Chapter 2
Forces & Motion

Edited by
Cikgu Desikan
SMK Changkat Beruas, Perak

In collaboration with
Cikgu Khairul Anuar
SMK Seri Mahkota, Kuantan
Dear students,

The two basic processes of education are knowing and valuing.

Learning Objectives:

1. Analysing linear motion
2. Analysing motion Graphs
3. Understanding inertia
4. Analysing momentum
5. Understanding the effects of a force
6. Analysing impulse and impulsive force
7. Being aware of the need for safety features in vehicles
8. Understanding gravity
9. Analysing forces in equilibrium
10. Understanding work, energy, power and efficiency
11. Appreciating the importance of maximising the efficiency of devices
12. Understanding elasticity

Analysis of Past Year Questions

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>8</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>9</td>
<td>8</td>
<td>7</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>P2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>P3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Dear students,

*It’s not the cards you’re dealt it’s how you play the game !!!*

**Concept Map**

**Forces & Motion**

- **Kinematics**
  - Linear Motion
    - Distance
    - Displacement
    - Speed
    - Velocity
    - Acceleration/Deceleration
    - Graphs
    - Linear Motion Equations

- **Dynamics**
  - Inertia
  - Mass
  - Newton’s 1st Law of Motion
  - Principle of Resultant Force
  - Effects of Forces
    - Newton’s 2nd Law of Motion
      - F=ma
    - Principle of Resolution of Force
      - Newton’s 3rd Law of Motion

- **Linear Momentum**
  - Elastic/Inelastic Collision
  - Explosion
  - Principle of Conservation of Momentum
    - Work
    - Power
    - Energy

---

**Chapter 2**

**Forces & Motion**
2.1 Linear Motion

**Physical Quantity**

**Distance, \( l \)**
Distance is the total path length traveled from one location to another.

**Velocity**
Rate of change of displacement.

**Average speed**

**Uniform speed**
Speed that remains the same in magnitude regardless of its direction.

**Displacement, \( l \)**
The distance of its final position from its initial position in a specified direction.

**Speed**
Rate of change of distance

**Average velocity**

**Uniform velocity**
Velocity that remains the same in magnitude and direction.

**Acceleration**
the rate of change of velocity
<table>
<thead>
<tr>
<th>Constant</th>
<th>=</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zero velocity</td>
<td>=</td>
</tr>
<tr>
<td>Negative velocity</td>
<td>=</td>
</tr>
<tr>
<td>Zero acceleration</td>
<td>=</td>
</tr>
<tr>
<td>Positive acceleration</td>
<td>=</td>
</tr>
<tr>
<td>Negative acceleration</td>
<td>=</td>
</tr>
</tbody>
</table>
An object has a **uniform velocity** only if:

- the direction of motion same or linear motion
- the magnitude of its velocity constant

An object has a **uniform speed** if:

- the magnitude of its speed constant regardless direction.
**Example 1**
An aeroplane flies towards the north with a velocity 300 km/hr in one hour. Then, the plane moves to the east with the velocity 400 km/hr in one hour.
(a) What is the average speed of the plane?
(b) What is the average velocity of the plane?

**Example 2**
The speedometer reading for a car traveling north shows 70 km/hr. Another car traveling at 70 km/hr towards south. Is the speed of both cars same? Is the velocity of both cars same?
Ticker timer

- Use: 12 V a.c power supply
- 1 tick =

- The time taken to make 50 ticks on the ticker tape is 1 second. Hence, the time interval between 2 consecutive dots is $1/50 = 0.02$ s.
- 1 tick = 0.02 s

No. of ticks = Bil. dots - 1

Velocity

- Time, $t$ =
- Displacement, $s = $
- Velocity $= \frac{s}{t} = $

Acceleration

- Elapse time, $t$
- Initial velocity, $u =$
- Final velocity, $v =$
- Acceleration =
The Equations of Motion

\[ u = \text{initial velocity} \]
\[ v = \text{final velocity} \]
\[ t = \text{time taken} \]
\[ s = \text{displacement} \]
\[ a = \text{constant acceleration} \]
1. The diagram above shows a ticker tape chart for a moving trolley. The frequency of the ticker-timer used is 50 Hz. Each section has 11 dots.
   a) What is the time between two dots.
   b) What is the time for one strip.
   c) What is the initial velocity.
   d) What is the final velocity.
   e) What is the time interval to change from initial velocity to final velocity?
   f) What is the acceleration of the object.
2. A rocket accelerates with 20 ms\(^{-2}\). Calculate its velocity after 2.5 minutes if its initial velocity is 3000 ms\(^{-1}\).

