

## 2.3 Free Fall Motion

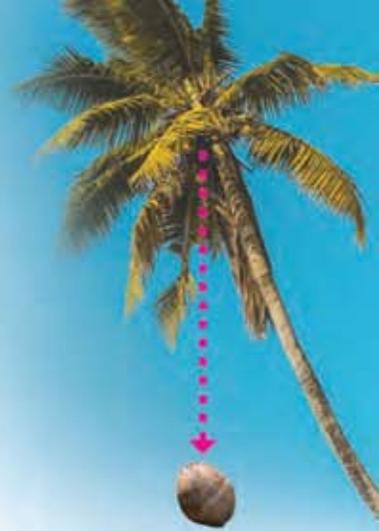
### Free Fall Motion and Gravitational Acceleration

An object experiences **free fall** if the motion of the object is affected only by **gravitational force**. This implies a free falling object **does not experience the action of other forces** such as air resistance or friction.

Photograph 2.2 shows a coconut falling from a coconut tree. Is this a free fall motion?

Carry out Activity 2.4 and Activity 2.5 involving free fall motion.

*Photograph 2.2 Coconut falling from a coconut tree*



### Activity 2.4

**Aim:** To watch a video on free fall motion

**Instructions:**

Scan the QR code or visit the website to watch a video on free fall motion.

**Discussion:**

What are your observations on the free fall motion shown in the video?

Video on free fall motion



<http://bt.sasbadi.com/p4046>



### Activity 2.5

**Aim:** To investigate the motion of falling objects

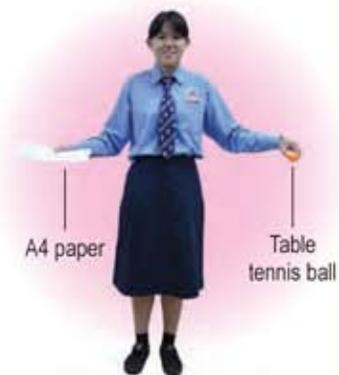
**Materials:** Table tennis ball and a piece of A4 paper

**Instructions:**

1. Work in pairs.
2. Hold a piece of A4 paper in the right hand and a table tennis ball in the left hand as shown in Photograph 2.3.
3. Release the paper and table tennis ball simultaneously from the same height.
4. Observe the motion of the paper and table tennis ball.
5. Repeat steps 2 to 4 with the A4 paper crumpled into a ball.

**Discussion:**

1. Why do the falling paper and table tennis ball reach the floor at different times in the first try?
2. The paper used in step 2 and step 5 is the same piece of paper. Why does the paper before and after being crumpled fall at different rates?



*Photograph 2.3*

In daily life, we see that heavy objects fall and reach the ground faster than light objects. This is due to other forces such as air resistance. Observe Figure 2.37.

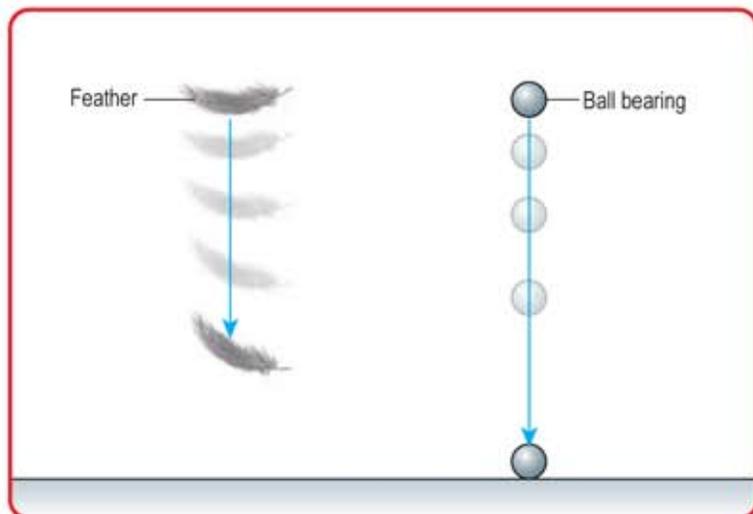


Figure 2.37 Motion of falling objects in air

Objects of different masses fall with the same acceleration if air resistance does not exist. This can happen in a vacuum. Observe Figure 2.38. A feather and a ball bearing released in a vacuum will reach the floor at the same time. The free fall that you watched in the video in Activity 2.4 was actually performed in a vacuum.

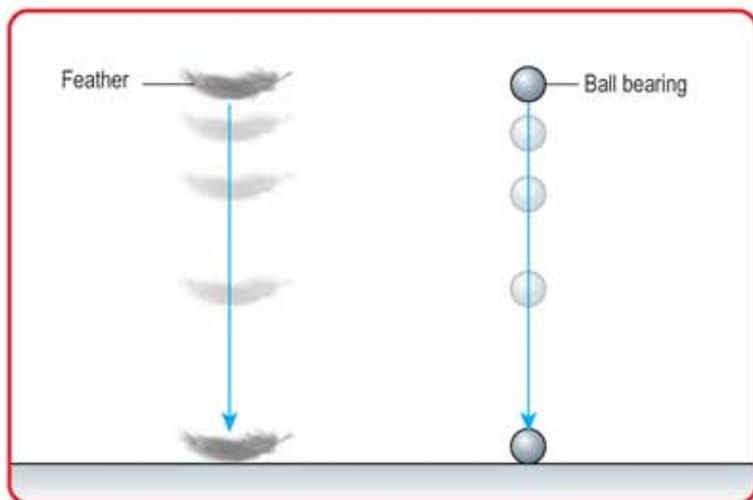


Figure 2.38 Free fall in a vacuum

The acceleration of a free falling object caused by gravitational force is known as **gravitational acceleration**,  $g$ . The average value of Earth's gravitational acceleration is  $9.81 \text{ m s}^{-2}$ . The velocity of a free falling object increases by  $9.81 \text{ m s}^{-1}$  per second in uniform gravitational field close to the surface of the Earth. When a heavy object falls in the gravitational field, air resistance can be ignored. The object is in **free fall** motion.



### INTEGRATION OF HISTORY

From 384–322 B.C., Aristotle concluded that the rate of an object falls depends on the weight, shape and orientation of the object. However, Galileo Galilei (1564–1642) discovered that objects fall with the same acceleration if air resistance is ignored.

Video of object falling in normal condition and in a vacuum



<http://bt.sasbadi.com/p4047>

## Determining the Value of Gravitational Acceleration

An object that falls freely in the gravitational field has gravitational acceleration. As such, the value of gravitational acceleration can be determined by measuring the acceleration of a heavy object such as a steel ball in a physics laboratory. Let us use a photogate system and an electronic timer to determine gravitational acceleration,  $g$ .



Figure 2.39 Releasing a steel ball



### Experiment

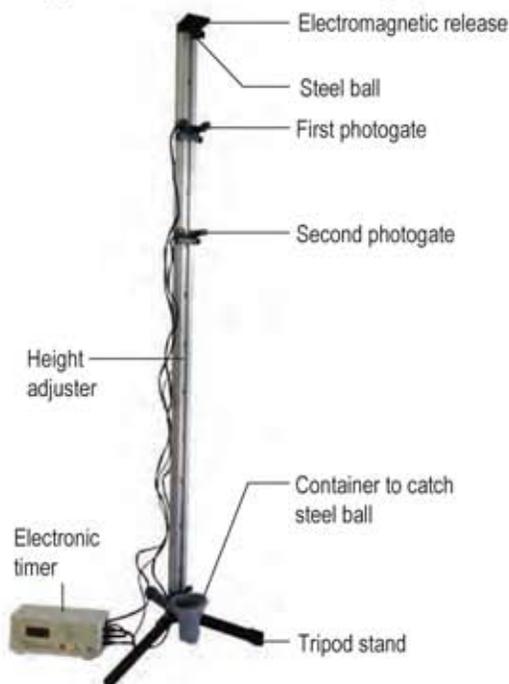
## 2.1

**Aim:** To determine Earth's gravitational acceleration

**Apparatus:** Photogate system and electronic timer, electromagnetic release, steel ball and container to catch steel ball released

**Procedure:**

1. Scan the QR Code or visit the website given to download the manual on the use of the photogate and electronic timer.
2. Set up the apparatus as shown in Photograph 2.4.



Photograph 2.4

Manual for the use of photogate and electronic timer for the experiment on free fall



<http://bt.sasbadi.com/p4048a>

Alternative method using ticker tape



<http://bt.sasbadi.com/p4048b>

3. Place the second photogate so that the distance is 30.0 cm away from the first photogate.
4. Ensure the steel ball can fall through both photogates into the container.
5. Release the steel ball from the electromagnetic release.
6. Record the time when the steel ball passes through the first photogate as  $t_1$  and the second photogate as  $t_2$  in Table 2.6.
7. Repeat steps 3 to 6 with distances 40.0 cm, 50.0 cm, 60.0 cm and 70.0 cm.

