9 Applications of Forces and Transfer of Energy

Using the knowledge of how forces can be applied between interacting bodies, we can better understand how energy is transferred within and across bodies, and how the state of motion of an object can be affected. Scientists and engineers use the knowledge of forces and the transfer of energy to study the impact of human activities on the environment, and propose solutions to minimise such impact.

- How do forces in nature affect us? (9.1)
- What are the types of forces? (9.2)
- What happens when two or more objects interact? (9.3)
- What are energy and work? (9.4)
- What are the sources of energy that we use? (9.5)

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9.1 How do Forces in Nature Affect Us?

Forces in nature have laid the foundation that allowed life to thrive. For example, countless volcanic eruptions have produced mountains, craters, and natural landforms that have evolved into majestic landscapes and fertile soil. However, forces in nature have also caused destruction to humans and our environment. Technological advancements such as satellites have enabled scientists to collect data that have revealed signs of a rapidly changing climate. These include a higher global average temperature, receding polar ice-caps, rising sea levels, and the increase in intensity of extreme weather events.

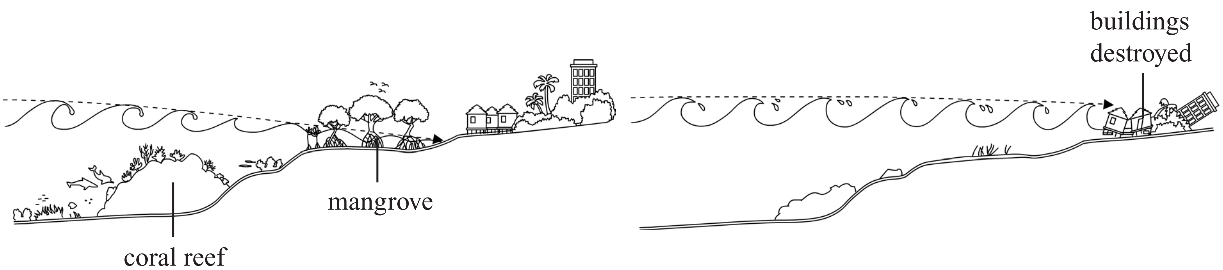

Fig. 9.1 Mangrove forests and coral reefs reduce the destructive force of water waves from storms or tsunamis by decreasing the height and speed of water waves.

1. Earthquakes happen when there is a sudden movement between large pieces of tectonic plates. Earth's surface is made up of huge pieces of solid rocks called tectonic plates, which normally move slowly. A sudden movement of tectonic plates interacting with one another could lead to a transfer of energy through the Earth to people on land. These could lead to violent ground shaking causing buildings to collapse, landslides, floods and tsunamis that lead to loss of lives.
2. A tsunami is a series of waves produced when there is a sudden movement of the seafloor that causes the water above the seafloor to be displaced. This sudden displacement of a large mass of water can be caused by earthquakes, landslides, volcanic activity or objects colliding or exploding. This gives rise to powerful waves that travel inland towards the shore. When the waves reach the coastal areas, The energy carried by the waves of the tsunami is transferred to its height, thereby increasing it. These powerful waves strike objects along the coast with a great force, impacting the buildings, damaging infrastructure and resulting in the loss of lives of people living near coastal areas.
3. Volcanic eruptions can be explosive when the pressure in molten rock together with gases deep inside the earth (magma) builds up until it finally erupts with a great force. Energy is transferred from within the Earth as heat, kinetic energy and light energy of the magma and also kinetic energy of the hot rocks and volcanic ash. Volcanic eruptions can cause buildings to collapse, trigger earthquakes, and bury towns that are within proximity to the site of eruption, leading to loss of lives.
4. Tropical cyclones are a rapidly rotating storm that originated over warm tropical ocean. Tropical cyclones are formed due to pressure difference when moist air over the ocean rises upwards, causing an area with low pressure near the ocean surface. This results in a force to push air from surrounding areas with high pressure to replace it. The process repeats as the whole system of clouds and wind grows to

reach a wind speed that can be classified as a tropical cyclone. When tropical cyclones move inland, strong winds, heavy rains and storm surge (elevation of sea) can strike objects along the coastal area with a large force, impacting the buildings, damaging infrastructure and resulting in the loss of lives of people living near coastal areas.

5. Storms are increasing in intensity and duration because of climate change. Scientists have predicted the continual increase of storm intensity and rainfall rates as the climate's global temperature increases. This potentially threatens global food supply and affects countries like Singapore that is largely dependent on food import.
6. The impact of natural disasters can be reduced by educating citizens on preparedness for emergencies and avoiding development in risk-prone areas. Technology can also be used for prediction and to develop warning systems. It can also be used to support disaster relief efforts such as reaching out to survivors in a timely manner and to transmit information to emergency teams.

9.2 What are the Types of Forces?

Forces also make walking, swimming, throwing, kicking and any other kind of motion possible. Understanding the types of forces and how they come together allows us to build vehicles for transportation, such as a plane for flying, for a ship sailing, a car for driving car and a rocket for lauching.

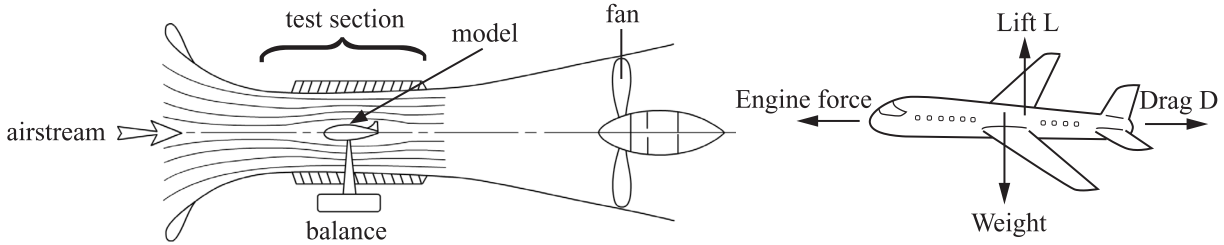

Fig 9.2 A wind tunnel is a large tube with air moving inside to simulate the air flowing past objects such as airplanes, drones and missiles. Engineers use the wind tunnel to test new materials or new shapes of parts of airplanes before flying a new airplane. One of the goals in aircraft design is to achieve high lift-to-drag ratio L/D which leads to better fuel economy.

Contact Forces and Non-contact Forces

1. Contact forces require the objects to have physical contact for the interaction to occur. Examples of contact forces are normal force, tension, friction and elastic force.

Normal force N is a contact force that acts when the surface of an object pushes against another object. The force acts perpendicularly to the surface of contact.

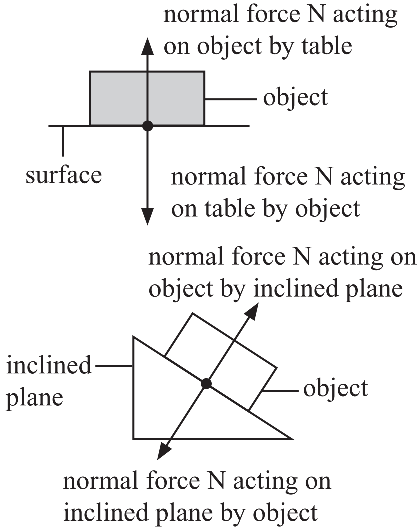

Fig 9.3 Normal forces act perpendicularly to the surface of contact.

Tension T is a pulling force exerted by each end of a string or cable.

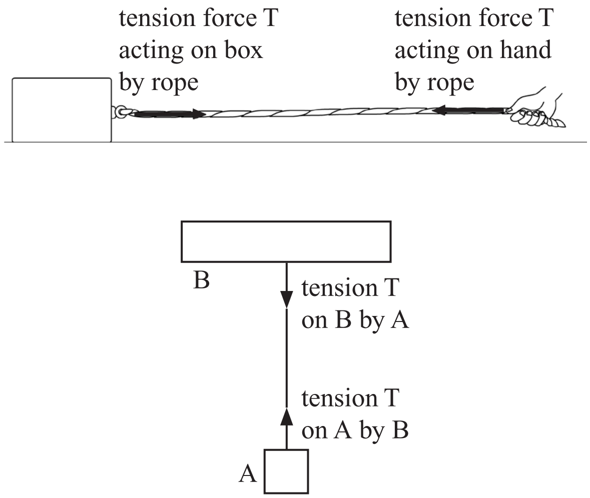

Fig 9.4 Tension acts along a taut flexible rope or cable.

Friction f is the force that resists motion between two surfaces that are in contact. Friction acting on an object is tangential to the surface of contact and opposite in direction to the motion of the object. It depends on the normal force N and the nature of the surfaces that are in contact.

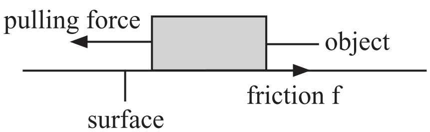

Fig 9.5 Friction opposes motion.

The greater the normal force N exerted by the object on the ground, and the greater is the friction f between the object and surface when a horizontal force pulls the object across the surface.

Elastic force acts within objects that can be stretched or compressed when a force is applied. If the material is elastic, the object will return to its initial length when these forces are removed.