3. A van travels up a slope and it stops after 12 seconds. Its initial velocity is 18 ms\(^{-1}\). Calculate its acceleration.
4. A group of student made a rocket and launched it vertically upwards with velocity of 27 ms$^{-1}$. What is the total distance travelled by the rocket? 
[Assume $g = 10$ ms$^{-2}$]
Exercise

**Question 1**

Based on the above portion of ticker tape, determine
a) time taken from point A to B  
b) average speed.

![Diagram of ticker tape with points A and B and distances 6 cm and 3 cm between points](image)

**Question 2**

Based on the ticker tape portion given above, determine the acceleration.

![Diagram of ticker tape with distances 3 cm and 5 cm](image)
<table>
<thead>
<tr>
<th>Ticker Tape</th>
<th>Ticker Chart</th>
<th>Type of Motion</th>
</tr>
</thead>
<tbody>
<tr>
<td>(i)</td>
<td><img src="chart1.png" alt="Chart" /></td>
<td>Constant velocity</td>
</tr>
<tr>
<td>(ii)</td>
<td><img src="chart2.png" alt="Chart" /></td>
<td>• Distance between the dots increases uniformly</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• The velocity of the object is</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• The object is moving at a uniform / constant</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type of Motion</th>
</tr>
</thead>
<tbody>
<tr>
<td>(i) __________________________</td>
</tr>
<tr>
<td>(ii) __________________________</td>
</tr>
</tbody>
</table>

• Distance between the dots decrease uniformly
• The velocity of the object is
• The object is experiencing uniform / constant
2.2 Motion Graphs

**Displacement – Time Graph**

<table>
<thead>
<tr>
<th>Part</th>
<th>Gradient</th>
<th>Velocity</th>
<th>Acceleration</th>
</tr>
</thead>
<tbody>
<tr>
<td>A – B</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B – C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C – D</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Velocity-time Graph**

<table>
<thead>
<tr>
<th>Part</th>
<th>Gradient</th>
<th>Acceleration</th>
<th>Displacement</th>
</tr>
</thead>
<tbody>
<tr>
<td>A – B</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B – C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C – D</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Zero velocity

- **s versus t:** Constant
- **v versus t:** Constant
- **a versus t:** Constant

### Constant velocity

- **s versus t:** Constant
- **v versus t:** Constant
- **a versus t:** Constant

### Negative & constant velocity

- **s versus t:** Constant
- **v versus t:** Constant
- **a versus t:** Constant
<table>
<thead>
<tr>
<th>Constant acceleration</th>
<th>s versus t</th>
<th>v versus t</th>
<th>a versus t</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><img src="#" alt="Graph" /></td>
<td><img src="#" alt="Graph" /></td>
<td><img src="#" alt="Graph" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Constant deceleration</th>
<th>s versus t</th>
<th>v versus t</th>
<th>a versus t</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><img src="#" alt="Graph" /></td>
<td><img src="#" alt="Graph" /></td>
<td><img src="#" alt="Graph" /></td>
</tr>
</tbody>
</table>

*** Gradient of s-t graph represent velocity. Gradient ↑, velocity ↑.***
2.3 Inertia

Every object continues in its state of rest or of uniform motion unless it is acted upon by an external force.

**Relation between inertia and mass**

The larger the mass, the larger the inertia

**TRY Experiment using buckets**

Situations Involving Inertia

When the cardboard is pulled away quickly, the coin drops straight into the glass. The inertia of the coin maintains its state at rest. The coin falls into the glass due to gravity.

When the bus stops suddenly our feet are brought to rest but due to inertia, our body tends to continue its forward motion. This causes our body to thrown forward.

When the bus moves suddenly from rest our feet are carried forward but due to inertia of our body tends to keep us rest. This causes our body to fall backwards.
A boy runs away from a cow in a zig zag motion. The cow has a large inertia making it difficult to change direction.

Tomato sauce in the bottle can be easily poured out if the bottle is moved down fast with a sudden stop. Why? The sauce inside the bottle moves (down) together with the bottle. When the bottle stops suddenly, the sauce continue in its state of motion due to the effect of its inertia.

### Ways to reduce the negative effects of inertia

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>The tank which carries liquid in a lorry should be divided into smaller tanks</td>
<td></td>
</tr>
<tr>
<td>The part between the driver’s seat and load should have strong steel structure</td>
<td></td>
</tr>
<tr>
<td>Safety belts</td>
<td></td>
</tr>
<tr>
<td>Airbag</td>
<td></td>
</tr>
</tbody>
</table>
2.4 Momentum

1. Momentum is defined as the
2. Momentum = mass × velocity
   \[ p = mv \]
3. Momentum is a vector quantity
4. The SI unit of momentum is \( \text{kg m s}^{-1} \)

The principle of conservation of momentum

The total momentum in a closed system of objects is constant. The total momentum before the collision is equal to the total momentum after the collision if no external force acts on the system.