Results:

Table 2.6

Distance between two photogates, $h$ / cm	Time when the steel ball passes through photogates		Gravitational acceleration, $g$ / $\text{m s}^{-2}$
	$t_1$ / s	$t_2$ / s	
30.0			
40.0			
50.0			
60.0			
70.0			

Analysis of data:

- Determine the value of  $g$  using the formula  $g = \frac{2h}{t_2^2 - t_1^2}$ .
- Calculate the average value of  $g$ .

Conclusion:

What conclusion can be made from this experiment?

Prepare a complete report on this experiment.

Discussion:

- Compare the average value of  $g$  from this experiment with the standard value of  $g$  at the equator,  $9.78 \text{ m s}^{-2}$ . Why are these two values different?
- Explain one precaution to improve the accuracy of the results in this experiment.

The value of gravitational acceleration,  $g$  changes from one place to another. For example, the value of  $g$  at the equator is  $9.78 \text{ m s}^{-2}$  while the value of  $g$  at the Earth's poles is  $9.83 \text{ m s}^{-2}$ . This is because Earth is actually not a perfect sphere.

Figure 2.40 shows that the distance from the equator to the centre of the Earth is further than the distance from the poles to the centre of the Earth. As such, the value of  $g$  is smaller at the equator than at the Earth's poles. Generally, the value of gravitational acceleration on the surface of the Earth,  $g$  used in calculations is  $9.81 \text{ m s}^{-2}$ .

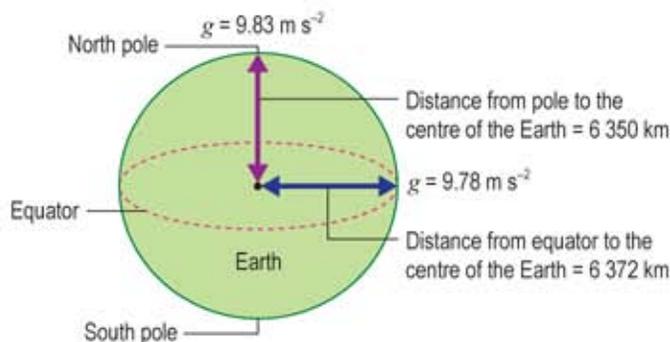


Figure 2.40 Different distances from the centre of the Earth

## Solving Problems Related to Free Falling Objects

Objects thrown vertically upwards or released and falls downwards experience gravitational acceleration,  $g$ . Therefore, the equations of linear motion below can be applied to free falling objects.

$$v = u + gt$$

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

$$v^2 = u^2 + 2gs$$

In solving problems, our assumptions are upward motion is motion in the positive direction and downward motion is motion in the negative direction as shown in Figure 2.41.

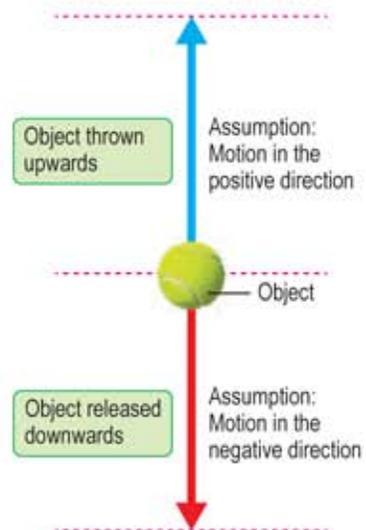


Figure 2.41 Assumption of direction of an object's vertical motion

### Example 1

Amirah threw a ball vertically upwards with an initial velocity of  $10 \text{ m s}^{-1}$ . Calculate the:

- time for the ball to achieve maximum height
  - maximum height that can be reached by the ball
- Ignore air resistance. [ $g = 9.81 \text{ m s}^{-2}$ ]

#### Solution:

- (a) **Step 1**  
List the given information in symbols.
- Initial velocity,  $u = 10 \text{ m s}^{-1}$   
Final velocity at maximum height,  $v = 0 \text{ m s}^{-1}$   
Acceleration,  $g = -9.81 \text{ m s}^{-2}$

- Step 2**  
Identify and write down the formula used.
- $v = u + gt$

- Step 3**  
Substitute numerical values into the formula and perform the calculations.
- $0 = 10 - 9.81t$   
 $t = \frac{10}{9.81}$   
 $= 1.02 \text{ s}$

- (b)  $v^2 = u^2 + 2gs$   
 $0 = 10^2 + 2(-9.81)s$   
 $s = \frac{10^2}{2 \times 9.81}$   
 $= 5.10 \text{ m}$

#### SMART INFO

Ball moves upwards,  $u$  is positive but  $g$  is negative.

#### SMART INFO

The equation  $s = ut + \frac{1}{2}gt^2$  can also be used.  
 $s = ut + \frac{1}{2}gt^2$   
 $= 10(1.02) + \frac{1}{2}(-9.81)(1.02)^2$   
 $= 5.10 \text{ m}$

**Example 2**

Chan released a stone from a cliff of 10 m height. Determine  
 (a) the time taken for the stone to reach the bottom of the cliff  
 (b) the velocity of the stone just before it touches the ground  
 Ignore air resistance. [ $g = 9.81 \text{ m s}^{-2}$ ]

**Solution:**

$$(a) \quad s = ut + \frac{1}{2}gt^2$$

$$-10 = (0)t + \frac{1}{2}(-9.81)t^2$$

$$2 \times (-10) = (-9.81)t^2$$

$$t = \pm \sqrt{\frac{-20}{-9.81}}$$

$$= 1.43 \text{ s}$$

$$(t = -1.43 \text{ is ignored})$$

$$(b) \quad v^2 = u^2 + 2gs$$

$$= 2 \times (-9.81) \times (-10)$$

$$v = \pm \sqrt{2 \times (-9.81) \times (-10)}$$

$$= \pm 14.0 \text{ m s}^{-1}$$

$$v = -14.0 \text{ m s}^{-1}$$

$$(v = 14.0 \text{ m s}^{-1} \text{ is ignored because the stone moves downwards}).$$

**SMART INFO**

Formula  $v = u + gt$   
 can also be used  
 $v = -9.81 \times 1.43$   
 $= -14.0 \text{ m s}^{-1}$

**Formative Practice 2.3**

- What is meant by free fall?
- A light hollow plastic ball and a solid steel ball of the same size are released from the cliff of a hill. Will both balls reach the foothill at the same time? Explain your answer.
- An object thrown vertically upwards reached a maximum height of 5.0 m. Calculate:
  - the velocity of the object when thrown 🍷
  - the time taken for the object to reach its maximum height 🍷
  - the time required for the object to return to its original level 🍷
 Ignore air resistance. [ $g = 9.81 \text{ m s}^{-2}$ ]
- A tennis ball that is released falls vertically from a building of height 50 m. Calculate:
  - the time taken for the ball to reach the base of the building 🍷
  - the velocity of the ball just before hitting the base of the building 🍷
  - the vertical distance passed at the third second 🍷
 Ignore air resistance. [ $g = 9.81 \text{ m s}^{-2}$ ]

## 2.4 Inertia

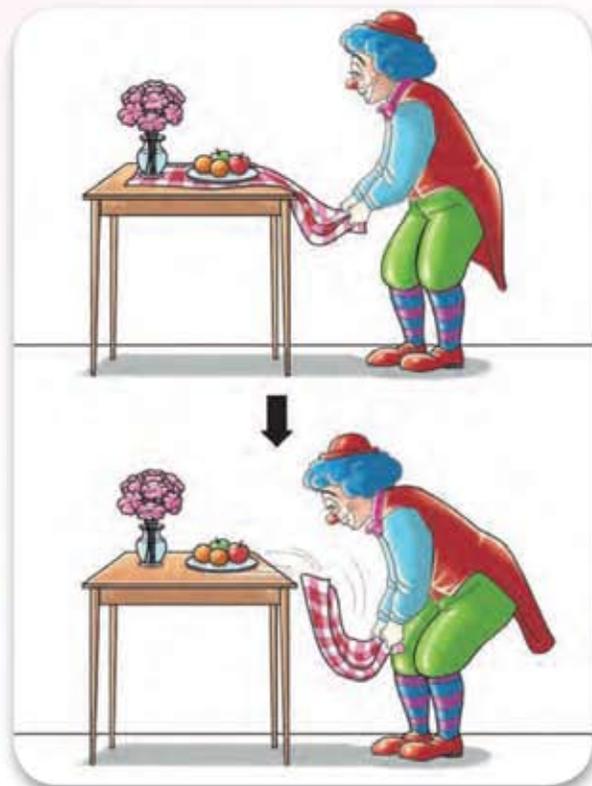
### Concept of Inertia

Figure 2.42 shows objects placed on a table remain stationary even though the table cloth under the objects is jerked by the entertainer. This is due to **inertia**.