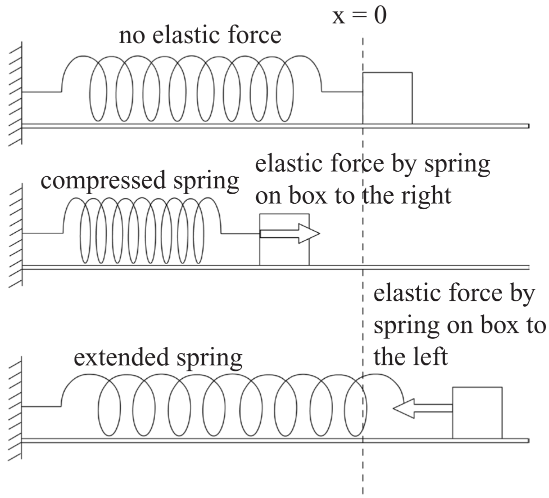

Fig 9.6 A stretched or compressed spring exerts an elastic force to return to its original length.

2. Non-contact forces do not require objects to be in contact (i.e. not touching one another) for the interaction to occur. Examples of non-contact forces are gravitational force, magnetic force, and electric force.

Gravitational force is an attractive force that acts between two masses. This force is also commonly known as weight, which is due to Earth exerting gravitational force on an object within the Earth's gravitational field.

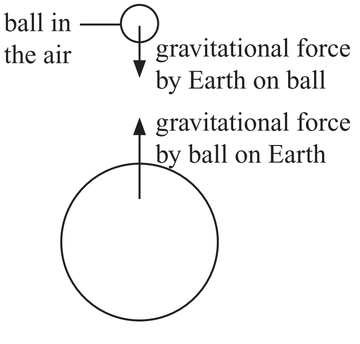

Fig 9.7 Gravitational attractive force between two masses

Magnetic force is an attractive or repulsive force due to the interactions of magnetic fields (represented by dotted lines). It can exist between a magnet and another magnetic material such as iron or steel, or between two magnets. Like poles of magnets repel, unlike poles attract.

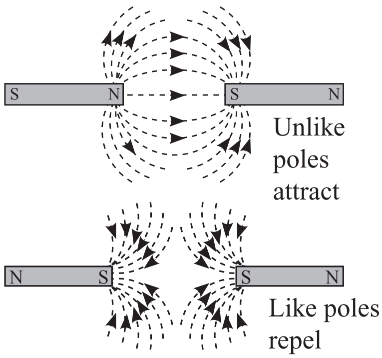

Fig 9.8 Magnetic force between two magnets

Electric force is the attractive or repulsive force due to the interaction between electric fields. Like charges repel, unlike charges attract.

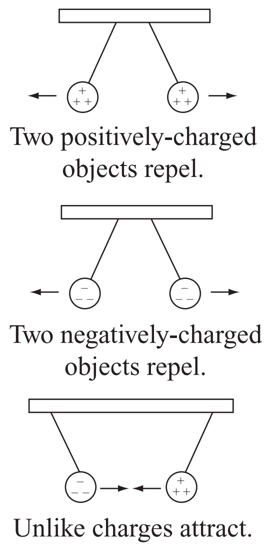

Fig 9.9 Electric force between two charged objects

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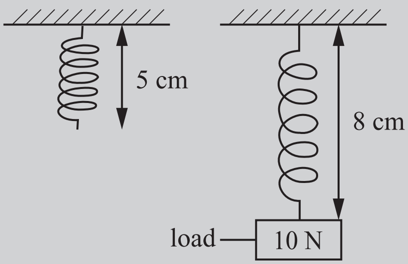
The diagram shows how the length of a spring changes when a load of 10 N is hung on it. You are given that the extension of the spring is directly proportionately to the load. Calculate the new length of the spring when the 10 N load is replaced by a 20 N load. [3]



ANSWER

When load = 10 N, the extension is (8 − 5 =) 3 cm

When load = 1 N, the extension is ($\frac{3}{10}$ =) 0.3 cm

When load = 20 N, the extension is (0.3 × 20 =) 6 cm

Therefore, the new length when the load is 20 N is (5 + 6 =) 11 cm

3. Drawing Forces:
   Not only are the magnitudes of forces important, the directions of forces acting on an object are also important. Identify all the forces acting directly on an object or a point of interest and draw arrows. Always label the forces.

> **Note**
> You are encouraged to practise drawing these forces on a piece of blank paper. Remember to label them.

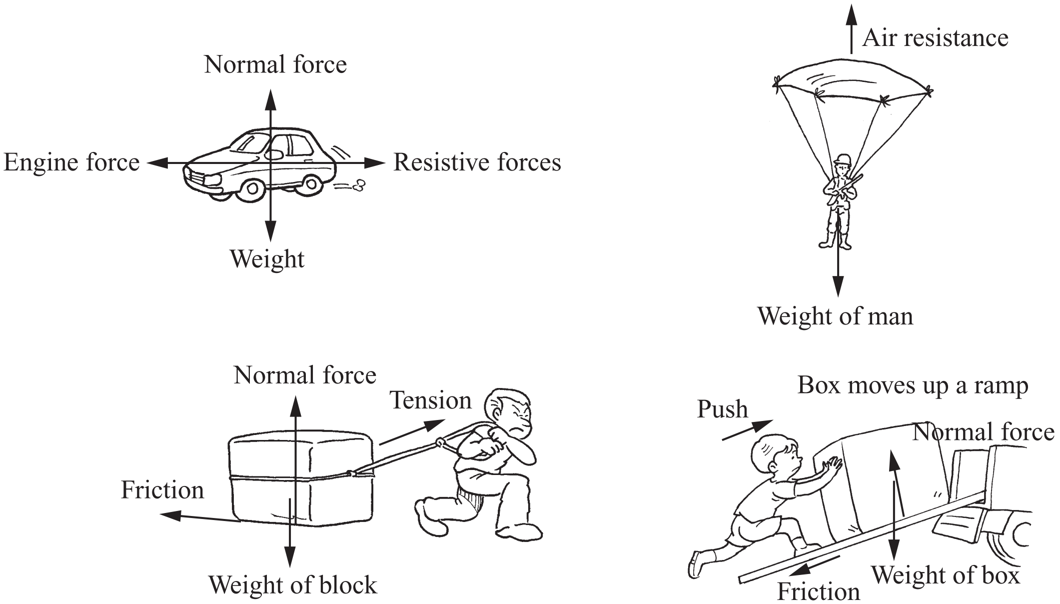


Fig 9.10 Examples of drawing forces in diagrams

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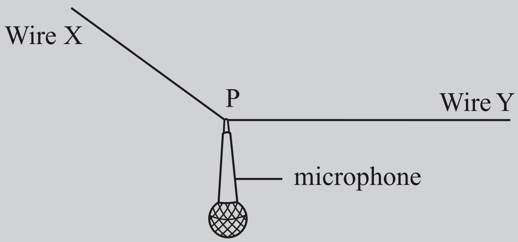
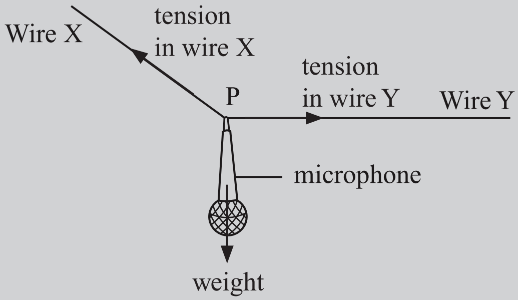
A microphone is suspended by a wire X from the ceiling in a radio studio. It is held in the correct position by a horizontal wire Y. Draw and label the forces in the diagram. Explain why the microphone is stationary. [4]



ANSWER

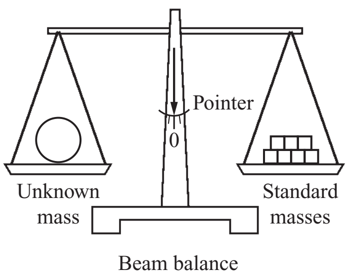
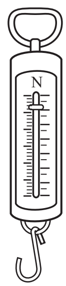
The forces are the tension in wire X, tension in wire Y and the weight of the microphone.



The three forces acting on the point P are balanced (no resultant force) and so the microphone is held stationary.

Differences between Mass and Weight

1. Weight and mass are different although they are related.

Mass	Weight
Mass is the amount of matter in an object.	Weight is the gravitational force that a planet exerts on objects, pulling objects towards the centre of the planet.
Mass does not change when an object is brought from one place to another.	When the object is brought to another location (for example, to a planetary body with different mass or to different distance from centre of planetary body), the gravitational force (weight) exerted on the object varies.
The SI unit of mass is the kilogram (kg).	As weight is a type of force, it has the same SI unit as force, which is the newton (N).
An electronic balance or a beam balance is used to measure mass.  *Fig 9.11 The beam balance works by comparing an unknown mass with standard masses.*	A newton meter or a spring balance is used to measure force.  Spring balance *Fig 9.12 The spring balance works by the concept that the spring lengthens by the same amount for every increase in 1 N of the load.*

2. On Earth, 1 kg of mass weighs 10 N. On the Moon, 1 kg of mass weighs 1.67 N.

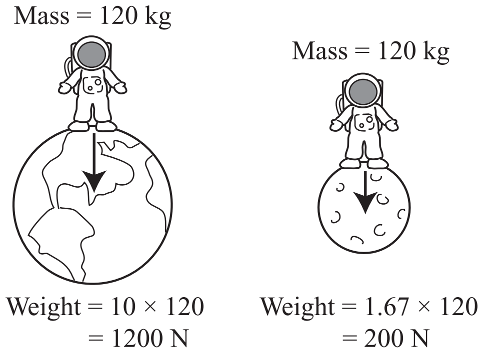


Fig 9.13 An object has the same mass but different weight on different planetary bodies.