Both objects move independently at their respective velocities after the collision.
- Momentum is conserved.
- Kinetic energy is conserved.
- Total energy is conserved.

The two objects combine and move together with a common velocity after the collision.
- Momentum is conserved.
- Kinetic energy is not conserved.
- Total energy is conserved.
Elastic Collision and Inelastic Collision.
Before explosion both object stick together and at rest. After explosion, both object move at opposite direction.

**Before explosion**

<table>
<thead>
<tr>
<th>m₁</th>
<th>m₂</th>
</tr>
</thead>
</table>

**After explosion**

<table>
<thead>
<tr>
<th>m₁</th>
<th>m₂</th>
</tr>
</thead>
</table>

Before explosion both object stick together and at rest. After explosion, both object move at opposite direction.

**Total Momentum before explosion is zero.**

\[
\text{Total Momentum after explosion} = m_1v_1 + m_2v_2
\]

From the law of conservation of momentum:

\[
\text{Total Momentum} = \text{Total Momentum before explosion} = \text{Total Momentum after explosion}
\]

\[
0 = m_1v_1 + m_2v_2
\]

\[
m_1v_1 = -m_2v_2
\]

-ve sign means opposite direction
Exercise 2.4

1. A trolley A of mass 3 kg is moving with velocity 2 m/s and collides with another stationary trolley B. After the collision, trolley A moves with velocity 0.4 m/s. If the collision is elastic, calculate the momentum of trolley B after collision.
2. A car travels with velocity $32 \text{ ms}^{-1}$ collides head on with a lorry which moving at a velocity of $17 \text{ms}^{-1}$. If the masses of the car and the lorry are 1 200 kg and 5 500 kg respectively, calculate
(a) the momentum of the car before collision
(b) the total momentum
(c) the final velocity of the two vehicles after collision if the collision is inelastic.

$m_c=1200 \text{kg}$  \hspace{1cm}  $m_L=5500 \text{ kg}$
3. A bullet of mass 5 g with a velocity of 150 ms\(^{-1}\) hits a 1.5 kg of stationary ice cube on a smooth surface. The bullet passes through the ice cube and travels with velocity of 70 ms\(^{-1}\). What is the resulting velocity of the ice cube?
4. A rifle fires out a bullet of mass 10 g at a velocity of 300 ms\(^{-1}\). If the mass of the rifle is 7.5 kg, calculate the recoil speed of the rifle.
2.5 Force

Balanced Force
When the forces acting on an object are balanced, they cancel each other out. The net force is zero.

Effect:

Object at rest [velocity = 0]

or

moves at constant velocity [a = 0]

Unbalanced Force/ Resultant Force
When the forces acting on an object are not balanced, there must be a net force acting on it. The net force is known as the unbalanced force or the resultant force.

Effect of force: change

• shape and size of object    • movement of object    • position of object
When a net force, \( F \), acts on a mass, \( m \) it causes an acceleration, \( a \).

The acceleration produced by a force on an object is **directly proportional** to the magnitude of the net force applied and is **inversely proportional to the mass** of the object. The direction of the acceleration is the same as that of the net force.

**Force = Mass x Acceleration**
1. Find the acceleration of the objects.
   a) \( F = 10 \text{ N} \)
   \[
   \begin{align*}
   \text{5 kg} & \quad \text{Frictionless surface}
   \end{align*}
   \]

   b) \( F_R = 15 \text{ N} \)
   \[
   \begin{align*}
   \text{3 kg} & \quad \text{Frictionless surface}
   \end{align*}
   \]

2. Find the value of \( F \).
   \[
   \begin{align*}
   a &= 4 \text{ ms}^{-2} \\
   \text{10 kg} & \quad \text{Frictionless surface}
   \end{align*}
   \]

3. Find the value of \( m \).
   \[
   \begin{align*}
   a &= 2 \text{ ms}^{-2} \\
   \text{m kg} & \quad \text{Frictionless surface}
   \end{align*}
   \]
4. What force is required to move a 2 kg object with an acceleration of 3 m s\(^{-2}\), if a) the object is on a smooth surface? b) the object is on a surface where the average force of friction acting on the object is 2 N?

5. Ali applies a force of 50 N to move a 10 kg table at a constant velocity. What is the frictional force acting on the table?
6. A car of mass 1200 kg traveling at 20 m/s is brought to rest over a distance of 30 m. Find
a) the average deceleration,
b) the average braking force.