Inertia is the tendency of an object to remain at rest or, if moving, to continue its motion in a straight line at uniform velocity. The concept of inertia is explained in Newton's First Law of Motion.

#### Newton's First Law of Motion

Newton's First Law states that an object will remain at rest or move at uniform velocity unless acted upon by an external force.



**Figure 2.42** An entertainer jerks a table cloth without moving the objects on the table



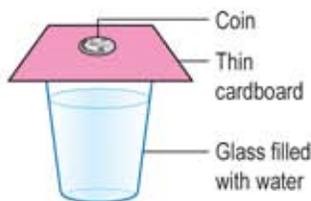
### Activity 2.6

**Aim:** To demonstrate the concept of inertia

**Materials:** Glass filled with water, coin and thin cardboard

**Instructions:**

1. Arrange the materials as shown in Figure 2.43.



**Figure 2.43**

2. Jerk the cardboard under the coin horizontally.

**Discussion:**

1. Why is the coin not moving with the thin cardboard?
2. What happens if the cardboard is pulled slowly? Explain your answer by referring to Newton's First Law of Motion.

## Recognising the Relationship between Inertia and Mass

Photograph 2.5 shows a bowling ball and a football. Is it easier to move a bowling ball or a football? Which ball is difficult to stop when in motion?



Photograph 2.5 Two balls of different masses

An object with a bigger mass is more difficult to set in motion or stop from moving as compared to a lighter object. What is the relationship between mass and inertia? Let us carry out an experiment using a simple inertial balance.



### Experiment

## 2.2

**Inference:** Inertia of an object depends on its mass

**Hypothesis:** The larger the mass of an object, the larger the inertia of the object

**Aim:** To study the relationship between inertia and mass

**Variables:**

- (a) Manipulated variable: Mass of plasticine,  $m$
- (b) Responding variable: Period of oscillation,  $T$
- (c) Constant variable: Distance between G-clamp and plasticine

**Apparatus:** Stopwatch, G-clamp, ruler and jigsaw blade

**Materials:** Plasticine of mass 20.0 g, 30.0 g, 40.0 g, 50.0 g and 60.0 g

**Procedure:**

1. Set up the apparatus as shown in Figure 2.44.
2. Fix a piece of 20.0 g plasticine to the free end of the jigsaw blade.
3. Displace the free end of the jigsaw blade horizontally and release it so that the plasticine oscillates.
4. Record the time,  $t_1$  for 10 complete oscillations of the plasticine in Table 2.7.
5. Repeat steps 3 and 4 and record the time as  $t_2$ .
6. Repeat steps 2 to 5 using plasticine of mass 30.0 g, 40.0 g, 50.0 g and 60.0 g.

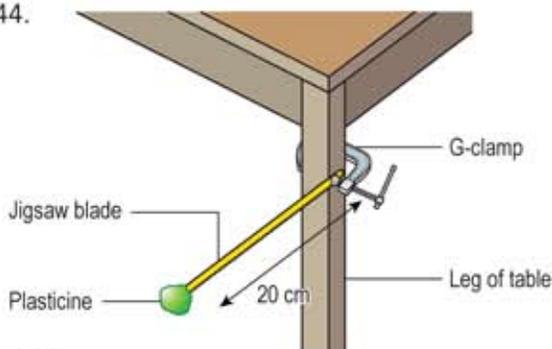


Figure 2.44

**Results:****Table 2.7**

Mass of plasticine $m / \text{g}$	Time for 10 complete oscillations, $t / \text{s}$			Period of oscillation $T / \text{s}$
	$t_1$	$t_2$	$t_{\text{average}}$	
20.0				
30.0				
40.0				
50.0				
60.0				

**Analysis of data:**

1. Determine the period of oscillation,  $T$  of the plasticine, with the following equation:

$$T = \frac{t_{\text{average}}}{10}, \text{ where } t_{\text{average}} = \frac{t_1 + t_2}{2}$$

2. Plot a graph of  $T^2$  against  $m$ .
3. Based on your graph, state the relationship between period of oscillation,  $T$  and mass of plasticine,  $m$ .
4. Explain how the relationship between mass and inertia is determined from this experiment.

**Conclusion:**

What conclusion can be made from this experiment?

**Prepare a complete report on this experiment.**

**Discussion:**

1. How can this apparatus set up be used to determine the mass of an object?
2. Explain one precaution to improve the accuracy of the results.

Experiment 2.2 shows that the inertia of an object is related to its mass. The horizontal oscillations in an inertial balance are not influenced by gravitational force. The period of horizontal oscillation of the inertial balance depends only on the mass of the plasticine. The larger the mass of an object, the larger the inertia of the object.

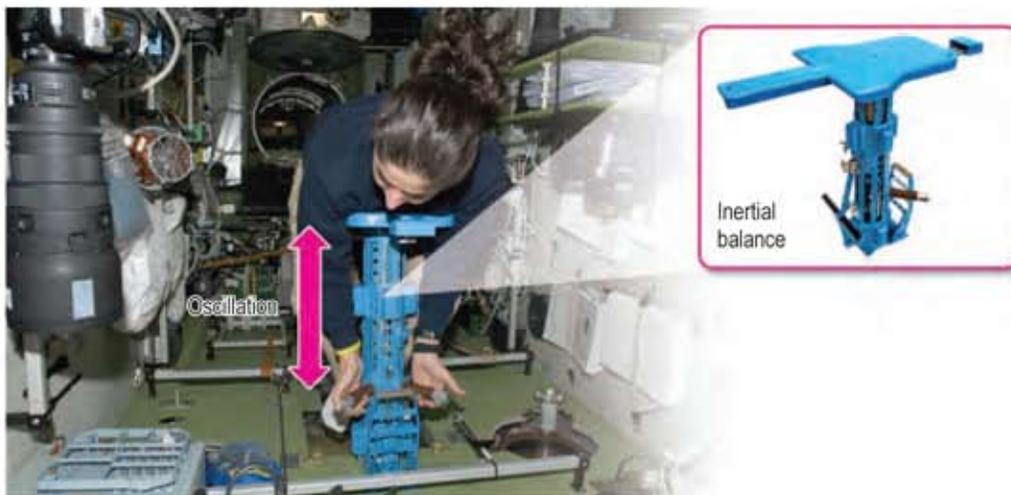
### Effects of Inertia in Daily Life

Astronauts in a spaceship such as the International Space Station (ISS) are in a condition of zero gravity. Under the condition of zero gravity, only the inertial balance can be used to measure mass. Photograph 2.6 shows a special type of inertial balance used by astronauts. The periods of oscillation of astronauts are used to determine their body mass.

#### Inertial balance video



<http://bt.sasbadi.com/p4055>



*Photograph 2.6 An astronaut using an inertial balance*

Inertia can have good and bad effects to our daily lives. Let us discuss situations that involve inertia.



### Activity 2.7

ISS

ICS

**Aim:** To discuss situations in daily life that involve inertia

**Instructions:**

1. Carry out a Hot Seat activity.
2. Gather information on situations in daily life that involve inertia.
3. Discuss whether the situations have good or bad effects on human.
4. Suggest a method to reduce the bad effects of inertia.
5. Choose a group representative to answer questions from other groups.

Several examples of daily life situations that involve inertia and its effects are as follows.

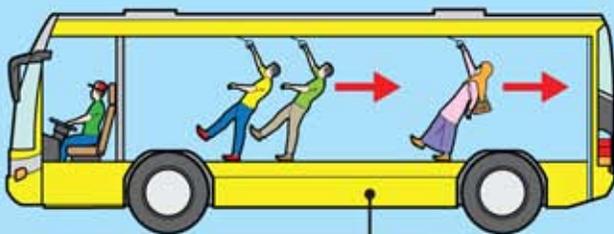
### Situation 1



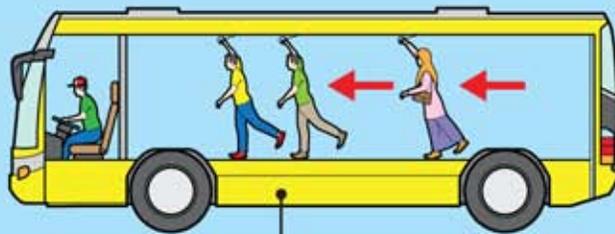
Raindrops spun off when a wet umbrella is rotated and suddenly stopped.

