

# Theme 2

## Newtonian Mechanics

Newtonian mechanics is a branch of physics that studies the motion of an object. The topics in this theme investigate the concepts and factors that cause changes in the motion of an object.



# FORCE AND MOTION I

How is linear motion of an object investigated?

What causes the changes in the state of motion of an object?

Why are Newton's Laws of Motion important in the study of motion of an object?

## Let's Study

- 2.1 Linear Motion
- 2.2 Linear Motion Graphs
- 2.3 Free Fall Motion
- 2.4 Inertia
- 2.5 Momentum
- 2.6 Force
- 2.7 Impulse and Impulsive Force
- 2.8 Weight





Have you seen a personal transporter (PT) before? PT is a smart personal transporter as shown in the photograph. The device is used by security personnel to patrol in airports or shopping malls. This device is also used by tourists to make tours in tourist areas such as Perdana Botanical Gardens and Putrajaya.

This device is environmentally friendly because it runs on batteries. Fully charged batteries allow a rider to travel as far as 28 km on level roads.

Do you know that this transporting device does not have an accelerator or brakes? So, how does this device accelerate or stop? The rider needs to lean forward for the PT to start moving. If turning is required, the rider needs to turn his body to the left or to the right. To stop the device, the rider needs to stand upright.

Video on PT movement



<http://bt.sasbadi.com/p4025a>

Learning Standards and  
List of Formulae



## 2.1 Linear Motion

Photograph 2.1 shows various objects in motion. How do you describe motion in daily life? Motion in a straight line is called **linear motion**.



Photograph 2.1 Various types of moving objects

Linear motion can be described in terms of **distance**, **displacement**, **speed**, **velocity** and **acceleration**. Figure 2.1 shows a taxi waiting for passengers in a parking lot. The position of the taxi remains unchanged with time. Therefore, the taxi is said to be at **rest**.



Figure 2.1 Taxi at rest

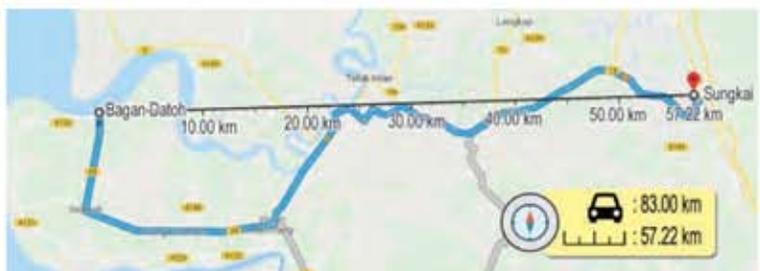


Figure 2.2 Journey from Bagan Datoh to Sungkai

Madam Chong wants to go to Sungkai from Bagan Datoh. Figure 2.2 shows the route marked in blue to be taken by the taxi through a distance of 83.00 km. However, after reaching Sungkai, the position of the taxi is 57.22 km due East from Bagan Datoh. In fact, 83.00 km and 57.22 km due East are the **distance** and the **displacement** respectively of the taxi movements. Table 2.1 shows the comparison between distance and displacement.

Table 2.1 Comparison between distance and displacement

Distance	Displacement
Length of route covered by an object	Shortest distance between the initial position and the final position in a specific direction
Its magnitude depends on the route covered by the object	Its magnitude is the straight-line distance between the initial position and the final position
A scalar quantity	A vector quantity

While riding in a taxi, Madam Chong observed that at times, the reading on the speedometer remains constant and at other times, the reading on the speedometer varies even along straight roads. Her observation can be summarised as shown in Figure 2.3.

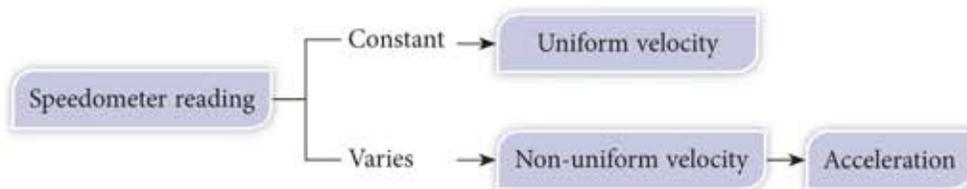


Figure 2.3 Speedometer reading and motion of vehicle

Figure 2.4 illustrates the difference in motions between uniform and non-uniform velocity of a car. Observe the displacement and the time intervals for both cars. Assume that the motion to the right is positive and to the left is negative.

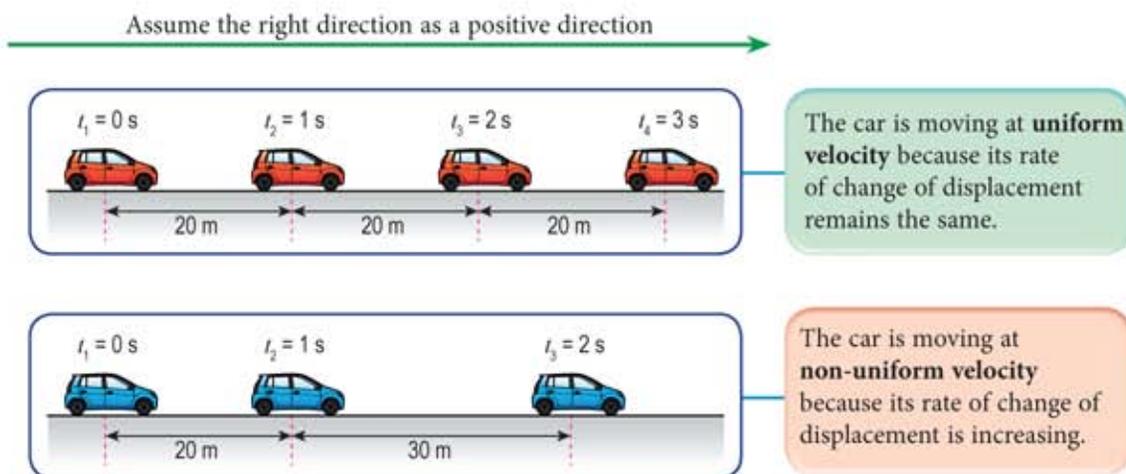


Figure 2.4 Motions at uniform and non-uniform velocity

In Figure 2.4, the displacement of the blue car increases at equal time intervals. Therefore, the blue car is moving at increasing velocity. In this case, the blue car accelerates in the same direction as the motion of the car.

Conversely, if the displacement decreases at equal time intervals, the velocity decreases as shown in Figure 2.5. The car accelerates but in the opposite direction to the motion of the car.

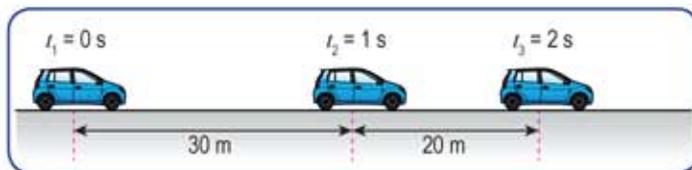


Figure 2.5 Motion with decreasing velocity

Examples of motion at non-uniform velocity



<http://bt.sasbadi.com/p4027>

## Determining Distance, Displacement, Speed, Velocity and Acceleration

The motion of an object is investigated by determining the values of its distance travelled, displacement, speed, velocity and acceleration. The formulae to determine speed, velocity and acceleration are as follows:

$$\begin{aligned}\text{Speed} &= \text{rate of change of distance travelled} \\ &= \frac{\text{distance travelled}}{\text{time taken}} \\ v &= \frac{d}{t}\end{aligned}$$

$$\begin{aligned}\text{Velocity} &= \text{rate of change of displacement} \\ &= \frac{\text{displacement}}{\text{time taken}} \\ v &= \frac{s}{t}\end{aligned}$$

$$\begin{aligned}\text{Acceleration} &= \text{rate of change of velocity} \\ &= \frac{\text{final velocity} - \text{initial velocity}}{\text{time taken for change of velocity}} \\ a &= \frac{v - u}{t}\end{aligned}$$



The Smart Tunnel in Kuala Lumpur has a dual function. It functions as a storage space and passage of flood flow as well as an alternative route with a shorter distance.



