Answers

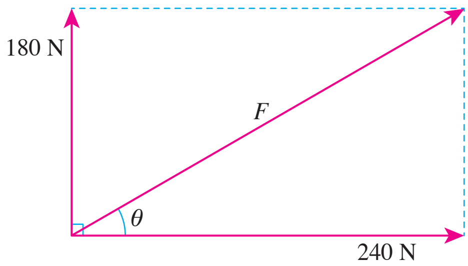
Chapter 1 Force and Motion II

Formative Practice 1.1

1. (a) Resultant force = 9 + 17 + (–11)
= 15 N to the right

(b) Resultant force = 13 + (–5) + (–2)
= 6 N downwards

2. (a)



F = resultant force

(b) $F = \sqrt{240^2 + 180^2}$

F = 300 N

(c) Moves along the direction of the resultant force

$\theta = \tan^{-1}\left(\frac{180}{240}\right)$

$= 36.87°$

Formative Practice 1.2

1. (a) Horizontal component = 70 cos 42°
= 52.02 N

Vertical component = 70 sin 42°
= 46.84 N

(b) Horizontal component = 90 cos 64°
= 39.45 N

Vertical component = 90 sin 64°
= 80.89 N

2. (a) Horizontal component = 90 sin 60°
= 77.94 N

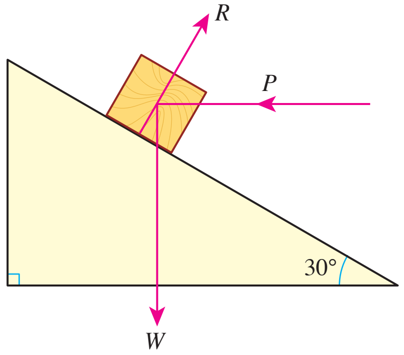
Vertical component = 90 cos 60°
= 45.00 N

(b) The horizontal component moves the lawn mower forward.
The vertical component pushes the lawn mower on the surface of the field.

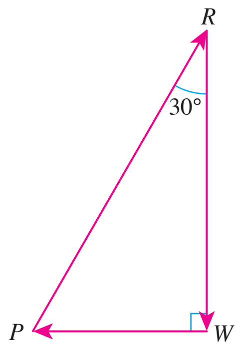
Formative Practice 1.3

1. An object is said to be in equilibrium of forces when the forces acting on it produce a zero resultant force.

2. (a)



(b)



Formative Practice 1.4

1. Elasticity is the property of material that enables an object to return to its original shape and size when the force applied on it is removed.

2. (a) Hooke's law states that the extension of a spring is directly proportional to the force applied on the spring provided the elastic limit of the spring is not exceeded.

(b) The spring obeys Hooke's law because the graph is a straight line passing through the origin.

(c) Spring constant, k

= gradient of the graph F against x

$= \frac{15}{0.06}$

$= 250$ N m^{-1}

(d) Elastic potential energy = area under the graph

$= \frac{1}{2} \times 0.04 \times 10$

$= 0.2$ J

3. (a) Spring $P = 8$ N

Spring $Q = 4$ N

Spring $R = 4$ N

(b) $F = kx$, $k = 4$ N cm^{-1}

Compression, $x = \frac{F}{k}$

Spring P: $x = \frac{8}{4}$

$= 2$ cm

Spring Q: $x = \frac{4}{4}$

$= 1$ cm

Spring R: $x = 1$ cm

(c) Total compression = 2 + 1
= 3 cm

4. (a) Extension = 5 cm
= 0.05 m

Force that produces an extension 0.05 m = F

Elastic potential energy = Shaded area

$$0.4 = \frac{1}{2} \times 0.05 \times F$$

$$F = 16 \text{ N}$$

(b) Force, F = 16 N

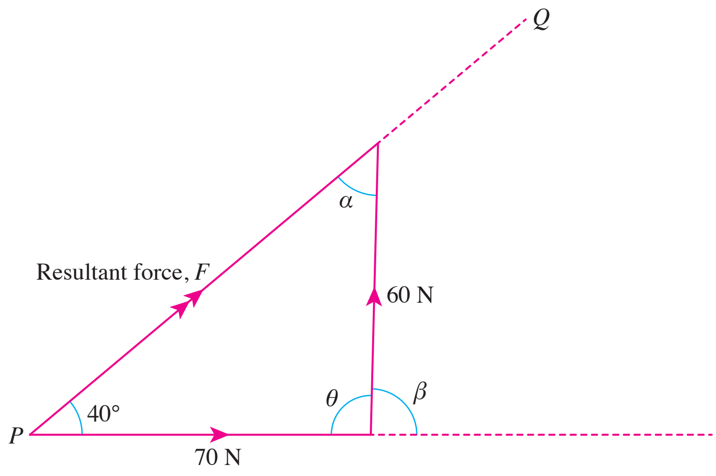
Extension, x = 0.05 m

$F = kx$

$$\text{Spring constant, } k = \frac{F}{x}$$
$$= \frac{16}{0.05}$$
$$= 320 \text{ N m}^{-1}$$

