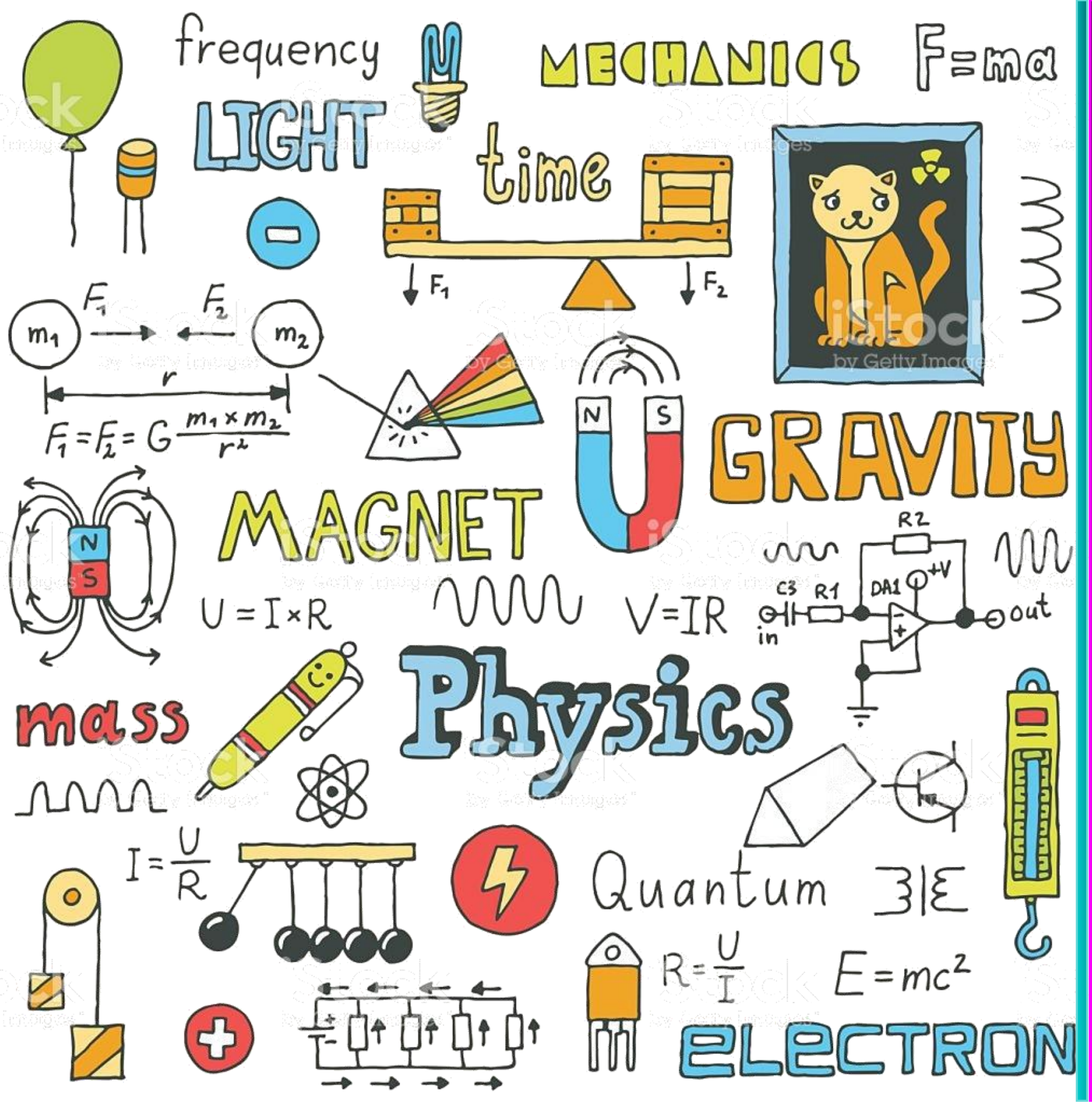


Physics

L3

Wiam Al Drees

Al-imam Muhammad Ibn Saud Islamic University

What are we going to talk about today?

Ch 1 : Motion in One Dimension

2.1 Position, Velocity, and Speed

2.2 Instantaneous Velocity and Speed

2.3 Analysis Model: Particle Under Constant Velocity

2.4 Acceleration

2.6 Analysis Model: Particle Under Constant Acceleration

2.7 Freely Falling Objects

Mechanic

Kinematics

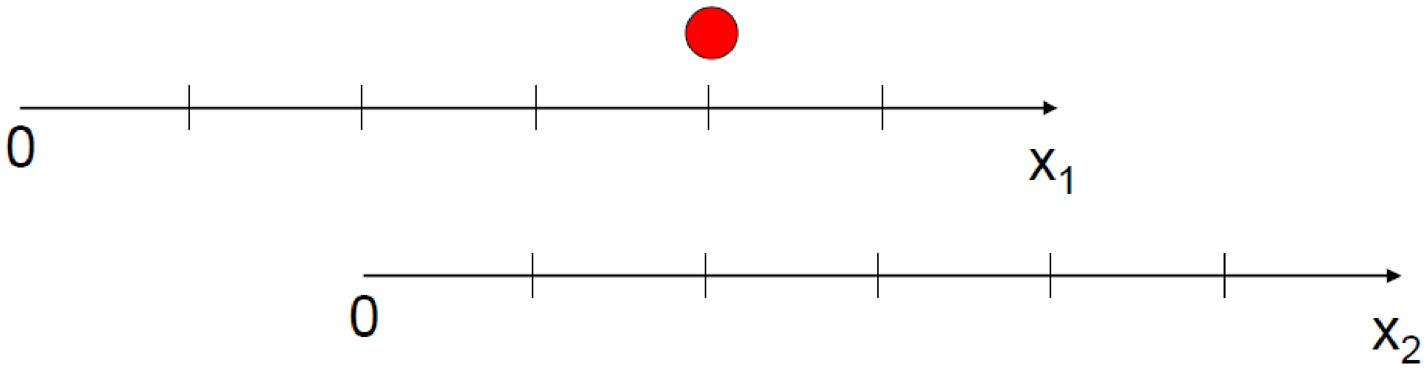
describes **HOW** objects move

Dynamics

shows **WHY** objects move

▪ Position:

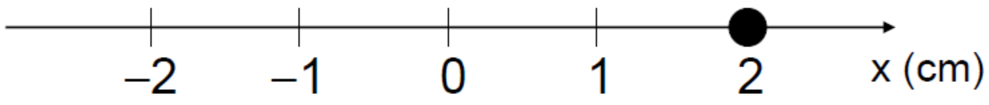
The **position** (x) of an object describes its location relative to some origin or other reference point.



The position of the ball differs in the two shown coordinate systems.

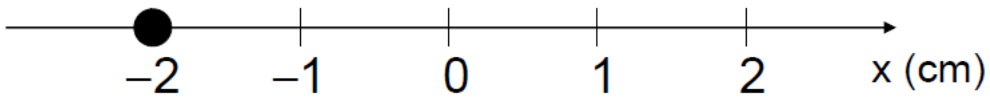
1.2 Displacement; Average Velocity.

Exercise 1–a: What is the position of the ball ?



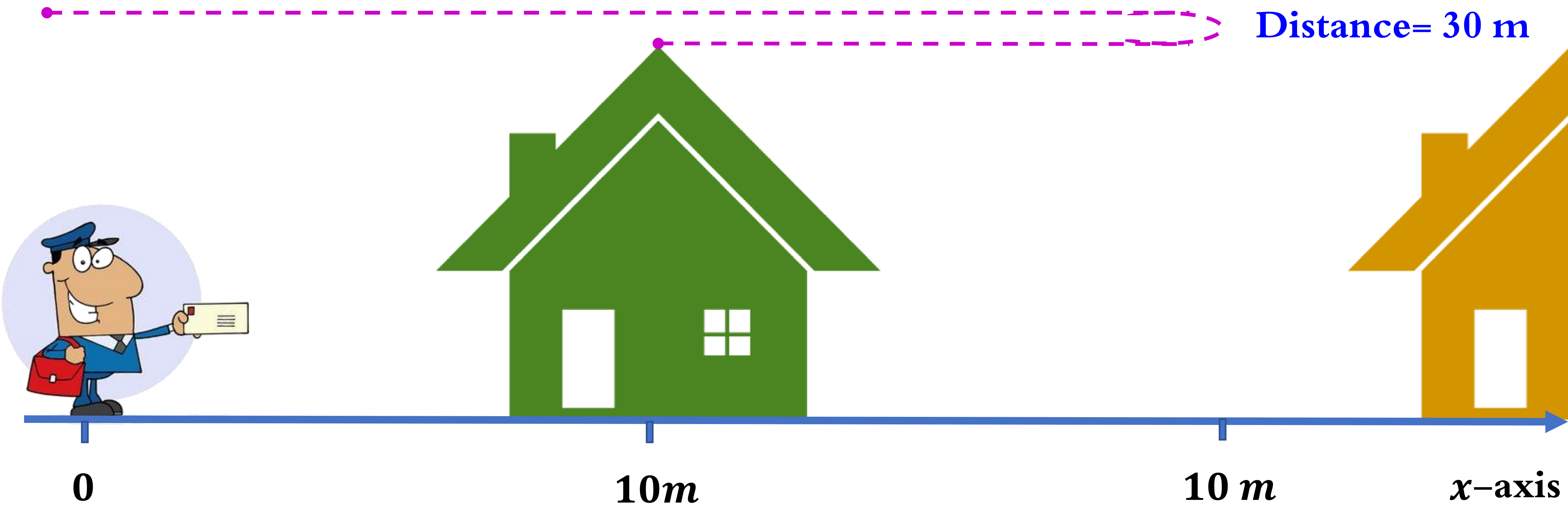
The position of the ball is $x = +2\ cm$.
The positive sign indicates the direction is to the right of the origin.

Exercise1–b: What is the position of the ball ?



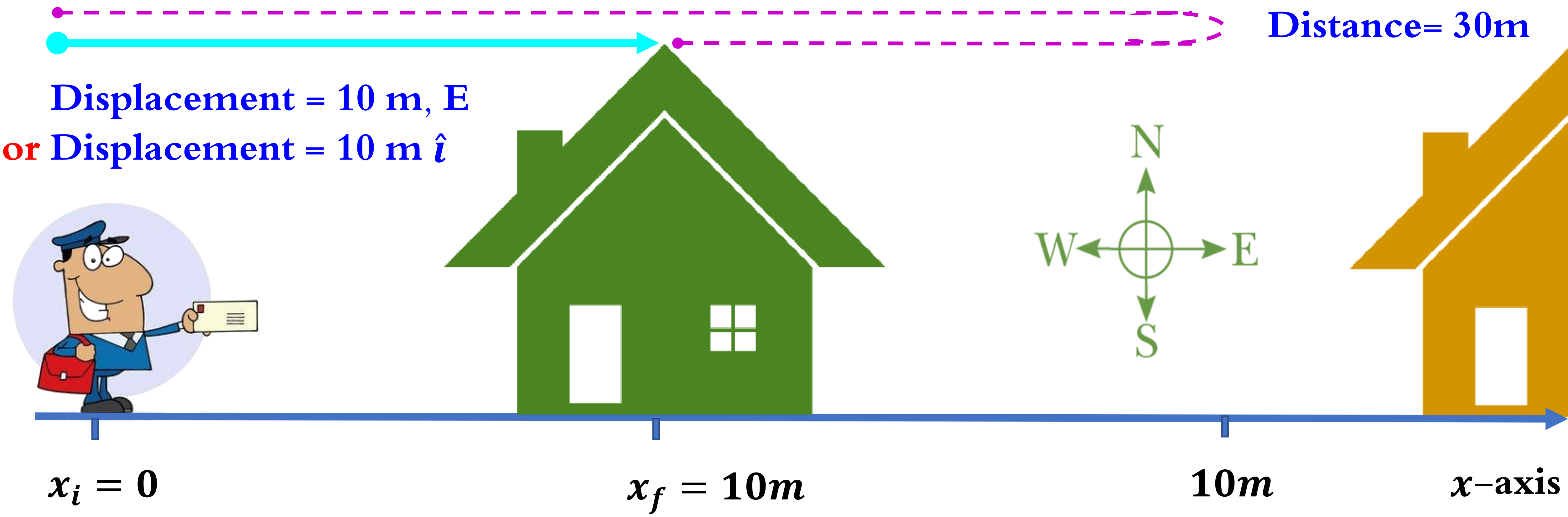
The position of the ball is $x = -2\ cm$.
The negative sign indicates the direction is to the left of the origin.