Note
- If a question gives mass in g and asks for weight in newton, remember to convert the mass to kg.
- The mass of an object is also given by mass = density × volume.

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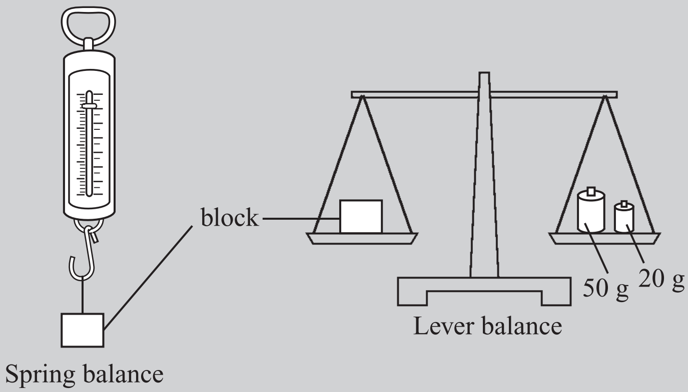
A block is placed on a spring balance and also on a lever balance.



On Earth, 1.0 kg of mass weighs 10 N. On the Moon, 1.0 kg of mass weighs 1.6 N. Which is not correct about the block?

A Mass on Earth = 70 g
B Mass on Moon = 0.070 kg
C Weight on Earth = 7.0 N
D Weight on Moon = 0.11 N

ANSWER

C

The mass of the block is (50 g + 20 g =) 70 g or 0.070 kg which is the same on Earth and on the Moon. Therefore, A and B are correct.

The weight of the block on Earth is (0.070 × 10 =) 0.70 N and the weigh of block on the Moon is (0.070 × 1.6 =) 0.11 N.

9.3 What Happens when Two or More Objects Interact?

We cannot see forces but we can observe the effects of forces on objects around us. Forces can cause an object to change its motion, size or shape, and turn or rotate.

Climate change

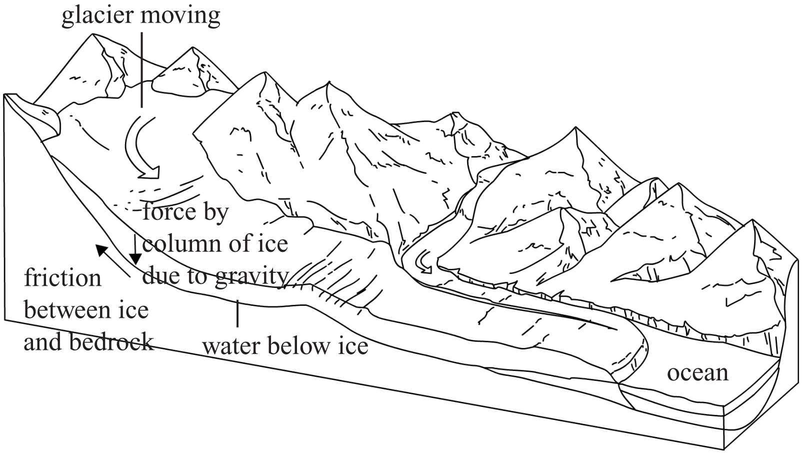


Fig 9.14 Glaciers are frozen rivers. They move downslope slowly due to gravity. Although a glacier changes in speed very slowly, it exerts a great force due to its large mass. There is friction between the ice and the bedrock to oppose the motion but this friction can be reduced by the lubrication of water. Due to global warming, glaciers are melting and hence slowly disappearing.

Effects of a Force on Objects

1. Let's look at some examples on how effects of forces can be observed in our daily lives.

Effect of force	Observations in everyday life
Move a stationary object	• A standing person begins to move forward when his foot pushes backward against the floor. • A stationary barbell is lifted off the floor when a person applies sufficient force to lift it up.
Change the speed of an object	• A car is already moving with a certain speed. When the driver steps on the accelerator, the engine produces a larger forward force so that the car speeds up. • A child on the swing moves faster when she is pushed in the same direction as her motion. She slows down eventually as there are resistive forces acting on her.
Change the direction in which an object is moving	• A goalkeeper kicks the ball to prevent it from entering the goal post, changing the direction of motion of the ball. • A ball moving upwards changes direction when gravitational force acts on it to slow it down.

Effect of force	Observations in everyday life
Stop a moving object	• A moving bicycle slows down and stops when the rider applies the brakes. The friction between the brakes in bicycles and the wheels help slow down and stop the bicycle. • A goalkeeper uses his hands to catch a ball and stop it from moving.
Change size and/or shape of a body	• A baker uses his hands to apply a force to knead dough into different shapes and sizes. • A spring extends when an object is hung on it changing its shape/size.
Pressure on objects	• When air is blown into a balloon, the elastic rubber enlarges due to the increasing air pressure inside the balloon. • Sharp objects such as injection needles allow us to apply a minimal force for a quick and easy administering of medication to the body.

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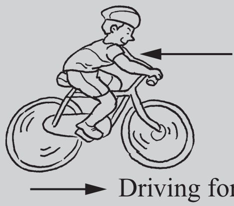
The following shows the horizontal forces as a cyclist travels forward.



(a) The cyclist produces the driving force that acts on the back wheel. What effect does this force have on the motion of the cyclist? [1]

(b) Air resistance is the resistive force exerted by the air as the cyclist moves through air. What would happen to his motion if the cyclist stops pedalling? Explain your answer. [2]

(c) What do you think will happen if the amount of driving force is equal to the amount of air resistance? [1]

ANSWER

(a) *The cyclist speeds up.*

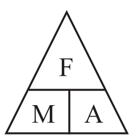
(b) *When the cyclist stops pedalling, the driving force is zero. The air resistance would then slow down the cyclist. The cyclist would eventually come to a stop.*

(c) *As there is no resultant force acting on the cyclist, the cyclist will continue to move at the same speed.*

2. **Extension Knowledge**

The resultant force (or overall force) F acting on an object of mass m is related to its acceleration a (rate of change of speed in m/s^2) by the equation (shown on the right) which is sometimes referred to as Newton's Second Law.

$F = ma$



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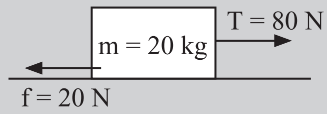
Extension Knowledge

A block of mass 20 kg is pulled on a surface as shown.



Calculate the acceleration of the block. [3]

ANSWER

Resultant force $F = T - f = 80 \text{ N} - 20 \text{ N} = 60 \text{ N}$

Acceleration $a = \frac{F}{m} = \frac{60}{20} = 3 \text{ m/s}^2$

This means that for every second, the block increases in speed by 3 m/s. What would be the acceleration a of the block if T = 100 N? Try it out.

3. Some forces cause objects to turn or rotate about a fixed point known as pivot or fulcrum. The hinge of a door is an example of a pivot. When we pull the handle of a door, the door turns about its hinges. The turning effects of forces are used in simple machines called levers.

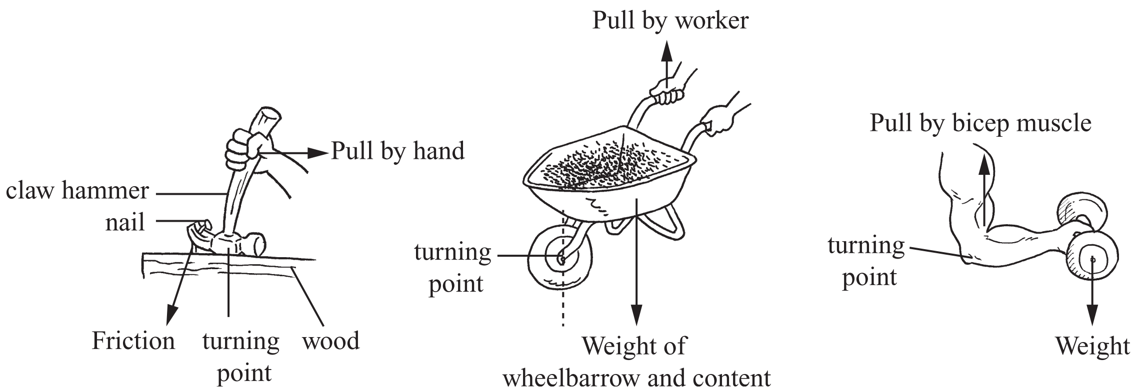


Fig 9.15 Examples of turning effects of forces

4. **Extension Knowledge**

The turning effect of a force or moment of a force can be varied by increasing the force, or by applying the force at a greater distance from the pivot.