Summative Practice

1. The resultant force of worker X (70 N) and worker Y (60 N) has to act along the line PQ. The triangle of forces for forces 70 N, 60 N and resultant force, F is as follows:



Using the sine rule,

$$\frac{70}{\sin \alpha} = \frac{60}{\sin 40°}$$

$$\sin \alpha = \frac{70 \times \sin 40°}{60}$$

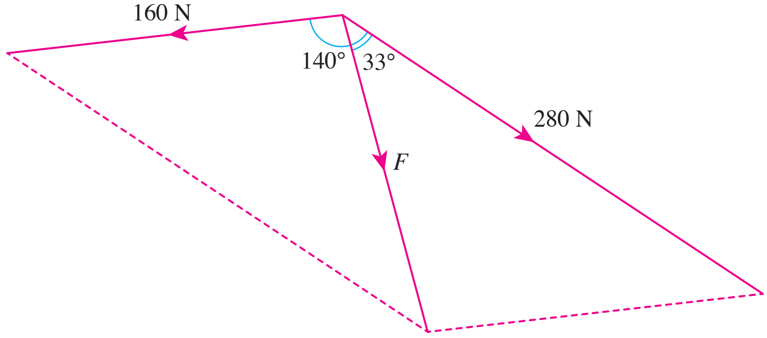
$$\alpha = 48.58°$$

$$\theta = 180 - 40 - 48.58$$
$$= 91.42°$$

$$\beta = 180 - 91.42$$
$$= 88.58°$$

Therefore, worker Y has to apply a force that makes an angle of 88.58° with the direction of the force from worker X.

2. (a) Use the scale: 1.0 cm = 20 N



Length of the diagonal of the parallelogram = 9.4 cm
Resultant force, $F = 9.4 \times 20$
$= 188$ N
$F = 188$ N at an angle of 33° with the direction of the force applied by P.

(b) – Advantage: The tree will fall in the direction of the resultant force. A larger angle will ensure that there is a large space between P and Q. The tree will fall on to the ground without endangering P dan Q.
– Disadvantage: The large angle between the directions of the forces produces a resultant force with a smaller magnitude.

(c) The direction of the resultant force makes a smaller angle with the direction of the force by P. The tree will fall nearer to P. Therefore, P has to be more careful.

3. Force on spring, F = weight of child
$= mg$
$= 28 \times 9.81$
$= 274.68$ N

Compression, $x = 5.0$ cm
$= 0.05$ m

From $F = kx$

$$k = \frac{F}{x}$$
$$= \frac{274.68}{0.05}$$
$$= 5\,493.6 \text{ N m}^{-1}$$

4. The resultant force of the two forces has the largest magnitude when the forces act on an object in the same direction.
If the force 17 N and the force 13 N are in the same direction, resultant force = 17 + 13
= 30 N
The resultant force of the two forces has the smallest magnitude when the forces are in opposite directions.
If the force 17 N and the force 13 N are in opposite directions, resultant force = 17 + (–13)
= 4 N
Therefore, the resultant forces of 17 N and 13 N has magnitude between 4 N and 30 N.

5. Stage I: For a stationary object, velocity = 0 and acceleration, $a = 0$.
Resultant force, $F = ma$
$F = 0$ N

Stage II: $u = 0$, $v = 20$ m s^{-1}, $t = 8$ s

Acceleration, $a = \frac{20 - 0}{8}$
$= 2.5$ m s^{-2}

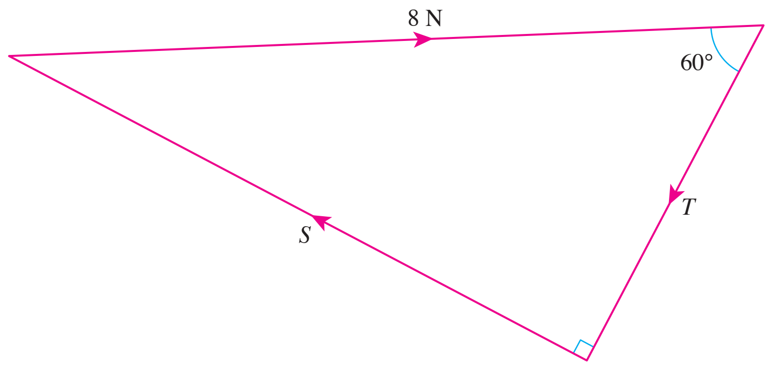
Resultant force, $F = 180 \times 2.5$
$= 450$ N to the East