Raindrops on an umbrella are in motion as the umbrella rotates. When the umbrella stops rotating, the inertia of the raindrops causes the raindrops to continue in motion and leave the surface of the umbrella.

### Situation 2



Passengers are thrown backwards when a bus at rest suddenly starts moving forward.



Passengers are thrown forward when a moving bus suddenly stops.

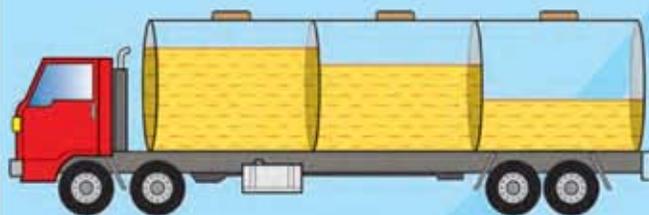
The inertia of the passengers keeps them in their initial state of rest or motion.

### Situation 3



Chilli sauce or tomato sauce in a bottle flow out when the glass is moved quickly downwards and then suddenly stopped. The inertia of the sauce causes it to continue moving downwards and out of the bottle.

### Situation 4



Oil tanker trucks have large inertia. In fact, an oil tanker truck has its storage tank divided into several separate tanks. The separated tanks reduce the impact of the inertia of the petrol.

## Situation 5

Riders on a roller coaster in a recreation park are assigned to seats through a specialised safety system. The roller coaster carriage moves at sudden changes of speed and direction.



When the carriage of the roller coaster changes its direction of motion suddenly, the inertia of the riders keeps them in their original state of motion. The safety system ensures the riders remain in their seats and are not thrown out during the motion.

## Situation 6

Driver and passengers of a car are advised to wear seat belts.



When a car stops abruptly, the driver and passengers in the car are thrown forward because of inertia. Seat belts prevent them from being thrown forward and hurting themselves.

## Formative Practice 2.4

1. Explain the concept of inertia.
2. Brian wishes to pull a table cloth without toppling the things on top of the table cloth. How can Brian do it? Explain your answer.
3. Study the following statements:

Statement 1: Objects can continue moving only if a force acts on them.

Statement 2: Rockets in outer space can move without any engine thrust.

Statement 3: Force is required to change the state of motion of objects.

- (a) Which of the statements can be explained correctly using Newton's First Law of Motion?
- (b) Give reasons of your choice. 🍌

## 2.5 Momentum

Photograph 2.7 shows a fast moving car and a lorry carrying a heavy load on the road. Which vehicle is more difficult to stop if both are driven at the same velocity?

Momentum is a vector quantity. All moving objects have momentum. The direction of momentum is the same as the direction of the velocity of an object. An object moving with high velocity or large mass has a large momentum. Momentum,  $p$  of a moving object can be calculated using the following formula:

$$p = mv, \text{ where } p = \text{momentum} \\ m = \text{mass} \\ v = \text{velocity}$$

S.I. unit for momentum is  $\text{kg m s}^{-1}$



Photograph 2.7 A fast moving car and a lorry on the road

### INTEGRATION OF LANGUAGE

The word momentum originates from Latin that means *movement*. Isaac Newton described it as "quantity of motion".

### Activity 2.8

**Aim:** To study how the mass and velocity of an object influence the effect of stopping the object

**Materials:** Two marbles of different masses, ruler with a groove in the centre, two books of equal thickness, thin cardboard and sticky tape

**Instructions:**

1. Arrange the materials as shown in Figure 2.45. Raise one end of the ruler using one thick book.
2. Release the marble from the top end of the ruler so that it hits the cardboard.
3. Measure the displacement,  $s_1$ , of the cardboard and record it in Table 2.8.
4. Repeat steps 2 to 3 and record the displacement as  $s_2$ .
5. Calculate  $s_{\text{average}} = \frac{s_1 + s_2}{2}$  and record it.
6. Repeat steps 1 to 5 using two books of equal thickness.
7. Repeat steps 1 to 5 using a marble of larger mass.

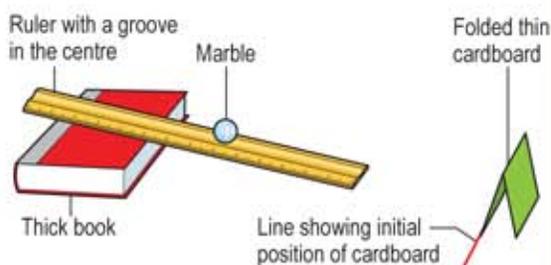


Figure 2.45

## Results:

Table 2.8

Mass	Number of books	Displacement of cardboard, $s$ / cm		
		$s_1$	$s_2$	$s_{\text{average}}$
Small	1			
Small	2			
Large	1			

## Discussion:

1. What is represented by the displacement of the cardboard?
2. How does the velocity of the marble influence the displacement of the cardboard?
3. How does the mass of the marble influence the displacement of the cardboard?

The marble that is released from a high position moves downwards at a high velocity and displaces the cardboard further. This also happens when the marble has larger mass. The displacement of the cardboard represents the difficulty in stopping the marble. Objects with larger momentum are more difficult to stop.

## Example

A lorry of mass 20 000 kg moves with a velocity of 22 m s<sup>-1</sup>. A car of mass 2 000 kg moves with a velocity of 30 m s<sup>-1</sup>.

- (a) What is the momentum of the lorry and the car?
- (b) If the lorry moves with the same velocity as the car, what is the momentum of the lorry?

## Solution:

- (a)
- |   |   |  |
|---|---|--|
| <p><b>Step 1</b><br/>List the given information in symbols.</p>                                   | } | <p>Mass of lorry, <math>m = 20\,000</math> kg<br/>Velocity of lorry, <math>v = 22</math> m s<sup>-1</sup></p>  |
| <p><b>Step 2</b><br/>Identify and write down the formula used.</p>                                | } | <p>Momentum of lorry,<br/><math>p = mv</math></p>  |
| <p><b>Step 3</b><br/>Substitute numerical values in the formula and perform the calculations.</p> | } | <p><math>p = 20\,000</math> kg <math>\times</math> 22 m s<sup>-1</sup><br/><math>= 440\,000</math> kg m s<sup>-1</sup><br/><math>= 440\,000</math> N s</p> |

$$\begin{aligned} \text{Momentum of the car, } p &= 2\,000 \text{ kg} \times 30 \text{ m s}^{-1} \\ &= 60\,000 \text{ kg m s}^{-1} \\ &= 60\,000 \text{ N s} \end{aligned}$$

- (b) Momentum of the lorry moving at the velocity of the car
- $$\begin{aligned} &= 20\,000 \text{ kg} \times 30 \text{ m s}^{-1} \\ &= 600\,000 \text{ kg m s}^{-1} \\ &= 600\,000 \text{ N s} \end{aligned}$$

## SMART TIP

From Chapter 1, the unit newton (N) in base unit is kg m s<sup>-2</sup>.

Unit for momentum:  
kg m s<sup>-1</sup> = (kg m s<sup>-2</sup>) s  
= N s

## Applications of the Concept of Momentum in Daily Life

You have learned the concept of momentum. Carry out Activity 2.9 to understand the applications of momentum in daily life.

### Activity 2.9

ICS

**Aim:** To discuss the applications of the concept of momentum in daily life

**Instructions:**

1. Work in groups.
2. Visit websites to gather information on the applications of momentum in daily life and present the results of your findings.

### Applying the Principle of Conservation of Momentum in Collisions and Explosions

Figures 2.46(a) and (b) show two firemen putting out a fire. In Figure 2.46(b) both firemen are thrown backwards when water at high speed gushes out of the hose. Why does this happen?

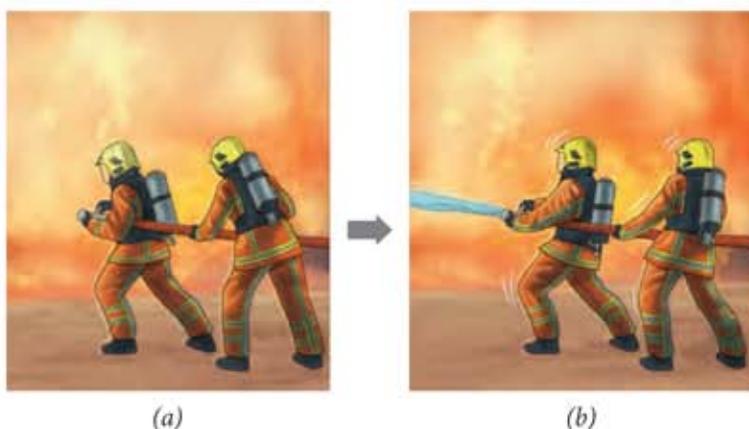


Figure 2.46 Firemen putting out a fire

Water gushing out of the hose at high speed has a high forward momentum. Due to this, two or more firemen are needed to balance the momentum by holding the hose tightly.