- **Distance**: **measured along the actual path (dashed line)**
- **It is a scaler quantity, with SI unit: m**



2.1 Position, Velocity, and Speed

- **Displacement**: Displacement (blue line) is how far the object is from its starting point to ending point, regardless of how it got there.
- It is a vector quantity, with SI unit: m



2.1 Position, Velocity, and Speed

- **Displacement**:

The displacement is defined as : $\boxed{\overrightarrow{\Delta x} \equiv \overrightarrow{x_f} - \overrightarrow{x_i}}$

Exercise 2:

1) **the displacement in Fig.a is :**

$$\overrightarrow{\Delta x} = \overrightarrow{x_f} - \overrightarrow{x_i} = 30\text{m}\,\hat{\imath} - 10\text{m}\,\hat{\imath} = 20\text{m}\,\hat{\imath}$$

2) **the displacement in Fig.b is :**

$$\overrightarrow{\Delta x} = \overrightarrow{x_f} - \overrightarrow{x_i} = 10\text{m}\,\hat{\imath} - 30\text{m}\,\hat{\imath} = -20\text{m}\,\hat{\imath}$$

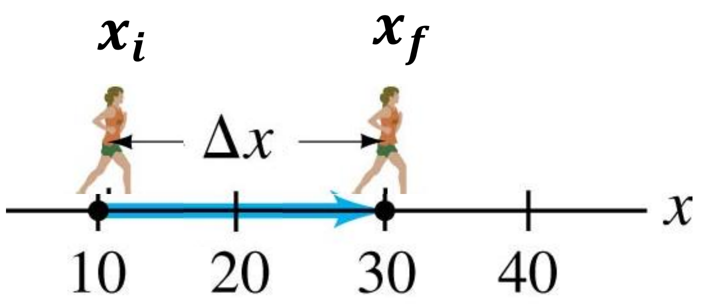


Fig.a

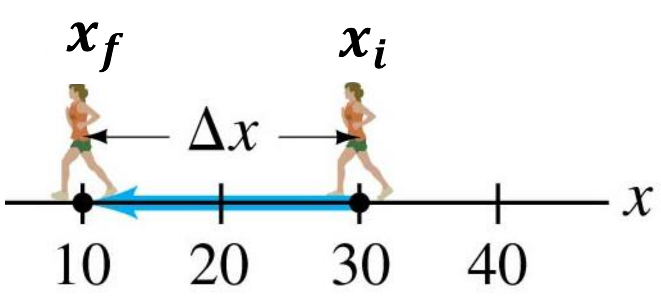
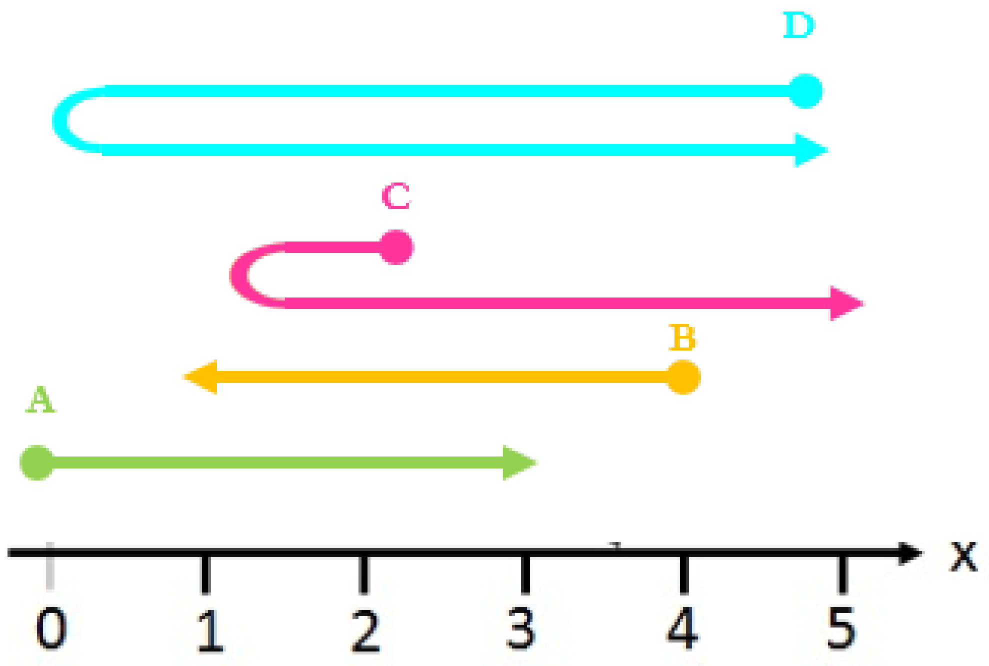


Fig.b

The displacement can be positive or negative; it is negative if the motion is in the negative direction

Exercise 3: **Use the diagram to determine the resulting distance and the displacement traveled for A, B, C and D.**

#	Distance	Displacement
A		
B		
C		
D		

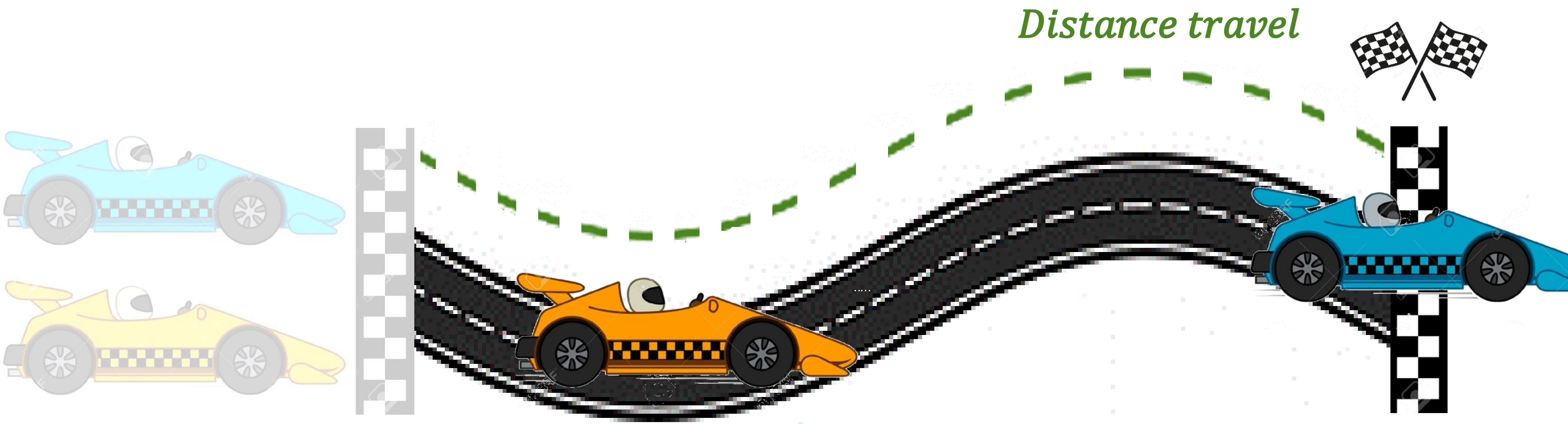


Distance	Displacement
Scaler quantities	Vector quantities
Always positive	Can be negative, positive
Distance= actual path	$\overrightarrow{\Delta x} = \overrightarrow{x_f} - \overrightarrow{x_i}$
Dimension: length (L)	Dimension: length (L)
SI unit: m	SI unit: m

- **Average Speed**:

Average speed is the distance traveled divided by the elapsed time Δt.

$$\boxed{Average\ speed \equiv \frac{Distance\ travel}{Time\ elapsed}}$$

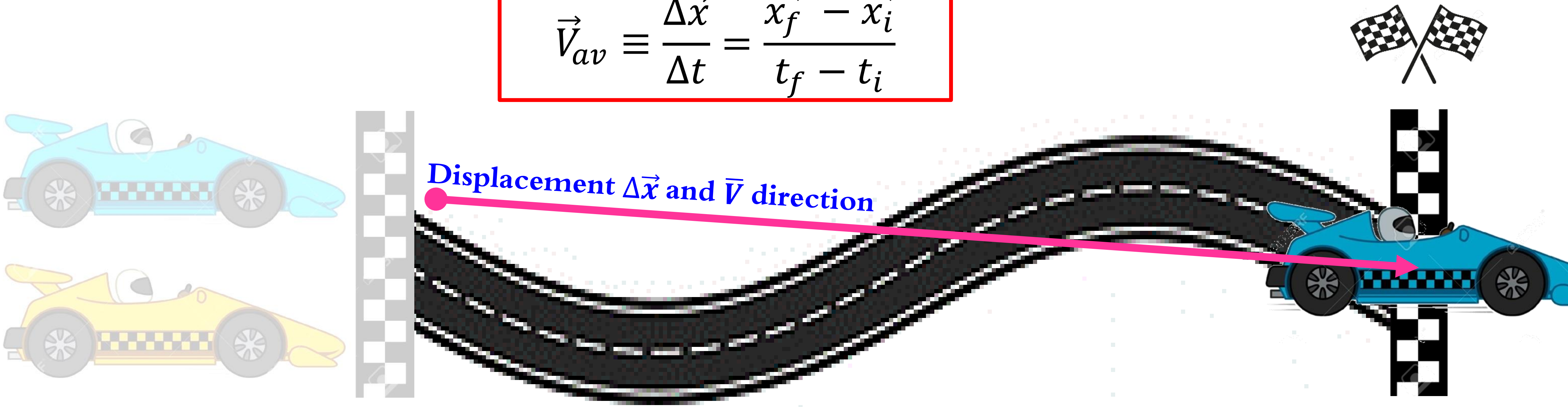


- **Average Velocity**:

Average velocity is displacement divided by elapsed time Δt of the displacement.

$$\text{Average velocity} \equiv \frac{\text{Displacement}}{\text{Time elapsed}}$$

$$\vec{V}_{av} \equiv \frac{\Delta\vec{x}}{\Delta t} = \frac{\vec{x_f} - \vec{x_i}}{t_f - t_i}$$