7. Which of the following systems will produce maximum acceleration?

A. \( \begin{align*} &80 \text{ N} \quad \quad \quad 100 \text{ N} \\
&\text{m} \quad \quad \quad \text{m} \end{align*} \)

B. \( \begin{align*} &14 \text{ N} \quad \quad \quad 6 \text{ N} \\
&\text{m} \quad \quad \quad \text{m} \end{align*} \)

C. \( \begin{align*} &15 \text{ N} \quad \quad \quad 5 \text{ N} \\
&\text{m} \quad \quad \quad \text{m} \end{align*} \)

D. \( \begin{align*} &28 \text{ N} \quad \quad \quad 52 \text{ N} \\
&\text{m} \quad \quad \quad \text{m} \end{align*} \)
### Impulse

**The change of momentum**

Unit: \( \text{kgms}^{-1} \) or Ns

### Impulsive Force, \( F_i \)

**The rate of change of momentum in a collision or explosion**

Unit = N

---

**Effect of time**

- Longer period of time → Impulsive force decrease
- Shorter period of time → Impulsive force increase

---

Impulsive force is inversely proportional to time of contact.
Situations for Reducing Impulsive Force in Sports

Thick mattress with soft surfaces are used in events such as high jump so that the time interval of impact on landing is extended, thus reducing the impulsive force. This can prevent injuries to the participants.

Goal keepers will wear gloves to increase the collision time. This will reduce the impulsive force.

When a gymnast perform Squat vault, she will bend her legs upon landing. This is to increase the time of impact in order to reduce the impulsive force acting on his legs. This will reduce the chance of getting serious injury.

A baseball player must catch the ball in the direction of the motion of the ball. Moving his hand backwards when catching the ball prolongs the time for the momentum to change so as to reduce the impulsive force.
A karate expert can break a thick wooden slab with his bare hand that moves at a very fast speed. The short impact time results in a large impulsive force on the wooden slab.

A massive hammer head moving at a fast speed is brought to rest upon hitting the nail. The large change in momentum within a short time interval produces a large impulsive force which drives the nail into the wood.

A football must have enough air pressure in it so the contact time is short. The impulsive force acted on the ball will be bigger and the ball will move faster and further.

Pestle and mortar are made of stone. When a pestle is used to pound chilies the hard surfaces of both the pestle and mortar cause the pestle to be stopped in a very short time. A large impulsive force is resulted and thus causes these spices to be crushed easily.
Question 1
A 60 kg resident jumps from the first floor of a burning house. His velocity just before landing on the ground is 6 m/s.

a) Calculate the impulse when his legs hit the ground.

b) What is the impulsive force on the resident’s legs if he bends upon landing and takes 0.5 s to stop?

c) What is the impulsive force on the resident’s legs if he does not bend and stops in 0.05 s?

d) What is the advantage of bending his legs upon landing?

Question 2
Rooney kicks a ball with a force of 1500 N. The time of contact of his boot with the ball is 0.01 s. What is the impulse delivered to the ball? If the mass of the ball is 0.5 kg, what is the velocity of the ball?
Question 3
A trolley with a mass of 500 g is at rest on a smooth surface. The trolley is given a horizontal impulse of 5 Ns. What is the velocity of the trolley after the impact?

Question 5
A rocket of 50 kg mass is launched vertically. Its fuel is being burnt at a rate of 2 kg s\(^{-1}\) and its exhaust gas is being forced out with a speed of 1000 ms\(^{-1}\). What is the initial acceleration of the rocket?

Question 4
A horizontal impulse of 500 Ns is exerted on a stationary trolley with a mass of 2 kg. What is the velocity of the trolley after the impact?
2.7 Safety in Vehicle
<table>
<thead>
<tr>
<th>Component</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Headrest</td>
<td>Reduce the inertia effect of the driver’s head</td>
</tr>
<tr>
<td>Air bag</td>
<td>Prolong the time the driver’s head to come to the steering. Thus, the impulsive force acting on the driver reduced.</td>
</tr>
<tr>
<td>Windscreen</td>
<td>Protect the driver and passengers. Designed to fracture into rounded pieces instead of shattering</td>
</tr>
<tr>
<td>Front bumper</td>
<td>Prolong the time of impact during collision in order to reduce impulsive force.</td>
</tr>
<tr>
<td>Anti-lock Braking System</td>
<td>Enables drivers to quickly stop the car without causing the brakes to lock.</td>
</tr>
<tr>
<td>Crumple zone</td>
<td>Can be compressed during accident. So it can increase the amount of time the car takes to come to a complete stop. So it can reduce the impulsive force.</td>
</tr>
<tr>
<td>Seat belt</td>
<td>Reduce the inertia effect by avoiding the driver from thrown forward.</td>
</tr>
<tr>
<td>Side impact bar</td>
<td>Increase the amount of time the car takes to come to a complete stop (compressed during accident). Reduce the impulsive force.</td>
</tr>
<tr>
<td>Threaded tyres</td>
<td>Increase frictional force on road surface while raining</td>
</tr>
</tbody>
</table>

Automakers are competitively blending performance and comforts with cutting-edge safety technology that tries to stay one step ahead of you — and everyone else on the road. Click the link below to see some of advanced safety technologies.