### Activity 2.10

ICS

**Aim:** To study a situation involving the Principle of Conservation of Momentum in daily life

**Instructions:**

1. Work in groups.
2. Gather information on a situation which involves the Principle of Conservation of Momentum in daily life.
3. Present your findings using multimedia presentation.



## Activity 2.11

**Aim:** To investigate the Principle of Conservation of Momentum

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

**Materials:** Ticker tape, cellophane tape, plasticine, pin and cork

**Instructions:**

1. Work in groups.
2. Set up the apparatus as shown in Figure 2.47.

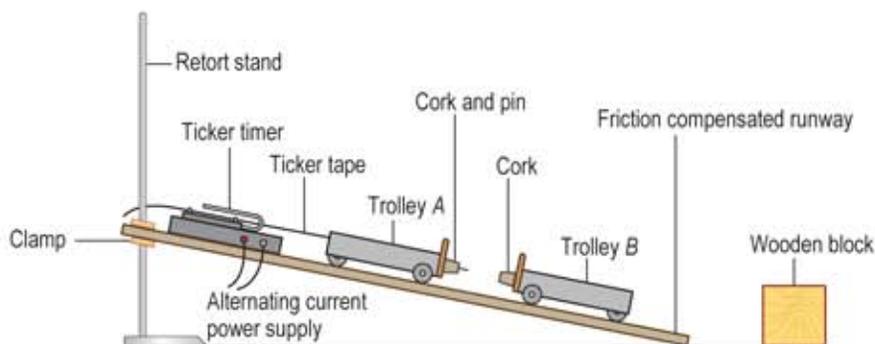


Figure 2.47

3. Raise one end of the runway so that it is friction compensated.
4. Switch on the ticker timer and push trolley A hard towards trolley B.
5. Determine the following velocity in cm per 10 ticks:
  - (a) Velocity of trolley A before collision,  $u_1$ .
  - (b) Common velocity of trolleys A and B after collision,  $v$
6. Record the results in Table 2.9 on page 62.
7. Repeat steps 4 to 6 for 1 trolley colliding with 2 trolleys at rest.
8. Repeat steps 4 to 6 for 2 trolleys colliding with 1 trolley at rest as shown in Figure 2.48.

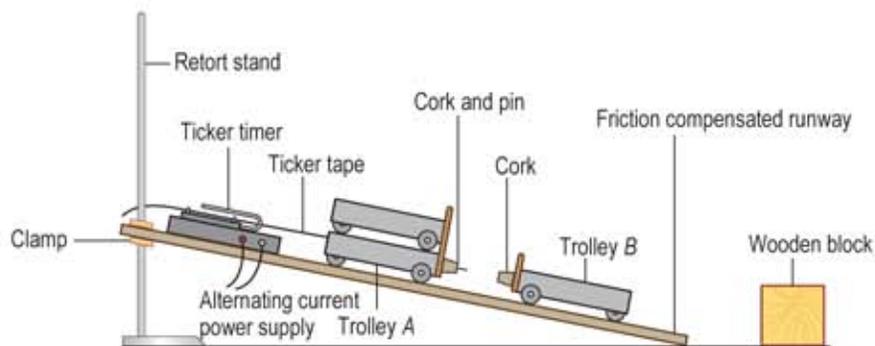


Figure 2.48

9. Repeat steps 4 to 6 for 3 trolleys colliding with 1 trolley.

**Results:**

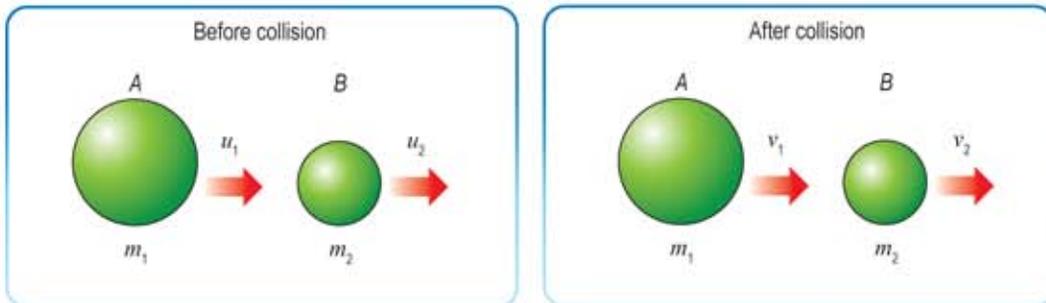
*Table 2.9*

Before collision					After collision		
Trolley A		Trolley B		Total momentum	Trolley A and trolley B		Total momentum
$m_1$	$u_1$ (cm per 10 ticks)	$m_2$	$u_2$	$m_1u_1 + m_2u_2$	$m_1 + m_2$	$v$ (cm per 10 ticks)	$(m_1 + m_2)v$
1		1	0		2		
1		2	0		3		
2		1	0		3		
3		1	0		4		

**Discussion:**

1. What is a friction compensated runway?
2. Compare the total momentum before and after collision.
3. Is the total momentum conserved? Explain your answer.

In Activity 2.11, you may find that the total momentum before and after collision differs slightly. This difference is due to external forces such as friction that cannot be compensated completely.



*Figure 2.49 A system of two objects before and after collision*

Figure 2.49 shows a system of two objects before and after collision. The Principle of Conservation of Momentum states that the total momentum before collision is equal to the total momentum after collision if no external force is acting on it.

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

Figure 2.50 shows the launching of a rocket. Launching of a rocket is an example of explosion. Explosion refers to a situation where an object at rest breaks up into two or more parts. Before launch, the rocket is at rest at the base of the launch pad with zero momentum. During launch, hot gases move downwards and the rocket moves upwards. Explosion is also a closed system which does not involve external forces. As such, total momentum is also conserved in explosion.

$$\begin{aligned} \text{Total momentum before explosion} &= \text{total momentum after explosion} \\ 0 &= m_1 v_1 + m_2 v_2 \\ m_1 v_1 &= -m_2 v_2 \end{aligned}$$

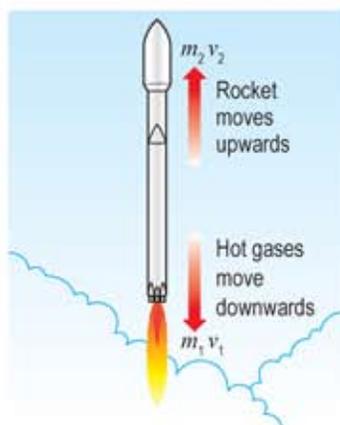


Figure 2.50 Launching of a rocket



## Activity 2.12

ICS

STEM

**Aim:** To build and launch a water rocket

**Instructions:**

1. Work in groups.
2. Gather information on the following:
  - (a) materials needed to build and launch a water rocket
  - (b) ways to build a water rocket
  - (c) safety precautions to be taken
3. Discuss the required information and complete the K-W-L Chart as a guide in the search for information.
4. Design, build and launch your group's water rocket in your school field.
5. Prepare a report on how the Principle of Conservation of Momentum is applied in the water rocket launching technology.

K-W-L Chart



<http://bt.sasbadi.com/p4063>

## Formative Practice 2.5

1. What is meant by momentum and conservation of momentum?
2. A lorry of mass 1 000 kg moves at a velocity of 5.0 m s<sup>-1</sup>. It collides with a car of mass 800 kg moving at a velocity of 2.0 m s<sup>-1</sup> in the same direction. If the lorry moves at a velocity of 3.4 m s<sup>-1</sup> in the same direction after the collision, calculate the velocity of the car. 🍒

## 2.6 Force

Most of our daily activities involve forces. A force can change the state of motion of an object. How does a force change the momentum of an object in motion along a straight line?

*Recall*

Force and Motion



### Activity 2.13

**Aim:** To investigate the relationship between force and acceleration and the relationship between mass and acceleration

**Apparatus:** Ticker timer, alternating current power supply, runway, three trolleys and retort stand

**Materials:** Ticker tape, cellophane tape, three elastic strings with a knotted loop at each end

**(A) To investigate the relationship between force and acceleration with a fixed mass**

**Instructions:**

1. Set up the apparatus as shown in Figure 2.51.
2. Switch on the ticker timer and pull the trolley down the runway with one elastic string (one unit of force).
3. Calculate the acceleration of the trolley using the ticker tape obtained and record it in Table 2.10.
4. Repeat steps 2 to 3 using two elastic strings and three elastic strings with each of the strings stretched to the same length as that of the first elastic string in step 2.
5. Plot the graph of acceleration,  $a$  against force,  $F$  and state the relationship between acceleration,  $a$  and force,  $F$ .