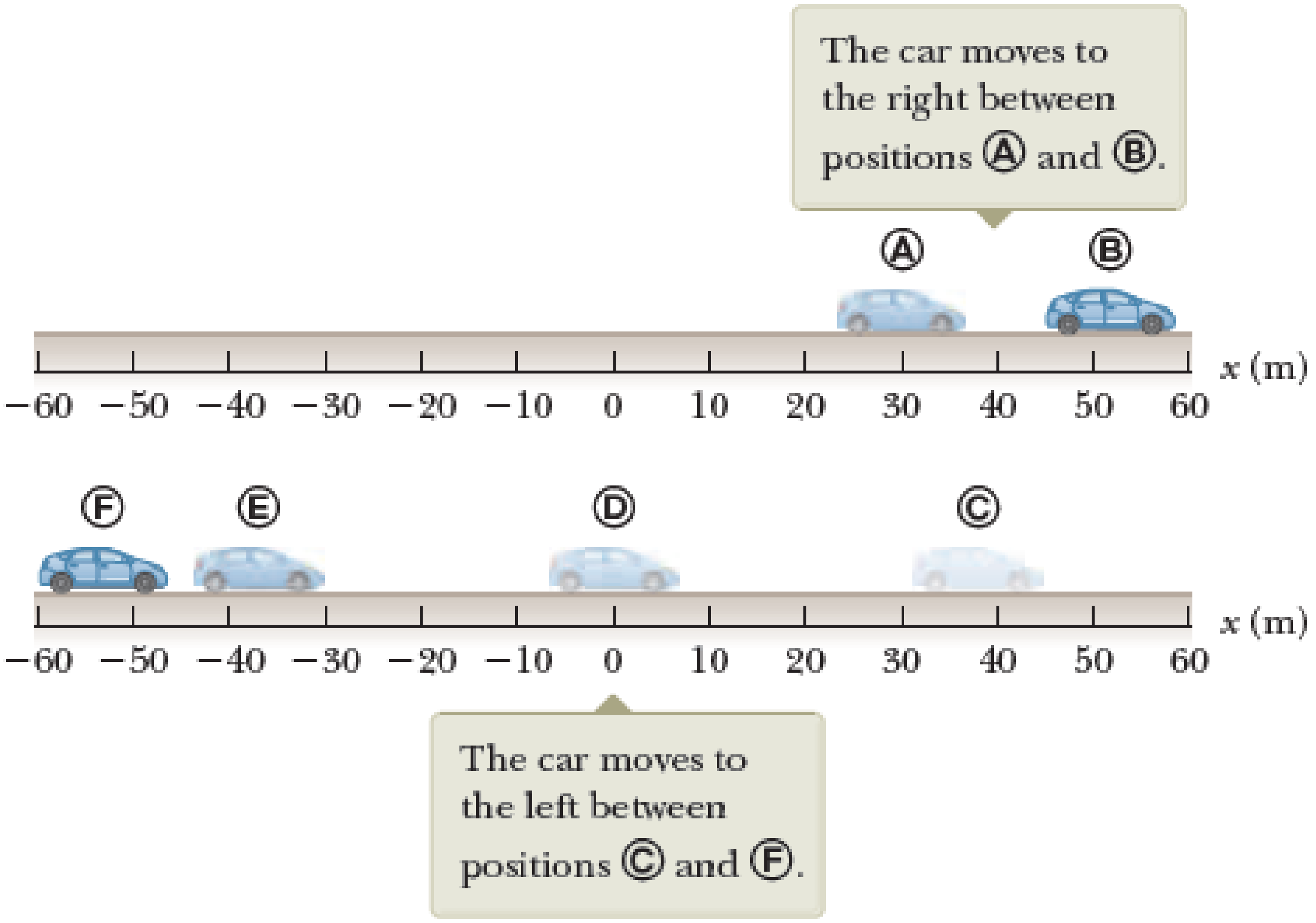


2.1 Position, Velocity, and Speed

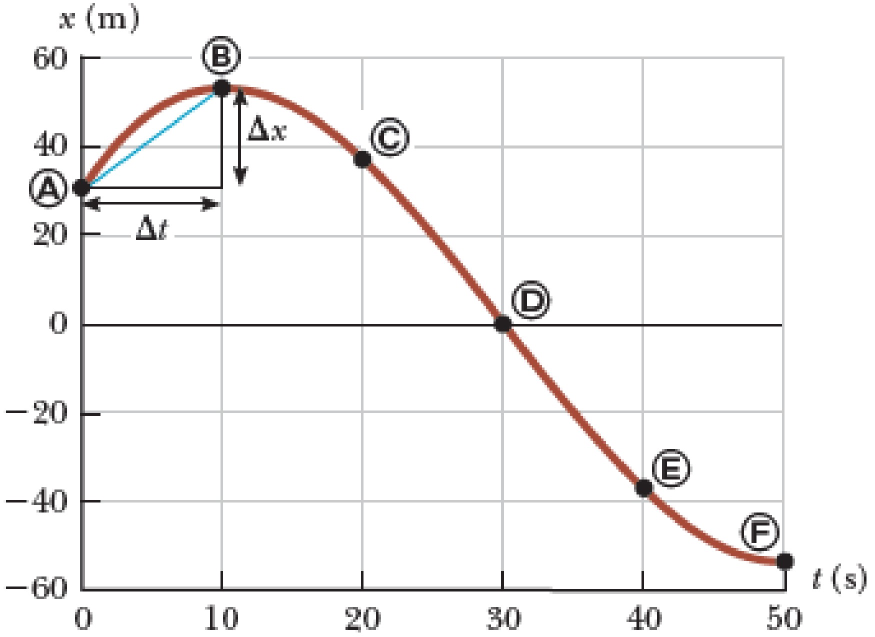
Average Speed	Average Velocity
Scaler quantities	Vector quantities
Always positive	Can be negative, positive
$\boldsymbol{average\ speed} \equiv \dfrac{Distance\ travel}{Time\ elapsed}$	$\vec{V}_{av} \equiv \dfrac{\Delta\vec{x}}{\Delta t} = \dfrac{\vec{x_f} - \vec{x_i}}{t_f - t_i}$
Dimension: length/time (L/T)	Dimension: length/time (L/T)
SI unit: m/s	SI unit: m/s

2.1 Position, Velocity, and Speed

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



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



SOLUTION

Consult Figure 2.1 to form a mental image of the car and its motion. We model the car as a particle. From the position–time graph given in Figure 2.1b, notice that $x_{Ⓐ} = 30$ m at $t_{Ⓐ} = 0$ s and that $x_{Ⓕ} = -53$ m at $t_{Ⓕ} = 50$ s.

Use Equation 2.1 to find the displacement of the car: $\Delta x = x_{Ⓕ} - x_{Ⓐ} = -53 \text{ m} - 30 \text{ m} = \boxed{-83 \text{ m}}$

This result means that the car ends up 83 m in the negative direction (to the left, in this case) from where it started. This number has the correct units and is of the same order of magnitude as the supplied data. A quick look at Figure 2.1a indicates that it is the correct answer.

Use Equation 2.2 to find the car's average velocity:

$$v_{x,\text{avg}} = \frac{x_{Ⓕ} - x_{Ⓐ}}{t_{Ⓕ} - t_{Ⓐ}}$$

$$= \frac{-53 \text{ m} - 30 \text{ m}}{50 \text{ s} - 0 \text{ s}} = \frac{-83 \text{ m}}{50 \text{ s}} = \boxed{-1.7 \text{ m/s}}$$

We cannot unambiguously find the average speed of the car from the data in Table 2.1 because we do not have information about the positions of the car between the data points. If we adopt the assumption that the details of the car's position are described by the curve in Figure 2.1b, the distance traveled is 22 m (from Ⓐ to Ⓑ) plus 105 m (from Ⓑ to Ⓕ), for a total of 127 m.

Use Equation 2.3 to find the car's average speed: $v_{\text{avg}} = \frac{127 \text{ m}}{50 \text{ s}} = \boxed{2.5 \text{ m/s}}$

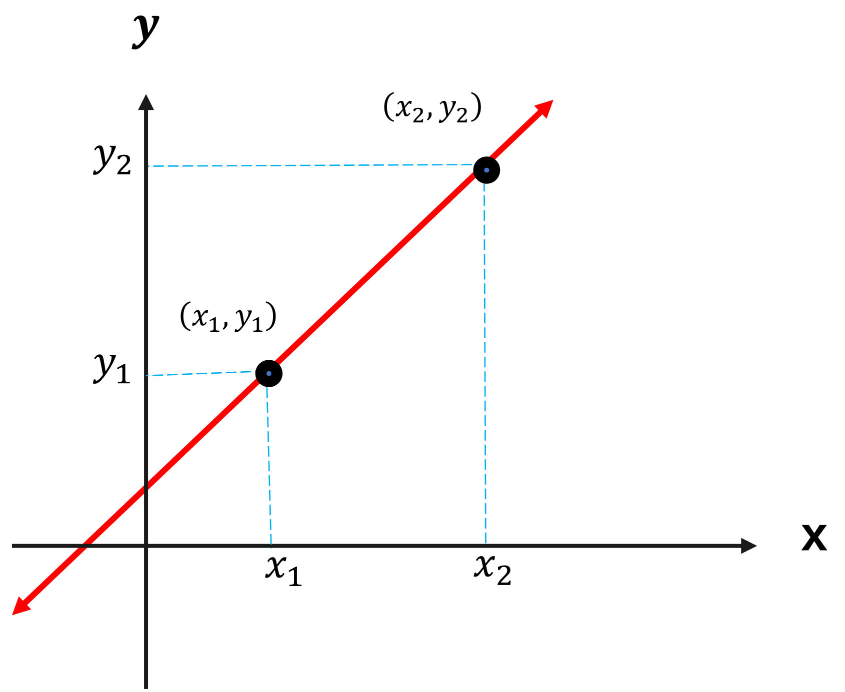
Notice that the average speed is positive, as it must be. Suppose the red-brown curve in Figure 2.1b were different so that between 0 s and 10 s it went from Ⓐ up to 100 m and then came back down to Ⓑ. The average speed of the car would change because the distance is different, but the average velocity would not change.

Revision

- **Slope of Line**

The slope, represented by the letter m, measures the inclination of the line, If the line passes by the points (x_1, y_1) and (x_2, y_2), the slope is obtained by the relation :

$$\boxed{m = \frac{y_2 - y_1}{x_2 - x_1}}$$



- **derivative (Rules)**

- $\frac{d}{dx}Ax^n = nAx^{n-1}$ **,where n and A are constant, For example** $\frac{d}{dx}\,2x^3 = 6x^2$
- **The derivative of constant number c is zero, For example** $\frac{d}{dx}\,34 = 0$

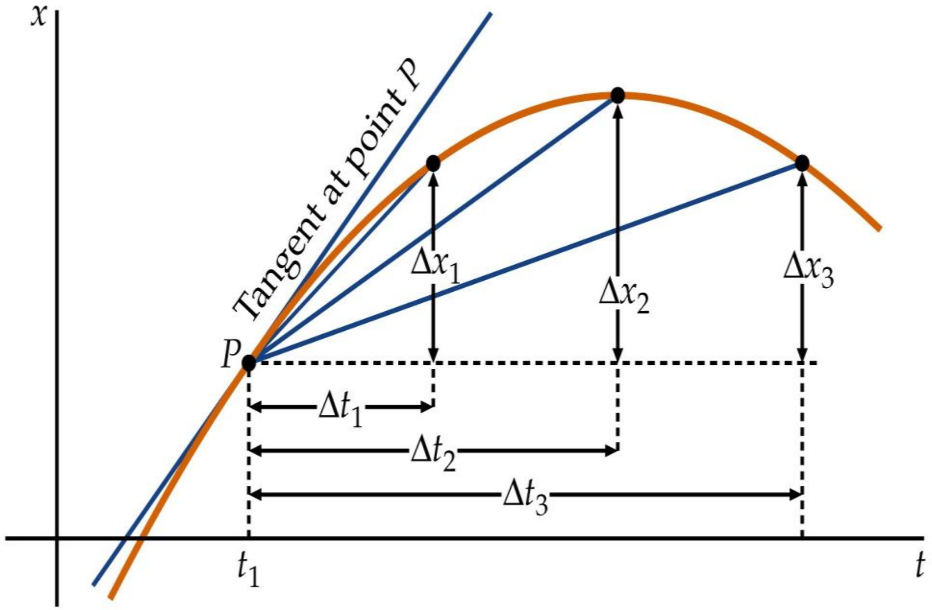
2.2 Instantaneous Velocity and Speed

- **Instantaneous Velocity**: **It can be calculated in two ways**:

a) Mathematical (differentiation):

The instantaneous velocity is side to be the limit of the average velocity $\vec{v}$ as Δt approaches zero. This evaluating limit is called differentiation.

$$\boxed{\vec{v} = \lim_{\Delta t \to 0} \frac{\Delta \vec{x}}{\Delta t} = \frac{d\vec{x}}{dt}}$$



b) Graphical (tangent): The instantaneous velocity can be found graphically by drawing a tangent (straight line) to the (x–t) curve at the instant of time, then the velocity is to be found as shown in the figure

$$\boxed{\vec{v} = Slope\ of\ tangent = \frac{\Delta \vec{x}}{\Delta t}}$$

2.2 Instantaneous Velocity and Speed

- **Instantaneous Speed :**

The instantaneous speed of a particle is defined as the magnitude of its instantaneous velocity. As with average speed, instantaneous speed has no direction associated with it.