<http://bt.sasbadi.com/p4028>

Observe the following examples to understand how to determine distance, displacement, speed, velocity and acceleration in linear motion.

### Example 1

Figure 2.6 shows Radzi's run from A to B and then back to C. The total time taken is 20 s.

Determine the

- distance
- displacement
- speed
- velocity of Radzi's motion.

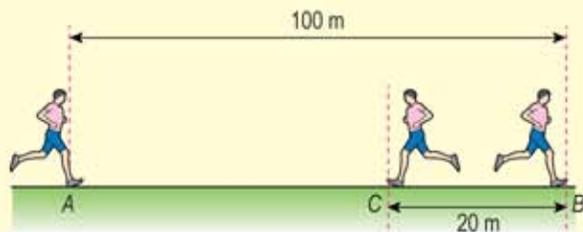


Figure 2.6

**Solution:**

- (a) Distance = Length of route covered  
 $= AB + BC$   
 $= 100 \text{ m} + 20 \text{ m}$   
 $= 120 \text{ m}$
- (b) Displacement = Distance between initial position and final position in a specific direction  
 $= AB + BC$   
 $= (100 \text{ m}) + (-20 \text{ m})$   
 $= 80 \text{ m (to the right)}$
- (c) Speed =  $\frac{\text{Distance travelled}}{\text{Time taken}}$   
 $= \frac{120 \text{ m}}{20 \text{ s}}$   
 $= 6 \text{ m s}^{-1}$
- (d) Velocity =  $\frac{\text{Displacement}}{\text{Time taken}}$   
 $= \frac{80 \text{ m}}{20 \text{ s}}$   
 $= 4 \text{ m s}^{-1} \text{ (to the right)}$

**Example 2**

Muthu moves from  $O$  to  $B$  along the route  $OAB$  as shown in Figure 2.7. The time taken is 15 s.

Determine the

- (a) distance  
 (b) displacement  
 (c) speed  
 (d) velocity  
 of Muthu's motion.

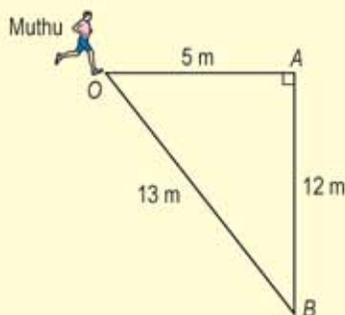


Figure 2.7

**Solution:**

- (a) Distance =  $OA + AB$   
 $= 5 \text{ m} + 12 \text{ m}$   
 $= 17 \text{ m}$
- (b) Displacement = Shortest straight line distance from  $O$  to  $B$   
 $= OB$   
 $= \sqrt{5^2 + 12^2}$   
 $= 13 \text{ m (in the direction of } OB)$

$$(c) \text{ Speed} = \frac{\text{Distance travelled}}{\text{Time taken}}$$

$$= \frac{17 \text{ m}}{15 \text{ s}}$$

$$= 1.13 \text{ m s}^{-1}$$

$$(d) \text{ Velocity} = \frac{\text{Displacement}}{\text{Time taken}}$$

$$= \frac{13 \text{ m}}{15 \text{ s}}$$

$$= 0.87 \text{ m s}^{-1} \text{ (in the direction of } OB)$$

### Example 3

After landing on the runway, a plane slows down so that its velocity reduces from  $75 \text{ m s}^{-1}$  to  $5 \text{ m s}^{-1}$  in 20 s. What is the acceleration of the plane?

#### Solution:

Initial velocity,  $u = 75 \text{ m s}^{-1}$ , final velocity,  $v = 5 \text{ m s}^{-1}$ ,  
time,  $t = 20 \text{ s}$

$$\begin{aligned} \text{Acceleration, } a &= \frac{v - u}{t} \\ &= \frac{5 - 75}{20} \\ &= -3.5 \text{ m s}^{-2} \end{aligned}$$

### Info File

Deceleration is a condition in which the velocity of motion of an object is decreasing.

A ticker timer fitted with ticker tape as shown in Figure 2.8 is used to investigate linear motion of objects in the laboratory.

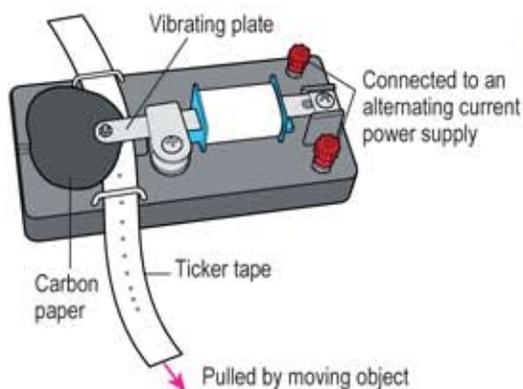


Figure 2.8 Ticker timer with ticker tape

A ticker timer works on alternating current of frequency 50 Hz to make 50 ticks in 1 second on a ticker tape.

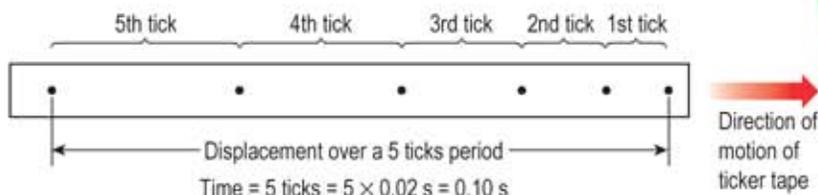
The time interval between two adjacent dots is called one tick.

$$\text{Therefore, 1 tick: } \frac{1}{50} \text{ s} = 0.02 \text{ s}$$

$$5 \text{ ticks: } 5 \times 0.02 \text{ s} = 0.10 \text{ s}$$

$$10 \text{ ticks: } 10 \times 0.02 \text{ s} = 0.2 \text{ s}$$

Figure 2.9 shows part of a ticker tape that is pulled by an object moving linearly.



### Info File

When an object moves along a straight line and does not go backwards, its distance and displacement are of the same value.

Figure 2.9 Part of a ticker tape pulled by an object

A ticker tape records the displacement of a moving object as well as the time taken. Subsequently, the velocity and acceleration can be calculated. Figures 2.10 and 2.11 show the calculations of velocity and acceleration of the linear motion of an object.

#### Calculating velocity

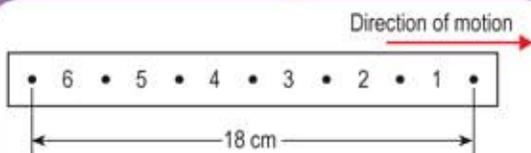


Figure 2.10

Displacement,  $s = 18 \text{ cm}$

Time taken,  $t = 6 \text{ ticks}$   
 $= 6 \times 0.02 \text{ s}$   
 $= 0.12 \text{ s}$

Velocity,  $v = \frac{s}{t}$   
 $= \frac{18 \text{ cm}}{0.12 \text{ s}}$   
 $= 150 \text{ cm s}^{-1}$

We already know how to calculate velocity and acceleration of the linear motion of an object.

Let us carry out an activity using a ticker timer and ticker tape to determine the velocity and acceleration of a trolley.