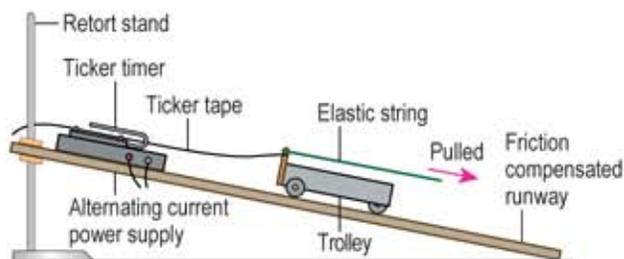


Figure 2.51

**Guide to carrying out Activity 2.13**



<http://bt.sasbadi.com/p4064b>

**Results:**

Table 2.10

Force, $F$	$u / \text{cm s}^{-1}$	$v / \text{cm s}^{-1}$	$t / \text{s}$	$a / \text{cm s}^{-2}$
1 elastic string				
2 elastic strings				
3 elastic strings				

**(B) To investigate the relationship between mass and acceleration at a constant force**

**Instructions:**

1. Repeat steps 1 and 2 in (A) by pulling the trolley using two elastic strings stretched together.
2. Repeat step 1 in (B) using two trolleys as shown in Figure 2.52 and then three trolleys.

- Calculate the acceleration of the trolley from the ticker tape obtained and record it in Table 2.11.
- Plot a graph of acceleration,  $a$  against the reciprocal of mass,  $\frac{1}{m}$  and state the relationship between acceleration,  $a$  and mass,  $m$ .

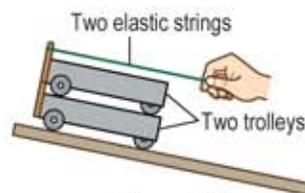


Figure 2.52

Results:

Table 2.11

Mass	$u / \text{cm s}^{-1}$	$v / \text{cm s}^{-1}$	$t / \text{s}$	$a / \text{cm s}^{-2}$
1 trolley, $m$				
2 trolleys, $2m$				
3 trolleys, $3m$				

The results of Activity 2.13 shows that the acceleration of an object depends on the applied force and the mass of the object.

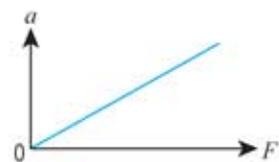


Figure 2.53 Acceleration-force graph

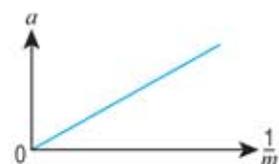


Figure 2.54 Acceleration-reciprocal of mass graph

Acceleration is directly proportional to the applied force when the mass of an object is fixed

$$a \propto F$$

$m$  constant

$F$  – Force  
 $m$  – Mass  
 $a$  – Acceleration

Combining the two relationships:

$$a \propto \frac{F}{m}$$

Therefore,  $F \propto ma$

Acceleration is inversely proportional to mass of an object when a constant force is applied on the object

$$a \propto \frac{1}{m}$$

$F$  constant

The relationship between force,  $F$ , mass,  $m$  and acceleration,  $a$  for an object in motion is

$$F \propto ma$$

$$F \propto m \frac{(v - u)}{t}$$

$$F \propto \frac{(mv - mu)}{t}$$

Expression of Newton's Second Law of Motion

### Info File

$$\text{Change of momentum} = mv - mu$$

$$\text{Rate of change of momentum} = \frac{(mv - mu)}{t}$$

Newton's Second Law of Motion states that the rate of change of momentum is directly proportional to the force and acts in the direction of the applied force. From the relationship

$$F \propto ma$$

$$F = kma, k \text{ is a constant}$$

In S.I. units, 1 N is the force that produces an acceleration of  $1 \text{ m s}^{-2}$  when applied on a mass of 1 kg.

As such,

$$1 \text{ N} = k \times 1 \text{ kg} \times 1 \text{ m s}^{-2}$$

$$k = 1$$

Therefore,  $F = ma$

## Solving Problems Involving the Formula $F = ma$

### Example 1

A worker pulls a load of mass 80 kg along a horizontal surface by a force of 160 N. If the surface is smooth and without any resistance that opposes the motion of the object, what is the acceleration of the load?

#### Solution:

##### Step 1

List the given information in symbols.

$$\text{Mass, } m = 80 \text{ kg}$$

$$\text{Force, } F = 160 \text{ N}$$

##### Step 2

Identify and write down the formula used.

$$F = ma$$

##### Step 3

Substitute numerical values into the formula and perform the calculations.

$$160 = 80 \times a$$

$$a = \frac{160}{80}$$

$$= 2 \text{ m s}^{-2}$$

### Example 2

A car of mass 1 200 kg moves with a velocity of  $30 \text{ m s}^{-1}$ . When the brakes of the car are applied, the car stops in 5 seconds. Calculate the average braking force of the car.

#### Solution:

$$\begin{aligned} \text{Deceleration of car, } a &= \frac{v - u}{t} \\ &= \frac{0 - 30}{5} \\ &= -6 \text{ m s}^{-2} \end{aligned}$$

$$\begin{aligned} \text{Average braking force, } F &= ma \\ &= 1\,200 \text{ kg}(-6 \text{ m s}^{-2}) \\ &= -7\,200 \text{ N} \text{ (Negative sign shows that the force acts in the opposite} \\ &\quad \text{direction to the motion of the car)} \end{aligned}$$

## Formative Practice

### 2.6

- A force,  $F$  acts on a body of mass 5 kg.
  - If the body accelerates uniformly from  $2 \text{ m s}^{-1}$  to  $8 \text{ m s}^{-1}$ , determine the value of  $F$ .
  - If  $F = 10 \text{ N}$ , determine the displacement of the body 6 seconds after the body starts to move from rest. 🍎
- A force of 80 N acts on a stationary object for 7 seconds and causes the object to reach a velocity of  $35 \text{ m s}^{-1}$ . Calculate:
  - the mass of the object. 🍎
  - the displacement of the object. 🍎

## 2.7 Impulse and Impulsive Force

Photograph 2.8 shows the action of a long jump athlete bending his legs while landing. What is the effect of this action?

The action of bending his legs is to reduce the magnitude of the impulsive force acting on his body.

**Impulse** is a change of momentum.

$$\text{Impulse, } J = mv - mu \\ = Ft$$

$F$  = applied force

$t$  = time of action of the force



**Photograph 2.8** Long jump athlete bending his legs

**Impulsive force** is the rate of change of momentum in a collision or impact in a short period of time. The formula for impulsive force is as follows.

$$\text{Impulsive force, } F = \frac{mv - mu}{t}$$

$t$  = impact time

$mv - mu$  = change of momentum

If change of momentum,  $mv - mu$  is constant, then  $F \propto \frac{1}{t}$ . If  $t$  is small, then the magnitude of  $F$  is big or vice versa.



### Activity 2.14

ISS

ICS

**Aim:** To discuss impulse and impulsive force

**Instructions:**

1. Work in groups.
2. Gather the following information from appropriate websites.
  - (a) effect of follow through action on magnitude of impulse.
  - (b) situations and applications in daily life that involve impulse.
  - (c) situations and applications in daily life that involve impulsive force, including safety features in vehicles.
3. Prepare a brief multimedia presentation and present it.

Video on impulse, momentum and impulsive force



<http://bt.sasbadi.com/p4067>

In fact, all the situations that you studied in Activity 2.14 involve a pair of forces, action and reaction. The relationship between action and reaction is explained in Newton's Third Law of Motion. **Newton's Third Law of Motion** states that for every action there is a reaction of equal magnitude, but in the opposite direction. Study the examples of situations and the explanations given below.

#### Action and reaction force



<http://bt.sasbadi.com/p4068>

#### Increasing the magnitude of impulse by follow through action

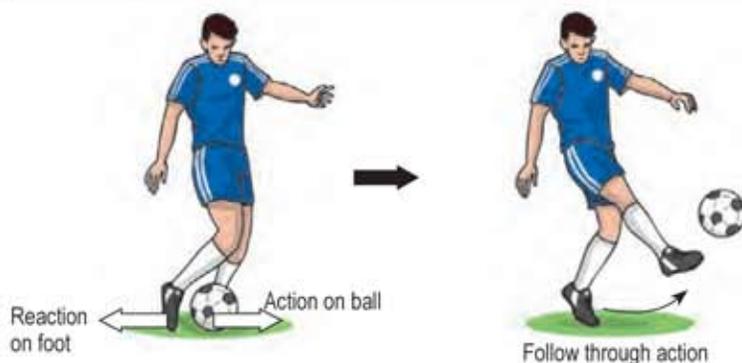


Figure 2.55 Follow through in football

A follow through action after a strong kick produces a large impulse. As a result, the ball experiences a large change in momentum and moves at a high velocity.