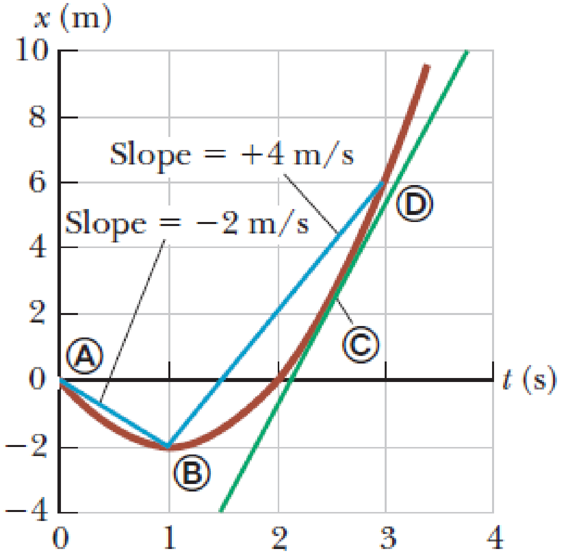
For example, if one particle has an instantaneous velocity of 125 m/s along a given line and another particle has an instantaneous velocity of –125 m/s along the same line, both have a speed of 125 m/s.

2.2 Instantaneous Velocity and Speed

Example 2.3 Average and Instantaneous Velocity

A particle moves along the x axis. Its position varies with time according to the expression $x = -4t + 2t^2$, where x is in meters and t is in seconds.[3] The position–time graph for this motion is shown in Figure 2.4a. Because the position of the particle is given by a mathematical function, the motion of the particle is completely known, unlike that of the car in Figure 2.1. Notice that the particle moves in the negative x direction for the first second of motion, is momentarily at rest at the moment $t = 1$ s, and moves in the positive x direction at times $t > 1$ s.

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



SOLUTION

Measure the slope of the green line at $t = 2.5$ s (point C) in Figure 2.4a:

$$v_x = \frac{10\text{ m} - (-4\text{ m})}{3.8\text{ s} - 1.5\text{ s}} = \boxed{+6\text{ m/s}}$$

or $$v = \frac{dx}{dt} = \frac{d}{dt}(-4t + 2t^2) = -4 + 4t$$

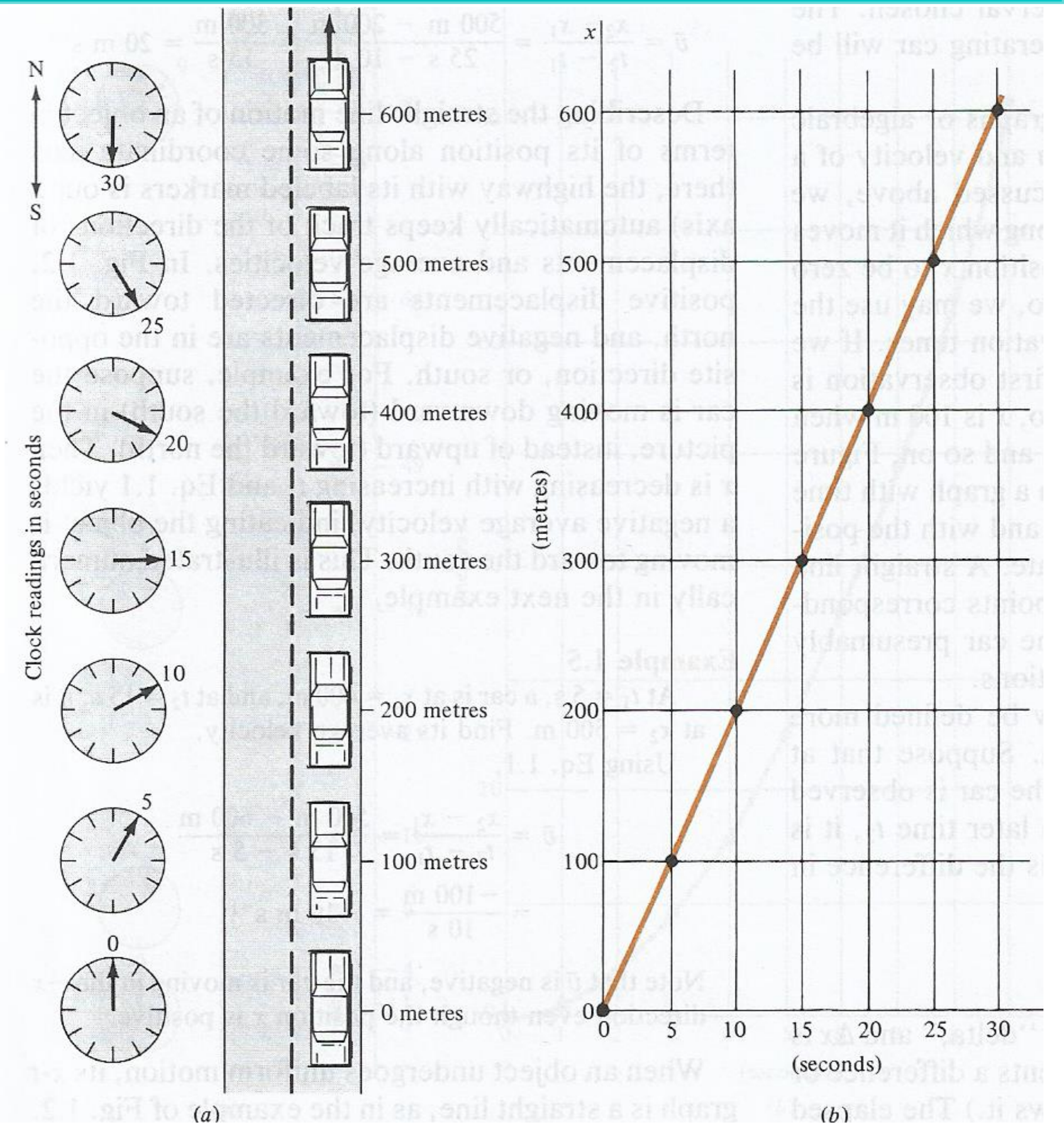
The instantaneous velocity at t=2.5s is $v = -4 + 4(2.5) = +6\ m/s$

2.3 Analysis Model: Particle Under Constant Velocity

If the velocity of a particle is constant, its instantaneous velocity at any instant during a time interval is the same as the average velocity over the interval.

Exercise 4: What is the average velocity of the car in the figure during the interval that the clock reading changes from 5 to 10 seconds?

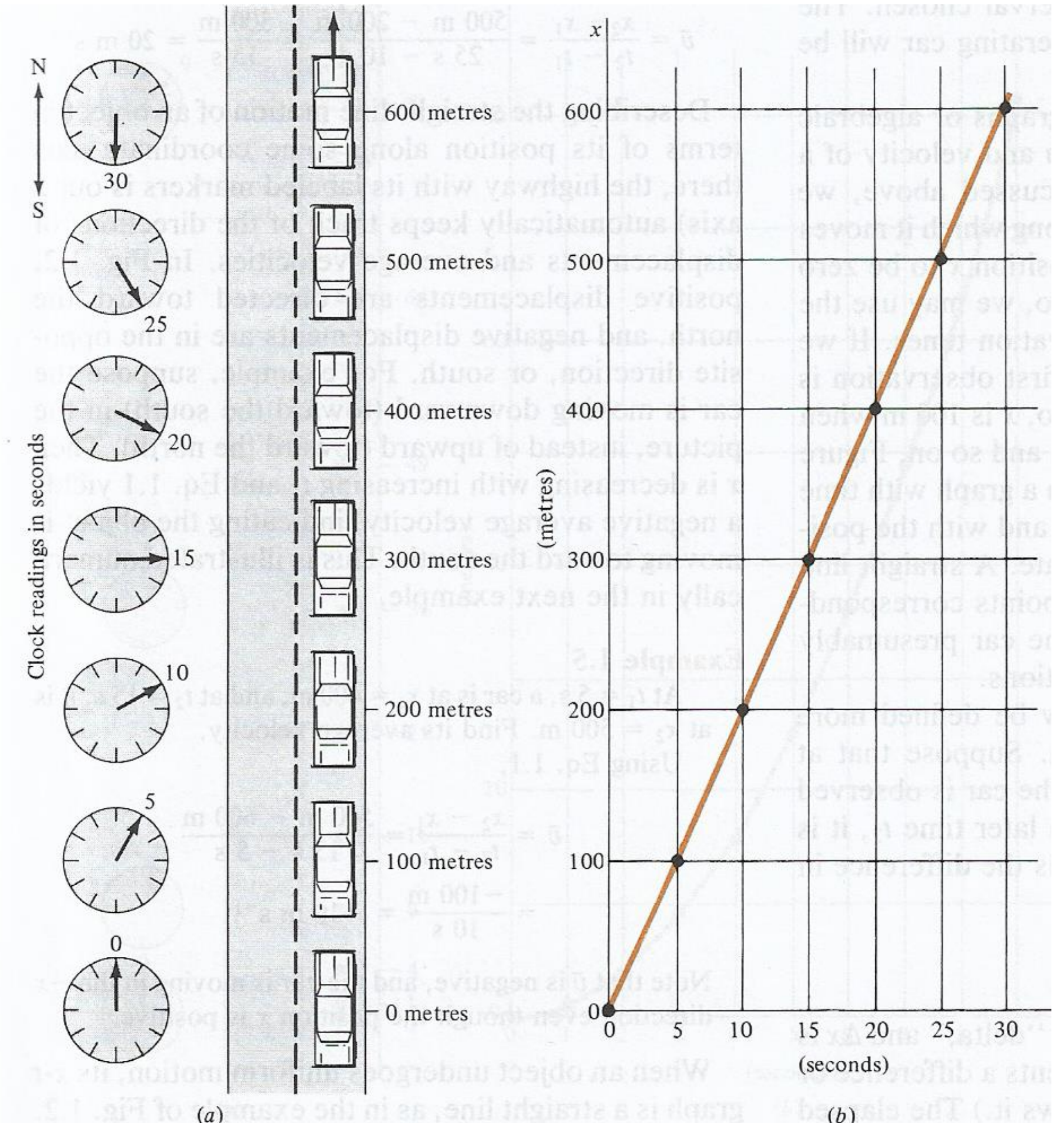
Ans (20 m/s)