*Top 10 High-Tech Car Safety Technologies*
2.8 Gravity

Gravitational Force

- Objects fall because they are pulled towards the Earth by the force of gravity.
- This force is known as the pull of gravity or the earth’s gravitational force.
- The earth’s gravitational force tends to pull everything towards its centre.

Free fall

- An object is falling freely when it is falling under the force of gravity only.
- A piece of paper does not fall freely because its fall is affected by air resistance.
- An object falls freely only in vacuum. The absence of air means there is no air resistance to oppose the motion of the object.
- In vacuum, both light and heavy objects fall freely. They fall with the same acceleration i.e. The acceleration due to gravity, g.
The gravitational field is the region around the earth in which an object experiences a force towards the centre of the earth. This force is the gravitational attraction between the object and the earth.

The gravitational field strength is defined as the gravitational force which acts on a mass of 1 kilogram. Its unit is N kg\(^{-1}\).

Gravitational field

- The gravitational field is the region around the earth in which an object experiences a force towards the centre of the earth. This force is the gravitational attraction between the object and the earth.
- The gravitational field strength is defined as the gravitational force which acts on a mass of 1 kilogram. Its unit is N kg\(^{-1}\).

Gravitational field strength, \( g = 10 \text{ N kg}^{-1} \)

Objects dropped under the influence of the pull of gravity with constant acceleration. This acceleration is known as the gravitational acceleration, \( g \).

The standard value of the gravitational acceleration, \( g \) is 9.81 m s\(^{-2}\). The value of \( g \) is often taken to be 10 m s\(^{-2}\) for simplicity.

Acceleration due to gravity, \( g = 10 \text{ m s}^{-2} \)

The magnitude of the acceleration due to gravity depends on the strength of the gravitational field.

\[ F = \text{Gravitational force} \]
\[ m = \text{mass} \]
The first step in the acquisition of wisdom is silence, the second listening, the third memory, the fourth practice, the fifth teaching others.

### Weight

- The gravitational force acting on the object.
- Weight = mass \times\text{gravitational acceleration}
- SI unit: Newton, N and it is a vector quantity

### Comparison between weight & mass

<table>
<thead>
<tr>
<th>Mass</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant everywhere</td>
<td>The weight of an object is the force of gravity acting on the object.</td>
</tr>
<tr>
<td>A base quantity</td>
<td>A vector quantity</td>
</tr>
<tr>
<td>SI unit:</td>
<td>SI unit : Newton, N</td>
</tr>
</tbody>
</table>
The difference between a fall in air and a free fall in a vacuum of a coin and a feather.

Both the coin and the feather are released simultaneously from the same height.

<table>
<thead>
<tr>
<th>At vacuum state</th>
<th>At normal state</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Initial Position</strong></td>
<td><strong>Final Position</strong></td>
</tr>
<tr>
<td><img src="image" alt="Diagram" /></td>
<td><img src="image" alt="Diagram" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>At vacuum state</strong></th>
<th><strong>At normal state</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>There is no air resistance. The coin and the feather will fall freely. Only gravitational force acted on the objects. Both will fall at the same time.</td>
<td>Both coin and feather will fall because of gravitational force. Air resistance effected by the surface area of a fallen object. The feather that has large area will have more air resistance. The coin will fall at first.</td>
</tr>
</tbody>
</table>
Two steel spheres are falling under gravity. The two spheres are dropped at the same time from the same height.

<table>
<thead>
<tr>
<th>At vacuum state</th>
<th>At normal state</th>
</tr>
</thead>
<tbody>
<tr>
<td>The two sphere are falling with an acceleration. The distance between two successive images of the sphere increases showing that the two spheres are falling with increasing velocity; falling with an acceleration.</td>
<td>The two spheres are falling down with the same acceleration. The two spheres are at the same level at all times. Thus, a heavy object and a light object fall with the same gravitational acceleration. Gravitational acceleration is independent of mass.</td>
</tr>
</tbody>
</table>