Moment of a force = force × perpendicular distance from the pivot

You will learn how moments can be used to determine the stability of objects in upper secondary Physics

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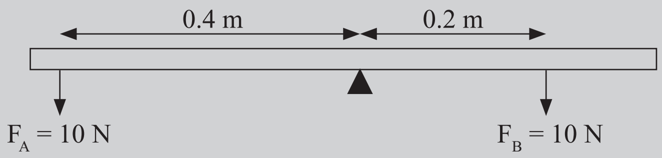
Extension Knowledge

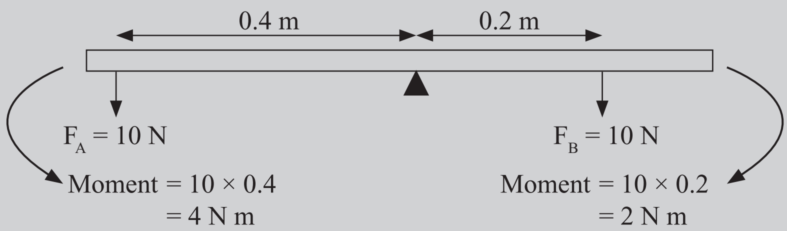
The following beam is acted on by two forces, Force A and Force B as shown. It is pivoted at its centre.



(a) Is the beam balanced? Explain your answer. [3]
(b) Will the beam turn in the clockwise or anticlockwise direction about the pivot? Explain your answer. [2]
(c) Suggest a way to make the beam balanced. [1]

ANSWER

(a) Let us calculate the moment due to Force A and Force B.



Force A has a moment of 4 N m.

Force B has a moment of 2 N m.

The beam is not balanced because Force A creates a greater moment compared to Force B.

(b) Moment due to Force A causes the beam to turn in an anticlockwise direction about the pivot.

Moment due to Force B causes the beam to turn in a clockwise direction about the pivot.

Since moment due to Force A is larger than moment due to Force B, the beam would turn in an anticlockwise direction about the pivot.

(c) Increase the magnitude of Force B on the right to 20 N or decrease the distance of Force A to the pivot to 0.2 m.

5. When a force is applied on an object, pressure is exerted. The area of contact and the amount of force applied affect the amount of pressure acting on an object.
6. To prevent an object from sinking into soft ground, we can use a large area of contact with the ground to reduce pressure.

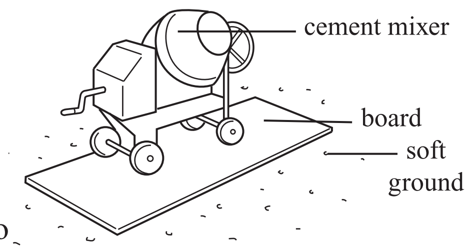


Fig 9.16 How does a large surface area of contact help to prevent an object from sinking into the soft ground?

Factors Affecting Pressure

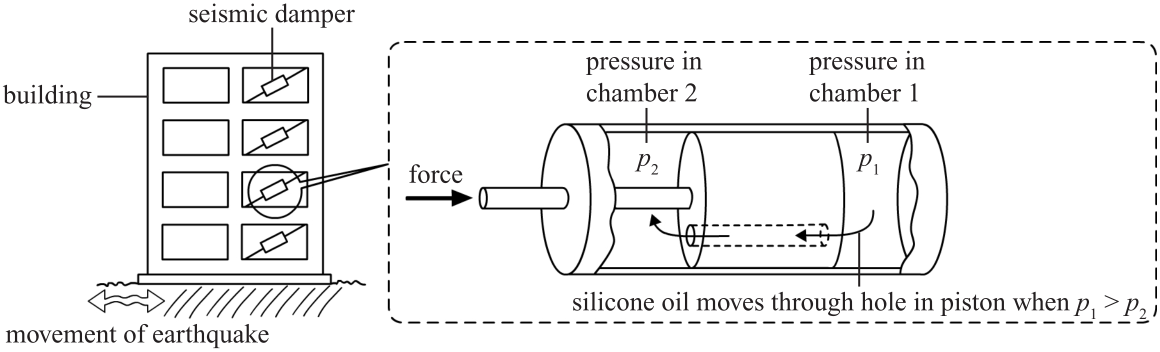
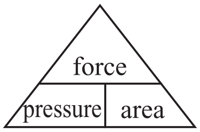


Fig 9.17 One of the techniques to protect buildings from earthquakes is to install seismic dampers. In the seismic damper shown, when the piston moves, the silicone oil flows through a small hole from the chamber of higher pressure to the chamber of lower pressure. The friction between the silicone oil and hole opposes the force of the earthquake.

1. Pressure is the force acting on a unit area. SI unit: Pascal (Pa)

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$



> **Note**
> The unit Pa is the same as the unit N/m^2. The unit of pressure can be written as N/cm^2 but this is not the same as Pa.

2. Consider a brick of 3.09 kg in different positions A and B.

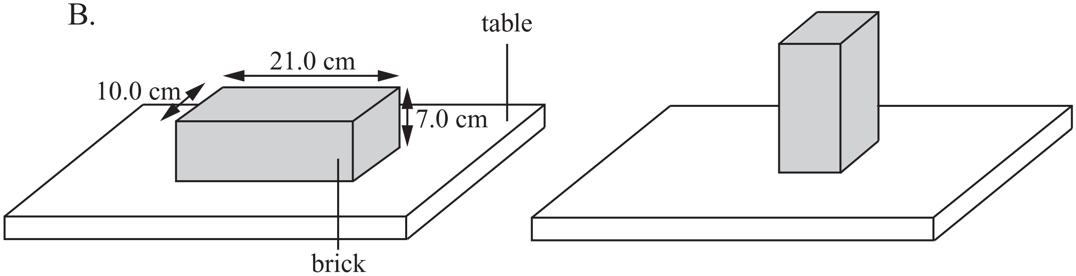


Fig 9.18 What are the values of pressure that a brick can exert on the ground?

Weight of brick = 3.09 × 10 = 30.9 N (On Earth, one kilogram weighs 10 N.)

Position A	Position B
Area in contact with ground = 21.0 cm × 10.0 cm = 210 cm^2 = 0.0210 m^2	Area in contact with ground = 10.0 cm × 7.0 cm = 70 cm^2 = 0.0070 m^2
$\text{Pressure} = \frac{\text{force}}{\text{area}} = \frac{30.9\text{ N}}{0.0210\text{ m}^2} = 1470\text{ Pa}$	$\text{Pressure} = \frac{\text{force}}{\text{area}} = \frac{30.9\text{ N}}{0.0070\text{ m}^2} = 4410\text{ Pa}$

Conclusion: For a similar object with the same weight, the smaller the contact area with the ground, the greater the pressure on the ground.

3. To prevent an object from sinking into soft ground, we can use a large area of contact with the ground to reduce pressure.

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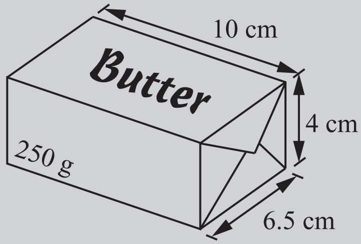
A block of butter is as shown.



(a) Calculate the density of the butter. [2]
(b) Calculate the weight of the block of butter. (On Earth, 1 kilogram weighs 10 N) [1]
(c) Calculate the pressure, in N/cm^2, the block of butter exerts on the table as shown on the right. [1]

ANSWER

(a) Density = mass ÷ volume
= 250 ÷ (10 × 4 × 6.5)
= 0.96 g/cm^3

(b) Weight = 0.250 × 10
= 2.50 N

(c) Pressure = force ÷ area
= 2.50 ÷ (6.5 × 10)
= 0.038 N/cm^2

4. Atmospheric Pressure:
   - Atmospheric pressure is the force per unit area exerted against a surface by the weight of the air above that surface.

     Atmospheric pressure on a surface area of 1 m^2
     = force ÷ area
     = weight of air column ÷ area
     = 10 000 × 10 ÷ 1
     = 100 000 Pa (1 atm)

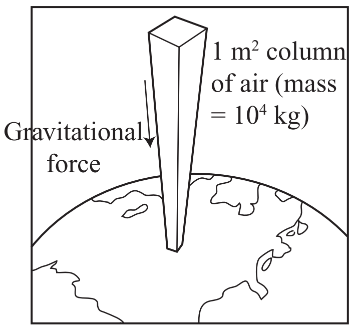


Fig 9.19 What is atmospheric pressure?

- Atmospheric pressure at sea level (surface of Earth) is higher than at the top of a mountain. More air particles at sea level exerts a larger force, causing a higher atmospheric pressure compared to at the top of a mountain.