2.3 Analysis Model: Particle Under Constant Velocity

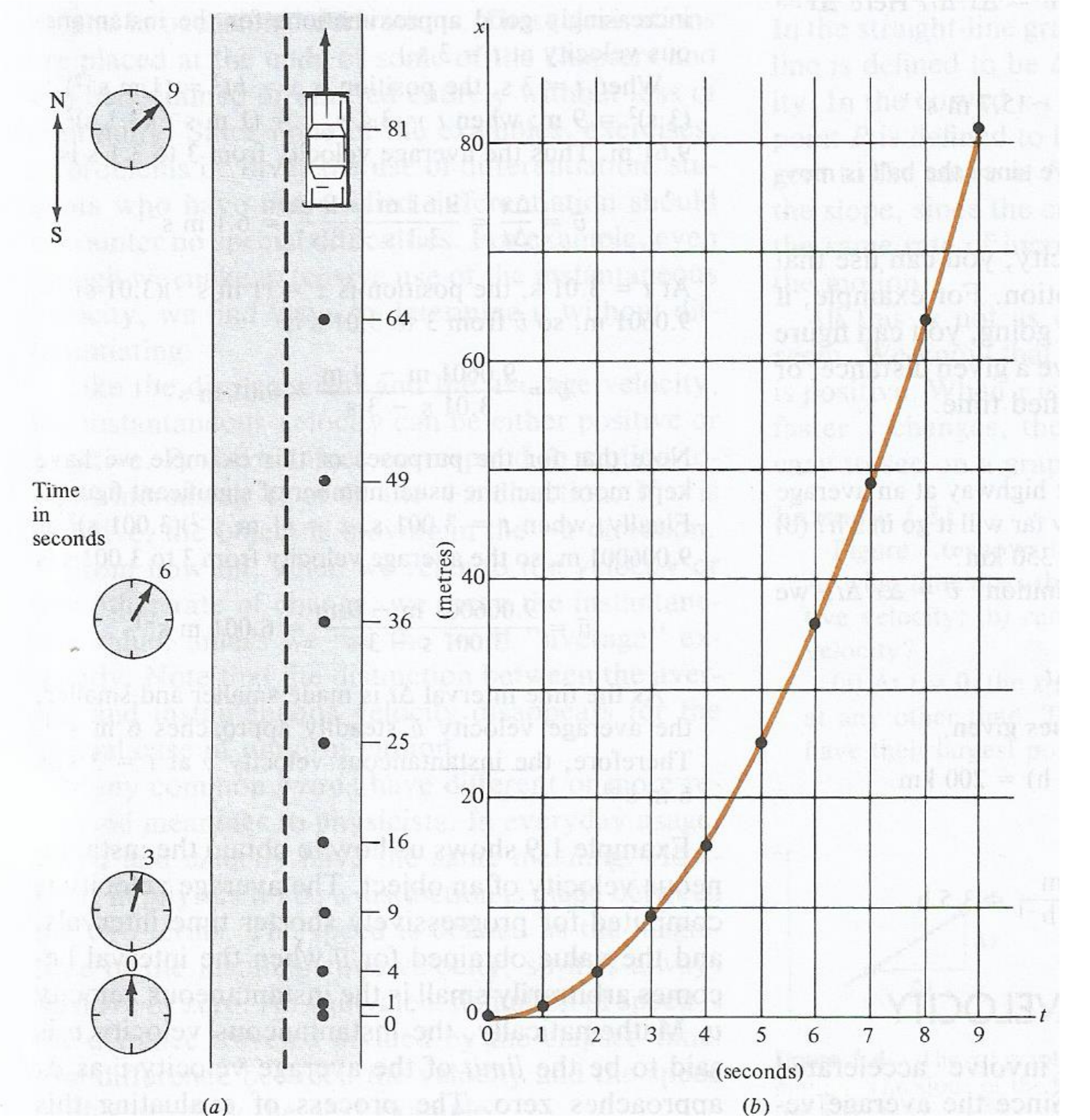
Exercise 5: **What is the average velocity of the car in the figure during the interval that the clock reading changes from 10 to 25 seconds?**

Ans $(20\ m/s)$



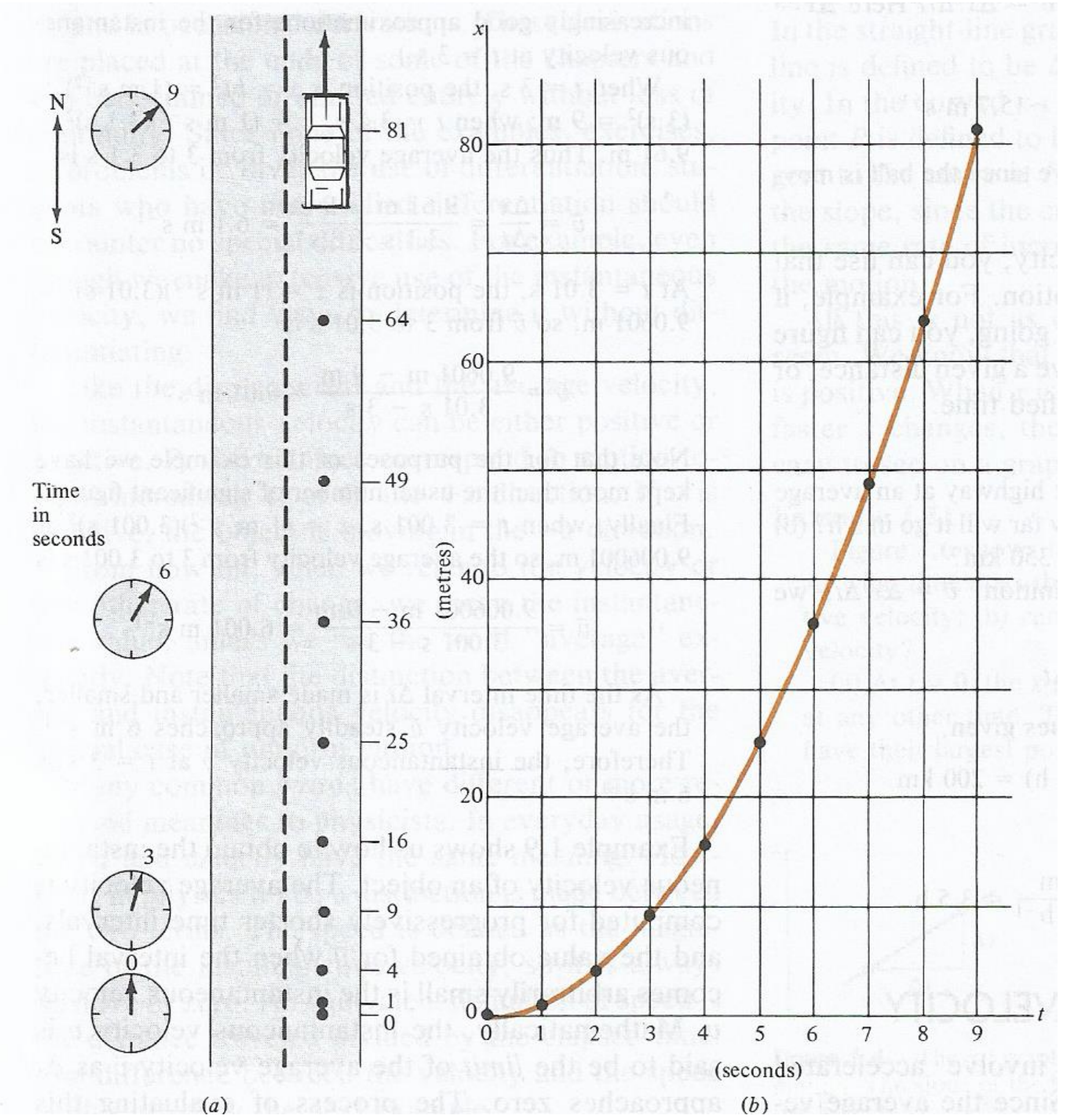
2.3 Analysis Model: Particle Under Constant Velocity

Exercise 6: **A car moves as shown in Figure. Find its average velocity from t=0 to t=1s.** *Ans* (1 m/s)



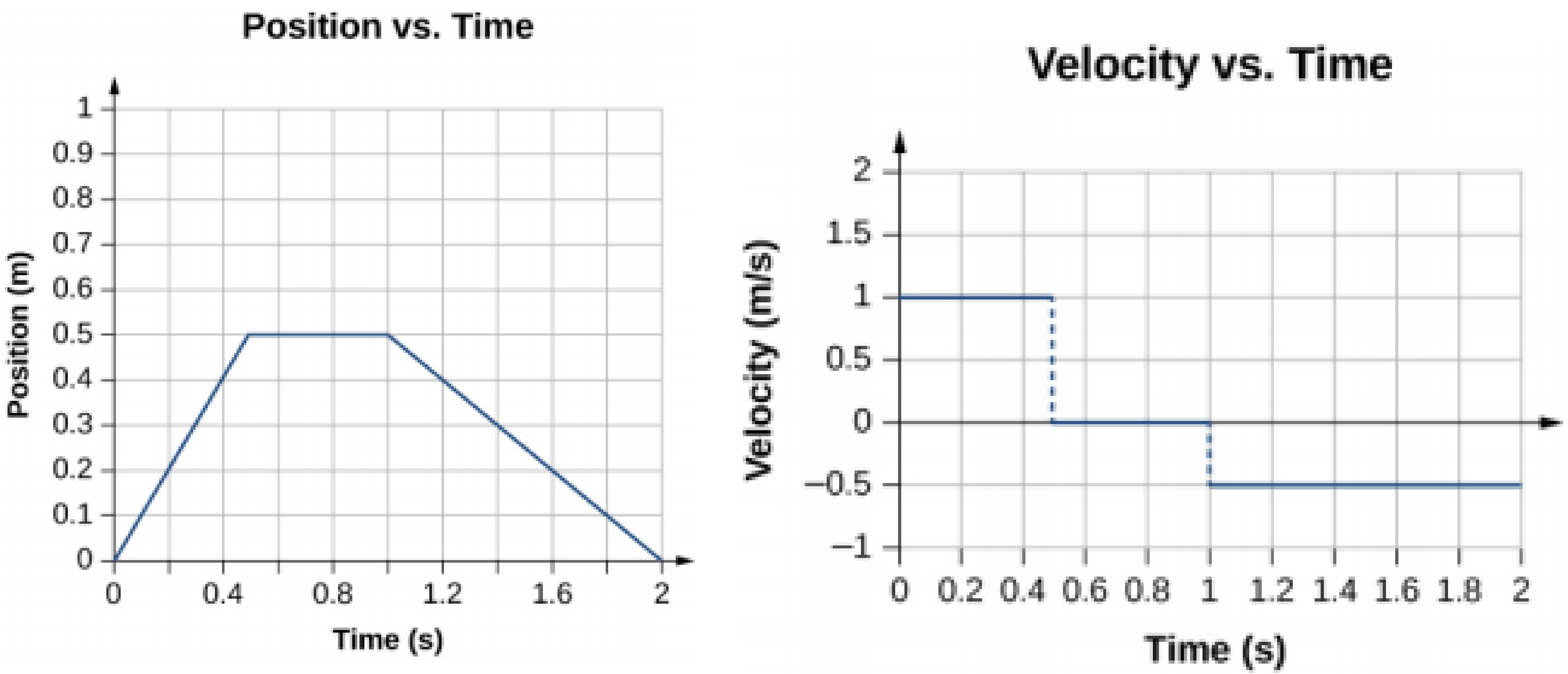
Exercise 7: **A car moves as shown in Figure. Find its average velocity from 1 s to 2 s.**

Ans (3 m/s)



2.3 Analysis Model: Particle Under Constant Velocity

Exercise 8: **Given the position–versus–time graph, find the velocity–versus–time graph.**



2.4 Acceleration

▪ Average acceleration

Average acceleration is defined as the change of velocity divided by the elapsed time (Δt)

$$\boxed{\vec{a}_{av} = \frac{\Delta\vec{v}}{\Delta t} = \frac{\overrightarrow{v_f} - \overrightarrow{v_i}}{t_f - t_i}}$$

- Acceleration is a vector quantity.
- Acceleration can be negative, positive.
- Acceleration has a dimension L/T^2.
- Acceleration has SI unit m/s^2.

Not that: a constant velocity means NO change in velocity, so in this case the acceleration must be zero (no acceleration).