Motion graph for free fall object

<table>
<thead>
<tr>
<th>Free fall object</th>
<th>Object thrown upward and fall</th>
<th>Object thrown downward and fall</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Graph" /></td>
<td><img src="image2" alt="Graph" /></td>
<td><img src="image3" alt="Graph" /></td>
</tr>
<tr>
<td><img src="image4" alt="Graph" /></td>
<td><img src="image5" alt="Graph" /></td>
<td><img src="image6" alt="Graph" /></td>
</tr>
<tr>
<td><img src="image7" alt="Graph" /></td>
<td><img src="image8" alt="Graph" /></td>
<td><img src="image9" alt="Graph" /></td>
</tr>
<tr>
<td><img src="image10" alt="Graph" /></td>
<td><img src="image11" alt="Graph" /></td>
<td><img src="image12" alt="Graph" /></td>
</tr>
<tr>
<td><img src="image13" alt="Graph" /></td>
<td><img src="image14" alt="Graph" /></td>
<td><img src="image15" alt="Graph" /></td>
</tr>
</tbody>
</table>
Question 1
An object is falling through a vacuum. Which of the following quantities does not change?
A. Momentum
B. Acceleration
C. Velocity
D. Impulse

Question 2
The gravitational acceleration on the moon is about 6 times less than that on the Earth. If the weight of a astronaut on the Earth is 720N, what will be his mass on the Moon? ($g_{\text{Earth}} = 10\text{ms}^{-2}$)

Question 3
A coconut takes 2.0 s to fall to the ground. What is
(a) its speed when it strikes the ground
(b) the height of the coconut tree.
Question 5
An astronaut jumps from a height of 10 m above the surface of the Moon. What is the time taken for him to reach the surface of the Moon?

Question 6
A stone is thrown upwards with an initial velocity of 10 m/s. If air resistance is negligible and gravitational field strength of the Earth is 10 N/kg, calculate the time taken for the stone to fall back to the initial position.
Forces in Equilibrium

When an object is in equilibrium, the resultant force acting on it is zero. The object will either be
1. at rest
2. move with constant velocity.

Newton’s 3\textsuperscript{rd} Law

Examples (Label the forces acted on the objects)
### Addition of Forces

<table>
<thead>
<tr>
<th>Diagram 1</th>
<th>Diagram 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Diagram 1" /></td>
<td><img src="image2.png" alt="Diagram 2" /></td>
</tr>
</tbody>
</table>

#### Resultant Force

<table>
<thead>
<tr>
<th>Force 1 ($F_1$)</th>
<th>Force 2 ($F_2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image3.png" alt="Force 1" /></td>
<td><img src="image4.png" alt="Force 2" /></td>
</tr>
</tbody>
</table>

Resultant force, $F = \text{Resultant force, } F = \text{Resultant force, } F =$
Two tugboats pulling a ship with forces, $F_1$ and $F_2$. What is the resultant force acting on the ship and its direction?

**Parallelogram Method**

**Step 1:**
Using ruler and protractor, draw the two forces $F_1$ and $F_2$ from a point.

**Step 2:**
Complete the parallelogram.
Step 3:
Draw the diagonal of the parallelogram. The diagonal represent the resultant force, \( F \) in magnitude and direction.

Scale: 1 cm = \( k \)
Resolution of Forces

A force $F$ can be **resolved into components which are perpendicular** to each other:

(a) horizontal component, $F_X$

(b) vertical component, $F_Y$

\[ F_x = F \cos \theta \]
\[ F_y = F \sin \theta \]

**Inclined Plane**

Component of weight parallel to the plane
\[ = mg \sin \theta \]

Component of weight normal to the plane
\[ = mg \cos \theta \]
Exercise 2.9.1

Find the Resultant Force

1. [Diagram with vectors 5 N and 12 N]
2. [Diagram with vectors 3 N and 8 N]
3. [Diagram with vectors 3 N and 6 N, 12 N]
4. [Diagram with vectors 20 N, 12 N]
### Addition of forces

$$ F = \sqrt{(F_1)^2 + (F_2)^2} $$

- Two forces which perpendicular to each other combined into a single force (Resultant force).

### Resolution of forces

$$ F_x = F \cos \theta $$
$$ F_y = F \cos(90 - \theta) $$

$$ F = \sqrt{(F_x)^2 + (F_y)^2} $$

- A single force split into 2 components (2 forces).
- The two new forces must be perpendicular to each other.
5. A vector of 8 N makes a 120° angle with another vector of 8 N.

6. A vector of 2 N makes a 120° angle with a vector of 5 N.

7. A boat is subjected to two forces: one of 1200 N at 40° and another of 800 N at an unspecified angle.
Figure shows a box with a mass of 3kg being placed on an inclined plane. The box is pushed with 50N force up along the plane which is inclined at an angle of 30° from the ground. The frictional force between the box and the inclined plane is 11 N.