#### Reducing impulsive force by extending impact time



Photograph 2.9 Car collision test

Collision causes a car to stop and experience a change in momentum. The crumple zone of the car extends the impact time during collision. As a result, the magnitude of the impulsive force on the car is reduced.

#### Increasing impulsive force by reducing impact time

A pestle moving at high velocity is stopped by a hard mortar in a short interval of time. A large impulsive force is produced.



Photograph 2.10 Using a mortar and pestle

## Solving Problems Involving Impulse and Impulsive Force

## Example 1

A plasticine ball of mass  $0.058 \text{ kg}$  is thrown at a velocity of  $10 \text{ m s}^{-1}$  and hits the wall. It sticks to the wall. What is the impulse of the plasticine?

## Solution:

## Step 1

List the given information in symbols.

Mass,  $m = 0.058 \text{ kg}$   
Initial velocity,  $u = 10 \text{ m s}^{-1}$   
Final velocity,  $v = 0 \text{ m s}^{-1}$

## Step 2

Identify and write down the formula used.

Impulse,  $J = mv - mu$

## Step 3

Substitute numerical values into the formula and perform the calculations.

$J = 0.058(0) - 0.058(10)$   
 $= 0 - 0.058(10)$   
 $= 0 - 0.58$   
 $= -0.58 \text{ N s}$  (in the opposite direction to the velocity of the plasticine)

## Example 2

A golfer hits a golf ball of mass  $45.93 \text{ g}$  at a velocity of  $50 \text{ m s}^{-1}$ . If the impact time is  $0.005 \text{ s}$ , what is the impulsive force acting on the golf ball?

## Solution:

$m = 0.04593 \text{ kg}$ ,  $u = 0 \text{ m s}^{-1}$ ,  $v = 50 \text{ m s}^{-1}$ ,  $t = 0.005 \text{ s}$

$$\begin{aligned} \text{Impulsive force, } F &= \frac{mv - mu}{t} \\ &= \frac{0.04593(50) - 0.04593(0)}{0.005} \\ &= 459.3 \text{ N (acting in the same direction as the velocity of the golf ball)} \end{aligned}$$

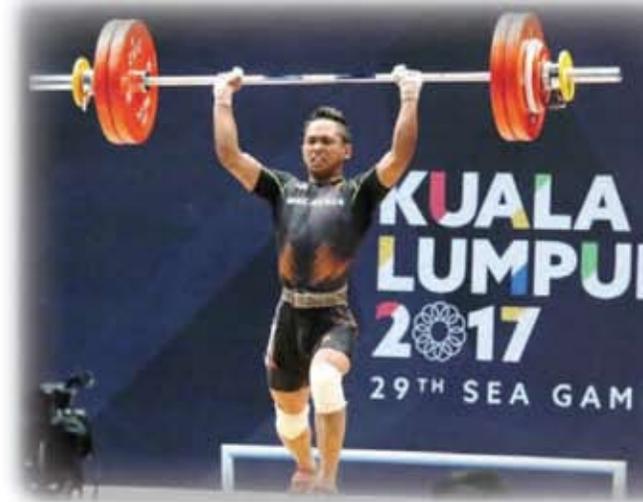
## Formative Practice 2.7

- In a car collision test, a car of mass  $1\,500 \text{ kg}$  hits the wall with a speed of  $15 \text{ m s}^{-1}$ . The car bounces back with a speed of  $2.6 \text{ m s}^{-1}$ . If the collision time is  $0.15 \text{ s}$ , calculate the:
  - impulse in the collision
  - impulsive force acting on the car
- A football player kicks a ball of mass  $450 \text{ g}$  with a force of  $1\,500 \text{ N}$ . The contact time of his shoe with the ball is  $0.008 \text{ s}$ . What is the impulse on the ball? If contact time is increased to  $0.013 \text{ s}$ , what is the velocity of the ball? 🍷

## 2.8 Weight

Photograph 2.11 shows a man lifting a barbell. Earth's gravitational pull acting on the barbell contributes to the weight of the barbell. The weight of the barbell makes it difficult for the man to lift it.

The barbell will drop to the ground with an acceleration if the man releases it. According to Newton's Second Law of Motion,



Photograph 2.11 Lifting a barbell

$$F = ma$$



$$W = mg$$

- Gravitational force acting on the barbell is its weight,  $W$ .
- Acceleration of the barbell is gravitational acceleration,  $g$ .

Weight is a vector quantity which has the same direction with gravitational force, that is towards the centre of Earth.

Unit for weight: N  
Unit for mass: kg

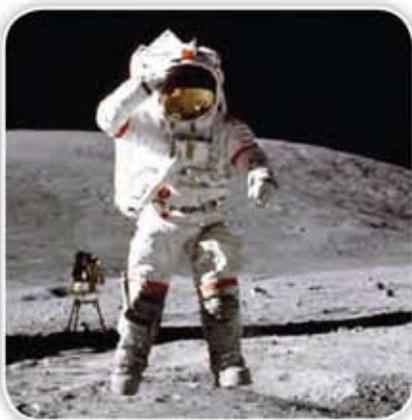
$$W = mg$$

$$g = \frac{W}{m}$$

Unit for  $g$ :  $\text{N kg}^{-1}$

Physical quantity,  $g$  with unit  $\text{N kg}^{-1}$  is the gravitational field strength. Gravitational field strength,  $g$  is the force acting per unit mass caused by gravitational pull. For objects on the surface of the Earth, gravitational field strength,  $g$  is  $9.81 \text{ N kg}^{-1}$ . Each 1 kg mass experiences a force of gravity of 9.81 N. Can you calculate your weight on the surface of the Earth?

Photograph 2.12 shows an astronaut wearing a full spacesuit when exploring the Moon. It is easier for the astronaut to walk on the Moon compared to walking on Earth. Why is this so?



Photograph 2.12 Astronaut wearing a full spacesuit on the Moon

Astronaut's movements on the Moon



<http://bt.sasbadi.com/p4070>

 **Malaysia**  
**MY PRIDE**

Dato. Dr. Sheikh Muszaphar Shukor bin Sheikh Mustapha is the first astronaut of Malaysia.

Mass of astronaut's suit on Earth is 81.65 kg.

$$W_{\text{Earth}} = 81.65 \text{ kg} \times 9.81 \text{ N kg}^{-1} \\ = 800.99 \text{ N}$$

Gravitational field strength on the Moon is  $\frac{1}{6}$  of the gravitational field strength on Earth.

$$W_{\text{Moon}} = \frac{1}{6} \times 800.99 \text{ N} \\ = 133.50 \text{ N}$$



### Activity 2.15

ISS

STEM

**Aim:** To create a vehicle model by applying Newton's Laws of Motion

**Instructions:**

- Work in groups. Gather information on the applications of Newton's Laws of Motion in the creation of cars. Give emphasis to the following:
  - shape of vehicle model
  - type of engine, transmission system, suspension system, steering system and braking system
  - safety aspects of driver and passengers
  - aspects of comfort of driver and passengers in the vehicle
  - type of fuel
- Discuss the required information and complete the K-W-L Chart as a guide in your search for information.
- Create the vehicle model.
- Present the applications of Newton's Laws of Motion of your group's vehicle model.