2.4 Acceleration

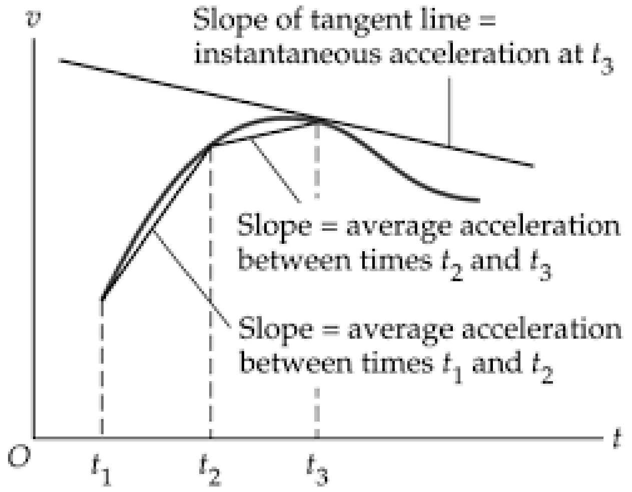
Instantaneous acceleration :

a) **Mathematical (differentiation):** Instantaneous acceleration is defined as the acceleration of an object at a given instant

$$\vec{a} = \lim_{\Delta t \to 0} \frac{\Delta \vec{v}}{\Delta t} = \frac{dv}{dt}$$

or

$$\vec{a} = \frac{d^2x}{dt^2}$$



b) **Graphical (tangent):** The instantaneous acceleration can be found graphically by drawing a tangent (straight line) to the $(v-t)$ curve at the instant of time, then the acceleration is to be found as shown in the figure

$$\vec{a} = Slope\ of\ tangent = \frac{\Delta \vec{v}}{\Delta t}$$

Acceleration can be either uniform or nonuniform. In this course acceleration is uniform

2.4 Acceleration

Example 2.6 **Average and Instantaneous Acceleration**

The velocity of a particle moving along the x axis varies according to the expression $v_x = 40 - 5t^2$, where v_x is in meters per second and t is in seconds.

(A) Find the average acceleration in the time interval $t = 0$ to $t = 2.0$ s.

Find the velocities at $t_i = t_Ⓐ = 0$ and $t_f = t_Ⓑ = 2.0$ s by substituting these values of t into the expression for the velocity:

$$v_{xⒶ} = 40 - 5t_Ⓐ^2 = 40 - 5(0)^2 = +40 \text{ m/s}$$

$$v_{xⒷ} = 40 - 5t_Ⓑ^2 = 40 - 5(2.0)^2 = +20 \text{ m/s}$$

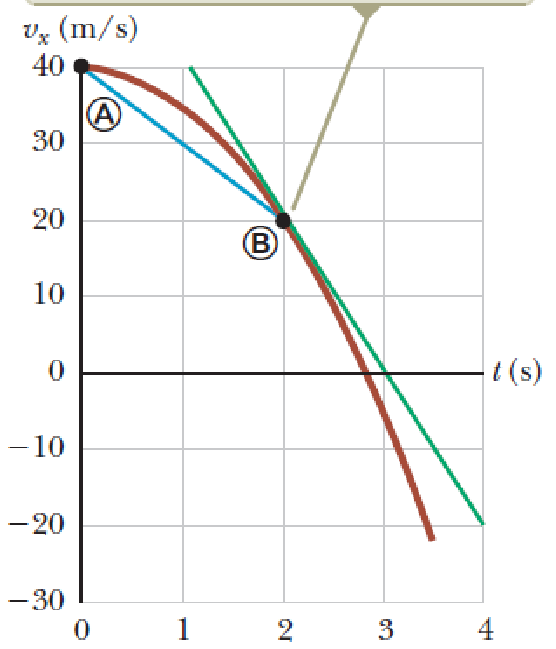
Find the average acceleration in the specified time interval $\Delta t = t_Ⓑ - t_Ⓐ = 2.0$ s:

$$a_{x,\text{avg}} = \frac{v_{xf} - v_{xi}}{t_f - t_i} = \frac{v_{xⒷ} - v_{xⒶ}}{t_Ⓑ - t_Ⓐ} = \frac{20 \text{ m/s} - 40 \text{ m/s}}{2.0 \text{ s} - 0 \text{ s}}$$

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

(B) Determine the acceleration at $t = 2.0$ s.

The acceleration at Ⓑ is equal to the slope of the green tangent line at $t = 2$ s, which is -20 m/s^2.



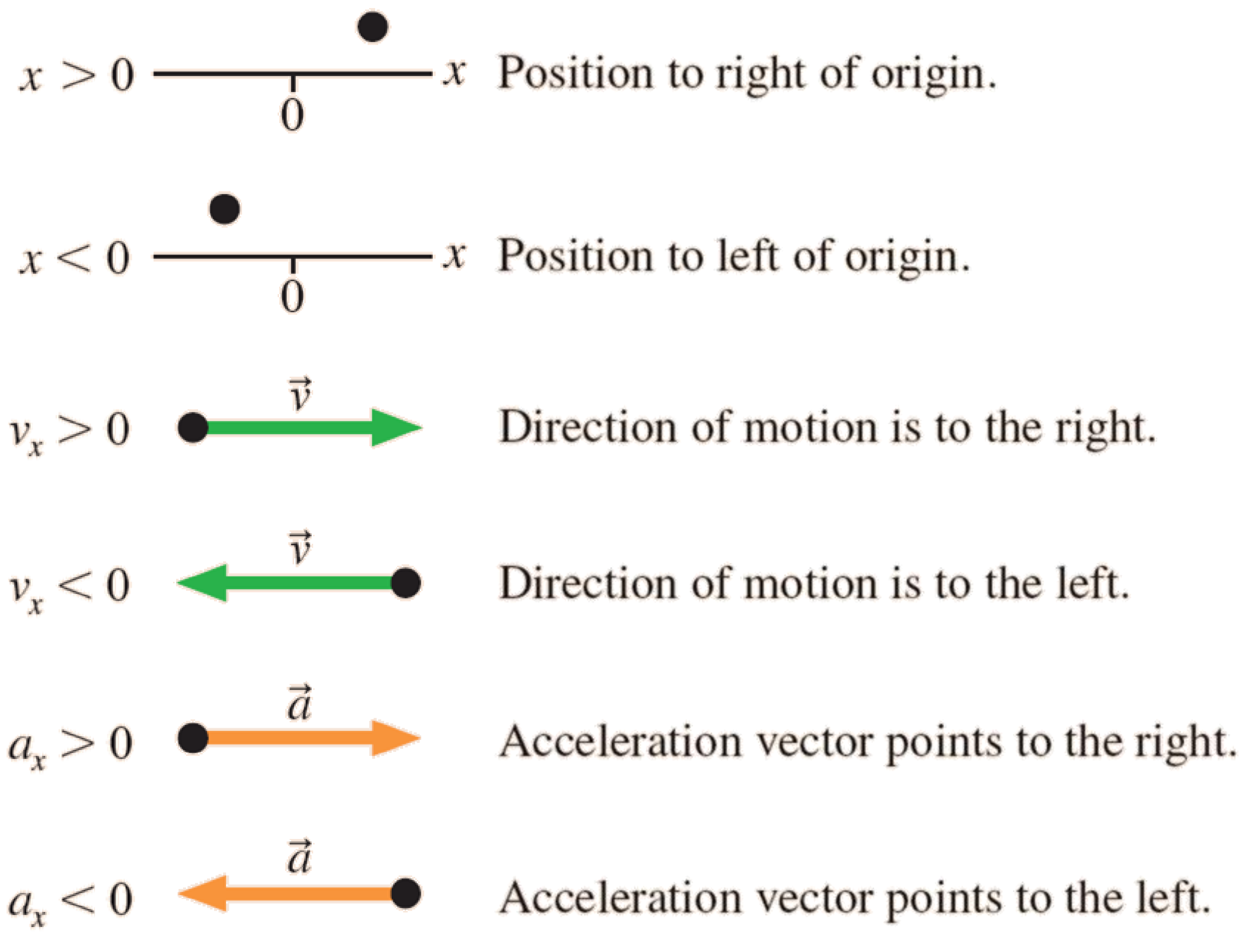
$$a = \frac{dv}{dt} = \frac{d}{dt}(40 - 5t^2) = -10t$$

The instantaneous acceleration at t=2.0 s is $v = -10(2) = -20 \; m/s^2$

2.4 Acceleration

▪ $\vec{x}$, $\vec{v}$, $\vec{a}$ a direction :

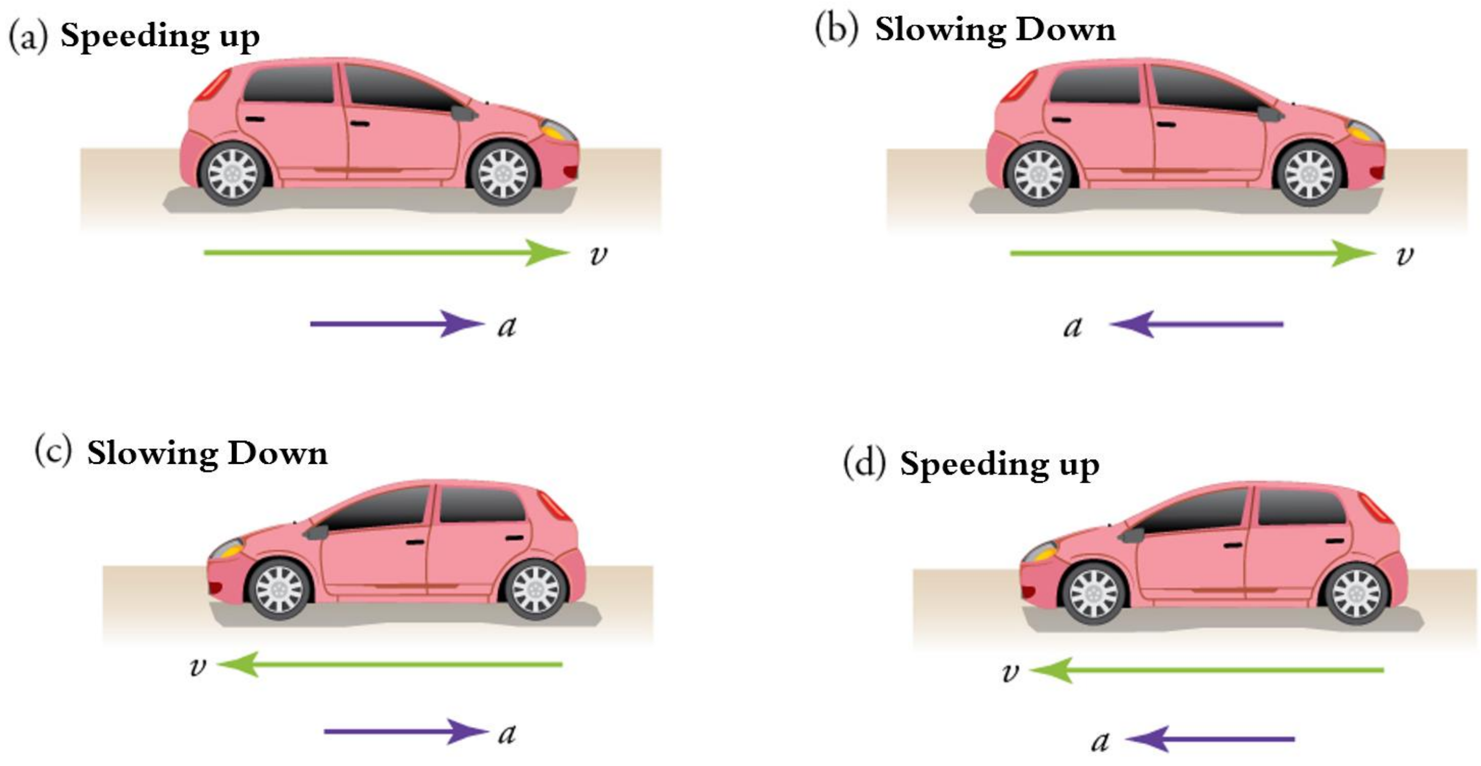
- A positive velocity simply means that the object is moving in the positive direction, as defined by the coordinate system, while a negative velocity means the object is traveling in the other direction.
- Moreover, even if an object has a positive acceleration, it does not mean that the object is speeding up! A positive acceleration means that the change in the velocity points in the positive direction.