Calculate:

a) the force exerted by the box along the inclined plane
b) the resultant force along the inclined plane
c) the acceleration of the box
<table>
<thead>
<tr>
<th>Stationary Lift</th>
<th>Lift accelerate upward</th>
<th>Lift accelerate downward</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Stationary Lift Diagram" /></td>
<td><img src="image2" alt="Lift accelerate upward Diagram" /></td>
<td><img src="image3" alt="Lift accelerate downward Diagram" /></td>
</tr>
</tbody>
</table>

**Resultant Force** =

- **Reading of weighing scale** =

---

*Accelerate → +a*  
*Decelerate → - a*
<table>
<thead>
<tr>
<th>Free Fall</th>
<th>Lift decelerate upward</th>
<th>Lift decelerate downward</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resultant Force =</td>
<td>Resultant Force =</td>
<td>Resultant Force =</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reading of weighing scale =</td>
<td>Reading of weighing scale =</td>
<td>Reading of weighing scale =</td>
</tr>
</tbody>
</table>

$\text{Accelerate} \rightarrow +a$  \hspace{1cm}  $\text{Decelerate} \rightarrow -a$
1. A boy of 45 kg standing on a balance scale in a lift. What is the reading of the balance scale if
   a) the lift is stationary
   b) accelerates 2 ms\(^{-2}\) upwards
   c) accelerates 2 ms\(^{-2}\) downwards
   d) decelerates 2 ms\(^{-2}\) downwards
   e) the lift cable snaps
1. Find the resultant force, $F$
2. Find the moving mass, $m$
3. Find the acceleration, $a$
4. Find string tension, $T$
Alternative Method

1. Find the resultant force, $F$
2. Find the moving mass, $m$
3. Find the acceleration, $a$
4. Find string tension, $T$

OR
2.10 Work, Energy, Power & Efficiency

Work

Work done is the product of an applied force and the displacement of an object in the direction of the applied force.

\[ W = Fs \]

- \( W \) = work,
- \( F \) = force
- \( s \) = displacement

The SI unit of work is the joule, J.

1 joule of work is done when a force of 1 N moves an object 1 m in the direction of the force.
No work is done when:

<table>
<thead>
<tr>
<th>Concept</th>
<th>Definition</th>
<th>Formula &amp; Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>The object is stationary</td>
<td>A student carrying his bag and standing at a place.</td>
<td></td>
</tr>
<tr>
<td>The direction of motion of the object is perpendicular to that of the applied force.</td>
<td>A waiter is carrying a tray of food and walking</td>
<td></td>
</tr>
<tr>
<td>No force is applied on the object in the direction of displacement (object moves because of its own inertia)</td>
<td>A satellite orbiting in space. There is no friction in space. No force is acting in the direction of movement of the satellite.</td>
<td></td>
</tr>
</tbody>
</table>

Power

\[ P = \text{Power}, \quad W = \text{Work / energy}, \quad t = \text{Time} \]
1. A trolley is released from rest at point X along a frictionless track. What is the velocity of the trolley at point Y?

2. A ball is released from point A of height 0.8 m so that it can roll along a curve frictionless track. What is the velocity of the ball when it reaches point B?
3. A ball moves upwards along a frictionless track of height 1.5 m with a velocity of 6 ms\(^{-1}\). What is its velocity at point B?

4. A stone is thrown upward with initial velocity of 20 ms\(^{-1}\). What is the maximum height which can be reached by the stone?
5. A boy of mass 20 kg sits at the top of a concrete slide of height 2.5 m. When he slides down the slope, he does work to overcome friction of 140 J. What is his velocity at the end of the slope?
Energy is the capacity to do work.

SI unit: Joule (J)

An object that can do work has energy

Work is done because a force is applied and the objects move. This is accompanied by the transfer of energy from one object to another object.

Therefore, when work is done, energy is transferred from one object to another.

When work done, energy transferred from one form to another.

Total energy transferred = Work done

<table>
<thead>
<tr>
<th>Potential Energy</th>
<th>Kinetic Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravitational potential energy is the energy of an object due to its higher position in the gravitational field.</td>
<td>Kinetic energy is the energy of an object due to its motion.</td>
</tr>
<tr>
<td>m = mass</td>
<td>m = mass</td>
</tr>
<tr>
<td>h = height</td>
<td>v = velocity</td>
</tr>
<tr>
<td>g = gravitational acceleration</td>
<td></td>
</tr>
</tbody>
</table>

**Principle of Conservation of Energy**

Energy can be changed from one form to another, but it cannot be created or destroyed. The energy can be transformed from one form to another, total energy in a system is constant.
2.11 Elasticity

- Two types of forces that exist between the atoms of the solid is the force of attraction and repulsion.
- In normal circumstances, these two forces are balanced because the distance of separation between the atoms are fixed.
- So solid has a fixed shape and a hard surface.