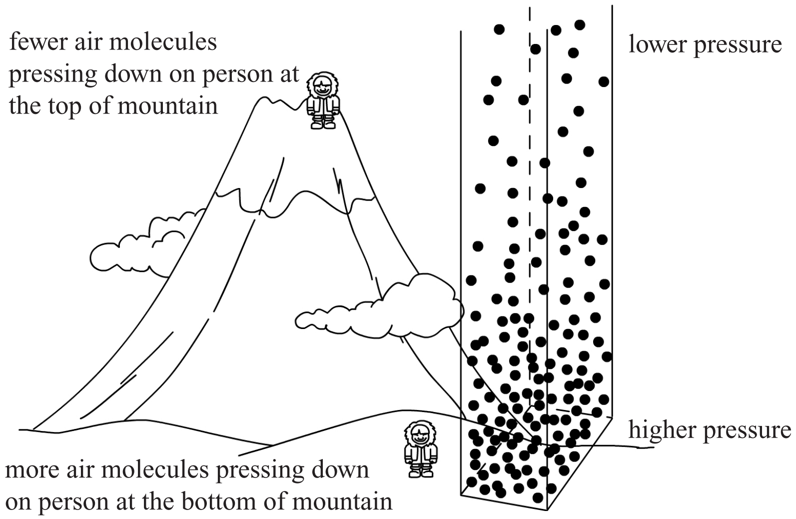


Fig 9.20 There are more air molecules pressing down on the person at the bottom of the mountain than at the top of the mountain.

Extra

Atmospheric pressure can be expressed in different units.
1 standard atmosphere
= 1 atm = 10^5 Pa
= 760 mmHg

- Applications of atmospheric pressure:

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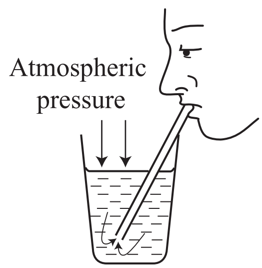
<td>When a person sucks on a straw, there is lower pressure inside the straw compared to the pressure acting on the surface of the liquid. The difference in pressure results in a force that pushes the liquid up the straw into the mouth.


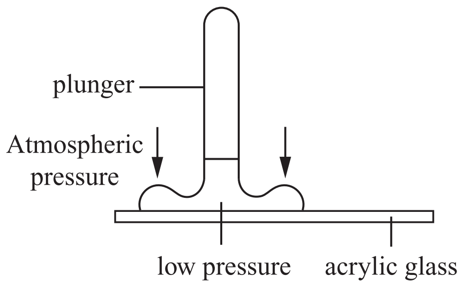
Fig 9.21 How does the water move up the straw?</td>
<td>When a rubber suction cup is pushed against a glass surface, some air is pushed out, reducing the air pressure between the cup and the surface. The greater atmospheric pressure outside the suction cup allows the suction cup to be held firmly on the surface without dropping.


Fig 9.22 How does the rubber suction cup work?</td>
</tr>
</table>

5. Liquid Pressure:
   - More water molecules at deeper sea level exert a larger gravitational force, causing a higher liquid pressure compared to the surface of the sea.
   - At sea level, the pressure on the surface of the sea is 1 atmosphere or 100 000 Pa. As we go deeper into the sea, the pressure in the sea water increases with depth.

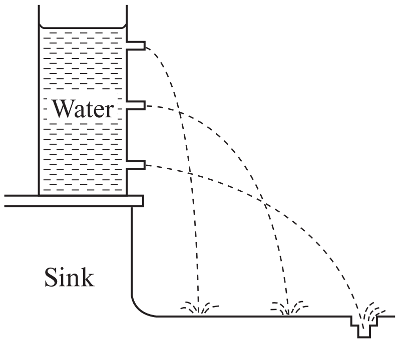
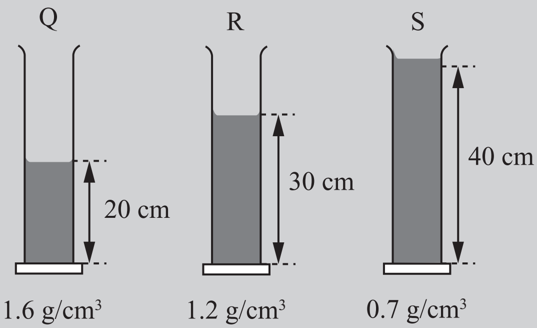


Fig 9.23 The lower the nozzle from the water level, the further the water shoots out. This shows that the greater the depth of liquid, the greater the pressure.

SCIENCE AROUND US

Suppose four different liquids are poured into identical measuring cylinders Q, R and S. Find out which liquid causes the largest pressure on the base of its measuring cylinder. (On Earth, 1 kg weighs 10 N.) [3]



ANSWER

Let the base area of each measuring cylinder be A cm^2.

Measuring cylinder	Q	R	S
Volume of liquid (cm^3)	20A	30A	40A
Mass of liquid (g) = density × volume	$1.6 \times 20A = 32A$	$1.2 \times 30A = 36A$	$0.7 \times 40A = 28A$
Mass of liquid (kg)	$\frac{32A}{1000}$	$\frac{36A}{1000}$	$\frac{28A}{1000}$
Weight of liquid (N)	$\frac{32A}{1000} \times 10 = \frac{8A}{25}$	$\frac{36A}{1000} \times 10 = \frac{9A}{25}$	$\frac{28A}{1000} \times 10 = \frac{7A}{25}$
Pressure (Pa) = force ÷ area	$\frac{8A}{25} \div A = \frac{8}{25}$	$\frac{9A}{25} \div A = \frac{9}{25}$	$\frac{7A}{25} \div A = \frac{7}{25}$

The liquid in R exerts the greatest pressure on the base of its measuring cylinder.

- **Extension Knowledge**

  Pressure in a liquid depends on the following factors, and can be calculated using the following formula:

  Pressure due to a liquid column = height of column × density of the liquid × gravitational field strength

  You will learn how the height of a liquid column may be used to measure the atmospheric pressure in upper secondary Physics.

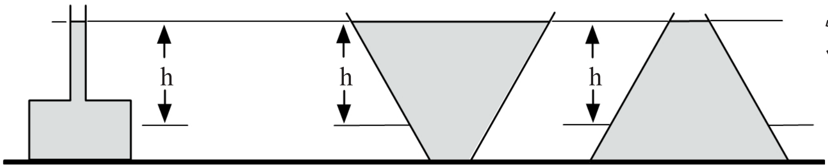


Fig 9.24 The pressure due to the weight of a liquid column depends on the depth h of the liquid, not on the shape, total mass or surface area of the liquid.

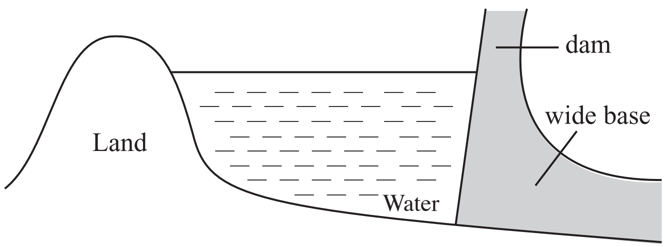


Fig 9.25 The width of a dam increases with depth to withstand the increasing pressure of the water body at the base of the dam.

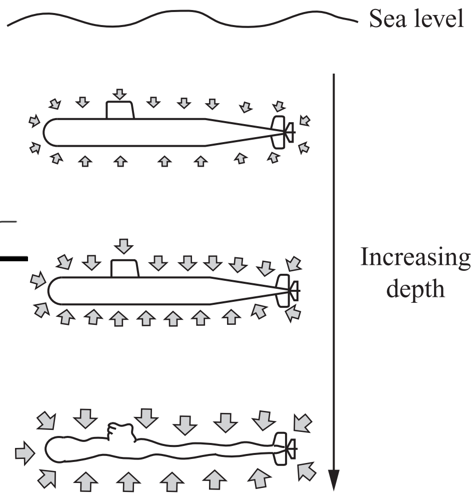


Fig 9.26 The body of a submarine is made of steel which is strong enough to withstand the high pressure as it ventures deeper into the sea. However, there is a limit to how deep the submarine can descend before it gets damaged.

SCIENCE AROUND US

Extension Knowledge | **Science behind Healthcare**

A soldier stands on his two feet. The distance between his heart and his feet is 1.4 m. The density of blood is 1050 kg/m^3. What is the increase in pressure in the feet relative to the heart? [2]

ANSWER

Increase in pressure

= height × density of blood × gravitational field strength

= 1.4 × 1050 × 10

= 14 700 Pa

Note

Standing a long time can lead to accumulation of blood in the legs. That is why soldiers who are required to stand still for long periods of time are known to faint. Elastic bandages around the calf can help to increase pressure to enable the veins to send blood back to the heart.

9.4 What are Energy and Work?

There are many forms of energy around us. Understanding energy transfers and conversions allows us to be more informed about how different sources of energy work and how it can be used for electricity generation. Collecting data on energy sources allows countries to select alternative sources of energy suited to be used based on geographical and environmental considerations, and play their part towards sustainable use of energy.