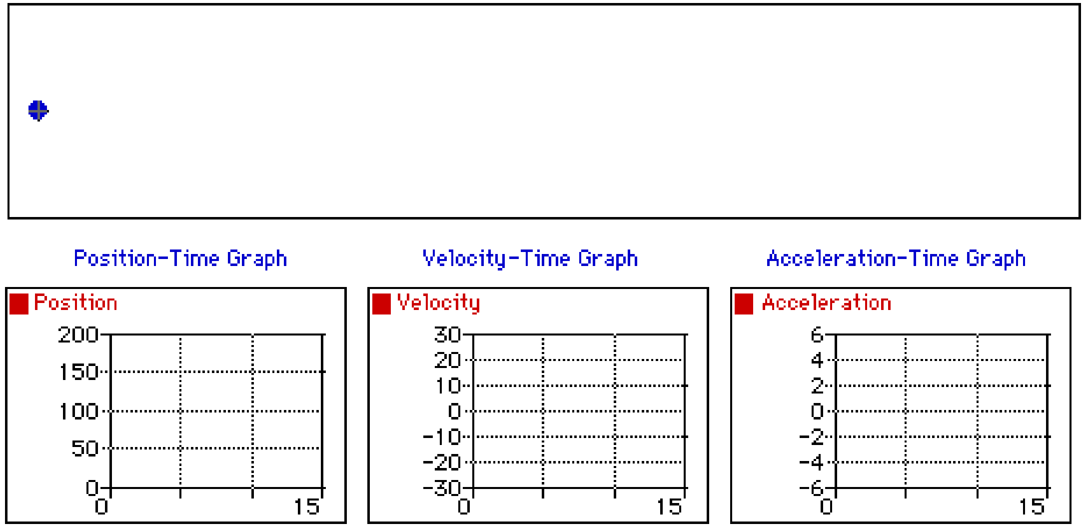
2.4 Acceleration

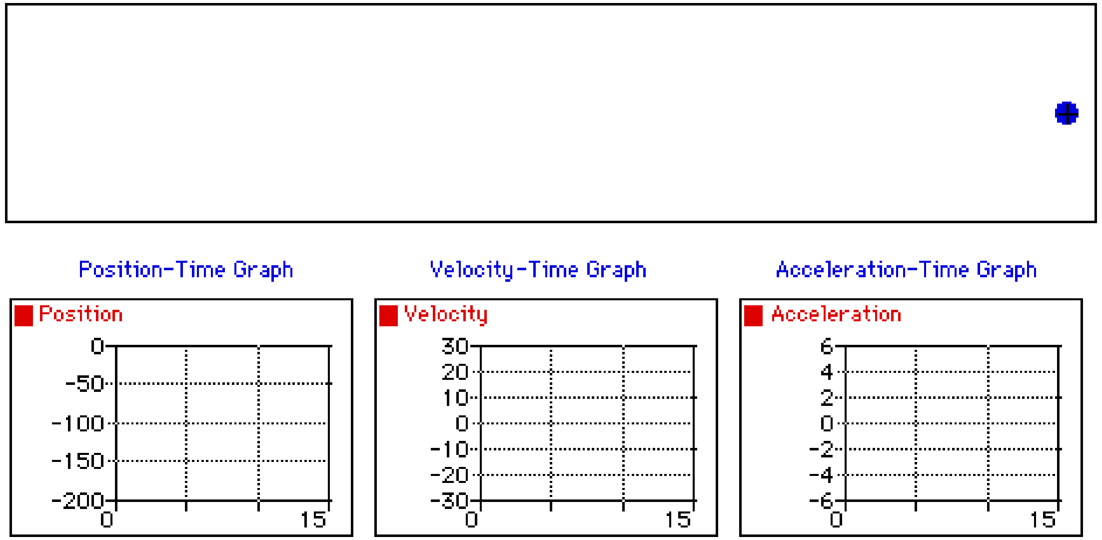
- **Speeding up and Slowing down:**

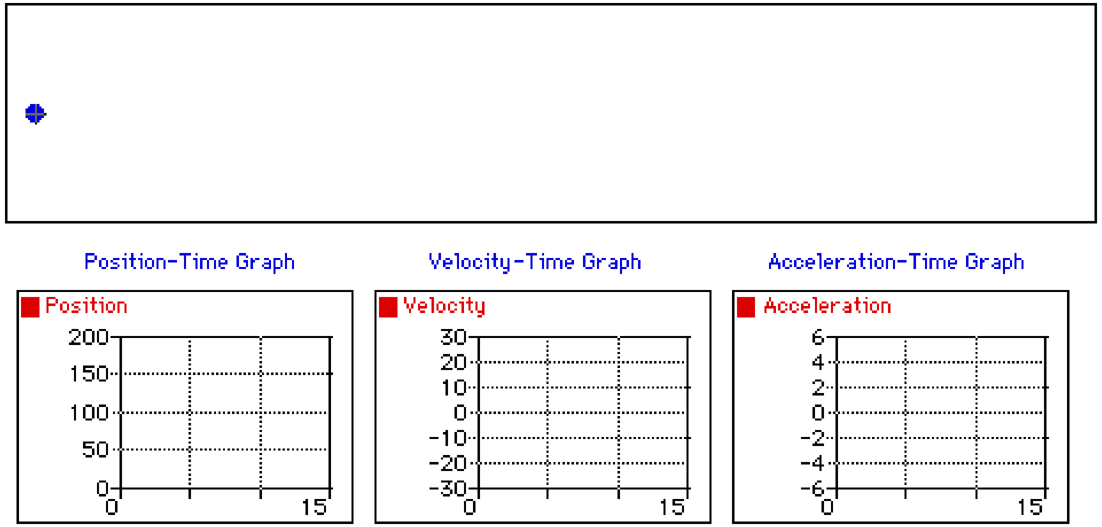
When an object's acceleration is in the same direction of its motion, the object will speed up. However, when an object's acceleration is opposite to the direction of its motion, the object will slow down.

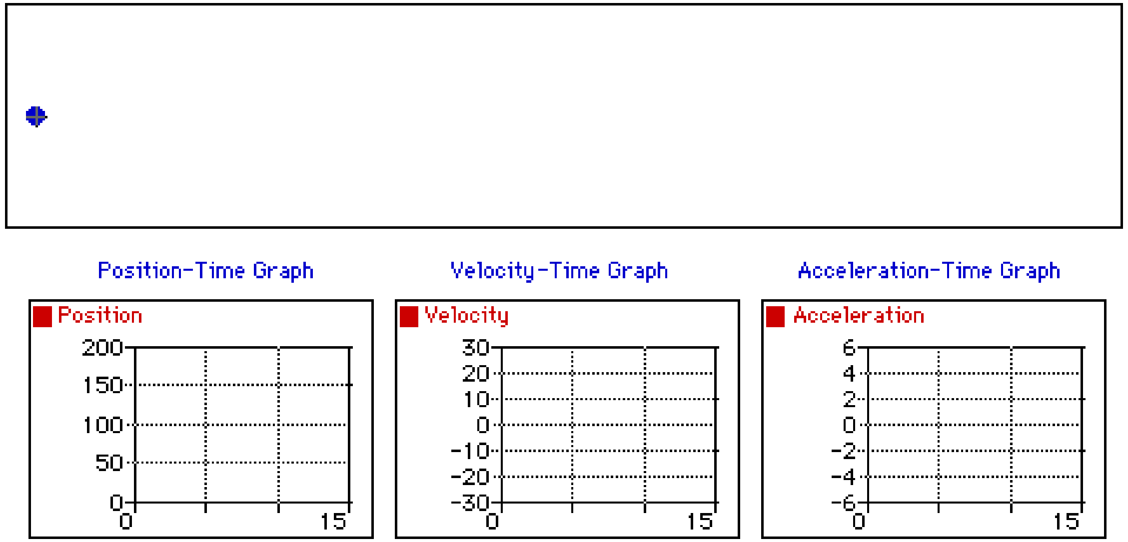


2.4 Acceleration









2.6 Analysis Model: Particle Under Constant Acceleration

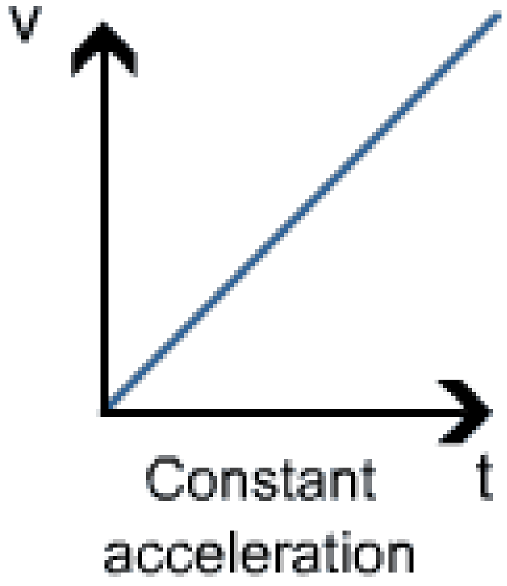
When the acceleration is constant, we can find the equations of motion. In this case:

1– The average acceleration and the instantaneous acceleration are equal $(\vec{a}_{av} = \vec{a})$

2– The average velocity is simply the average of the initial velocity and the final velocity

Text

$$\boxed{V_{av} = \frac{v_i + v_f}{2}}$$



2.6 Analysis Model: Particle Under Constant Acceleration

When the acceleration is constant, by take the initial time $t_i = 0$, then $\Delta t = t_f - t_i$ will be simply t, therefore following equations are obtained:

KINEMATICS equation: (motion in x–axis)

1	Average velocity	$\vec{V}_{av} = \dfrac{\vec{v}_{xi} + \vec{v}_{xf}}{2}$	Relating the final velocity to the initial velocity.
2	Final velocity	$\vec{v}_{xf} = \vec{v}_{xi} + \vec{v}_x t$	Relating the final velocity to the initial velocity and the acceleration,
3	Acceleration	$\vec{a}_x = \dfrac{\vec{v}_{xf}{}^2 - \vec{v}_{xi}{}^2}{2\Delta x}$	Relating the final velocity to the initial velocity, the acceleration and the position Change.
4	Change in position	$\Delta\vec{x} = \vec{v}_{xi} t + \dfrac{1}{2}\vec{a}_x t^2$	Relating the final position to the initial position, the initial velocity and the acceleration.

Solving Problems:

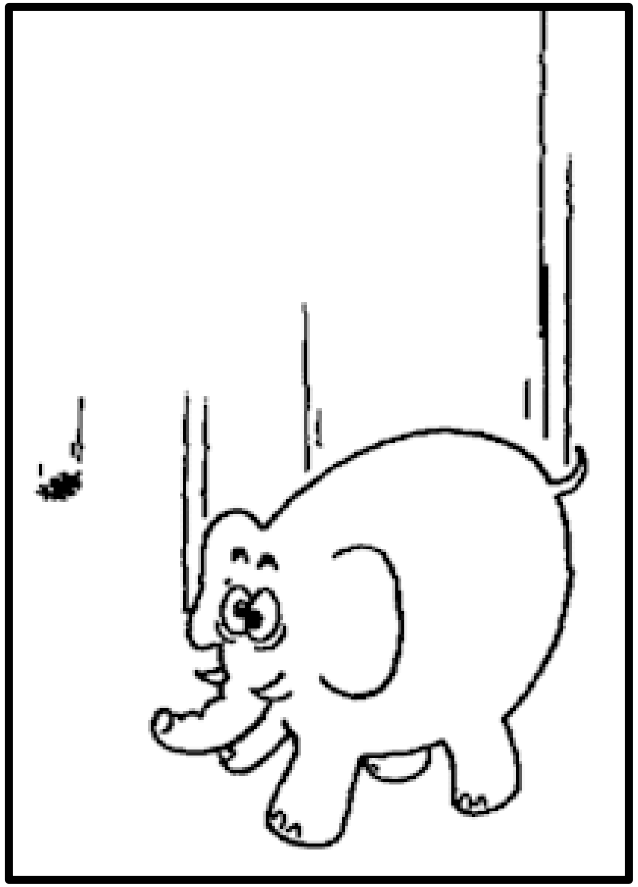
1. Read the whole problem and make sure you understand it. Then read it again.
2. Decide on the objects under study and what the time interval is.
3. Draw a diagram and choose coordinate axes.
4. Write down the known (given) quantities, and then the unknown ones that you need to find.
5. Which equations relate the known and unknown quantities? Are they valid in this situation? Solve algebraically for the unknown quantities, and check that your result is sensible (correct dimensions).
6. Look at the result—is it reasonable? Does it agree with a rough estimate?
7. Check the units again.