A wire stretched by an external force

- Atoms of the wire slightly away from each other and attractive force grow by more than repulsive forces between the atoms.
- This increased attractive force the will attract the atoms to restore the original shape when the force applied to the wire removed.

A wire compressed by an external force

- Atoms become closer and repulsive force increases until it exceeds the attractive force between the atoms.
- This increased repulsive force will push the atoms to restore the original shape when the force applied to the wire removed.
Examples of situations / applications involving elasticity

- Mattress
- Catapult
- Trampoline
- Archery
- Shock absorbers

### Hooke Law

\[ F = kx \]

- **F** = force on the spring
- **x** = extension
- **k** = force constant of the spring

**Examples of situations / applications involving elasticity**
Elastic limit

- The maximum force that can be applied to a spring such that the spring will be able to be restored to its original length when the force is removed.
- If a force stretches a spring beyond its elastic limit, the spring cannot return to its original length even though the force no longer acts on it.
- The Hooke’s law is not obeyed anymore.
- Elastic limit can be determined based on point on the graph where the straight line end and start to curve.

**Force constant of the spring, $k$**

- Defined as the force required to produce one unit of extension of the spring.
  - Unit: $N \text{ m}^{-1} @ N \text{ cm}^{-1} @ N \text{ mm}^{-1}$
- The spring with a larger force constant is harder to extend and is said to be more stiff.
- A spring with a smaller force constant is easier to extend and is said to be less stiff or softer.
Force constant of the spring, $k$ is given by:

$$k = \frac{\Delta F}{\Delta x}$$

The work done to extent/compress the spring is:

$$W = \frac{1}{2}k\Delta x^2$$
Factors that effect elasticity

Elasticity changes according to the type of material.

\[ k = \text{spring constant} \]

- \( k \uparrow \) stiffness ↑
- \( k \downarrow \) elasticity ↓

Steel \( k \) > Copper \( k \) > Aluminum \( k \)
The same load is applied to each spring. The load is shared equally among the springs.

<table>
<thead>
<tr>
<th>Description</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension in each spring</td>
<td>$T$</td>
</tr>
<tr>
<td>Extension of each spring</td>
<td>$x$</td>
</tr>
<tr>
<td>Total extension</td>
<td>$nx$</td>
</tr>
</tbody>
</table>

If $n$ springs are used:

<table>
<thead>
<tr>
<th>Description</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension in each spring</td>
<td>$T = \frac{W}{n}$</td>
</tr>
<tr>
<td>Total extension</td>
<td>$nx = \frac{Wn}{k}$</td>
</tr>
</tbody>
</table>

**Diagram:**

- Force constant = $k$
- Force constant = $\frac{k}{2}$
- Force constant = $2k$
Factors that affect the elasticity of a spring (i)

- Longer spring
- Bigger diameter of coil
- Made from copper
- Made from thin wire
- Arranged in series

Weak spring system
Factors that affect the elasticity of a spring (ii)

- Shorter spring
- Smaller diameter of coil
- Made from steel
- Made from thick wire
- Arranged in parallel
2. A spring is stretched from a length of 15cm to 21cm by a force of 50N. What is the elastic potential energy of the spring?
3. The original length of each spring is 10 cm. With a load of 10 g, the extension of each spring is 2 cm. What is the length of the spring system for (a), (b) and (c)?
As a researcher, you are assigned to investigate the characteristics of five springs, namely A, B, C, D and E that could be used in children’s mattresses. Based on the information given in the table below,

<table>
<thead>
<tr>
<th>Spring</th>
<th>Elastic constant</th>
<th>Density/kg m⁻³</th>
<th>Rate of rusting</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>200</td>
<td>7 800</td>
<td>Average</td>
<td>Low</td>
</tr>
<tr>
<td>B</td>
<td>600</td>
<td>2 200</td>
<td>High</td>
<td>Average</td>
</tr>
<tr>
<td>C</td>
<td>1 000</td>
<td>5 100</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>D</td>
<td>1 500</td>
<td>3 000</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>E</td>
<td>5 000</td>
<td>10 500</td>
<td>Low</td>
<td>High</td>
</tr>
</tbody>
</table>

(i) explain the suitable characteristics of the spring so that it can be used in children’s mattresses. [8 marks]

(ii) decide which spring is the most suitable to be used for your research and give reasons for your choice. [2 marks]

Dear students,
You are advised to answer essay type questions ( in Section B and C ) in table format.
Answer:

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>