2.1.2

#### Calculating acceleration

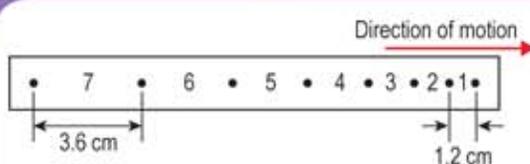


Figure 2.11

Initial velocity,  $u = \text{velocity at the first tick}$   
 $= \frac{1.2 \text{ cm}}{0.02 \text{ s}}$   
 $= 60 \text{ cm s}^{-1}$

Final velocity,  $v = \text{velocity at the seventh tick}$   
 $= \frac{3.6 \text{ cm}}{0.02 \text{ s}}$   
 $= 180 \text{ cm s}^{-1}$

Time between the final and initial velocity,  
 $t = (7 - 1) \text{ ticks}$   
 $= 6 \text{ ticks}$   
 $= 6 \times 0.02 \text{ s}$   
 $= 0.12 \text{ s}$

Acceleration,  $a = \frac{v - u}{t}$   
 $= \frac{(180 - 60) \text{ cm s}^{-1}}{0.12 \text{ s}}$   
 $= 1\,000 \text{ cm s}^{-2}$

## Activity 2.1

**Aim:** To use a ticker tape to determine the displacement, velocity and acceleration of a trolley

**Apparatus:** Ticker timer, trolley, runway, alternating current power supply, retort stand and wooden block

**Materials:** Ticker tape and connecting wires

**Instructions:**

1. Set up the apparatus as shown in Figure 2.12. Raise one end of the runway slightly so that the trolley can move slowly down the runway.

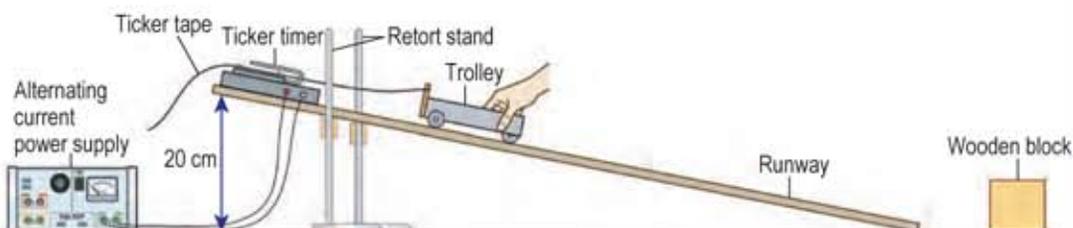


Figure 2.12

2. Attach a 100 cm ticker tape to the trolley, switch on the ticker timer and release the trolley. Observe the ticker tape obtained.
3. From the ticker tape, determine the displacement and calculate the average velocity of the trolley.
4. Raise the end of the runway further so that the trolley moves with a higher velocity down the runway.
5. Repeat steps 2 and 3. Then, calculate the acceleration of the trolley.
6. Rearrange the apparatus as shown in Figure 2.13.

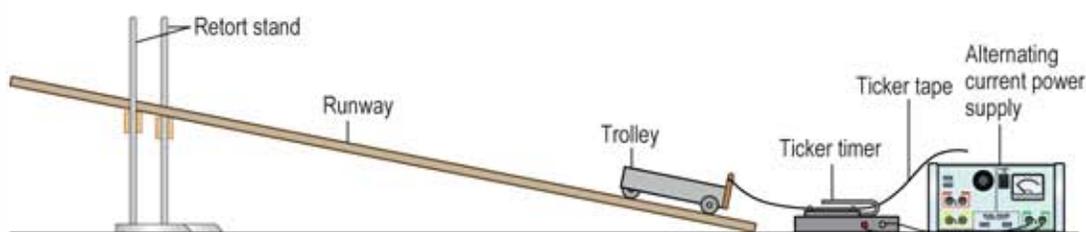


Figure 2.13

7. Push the trolley from the bottom of the runway and allow it to move up.
8. Stop the trolley when it starts to descend the runway.
9. From the ticker tape obtained, determine the deceleration of the trolley.

**Discussion:**

Discuss the patterns of motion obtained from the ticker tape.

If a long ticker tape is used, a large number of dots can be recorded on the ticker tape. As such, the ticker tape can be divided into strips with an equal number of ticks. These strips are cut and attached side by side on a piece of graph paper to form a ticker tape chart as shown in Figure 2.14.

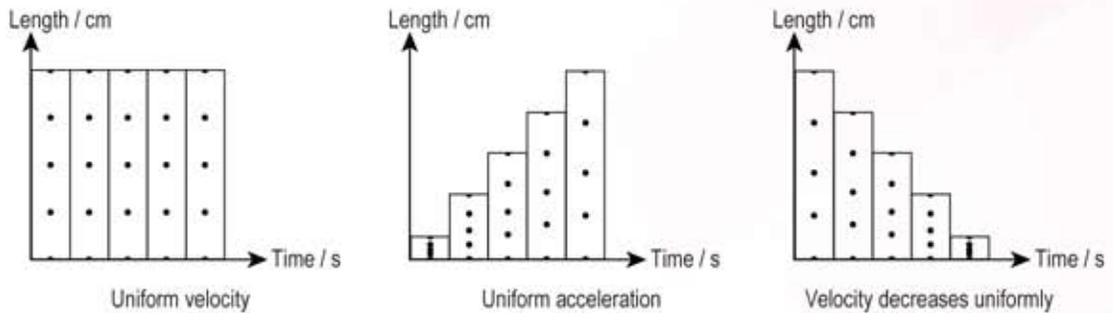


Figure 2.14 Ticker tape chart

Other than ticker timer, **photogate system and electronic timer** can be used to study linear motion more accurately. Figure 2.15 shows a photogate system and an electronic timer used with a non-motorised trolley moving on an inclined aluminium runway.

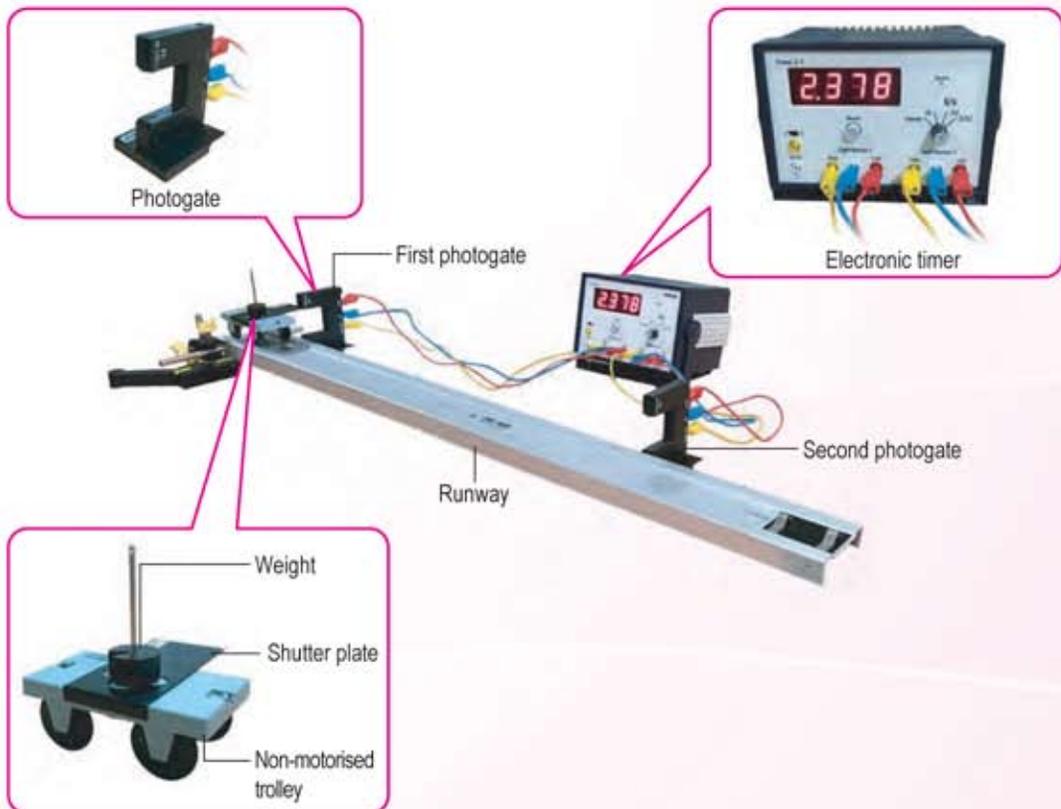


Figure 2.15 Photogate system and electronic timer



## Activity 2.2

**Aim:** To use a photogate system and an electronic timer to determine the velocity and acceleration of a moving trolley

**Apparatus:** Photogate system and electronic timer, trolley and runway

**Instructions:**

1. Set up the apparatus as shown in the manual of the QR code.
2. Raise one end of the runway to a height of 15 cm.
3. Adjust the distance of separation between the two photogates,  $s = 40.0$  cm.
4. Turn the electronic timer switch to the symbol . Release the trolley from the high end of the runway and catch the trolley after it passes the second photogate.
5. Record the total time,  $t$  in Table 2.2.
6. Remove the first photogate.
7. Turn the electronic timer switch to the symbol . Release the trolley again from its original point.
8. Record the time interval,  $\Delta t$  in Table 2.2.
9. Repeat steps 3 to 8 for  $s = 50.0$  cm,  $60.0$  cm,  $70.0$  cm and  $80.0$  cm.