Exercise9: A car, initially at rest at a traffic light, accelerates at $2m/s^2$ when the light turns green. After 4 seconds what are its

(a) Velocity (Ans: 8 m/s)

(b) Position (Ans: 16 m)

Which object–the elephant or the feather– will hit the ground first ?!



Near the surface of the Earth, all objects accelerate at the same rate $9.8\ m/s^2$ (ignoring air resistance).

- Free–fall acceleration is independent of mass.
- Magnitude: $g = 9.8\ m/s^2$.
- Direction: always downward, so $\overrightarrow{a_y}$ is negative if we define "up" (y–axis) as positive, $\overrightarrow{a_y} = -g = -9.8$ m/s2

2.7 Freely Falling Objects

When the $\vec{a}_y = -\vec{g} = -9.8\ m/s^2\hat{j}$, and by take the initial time $t_i = 0$, then $\Delta t = t_f - t_i$ will be simply t, therefore following equations are obtained (motion in y–axis) :

1	Average velocity	$\vec{V}_{av} = \dfrac{\vec{v}_{yi} + \vec{v}_{yf}}{2}$	Relating the final velocity to the initial velocity
2	Final velocity	$\vec{v}_{yf} = \vec{v}_{yi} - \vec{g}t$	Relating the final velocity to the initial velocity.
3	Change in position	$\Delta\vec{y} = \dfrac{\vec{v}_{yi}^{\ 2} - \vec{v}_{yf}^{\ 2}}{2\vec{g}}$	Relating the final velocity to the initial velocity and the position Change.
4	Change in position	$\Delta\vec{y} = \vec{v}_{yi}t - \dfrac{1}{2}\vec{g}t^2$	Relating the final position to the initial position and the initial velocity.

1.6 The Acceleration of Gravity and Falling Objects

Exercise11: A rock fall off a cliff from a rest. How fast will it be moving after 5 s?

(Ans: –49 m/s)

1.6 The Acceleration of Gravity and Falling Objects

Example 2.10 Not a Bad Throw for a Rookie! AM

A stone thrown from the top of a building is given an initial velocity of 20.0 m/s straight upward. The stone is launched 50.0 m above the ground, and the stone just misses the edge of the roof on its way down as shown in Figure 2.14.

(A) Using $t_Ⓐ = 0$ as the time the stone leaves the thrower's hand at position Ⓐ, determine the time at which the stone reaches its maximum height.

Text

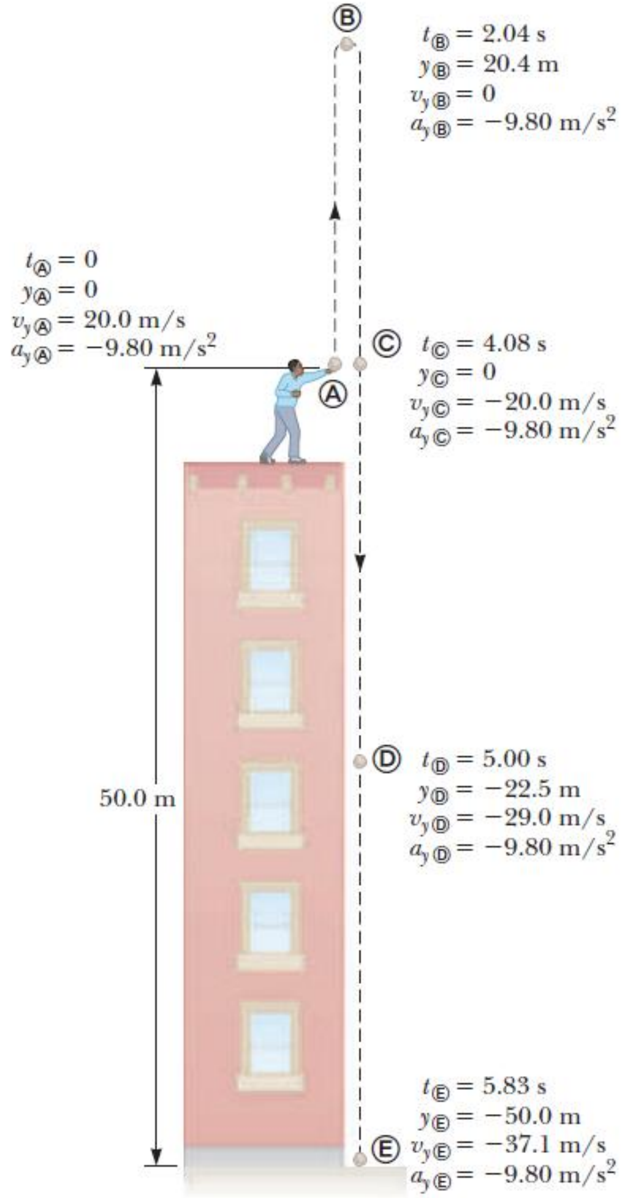
$$v_{yf} = v_{yi} + a_y t \quad \rightarrow \quad t = \frac{v_{yf} - v_{yi}}{a_y}$$

$$t = t_Ⓑ = \frac{0 - 20.0\ \text{m/s}}{-9.80\ \text{m/s}^2} = \boxed{2.04\ \text{s}}$$

(B) Find the maximum height of the stone.

$$y_{max} = y_Ⓑ = y_Ⓐ + v_{xⒶ} t + \tfrac{1}{2} a_y t^2$$

$$y_Ⓑ = 0 + (20.0\ \text{m/s})(2.04\ \text{s}) + \tfrac{1}{2}(-9.80\ \text{m/s}^2)(2.04\ \text{s})^2 = \boxed{20.4\ \text{m}}$$



1.6 The Acceleration of Gravity and Falling Objects

(C) Determine the velocity of the stone when it returns to the height from which it was thrown.

$$v_{yC}^2 = v_{yA}^2 + 2a_y(y_C - y_A)$$

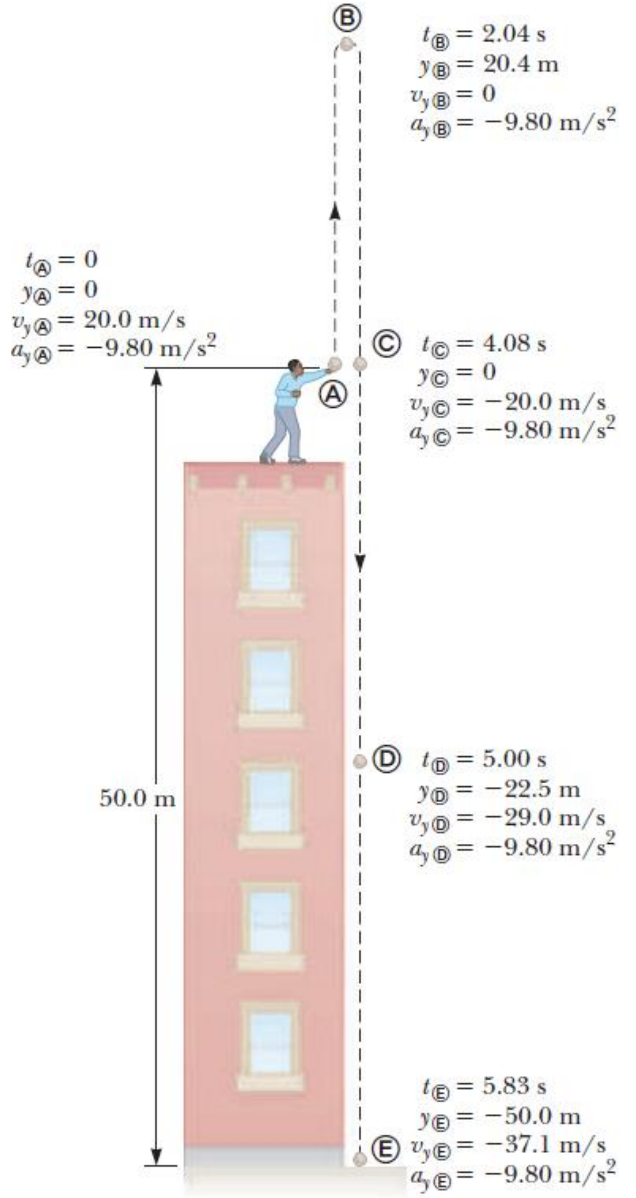
$$v_{yC}^2 = (20.0\ \text{m/s})^2 + 2(-9.80\ \text{m/s}^2)(0 - 0) = 400\ \text{m}^2/\text{s}^2$$

$$v_{yC} = \boxed{-20.0\ \text{m/s}}$$

(D) Find the velocity and position of the stone at $t = 5.00$ s.

$$v_{yD} = v_{yA} + a_y t = 20.0\ \text{m/s} + (-9.80\ \text{m/s}^2)(5.00\ \text{s}) = \boxed{-29.0\ \text{m/s}}$$

$$\begin{aligned} y_D &= y_A + v_{yA}t + \tfrac{1}{2}a_y t^2 \\ &= 0 + (20.0\ \text{m/s})(5.00\ \text{s}) + \tfrac{1}{2}(-9.80\ \text{m/s}^2)(5.00\ \text{s})^2 \\ &= \boxed{-22.5\ \text{m}} \end{aligned}$$



Name: Section

- # Homework 3

4. A particle moves according to the equation $x = 10t^2$, where x is in meters and t is in seconds. (a) Find the average velocity for the time interval from 2.00 s to 3.00 s. (b) Find the average velocity for the time interval from 2.00 to 2.10 s.

W

21. 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, and (c) its acceleration.

M

48. A baseball is hit so that it travels straight upward after being struck by the bat. A fan observes that it takes 3.00 s for the ball to reach its maximum height. Find (a) the ball's initial velocity and (b) the height it reaches.

W

51. A ball is thrown directly downward with an initial speed of 8.00 m/s from a height of 30.0 m. After what time interval does it strike the ground?

W

15. A velocity–time graph for an object moving along the x axis is shown in Figure P2.15. (a) Plot a graph of the acceleration versus time. Determine the average acceleration of the object (b) in the time interval $t = 5.00$ s to $t = 15.0$ s and (c) in the time interval $t = 0$ to $t = 20.0$ s.

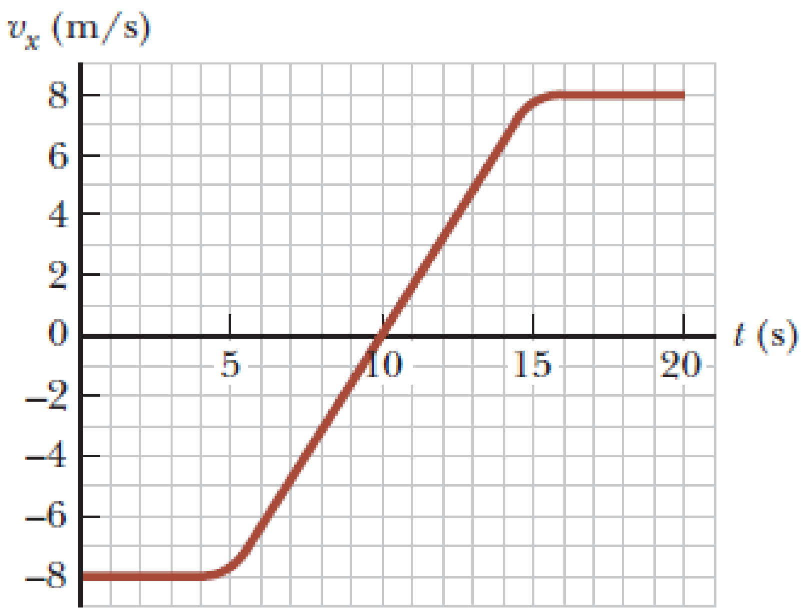


Figure P2.15