 10^3 = 10,000 + 5,000 = 15,000 \text{ m}$$

$$v = 90 \frac{\text{km}}{\text{h}} = \frac{90 \times 1000}{60 \times 60} = 25 \text{ m/s}$$

the time taken before the fuel run out

$$t_1 = \frac{x}{v} = \frac{10000}{25} = 400 \text{ s}$$



the time that the driver takes to reach the petrol station

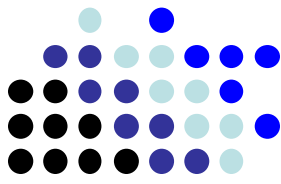
$$t_2 = 30 \times 60 = 1800 \text{ s}$$

Total time for the car and the driver is

$$t_{\text{Total}} = t_f = 400 + 1800 = 2200 \text{ s}$$

The average speed is

$$\begin{aligned} \bar{v} &= \frac{\Delta x}{\Delta t} = \frac{x_f - x_i}{t_f - t_i} \\ &= \frac{x_f - 0}{t_f - 0} = \frac{15000}{2200} = 6.8 \text{ m/s} \end{aligned}$$



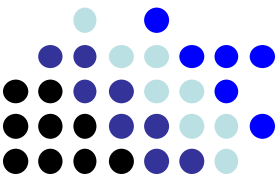
Example 2-3

Moving object in the positive direction of the x -axis with a relationship, as the following $x(t) = 8 + 2t + 3t^2$ where the distance is measured in meters and the time in second.

- A) Find the instantaneous velocity of the object after two seconds?
- B) Find the instantaneous acceleration of the object after two seconds?
- C) Find the distance of the object after two seconds?

Solution

- A) The instantaneous velocity of the object after two seconds is:



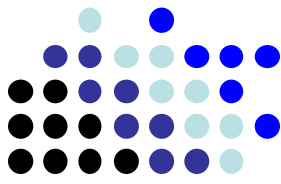
$$\begin{aligned}v &= \frac{dx}{dt} = \frac{d}{dt}(8 + 2t + 3t^2) \\&= 2 + 3 \times 2t = 2 + 6 \times 2 = 14 \text{ m/s}\end{aligned}$$

B) *The instantaneous acceleration of the object after two seconds is:*

$$\begin{aligned}a &= \frac{dv}{dt} = \frac{d}{dt}(2 + 6t) \\&= 6 \text{ m/s}^2\end{aligned}$$

C) *The distance of the object after two seconds is:*

$$\begin{aligned}x &= 8 + 2t + 3t^2 \\&= 8 + 2 \times 2 + 3 \times (2)^2 \\&= 8 + 4 + 12 = 24 \text{ m}\end{aligned}$$



Example 2-4

A car travels with a velocity of 20 m/s, the driver increased the velocity until it reaches 100 km/h in three seconds. Then the driver decided to stop, the car stopped after four seconds.

Find the average acceleration in both cases?

Solution

First: convert the units from km /h to m /s.

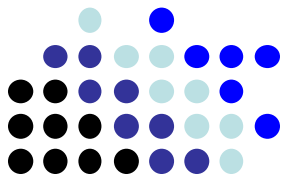
$$v_f = \frac{100 \times 1000}{60 \times 60} = 27.8 \text{ m/s}$$

$$a_{\text{ave},1} = \frac{\Delta v}{\Delta t}$$

$$= \frac{27.8 - 20}{3} = 2.6 \text{ m/s}$$

$$a_{\text{ave},2} = \frac{\Delta v}{\Delta t}$$

$$= \frac{0 - 27.8}{4} = -6.95 \text{ m/s}^2$$



Example 2-5

An object moves in x-axis according to the following formula: $x = t^3 + 5$

Note that the distance and the time are measured in meters and seconds, respectively.

Find:

- A) The velocity and the acceleration of the object?
- B) The velocity and the acceleration when $t = 3s$, $t = 2s$?
- C) Average of the velocity and the acceleration at $t = 3s$, $t = 2s$?

Solution

A) Defines the distance equation

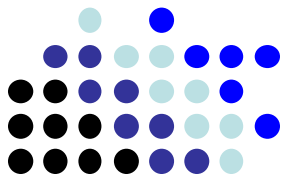
$$x = t^3 + 5 \dots \dots (1)$$

The velocity is:

$$v = \frac{dx}{dt} = \frac{d}{dt}(t^3 + 5) = 3t^2 \dots \dots \dots (2)$$

The acceleration is

$$a = \frac{dv}{dt} = \frac{d}{dt}(3t^2) = 6t \dots \dots \dots (3)$$



B) When the time ($t = 2$ s) the distance, velocity and the acceleration will be

The distance after 2 sec.

$$x_1 = t^3 + 5 = (2)^3 + 5 = 13 \text{ m}$$

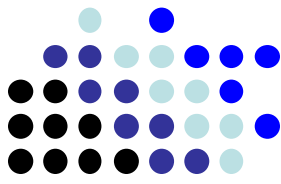
The velocity after 2 sec.

$$v_1 = \frac{dx}{dt} = 3t^2 = 3(2)^2 = 12 \text{ m/s}$$

The acceleration after 2 sec.

$$a_1 = \frac{dv}{dt} = 6t = 6(2) = 12 \text{ m/s}^2$$

When the time ($t=3$ s), the distance, velocity and the acceleration, as what we have



done in the previous (السابق) answers we get:

$$x = 32 \text{ m}, \quad v = 27 \text{ m/s} \quad a = 18 \text{ m/s}^2$$

C) The average velocity and acceleration are

$$\begin{aligned} v_{\text{avg.}} &= \frac{\Delta x}{\Delta t} = \frac{x_2 - x_1}{t_2 - t_1} \\ &= \frac{32 - 13}{3 - 2} = 19 \text{ m/s} \end{aligned}$$

$$\begin{aligned} a_{\text{avg.}} &= \frac{\Delta v}{\Delta t} = \frac{v_2 - v_1}{t_2 - t_1} \\ &= \frac{18 - 12}{3 - 2} = 6 \text{ m/s}^2 \end{aligned}$$