Emerging technology

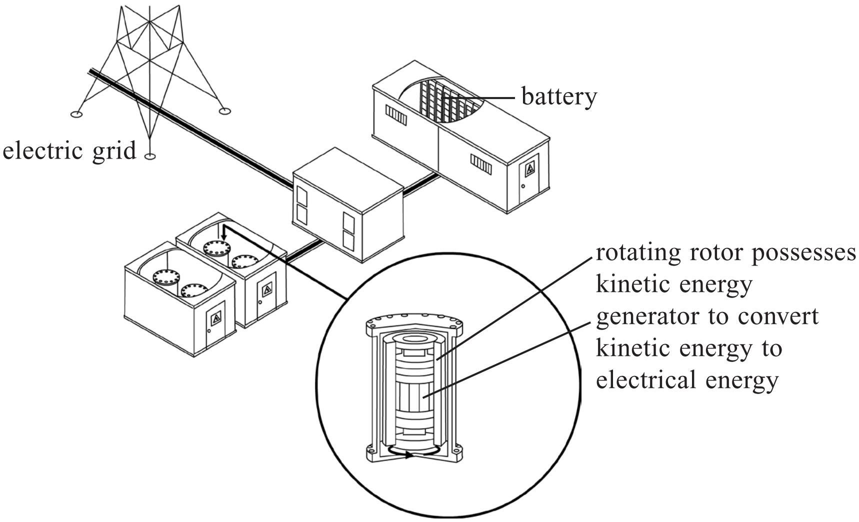


Fig 9.27 The Energy Storage System (ESS) refers to technologies that store energy for later use. Examples of ESS include batteries, the flywheel (shown in diagram) which stores kinetic energy, and pumped hydro energy storage which stores potential energy of water. The ESS is essential for the adoption of solar energy to manage intermittency and maintain grid stability.

Energy

1. Energy is the measure of the capacity to do work. SI unit: joule (J).
2. Different forms of energy exist around us. Examples:

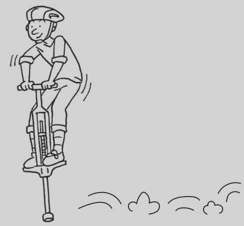
Note

The kilowatt-hour is the amount of energy we use in our electricity bill.
1 kWh = 3.6×10^6 J

Form of energy	Description
Heat or Internal energy – Energy that can be transferred as heat from a region of higher temperature to a region of lower temperature.	Heat or internal energy is due to the movement of particles (e.g. atoms, molecules). The faster the particles move, the greater the amount of heat / internal energy the substance has.
Light energy – Energy that enables us to see. We refer light to a small part of the electromagnetic (EM) radiation that is visible to our eyes.	A hot filament lamp emits light energy when it glows. It also emits heat in the form of IR. The greater the amount of light energy and smaller the amount of heat a bulb produces, the more efficient is the bulb.
Chemical potential energy – Energy in substances (e.g. fuels) that can be converted into other forms of energy through chemical reactions.	A mixture of fuels and oxygen can be ignited to produce carbon dioxide and water vapour. In the process, heat and light are emitted.
Elastic spring potential energy (EPE) – Energy stored in a stretched or compressed spring. **Extension Knowledge** Formula: $\text{EPE} = \frac{1}{2} \times \text{spring constant} \times \text{extension}^2$ The stiffer the spring, the larger is its spring constant (measured in N/m or N/cm).	Elastic potential energy is the result of deformation of an elastic object, such as a spring. This is work required to extend or compress the spring, which depends on the spring constant (stiffness of the spring) as well as distance stretched.
Electrical energy – Energy due to moving charges (e.g. electrons, ions). Formula: Energy = power × time	The electrical energy used can be calculated using the formula, energy = power of appliance × time taken. In electricity bills, energy is measured in kWh. (1 kWh = 3.6×10^6 J)
Gravitational potential energy (GPE) – Energy due to the position of an object above the ground. **Extension Knowledge** Formula: GPE = weight × height above the ground	GPE depends on mass, gravitational field strength and height.
Kinetic energy (KE) – Energy due to the motion of an object. **Extension Knowledge** Formula: $\text{KE} = \frac{1}{2} \times \text{mass} \times \text{speed}^2$	KE depends on mass and speed.
Nuclear energy – Energy present in the bonds that hold the nucleus together, that is released when these bonds are broken.	Nuclear energy can be released in two ways: 1. During fusion when nuclei fuse / combine together to form a large atom; or 2. During fission when a heavy nucleus splits into smaller atoms

SCIENCE AROUND US

Extension Knowledge



A boy of mass 42 kg balances on a pogo stick. This causes the spring in the stick to compress downward by 0.18 m.

(a) Find the spring constant. [2]
(Gravitational field strength = 10 N/kg, elastic spring force = spring constant × decrease in length)

(b) Determine the potential energy in the spring. [2]
(Elastic potential energy = $\frac{1}{2}$ × spring constant × extension^2)

ANSWER

(a) Weight of the boy = 42 × 10 = 420 N

As the boy is balanced on the pogo stick, elastic spring force = weight of boy.

Spring constant × decrease in length = weight of boy

Spring constant = $\frac{420 \text{ N}}{0.18 \text{ m}}$ = 2333 N/m

(b) Elastic potential energy

= $\frac{1}{2}$ × spring constant × extension^2

= $\frac{1}{2}$ × 2333 N/m × (0.18 m)^2

= 37.8 J

Conservation of Energy

1. Energy can be converted from one form to another.
2. Law of conservation of energy: Total energy in a system remains constant. Energy can be converted from one form to another but can neither be created nor destroyed.
   In general, for a non-ideal system,
   $KE_i + GPE_i$ + Energy supplied to the system
   $= KE_f + GPE_f$ + Energy lost to the surroundings
3. When a pendulum swings between A and C as shown below, its energy changes between GPE and KE. Its total energy at any point (GPE + KE) is constant because energy is conserved.

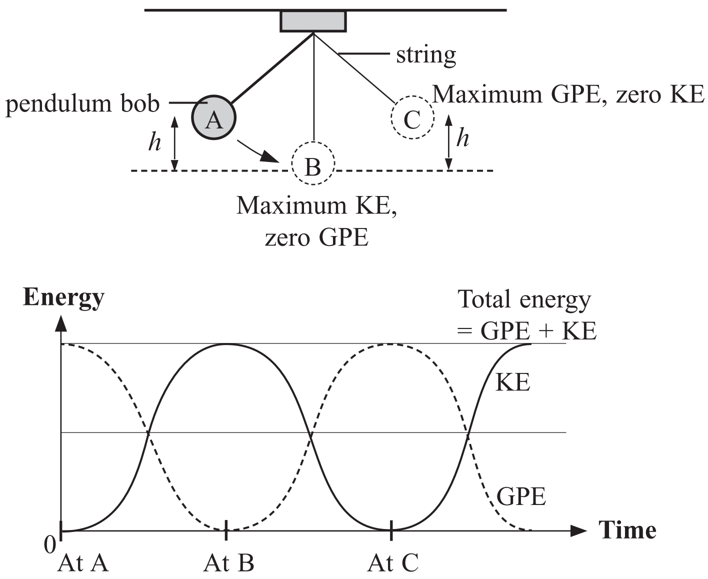


Fig 9.28 How do the KE and GPE of a swinging pendulum change?

SCIENCE AROUND US

Extension Knowledge

A child of mass 25 kg goes down a slide of 2.5 m tall.

(a) Calculate the
 (i) decrease in gravitational potential energy of the child, [2]
 (ii) speed of the child as he reaches the bottom of the slide. [2]
 (Gravitational field strength = 10 N/kg)

(b) Do you think the child will reach the speed you calculated in (a) when he reaches the bottom of the slide? Explain. [2]

ANSWER

(a) (i) Decrease in GPE
$= \text{mass} \times \text{gravitational field strength} \times \text{height}$
$= 25 \text{ kg} \times 10 \text{ N/kg} \times 2.5 \text{ m}$
$= 625 \text{ J}$

(ii) Since energy is conserved, GPE at the top of slide = KE at the bottom of slide.

$$\text{Kinetic energy} = \frac{1}{2} \times \text{mass} \times \text{speed}^2$$

$$625 \text{ J} = \frac{1}{2} \times 25 \text{ kg} \times \text{speed}^2$$

$$\text{Speed}^2 = 50$$

$$\text{Speed} = 7.07 \text{ m/s}$$

(b) No, the child will not reach this speed. The child will reach a lower speed because some of his kinetic energy would be lost as heat due to friction between him and slide.

4. Examples of energy conversions:
   - When a bulb glows, electrical energy is converted to light and heat.
   - When a person runs, chemical potential energy is converted to kinetic energy.
   - When plants photosynthesise, light energy is converted to chemical potential energy.
   - When rain ralls, gravitational potential energy is converted to kinetic energy.
   - When light is absorbed by solar photovoltaic cell, light energy is converted to electrical energy.

SCIENCE AROUND US

An object of mass 10 kg is released from rest at a height 1.0 m above the ground. At the height 1.0 m, its gravitational potential energy is 100 J. Assume there is no air resistance.

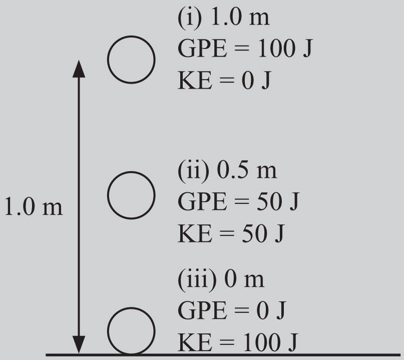
(a) State the forms of energy and their values at positions (i) 1.0 m (ii) 0.5 m (iii) 0 m just before it hits the ground. [3]

(b) The ball's shape changes a little as it hits the ground. This is due to the force during impact. The energy possessed by the ball as it changes its shape is called elastic potential energy. The ball then bounces up. State the energy conversions involved from the original maximum height to the new maximum height. [3]

(c) The ball, after hitting the ground, bounces to a lower new maximum height. Why does it not bounce to the original maximum height? [1]

ANSWER

(a)



(b) GPE at original maximum height → KE at 0 m just before hitting the ground → elastic potential energy as the ball changes its shape during impact → KE at 0 m just after the impact → GPE at new maximum height

(c) The ball does not bounce to the original maximum height because part of its energy has been lost as heat and sound energy when it hits the ground.