Stage III: For an object moving with a uniform velocity, acceleration, $a = 0$.
Resultant force, $F = ma$
$F = 0$ N

6. (a) Horizontal component = 12 sin 55°
= 9.83 N
Vertical component = 12 cos 55°
= 6.88 N

(b) The horizontal component moves the knife forward.
The vertical component pushes the knife downward.

7. Three forces S, T and 8 N form a triangle when drawn in sequence.

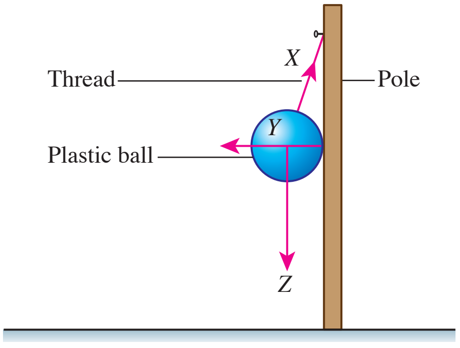


$\frac{T}{8} = \cos 60^o$

$T = 8 \cos 60^o$
$= 4.0$ N

$S = \sqrt{8^2 - 4^2}$
$= 6.93$ N

8.

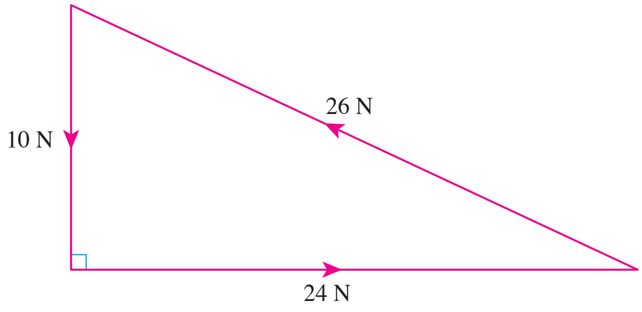


9. Since the object is stationary, the three coplanar forces 10 N, 24 N, 26 N are in equilibrium.

$10^2 + 24^2 = 676$
$26^2 = 676$

That is, $10^2 + 24^2 = 26^2$

The three forces drawn in sequence form a right-angled triangle.



10. (a) Spring M: force F = 18 N produces an extension, x = 4 cm
= 0.04 m

Spring constant of spring $M = \frac{18}{0.04}$
$= 450 \text{ N m}^{-1}$

(b) Spring N: extension, x = 6 cm
= 0.06 m

Elastic potential energy $= \frac{1}{2} \times 0.06 \times 18$
= 0.54 J

(c) The graph for both springs are straight lines passing through the origin.
Both springs obey Hooke's law.
Spring N obeys Hooke's law to a greater extension than spring M.
Gradient of graph M > gradient of graph N
Spring constant M > spring constant N
Spring M is stiffer than spring N.

When an 18 N force is applied, the area under the graph N is larger than the area under the graph M.

Spring N stores more elastic potential energy than spring M when both springs are stretched by the same force.

11. Elastic potential energy, E_P = 18 J
Extension of spring, x = 4.0 cm
= 0.04 m

$$E_P = \frac{1}{2}kx^2$$

$$\frac{1}{2} \times k \times 0.04^2 = 18$$

$$k = 22\ 500 \text{ N m}^{-1}$$

When x = 3.0 cm
= 0.03 m

$F = kx$
$= 22\ 500 \times 0.03$
$= 675$ N

12. (a) The extension of a spring is calculated as follows:
$F = kx$
Extension, $x = \frac{F}{k}$

Arrangement	Force applied / N	Tension in one spring / N	Extension of one spring / cm	Extension of system of springs /cm
Two springs of type X in series	400	400	2.00	4.00
Two springs of type X parallel	600	300	1.50	1.50
Two springs of type Y in series	300	300	1.00	2.00
Two springs of type Z parallel	600	300	0.50	0.50

(b) Each spring obeys Hooke's law.