Manual on the use of photogate system and electronic timer



<http://bt.sasbadi.com/p4034>

**Results:**

Table 2.2

Distance of separation between two photogates, $s$ / cm	40.0	50.0	60.0	70.0	80.0
Total time, $t$ / s					
Time interval, $\Delta t$ / s					
Final velocity, $v = \frac{s}{\Delta t}$ / cm s <sup>-1</sup>					
Acceleration, $a = \frac{v}{t}$ / cm s <sup>-2</sup>					

**Discussion:**

1. Based on the results in the table, determine the average acceleration of the trolley.
2. When  $s$  increased from 40.0 cm to 80.0 cm, the total time,  $t$  increased but the time interval  $\Delta t$  decreased. Why?

The use of a photogate system and electronic timer is more accurate because no ticker tape is attached to the trolley. As such, there will be no friction between the ticker tape and ticker timer affecting the motion of the trolley. An electronic timer can measure the time interval to an accuracy of 0.001 second compared to 0.02 second for a ticker timer. This short time interval enables us to determine velocity and acceleration of the trolley more accurately.

## Solving Problems of Linear Motion Using Linear Motion Equations

Figure 2.16 shows a car moving with uniform acceleration.

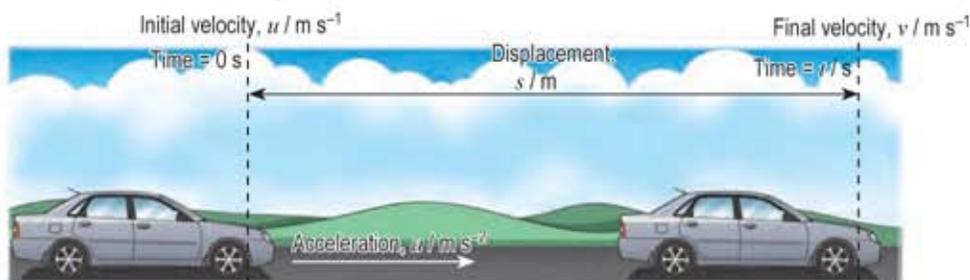


Figure 2.16 Car moving with uniform acceleration

Five physical quantities of linear motion with uniform acceleration can be expressed as four linear motion equations.

#### First linear motion equation

$$\text{Acceleration} = \frac{\text{Final velocity} - \text{initial velocity}}{\text{Time taken for change of velocity}}$$

$$a = \frac{v - u}{t}$$

$$at = v - u$$

$$v = u + at \quad \text{————— (1)}$$

#### Second linear motion equation

Displacement = Average velocity  $\times$  time

$$\text{Displacement} = \left( \frac{\text{Initial velocity} + \text{final velocity}}{2} \right) \times \text{time}$$

$$s = \frac{1}{2}(u + v)t \quad \text{————— (2)}$$

#### Third linear motion equation

Substitute equation (1) into equation (2)

$$s = \frac{1}{2}[u + (u + at)]t$$

$$s = \frac{1}{2}(2u + at)t$$

$$s = ut + \frac{1}{2}at^2 \quad \text{————— (3)}$$

#### Fourth linear motion equation

Square equation (1)

$$v^2 = (u + at)^2$$

$$v^2 = u^2 + 2uat + a^2t^2$$

$$v^2 = u^2 + 2a\left(ut + \frac{1}{2}at^2\right)$$

$$v^2 = u^2 + 2as \quad \text{————— (4)}$$

From equation (3)

$$s = ut + \frac{1}{2}at^2$$

### Example 1

A school bus moves from rest with an acceleration of  $2 \text{ m s}^{-2}$  for 5 s. Calculate its velocity after 5 s.

#### Solution:

##### Step 1

List the given information in symbols.

$$\left\{ \begin{array}{l} \text{Initial velocity, } u = 0 \text{ m s}^{-1} \\ \text{Time, } t = 5 \text{ s} \\ \text{Acceleration, } a = 2 \text{ m s}^{-2} \\ \text{Final velocity, } v = ? \end{array} \right.$$

##### Step 2

Identify and write down the formula used.

$$\left\{ \begin{array}{l} v = u + at \end{array} \right.$$

##### Step 3

Substitute numerical values in the formula and perform the calculations.

$$\left\{ \begin{array}{l} v = 0 + (2)(5) \\ = 10 \text{ m s}^{-1} \end{array} \right.$$

### Example 2

As a sports car moves along a straight track, its velocity is  $40 \text{ m s}^{-1}$ . After 3 seconds, the sports car has reached  $50 \text{ m s}^{-1}$ . Calculate its displacement.

#### Solution:

Initial velocity,  $u = 40 \text{ m s}^{-1}$

Final velocity,  $v = 50 \text{ m s}^{-1}$

Time,  $t = 3 \text{ s}$

Displacement,  $s = ?$

$$\begin{aligned}s &= \frac{1}{2}(u + v)t \\ &= \frac{1}{2}(40 + 50)(3) \\ &= 135 \text{ m}\end{aligned}$$

### Example 3

An athlete starts his run from rest and achieves a maximum velocity after accelerating uniformly for 8.0 s. If the displacement of the athlete is 40 m, determine his acceleration.

#### Solution:

Initial velocity,  $u = 0 \text{ m s}^{-1}$

Time,  $t = 8.0 \text{ s}$

Displacement,  $s = 40 \text{ m}$

Acceleration,  $a = ?$

$$\begin{aligned}s &= ut + \frac{1}{2}at^2 \\ 40 &= (0)(8) + \frac{1}{2}(a)(8^2) \\ 40 &= 0 + \frac{64a}{2} \\ a &= \frac{2 \times 40}{64} \\ &= 1.25 \text{ m s}^{-2}\end{aligned}$$

### Example 4

Maria rides a bicycle at a velocity of  $8 \text{ m s}^{-1}$ . She brakes suddenly and stops after a distance of 2 m. What is the acceleration of Maria and her bicycle?

#### Solution:

Initial velocity,  $u = 8 \text{ m s}^{-1}$

Final velocity,  $v = 0 \text{ m s}^{-1}$

Displacement,  $s = 2 \text{ m}$

Acceleration,  $a = ?$

$$\begin{aligned}v^2 &= u^2 + 2as \\ 0^2 &= 8^2 + 2(a)(2) \\ -4a &= 64 \\ a &= -16 \text{ m s}^{-2}\end{aligned}$$

Negative value shows that Maria accelerates at  $16 \text{ m s}^{-2}$  in the opposite direction to the motion of the bicycle.

## Formative Practice

### 2.1

- Explain the difference between
  - distance and displacement
  - speed and velocity
- A car moving along a straight road at a velocity of  $30 \text{ m s}^{-1}$  reduces its velocity at a constant rate until it stops after 5 s. What is the acceleration of the car? 🍌
- Aina rides a smart personal transporter at the Perdana Botanical Gardens. The transporter accelerates uniformly from a velocity of  $1 \text{ m s}^{-1}$  to a velocity of  $5 \text{ m s}^{-1}$  in 0.5 minutes. Calculate the displacement of the transporter. 🍌

## 2.2 Linear Motion Graphs

Interpretation of graphs is important to understand the type of linear motion of an object. Figure 2.17 shows the interpretation of the types of linear motion from graphs.