**K-W-L Chart**



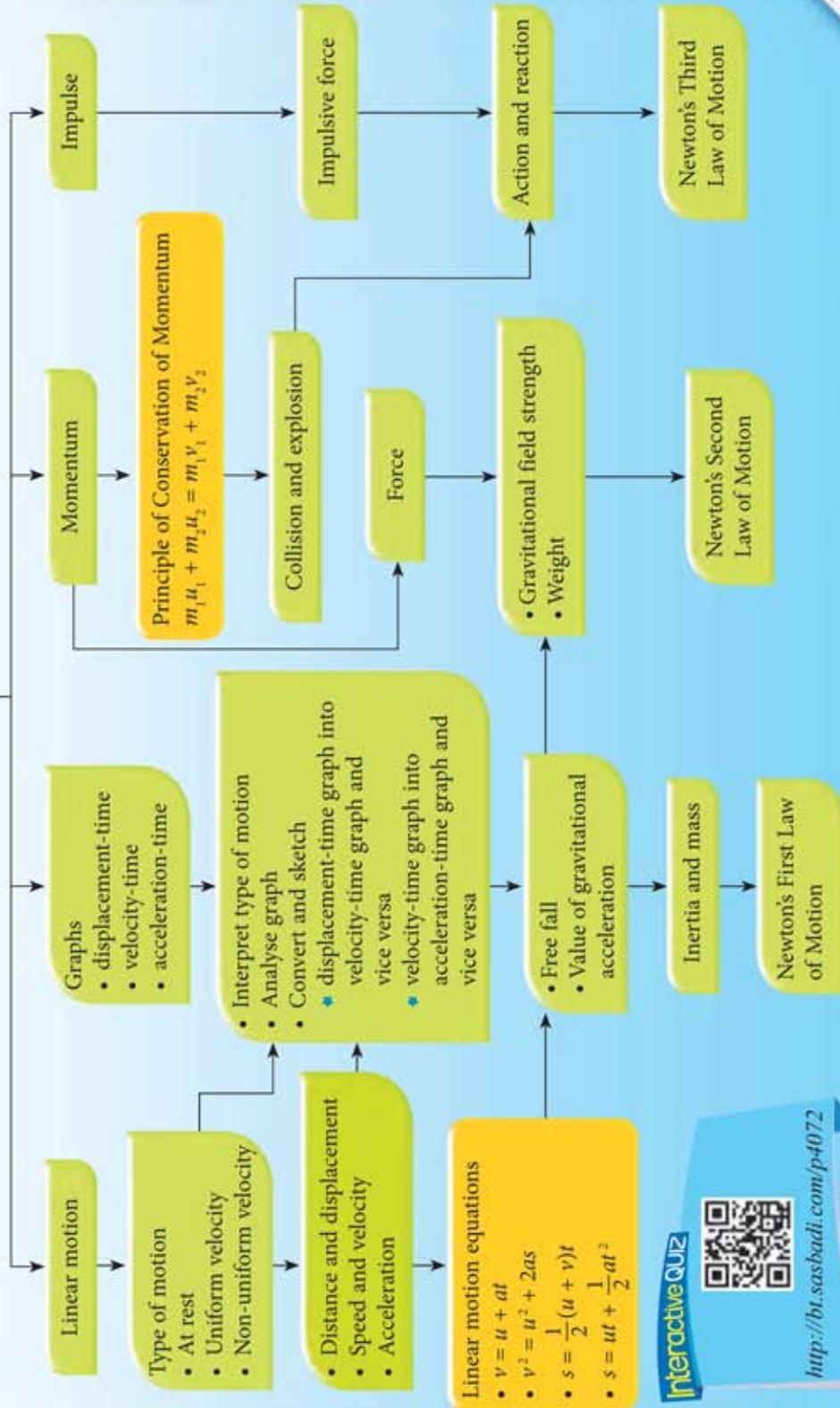
<http://bt.sasbadi.com/p4071>

### Formative Practice 2.8

- What is the meaning of gravitational field strength?
- State the differences between mass and weight.
- A 10 kg object has a weight of 150 N on a planet.
  - What is the gravitational field strength on the planet? 🧠
  - Is the planet bigger than Earth? Give reasons for your answer. 🧠
- An astronaut of mass 60 kg is assigned to explore the Moon. What is the astronaut's weight on the Moon's surface? 🧠

# Conceptual Framework

## Force and Motion I



Interactive QUIZ



<http://bt.sasbadi.com/p4072>

# SELF-REFLECTION

1. New things I learnt in this chapter on force and motion are \_\_\_\_\_ .
2. The most interesting thing I learnt in this chapter on force and motion is \_\_\_\_\_ .
3. Things I still do not fully understand or comprehend are \_\_\_\_\_ .
4. My performance in this chapter,
 

Poor 	1	2	3	4	5	 Excellent
--	---	---	---	---	---	---
5. I need to \_\_\_\_\_  to improve my performance in this chapter.

Download and print  
Self-reflection Chapter 2



<http://bt.sasbadi.com/p4073>



## Performance Evaluation

1. A car moves from rest with an acceleration of  $2.0 \text{ m s}^{-2}$ . Calculate:
  - (a) velocity of car after 5.0 s.
  - (b) distance travelled in 5.0 s.
  - (c) distance travelled in the fifth second.
2. Encik Nizam drives a car at a speed of  $108 \text{ km h}^{-1}$ . Suddenly he sees a car in front moving very slowly. Therefore, Encik Nizam slows down his car to a speed of  $72 \text{ km h}^{-1}$ . The displacement made by the car is 125 m. If the acceleration of the car is uniform, calculate
  - (a) acceleration of Encik Nizam's car
  - (b) time taken for the speed of the car to reduce from  $108 \text{ km h}^{-1}$  to  $72 \text{ km h}^{-1}$ .
3. Swee Lan rows a boat forward. She uses an oar to push the water backwards. Why is the boat able to move forward?
4. A car of mass 1 200 kg at rest is moved by a force of 150 N. Determine the acceleration of the car and time taken for the car to reach a velocity of  $1.5 \text{ m s}^{-1}$ .
5. Gravitational field strength on the Moon is 6 times lower than that on Earth. If a stone weighing 2 N is carried back from the Moon to Earth, calculate the weight of the stone on Earth.
6. A bullet of mass 10 g is fired from a gun of mass 2.0 kg. If the recoil velocity of the gun after firing the shot is  $0.5 \text{ m s}^{-1}$ , calculate the velocity of the bullet.

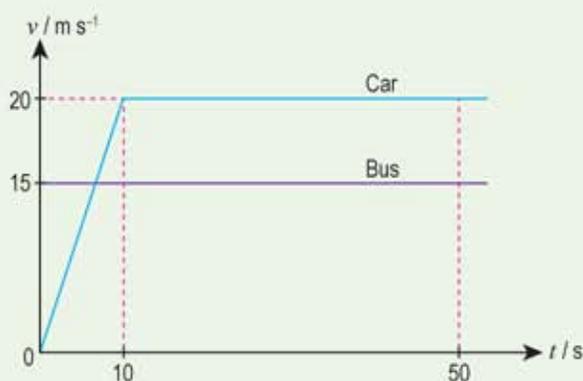
7. Photograph 1 shows a car moving along a road. Initially, the car moves at a uniform velocity of  $18 \text{ m s}^{-1}$  for 15 s. Then, the car accelerates at  $1.5 \text{ m s}^{-2}$  for 5 s. Subsequently, the car starts to decelerate to  $15 \text{ m s}^{-1}$  in 5 s. The car continues to move at this speed for 10 s and finally decelerates again and stops at time,  $t = 50 \text{ s}$ .



**Photograph 1**

Based on the given information, sketch the velocity-time graph for the motion of the car. Show the values of velocity and time in your sketch. 🧠

8. A rubber ball is released from a height,  $H$ . The ball drops vertically downwards and upon hitting the floor, bounces back a height,  $h$  ( $h < H$ ). If the velocity of downward motion is negative, sketch the velocity-time graph for the motion of the rubber ball. 🧠
9. A car at rest starts to move when a bus moves at a uniform velocity of  $15 \text{ m s}^{-1}$  passes by its side. The car reaches a velocity of  $20 \text{ m s}^{-1}$  in 10 seconds and continues to move at a constant velocity in the same direction with the bus. The graph in Figure 1 shows the motion of the car and the bus along a straight road.



**Figure 1**

- (a) Calculate the time taken for the car to reach the same speed as the bus. 🧠
- (b) What is the displacement of the car when it reaches the speed of the bus? 🧠
- (c) Calculate the distance travelled by the car and bus at time,  $t = 50 \text{ s}$ . 🧠
- (d) At time,  $t = 50 \text{ s}$ , is the car in front of the bus? 🧠

10. Photograph 2 shows the launching of a spacecraft using a rocket at a launch pad.



*Photograph 2*

- (a) Explain how the release of hot gases through the rocket's exhaust enables the rocket to accelerate upwards. 🧠
- (b) How can the acceleration of this rocket be increased? 🧠
11. Photograph 3 shows a hovercraft which can move on land or on the surface of water swiftly because of the support from a layer of air trapped under the hovercraft. The hovercraft of mass of 25 000 kg starts from rest and its engine produces a thrust,  $F$  of 22 000 N.
- (a) Determine the initial acceleration of the hovercraft if there is no friction at that instant. 🧠
- (b) What is the function of the layer of air trapped under the hovercraft? 🧠



*Photograph 3*



### *Enrichment Corner*

12. Kok Chew and Zulkefli wish to determine Earth's gravitational acceleration. They plan to release a table tennis ball from the third level of their school building. Discuss the suitability of the table tennis ball in this experiment. 🧠
13. Assume that you are an engineer who is assigned to invent a model of fast train in Malaysia. This train is required to travel at high speeds using levitation above the railway. Draw your model of the fast train and list its properties by taking into consideration its shape, materials, mechanism and safety aspects. 🧠