Work Done

1. **Work** is done when an object moves through a distance in the same direction as the **force**. SI unit: **Joule** (J)
2. There is work done by a force if these conditions are met:
   - the force is not zero; and
   - the object moves in the same direction as the force.

3. A car is initially at rest. The driver steps on the accelerator. The engine exerts a forward force F to cause the car to increase in speed from 0 to v. The car moves through a certain distance in the direction of the force.

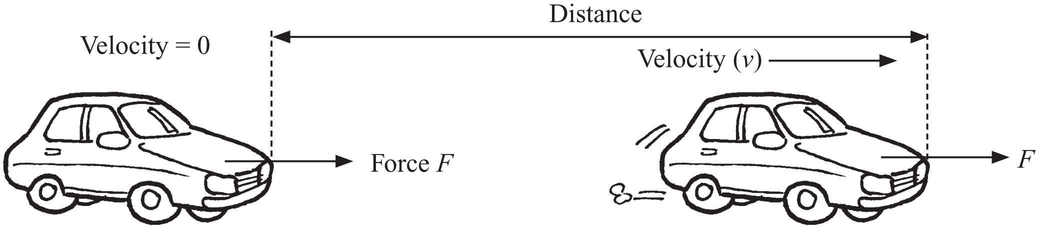
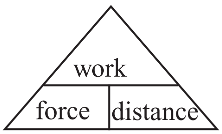


Fig 9.29 The engine force does work in moving the car over a distance. Energy is transferred during work done by F (= final KE – initial KE).

The force F has done work to move the car over a distance.
Overall energy conversion: Chemical energy in fuel → kinetic energy of car

4. Formula:
Work done = force × distance moved in the direction of force

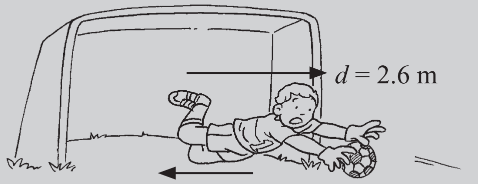


Note

Use SI units. The unit of force is Newton while the unit of distance is meter. If a question provides values which are not in the SI units, make sure to convert them.

SCIENCE AROUND US

A soccer player slides over a distance of 2.6 m on the ground until he stops.



(a) If the friction is 450 N, what is the work done by the friction to stop him? [2]
(b) What energy conversion occurs as work is done by friction? [1]

ANSWER

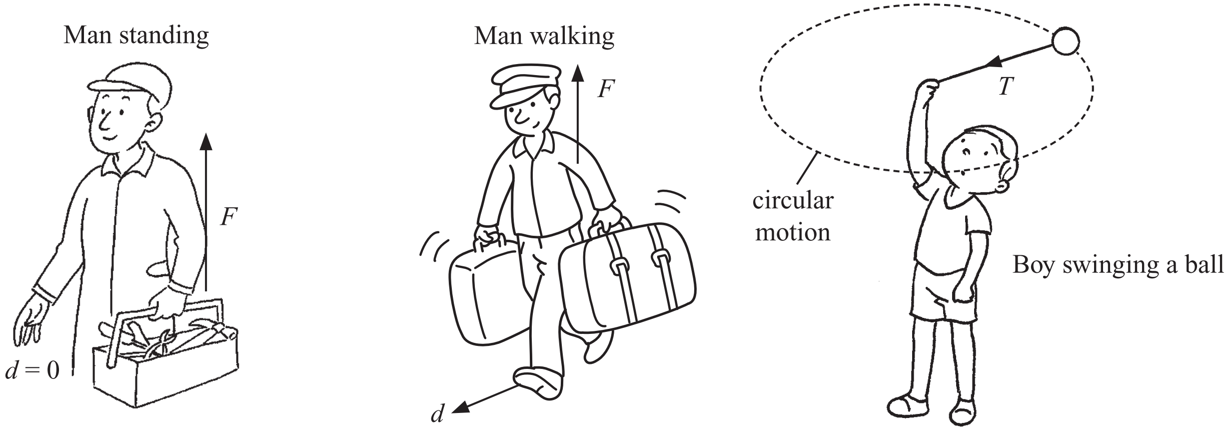
(a) Work done by friction = friction × distance
= 450 × 2.6
= 1200 J

(b) Kinetic energy of soccer player → heat due to friction

Note

The initial kinetic energy of the soccer player is 1200 J.

5. There is no work done if:
   - the force is 0 N
   - the distance moved is 0 m
   - the force is perpendicular to the distance moved



There is no work done as there is no distance moved in the direction of the force.

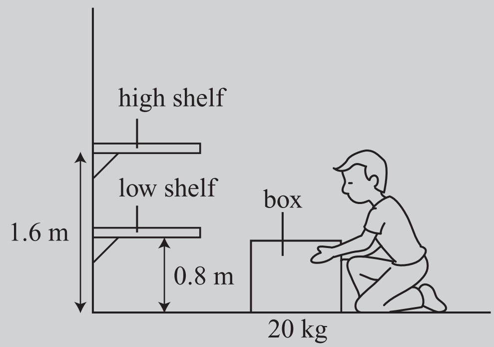
There is no work done as the force and distance moved are perpendicular to each other.

There is no work done by *T* as the tension in the string is perpendicular to the motion of the ball at every point of the ball's path.

Fig 9.30 Why is there no work done in these situations?

SCIENCE AROUND US

A man has to lift a box of mass 20 kg on to one of the shelves. (On Earth, 1 kg weighs 10 N.)



(a) Will the box on the high shelf or on the low shelf have more gravitational potential energy? Use calculations to explain. [3]

(b) State the energy conversions involved. [2]

ANSWER

(a) 1. Work done to lift box to low shelf
= force × distance moved
= weight × height
= 20 × 10 × 0.8
= 160 J

2. Work done to lift box to high shelf
= force × distance moved
= weight × height
= 20 × 10 × 1.6
= 320 J

Note

The work done is not zero as the lifting force is in the same direction as the distance moved.

More work is needed to lift the box to the high shelf than to the low shelf. The box on the high shelf will have more gravitational potential energy than the box on the low shelf.

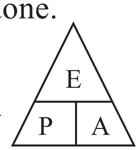
(b) Chemical potential energy of food in man → kinetic energy of box → gravitational potential energy of box on shelf

Power

Extension Knowledge

1. Power is the rate at which energy is transferred or the rate at which work is done.

$$\text{Power} = \frac{\text{work}}{\text{time}} = \frac{\text{energy}}{\text{time}}$$



- The table shows the energy consumption rates of various activities.

Note

Power is measured in watts (W) when energy is in joules (J) and time is in seconds (s). Power is measured in kilowatts (kW) if energy is in kilo-watt hour (kWh) and time is in hours (h).

Activity	Power (W)
Cycling	400 (at 13-18 km/h), 700 (at 21 km/h)
Climbing stairs (at 116 steps/min)	440
Walking (at 5 km/h)	280
Playing basketball	800
Sprinting	2415

Table 9.1 Energy consumption rates for different activities

SCIENCE AROUND US

Extension Knowledge

The engine of a car has a power rating of 73 kW. What is the work done by the engine in kWh and in J if the car drives along a road for 25 min?

ANSWER

Work done = power × time
= 73 kW × 25/60 h
= 30.4 kWh

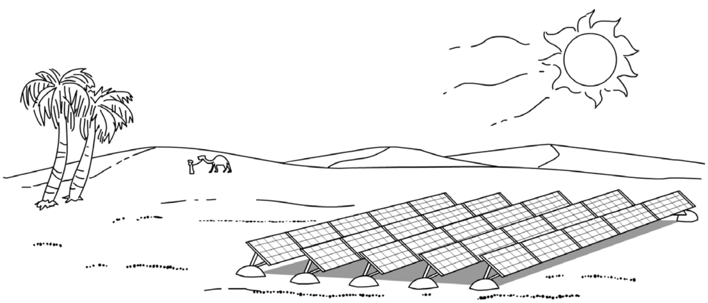
Also, work done = 73 000 W × (25 × 60) s
= 1.1×10^8 J

Note

The horizontal forces acting on the moving car are forward engine force and opposing resistive force (friction, air resistance). If the car drives along the road at a constant speed for 25 min, the engine has done work on the resistive force.

9.5 What are the Sources of Energy that We Use?

Human activities such as the burning of fossil fuels to generate energy and manufacture goods for our daily use have led to the increase in greenhouse gas emissions, trapping heat in the atmosphere. Most of the electricity generated in Singapore comes from natural gas, which is one of the cleanest forms of fossil fuels. As natural gas is considered a non-renewable energy source that will run out one day, Singapore is working to scale up the use of alternative sources of energy.