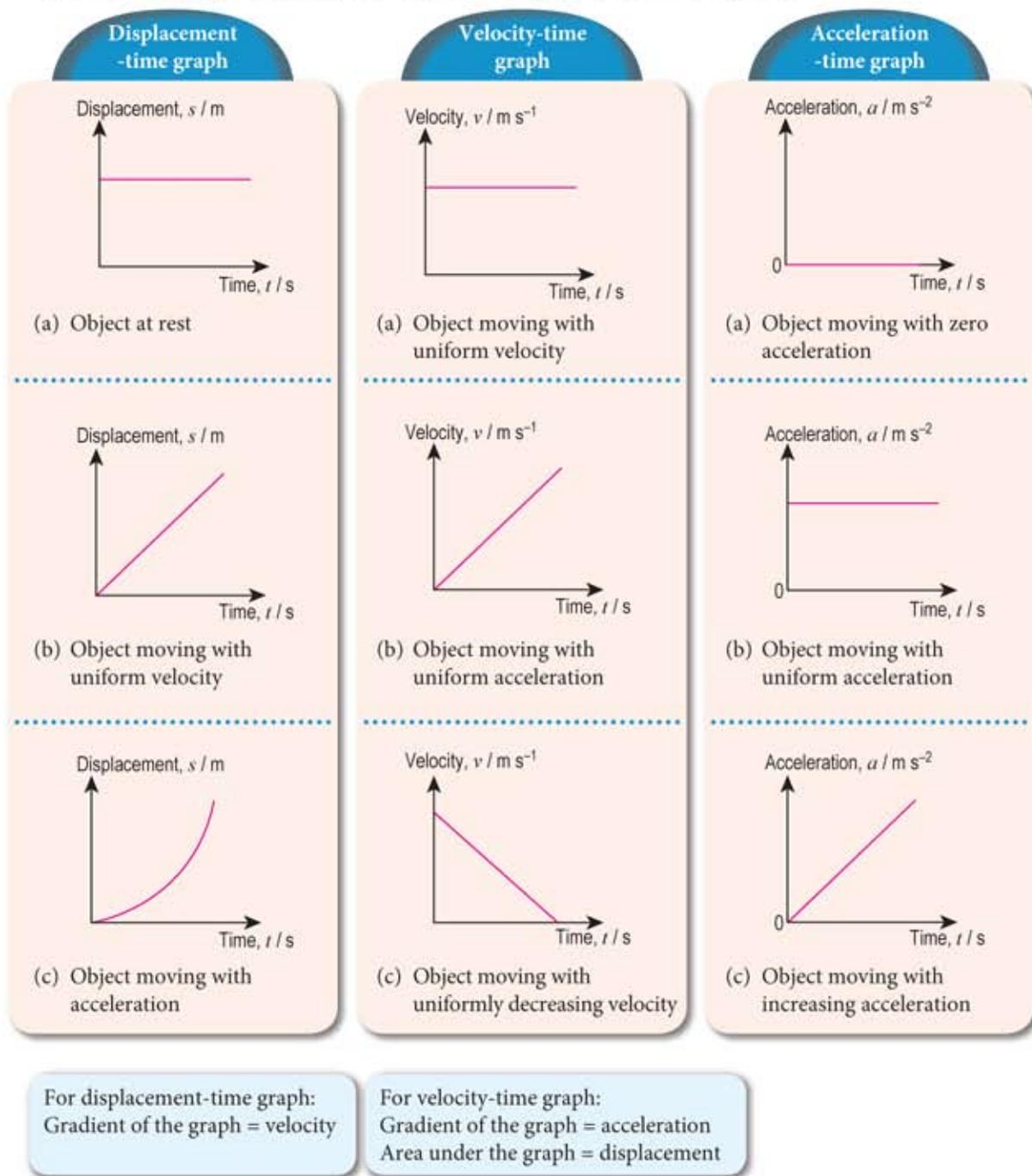


Figure 2.17 Interpretation of types of linear motion from graphs

## Analysis of Displacement-Time Graph to Determine Distance, Displacement and Velocity

Figure 2.18 shows the initial point and the final point of a motorcycle ridden to the right (positive direction) and then to the left (negative direction). The displacement-time graph in Figure 2.19 shows the linear motion of the motorcycle.

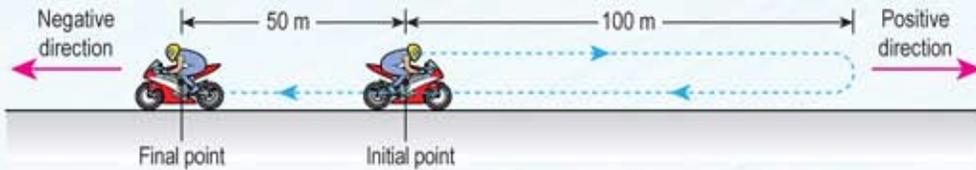


Figure 2.18 Motion of a motorcycle being ridden

### Section AB:

Motorcycle is ridden for a distance of 100 m to the right for 5 seconds.

$$\text{Gradient of graph} = \frac{100 - 0}{5 - 0} = 20 \text{ m s}^{-1}$$

Therefore, velocity of motorcycle is  $20 \text{ m s}^{-1}$  to the right.

### Section BC:

Motorcycle stops for 3 seconds.

$$\text{Gradient of graph} = 0 \text{ m s}^{-1}$$

Therefore, velocity of motorcycle is  $0 \text{ m s}^{-1}$ .

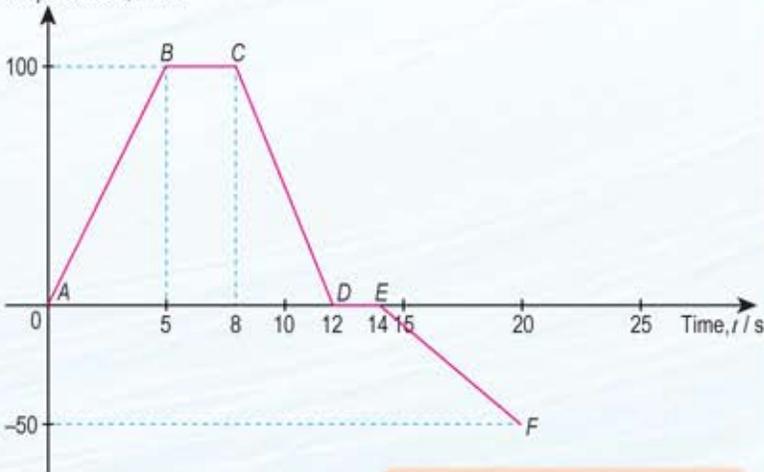
### Section CD:

Motorcycle is ridden back to initial point A in 4 seconds.

$$\text{Gradient of graph} = \frac{0 - 100}{12 - 8} = -25 \text{ m s}^{-1}$$

Therefore, velocity of motorcycle is  $25 \text{ m s}^{-1}$  to the left.

Displacement,  $s / \text{m}$



### Section DE:

Motorcycle is stationary at initial point for 2 seconds.

$$\text{Gradient of graph} = 0 \text{ m s}^{-1}$$

Therefore, velocity of motorcycle is  $0 \text{ m s}^{-1}$ .

### Section EF:

Motorcycle is ridden to the left for a distance of 50 m for 6 seconds.

$$\text{Gradient of graph} = \frac{-50 - 0}{20 - 14} = -8.33 \text{ m s}^{-1}$$

Therefore, velocity of motorcycle is  $8.33 \text{ m s}^{-1}$  to the left.

How are average speed and average velocity determined from the displacement-time graph?

$$\text{Distance travelled} = 100 + 100 + 50 = 250 \text{ m}$$

$$\text{Displacement} = 100 + (-100) + (-50) = -50 \text{ m}$$

Figure 2.19 Analysis of displacement-time graph

Distance travelled is 250 m in a total time of 20 s. Therefore, its average speed is

$$= \frac{250}{20} = 12.5 \text{ m s}^{-1}$$

Overall displacement is  $-50 \text{ m}$  in a total time of 20 s. Therefore, average velocity is

$$= \frac{-50}{20} = -2.5 \text{ m s}^{-1}$$

## Analysis of Velocity-Time Graph to Determine Distance, Displacement, Velocity and Acceleration

Figure 2.20 shows the linear motion of a bicycle. Figure 2.21 shows the velocity-time graph showing the motion of the bicycle.



Figure 2.20 Linear motion of a bicycle

**Time interval: 0 – 50 seconds**

Gradient of the graph =  $0 \text{ m s}^{-2}$

Therefore, the bicycle is moving to the right with a uniform velocity of  $10 \text{ m s}^{-1}$ .

**Time interval: 50 – 70 seconds**

Gradient of the graph =  $\frac{15 - 10}{70 - 50}$   
=  $0.25 \text{ m s}^{-2}$

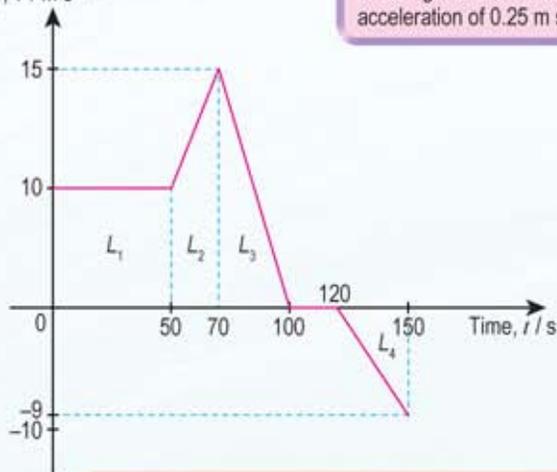
Therefore, the bicycle is moving to the right with a uniform acceleration of  $0.25 \text{ m s}^{-2}$ .

**Time interval: 70 – 100 seconds**

Gradient of the graph =  $\frac{0 - 15}{100 - 70}$   
=  $-0.5 \text{ m s}^{-2}$

Acceleration of bicycle =  $-0.5 \text{ m s}^{-2}$   
The velocity of the bicycle gradually decreases. The bicycle accelerates at  $-0.5 \text{ m s}^{-2}$  (in the opposite direction to the motion of the bicycle).

Velocity,  $v / \text{m s}^{-1}$



**Time interval: 100 – 120 seconds**

Gradient of the graph =  $0 \text{ m s}^{-2}$

Its velocity is  $0 \text{ m s}^{-1}$ . Therefore, the bicycle has stopped and is at rest for 20 seconds.

**Time interval: 120 – 150 seconds**

Gradient of the graph =  $\frac{-9 - 0}{150 - 120}$   
=  $-0.3 \text{ m s}^{-2}$

Acceleration of bicycle =  $-0.3 \text{ m s}^{-2}$   
The velocity of the bicycle gradually increases. The bicycle accelerates at  $-0.3 \text{ m s}^{-2}$  (in the same direction as the motion of the bicycle).

Area,  $L_1 = 500 \text{ m}$ ,  $L_2 = 250 \text{ m}$ ,  $L_3 = 225 \text{ m}$ ,  $L_4 = 135 \text{ m}$

Total overall distance =  $L_1 + L_2 + L_3 + L_4$   
=  $500 + 250 + 225 + 135$   
=  $1110 \text{ m}$

Displacement to the right =  $L_1 + L_2 + L_3$   
=  $500 + 250 + 225$   
=  $975 \text{ m}$

Displacement to the left =  $L_4$   
=  $135 \text{ m}$

Total displacement =  $L_1 + L_2 + L_3 + L_4$   
=  $500 + 250 + 225 + (-135)$   
=  $840 \text{ m to the right}$

Figure 2.21 Linear motion of a bicycle

Average speed and average velocity can be determined from the rate of change of the total distance and also from the rate of change of the total displacement. Try to determine the average speed and average velocity for the velocity-time graph above.



**Aim:** To use Tracker software to map the motion of a table tennis ball in the form of graphs

**Apparatus:** Retort stand, wooden block and metre rule

**Materials:** Table tennis ball and cellophane tape

**Instructions:**

1. Work in groups.
2. Scan the QR code to download Tracker software.
3. Set up the apparatus as shown in Figure 2.22 using two metre rules arranged in the shape of a "V" to form an inclined runway.

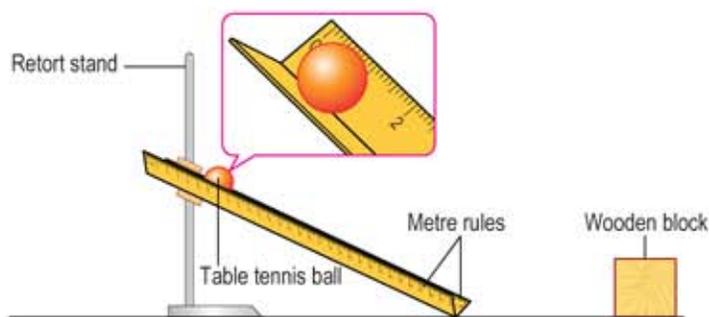


Figure 2.22

Download Tracker software



<http://bt.sasbadi.com/p4040a>

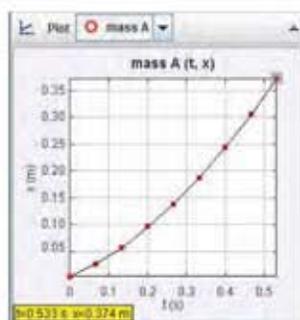
Instruction video on using Tracker software



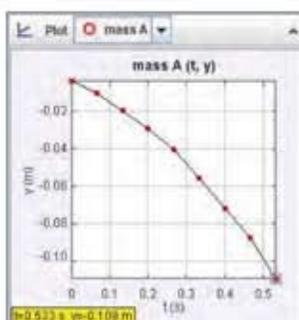
<http://bt.sasbadi.com/p4040b>

4. Record a video of the motion of the table tennis ball along a straight line.
5. Use Tracker software to analyse the motion of the table tennis ball in the video using displacement-time, velocity-time and acceleration-time graphs.
6. Figure 2.23 shows examples of graphs that you can obtain using the software.

Graph of horizontal displacement against time



Graph of vertical displacement against time



Graph of speed against time

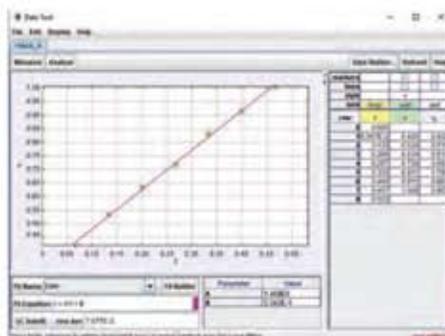


Figure 2.23 Examples of graphs obtained

7. Discuss and interpret the motion of the table tennis ball based on the graphs obtained.
8. Analyse the motion of the table tennis ball from the graphs.
9. Present your interpretation and analysis of the graphs.

## Interpreting and Sketching Graphs

Interpreting displacement-time graphs can help to sketch velocity-time graphs and vice versa. Velocity-time graphs can also be interpreted into acceleration-time graphs and vice versa. The skill in interpreting and sketching graphs is important to solve linear motion problems. Study the examples given.

### Example 1

Figure 2.24 shows the displacement-time graph of an object in linear motion.