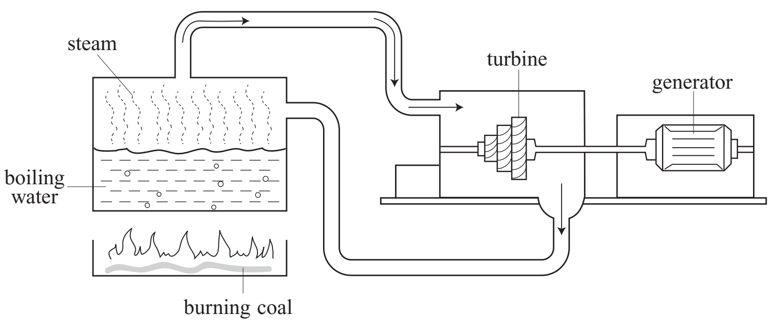
Climate change

Fig 9.31 It was said that a 254 km x 254 km solar farm in Sahara (92 million km²) could supply electricity for the whole world. However, in a 2018 study, a climate model revealed that when 20% of the desert is covered with solar panels (which are dark and hence absorb and emit heat more than sand), the local temperature would increase by 1.5 ºC. The warmed air may then spread around the world increasing global temperature by 0.16 ºC.

1. We need energy sources to produce electricity for households, factories, commercial buildings and vehicles.
2. Sources of energy include fossil fuels and alternative sources of energy such as solar energy, hydroelectric energy, wind energy, geothermal energy, biomass and nuclear energy.
3. Two types of energy sources: non-renewable and renewable

Non-renewable energy sources	Renewable energy sources
Do not renew themselves and are finite (i.e. will run out one day)	Can renew themselves and are naturally replenishing (i.e. will not run out)
Examples: fossil fuels (coal, oil, natural gas), nuclear energy	Examples: solar energy, hydroelectric energy, wind energy, geothermal energy, biomass (biofuels)

4. Sources of energy such as fossil fuels, geothermal energy, biofuels and nuclear energy can produce electricity when power stations boil water into steam. The moving steam then drives the turbine which in turn causes the generator to produce electricity. The difference is the source of heat to boil the water.

Type of power station	How heat is produced to boil water
Fossil fuel power station	Combustion of fossil fuel (e.g. coal, oil, natural gas) produces heat.  *Fig 9.32 A fuel power station uses the chemical energy of fuels to produce electricity.*

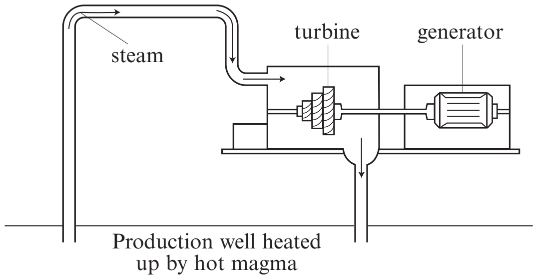
<table>
<tr><th>Type of power station</th><th>How heat is produced to boil water</th></tr>
<tr><td>Geothermal power station</td><td>Rock and water in the Earth’s crust are heated by the magma in Earth’s interior.


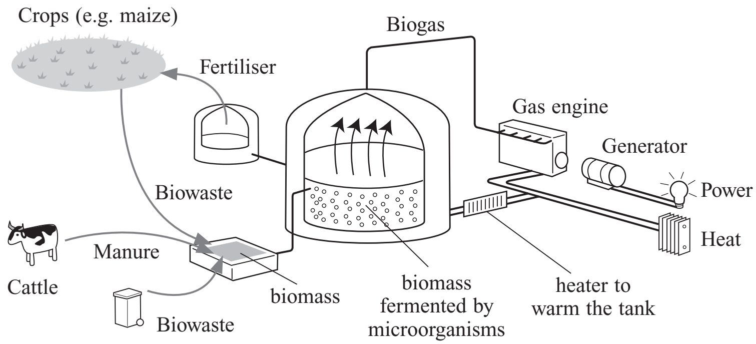
Fig 9.33 Geothermal power uses the kinetic energy of steam that is generated from the Earth’s crust.</td></tr>
<tr><td>Biomass power station</td><td>Biomass is fuel made from dead plants or animal wastes. This biomass can be directly burnt to produce heat. Biomass power is said to be carbon neutral as the amount of carbon dioxide captured by the plants through photosynthesis is almost the same as that released when biomass is burned.


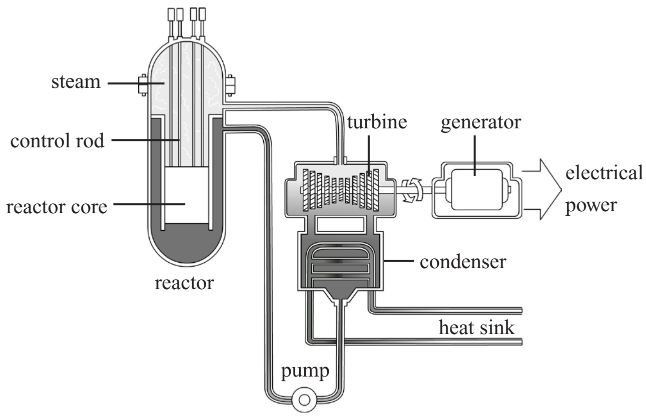
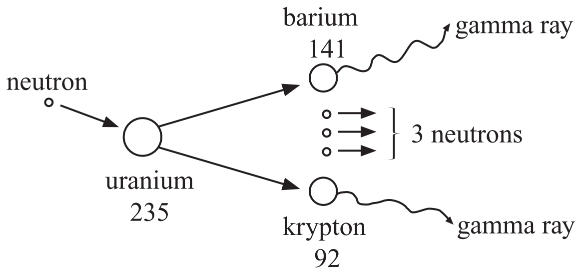
Fig 9.34 Biomass power generates electricity from chemical energy in renewable organic waste that would otherwise be dumped in landfills.</td></tr>
<tr><td>Nuclear power station</td><td>Nuclear energy is harnessed from the nucleus of an atom. In nuclear power plants, heavy nucleus undergoes nuclear fission to release a great amount of energy.


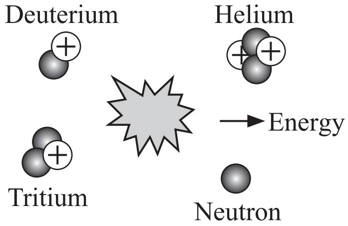
Fig 9.35 Nuclear power generates power through fission which is the splitting of uranium atoms to release heat energy.</td></tr>
</table>

Note

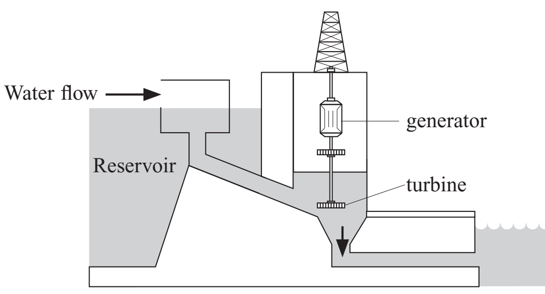
Currently, nuclear power plants use the nuclear fission of uranium atoms to release large amount of heat and radiation. When a neutron collides with a uranium atom, it splits into lighter atoms and neutrons which then collide with more uranium atoms. This chain reaction can be controlled using 'control rods' (which contains elements such as Hf, B, Cd, Ag, In) that absorb neutrons without undergoing fission.

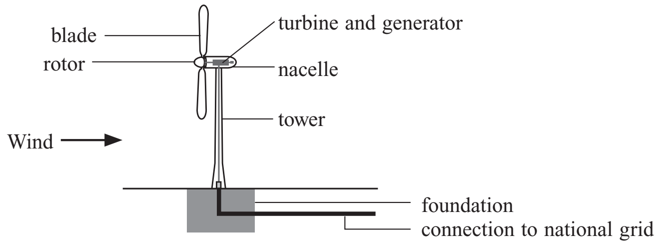


On the other hand, the nuclear fusion in the Sun involves hydrogen nuclei combining to form helium.



5. Some power stations make use of the forces in nature directly to drive the turbine and generator.

Type of power station	How heat is produced to boil water
Hydroelectric power station	Water from an elevated reservoir flows down a turbine passageway. This rotates the turbine and hence generator.  *Fig 9.36 The hydroelectric power station harnesses the kinetic energy in moving water.*

Type of power station	How heat is produced to boil water
Wind power station (or wind farm)	The wind turns the blades which in turn rotate the turbine and hence generator.  *Fig 9.37 The wind turbine harnesses the kinetic energy in wind.*

6. Solar energy can be harnessed from the Sun using solar PV cells. Sunlight is absorbed and light energy is converted into electrical energy.
7. Impact of use of sources of energy on the environment:
   - When there is a need to clear land space to build a power plant, livelihood of the local community and the ecosystem needs to be considered.
   - Building hydroelectric dams may cause areas behind the dam to flood, killing animals and plants.
   - Birds flying near a wind turbine might be killed and noise produced by the wind turbines can be quite loud.
   - Water and air pollution due to disposal of and leakage of by-products and toxic waste should be closely monitored as some may be harmful to the environment.
   - Burning of fossil fuels and biomass releases greenhouse gases and contributes to air pollution. Increase in greenhouse gases contributes to global warming.