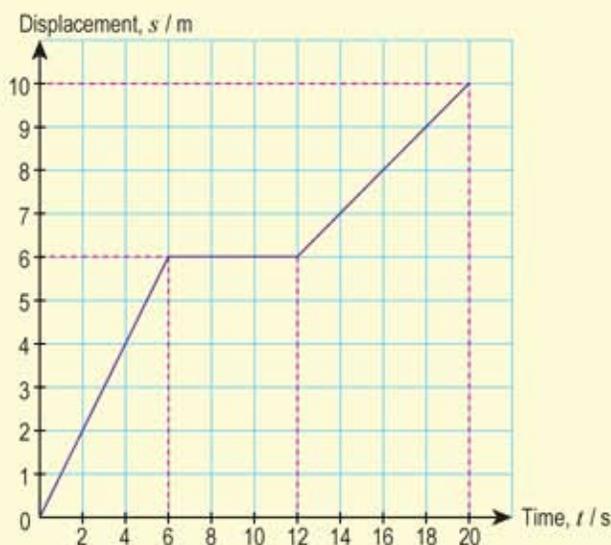


Figure 2.24

- Determine the velocity of the object at each stage of its motion.
- Interpret the displacement-time graph in Figure 2.24 to sketch a velocity-time graph.

### Solution:

- Velocity = Gradient of displacement-time graph

Table 2.3

0 s to 6 s	$v_1 = \frac{6 - 0}{6 - 0}$ $= 1 \text{ m s}^{-1}$
6 s to 12 s	$v_2 = \frac{6 - 6}{12 - 6}$ $= 0 \text{ m s}^{-1}$
12 s to 20 s	$v_3 = \frac{10 - 6}{20 - 12}$ $= 0.5 \text{ m s}^{-1}$

- Velocity-time graph

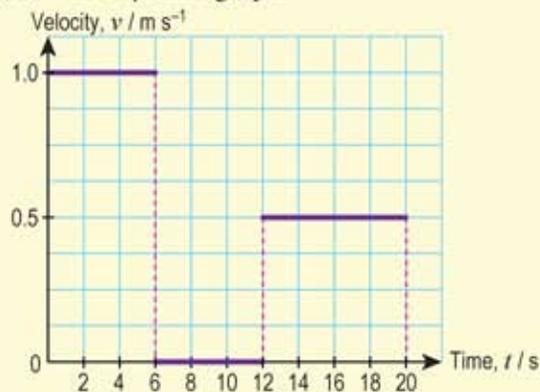


Figure 2.25

## Example 2

Figure 2.26 shows the velocity-time graph that is plotted based on the linear motion of a car driven by Encik Kassim. He drives his car at a speed of  $30 \text{ m s}^{-1}$  and applies the brakes when he sees an obstruction on the road.

- Interpret the velocity-time graph of the motion of his car and sketch
- displacement-time graph
  - acceleration-time graph

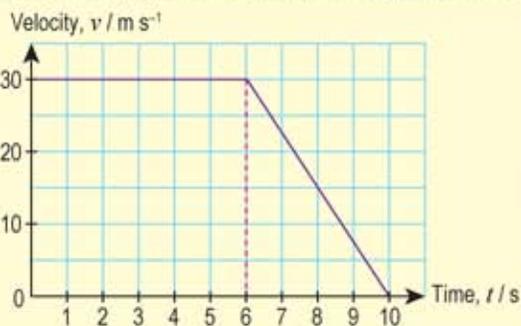


Figure 2.26

Table 2.4

Time	Displacement	Acceleration
0 s – 6 s	Displacement = area A = $30 \times 6$ = 180 m	Acceleration = gradient of the graph = $0 \text{ m s}^{-2}$
6 s – 10 s	Displacement = area B = $\frac{1}{2} \times 30 \times 4$ = 60 m	Acceleration = $\frac{0 - 30}{10 - 6}$ = $-7.5 \text{ m s}^{-2}$

### Solution:

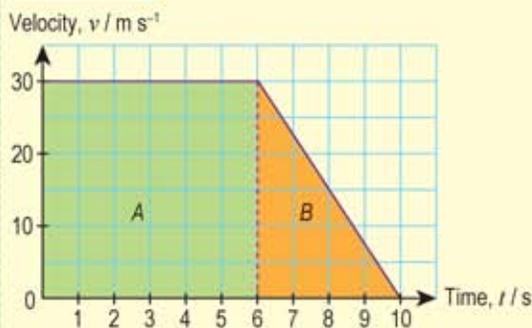


Figure 2.27

Displacement after 10 s,  
 $s = 180 + 60$   
 $= 240 \text{ m}$

### SMART INFO

To determine displacement, the area under the graph needs to be calculated. To simplify the calculation of area, the graph can be divided into several areas as shown in Figure 2.27.

- (a) Displacement-time graph

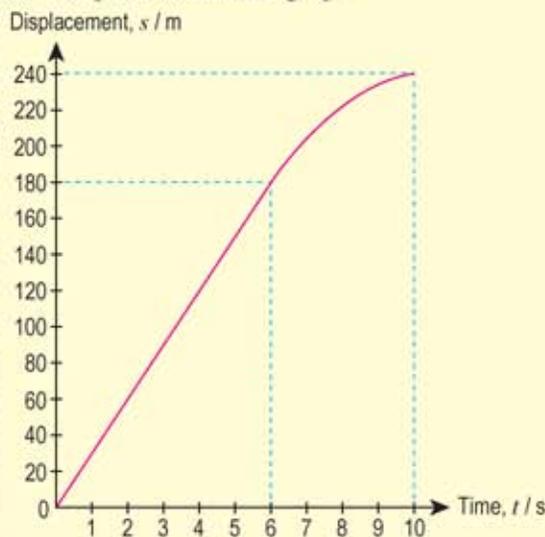


Figure 2.28

- (b) Acceleration-time graph

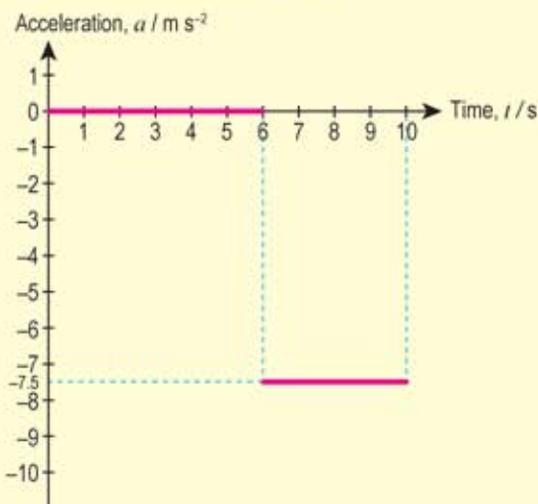


Figure 2.29

## Solving Problems Involving Linear Motion Graphs

## Example 1

The velocity-time graph in Figure 2.30 shows the motion of Hasri. Determine his

- acceleration
- displacement
- average velocity

## Solution:

- (a) Acceleration = gradient of the graph

From 0 s – 3 s:

$$\begin{aligned} \text{Acceleration } a_1 &= \frac{6 - 0}{3 - 0} \\ &= 2 \text{ m s}^{-2} \end{aligned}$$

From 3 s – 6 s:

$$\text{Acceleration } a_2 = 0 \text{ m s}^{-2}$$

From 6 s – 10 s:

$$\begin{aligned} \text{Acceleration } a_3 &= \frac{0 - 6}{10 - 6} \\ &= -1.5 \text{ m s}^{-2} \end{aligned}$$

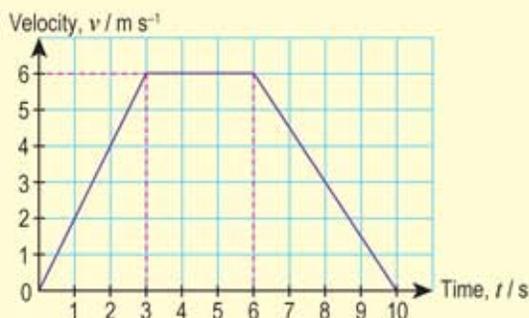


Figure 2.30

- (b) Displacement,  $s$  = area under the graph  
= area of trapezium

$$\begin{aligned} &= \frac{1}{2}(3 + 10)(6) \\ &= 39 \text{ m} \end{aligned}$$

- (c) Average velocity,  $v = \frac{\text{Total displacement}}{\text{Time taken}}$

$$\begin{aligned} &= \frac{39}{10} \\ &= 3.9 \text{ m s}^{-1} \end{aligned}$$

## Example 2

Figure 2.31 shows the velocity-time graph of the linear motion of a car. Interpret the velocity-time graph and sketch a graph of:

- displacement against time
- acceleration against time

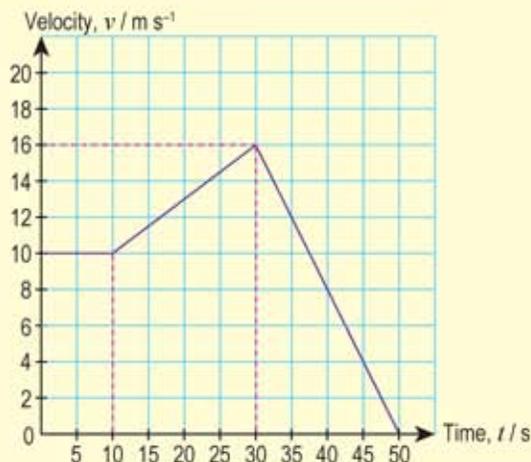


Figure 2.31

**Solution:**

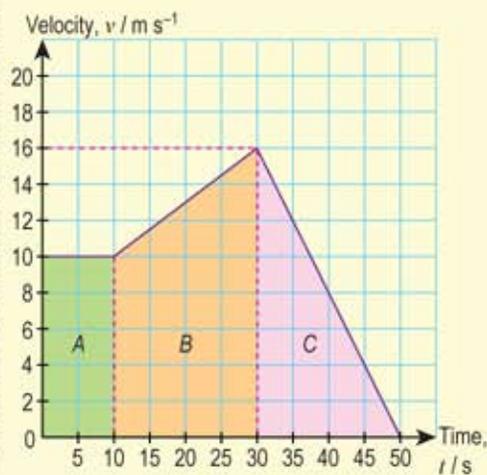


Figure 2.32

$$\begin{aligned} \text{Displacement after 30 s} &= 100 + 260 \\ &= 360 \text{ m} \end{aligned}$$

$$\begin{aligned} \text{Displacement after 50 s} &= 100 + 260 + 160 \\ &= 520 \text{ m} \end{aligned}$$

Table 2.5

Time	Displacement	Acceleration
0 s – 10 s	Displacement = area A = $10 \times 10$ = 100 m	Acceleration = gradient of the graph = $0 \text{ m s}^{-2}$
10 s – 30 s	Displacement = area B = $\frac{1}{2} (10 + 16)(20)$ = 260 m	Acceleration = $\frac{16 - 10}{30 - 10}$ = $0.3 \text{ m s}^{-2}$
30 s – 50 s	Displacement = area C = $\frac{1}{2} \times 20 \times 16$ = 160 m	Acceleration = $\frac{0 - 16}{50 - 30}$ = $-0.8 \text{ m s}^{-2}$

(a) Displacement-time graph

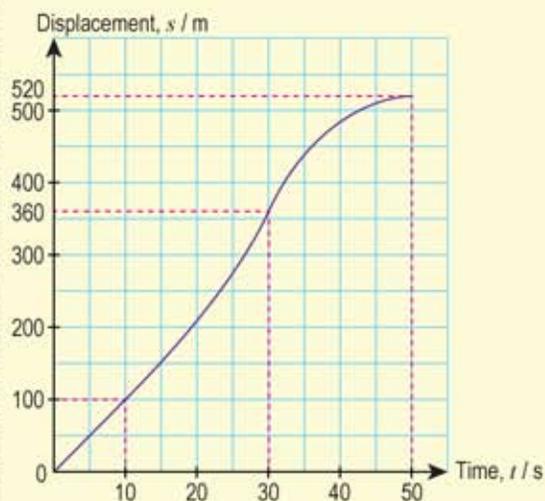


Figure 2.33

(b) Acceleration-time graph

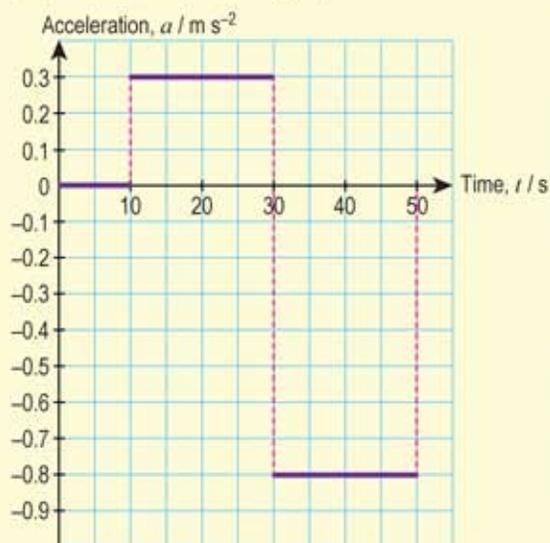


Figure 2.34

## Formative Practice 2.2

- How do you determine
  - velocity from a graph of displacement against time?
  - acceleration from a graph of velocity against time?
  - displacement from a graph of velocity against time?
- Based on Figure 2.35, describe the motion of the object from  $O$  to  $D$ .

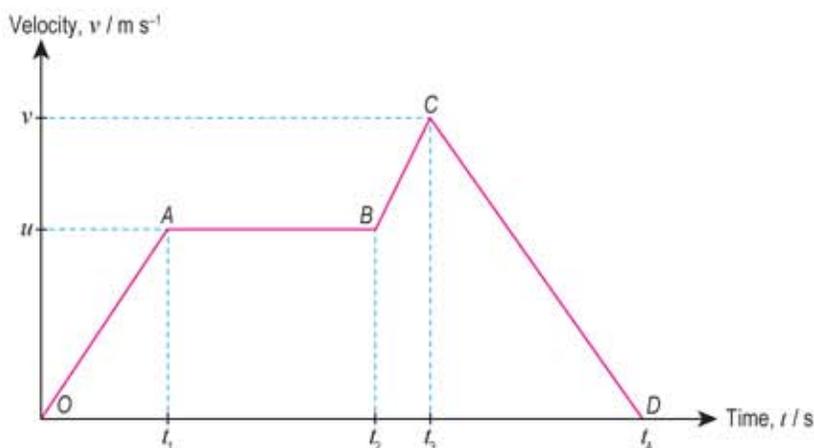


Figure 2.35

- Figure 2.36 shows Rokiah taking 3 minutes to walk to the sundry shop located 400 m to the right of her house. After 1 minute, she buys an ice cream and walks to the playground located 300 m from the sundry shop in 2 minutes. She sits and rests on a bench near the playground for 2 minutes. Then, using a shortcut to return to her house, Rokiah reaches her house in 2 minutes. 🧠

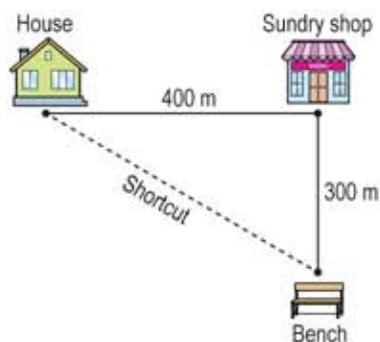


Figure 2.36

- What is the average velocity of the motion of Rokiah from
    - house to the sundry shop?
    - sundry shop to the playground?
    - playground to the house?
  - Calculate Rokiah's average speed. 🧠
- A car is driven from rest and accelerated at  $4 \text{ m s}^{-2}$  for 8 s along a straight road. The car is driven at the constant velocity for 20 s and then its brakes are applied. The car reduces its velocity at the rate of  $2 \text{ m s}^{-2}$  till it stops. Sketch a graph of: 🧠
    - acceleration against time
    - velocity against time
    - displacement against time