21st Century Challenge

13. Maximum weight of load = 3 600 × 9.81
= 35 316 N
Let the number of springs be arranged in parallel below the iron plate = n

Compression force on each spring, $F = \frac{35\ 316}{n}$

From $F = kx$, k = spring constant
x = compression of spring

$$\frac{35\ 316}{n} = kx$$
$$n = \frac{35\ 316}{kx}$$

If spring X is used, $k = 800$ N cm^{-1}, $x = 5.0$ cm

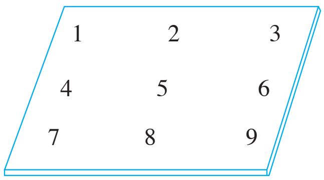
$$n = \frac{35\ 316}{800 \times 5}$$
$$= 8.829$$
$$\approx 9$$

If spring Y is used, $k = 1\ 800$ N cm^{-1}, $x = 5.0$ cm

$$n = \frac{35\ 316}{1\ 800 \times 5}$$
$$= 3.924$$
$$\approx 4$$

The maximum load will produce a compression of 5.0 cm when 9 springs X are arranged in parallel or 4 springs Y are arranged in parallel.

Suggested design of spring system:
(a) Spring X is used.
 – Spring X has a smaller spring constant. More springs X are required.
(b) 9 spring X are arranged in parallel below the iron plate.
 – The maximum load is divided into nine smaller components, that is 4 000 N on each spring.
(c) The 9 spring X are placed at positions numbered 1 to 9.



 – The uniform distribution of springs ensures that the iron plate is supported in a balanced and stable condition.

Chapter 2 Pressure

Formative Practice 2.1

1. Depth, density of liquid, gravitational acceleration

2. Water pressure $= h\rho g$
$= 24 \times 1\ 000 \times 9.81$
$= 2.35 \times 10^5$ Pa

3. Water pressure $= h\rho g$
$= 35 \times 1\ 060 \times 9.81$
$= 363\ 951$ Pa
$= 364$ kPa

Actual pressure $= 364 + 100$
$= 464$ kPa

Formative Practice 2.2

1. Atmospheric pressure is the pressure due to the weight of the layer of air acting on the surface of the earth.

2. Atmospheric pressure = 756 mm Hg = 0.756 m Hg
Atmospheric pressure $= h\rho g$
$= 0.756 \times 13\ 600 \times 9.81$
$= 100\ 862$ Pa

3. Actual pressure = water pressure + atmospheric pressure
= 125 + 10.3
= 135.3 m H_2O
Actual pressure = 135.3 × 1 000 × 9.81
= 1 327 293 Pa
= 1.33×10^6 Pa

Formative Practice 2.3

1. (a) The gas pressure is higher than the atmospheric pressure.
(b) Pressure difference = 36.0 cm H_2O
= 0.36 m H_2O
(c) Gas pressure = (0.36 + 10.3) m H_2O
= 10.66 m H_2O
Gas pressure = 10.66 × 1 000 × 9.81
= 104 575 Pa

2. • Can measure higher pressure because mercury is a denser liquid
• Does not need a very long tube
• Rate of evaporation of mercury is lower than rate of evaporation of water

3. Difference in pressure between the compressed gas and atmospheric pressure = 180 – 101
= 79 kPa
= 79 000 Pa

$h\rho g = 79\ 000$
$h \times 13600 \times 9.81 = 79\ 000$
$h = 0.592$ m
$h = 59.2$ cm

Difference in height of the two mercury columns in the manometer = 59.2 cm

Formative Practice 2.4

1. Pascal's principle states that the pressure applied on an enclosed fluid is transmitted uniformly in all directions in the fluid.

2. A small force, F_1 exerts pressure on the liquid below the small piston.
Pressure = $\frac{F_1}{A_1}$
A_1 = cross-sectional area of the small piston
According to Pascal's principle, this pressure is transmitted uniformly throughout the liquid.
This pressure exerts a force on the large piston.
Force on the large piston, F_2 = pressure × cross-sectional area of the large piston.
$F_2 = \frac{F_1}{A_1} \times A_2$
A_2 = cross-sectional area of the large piston
Force on the large piston, $F_2 = \frac{A_2}{A_1} \times F_1$
Since $A_2 > A_1$, $F_2 > F_1$
Therefore, a small input force on the small piston is multiplied to become a larger output force on the large piston.

3. $F_2 = \frac{6.4}{0.50} \times 4.0$
$F_2 = 51.2$ N

4. $\frac{F_1}{A_1} = \frac{F_2}{A_2}$
$\frac{A_2}{A_1} = \frac{F_2}{F_1}$

$$\frac{A_2}{A_1} = \frac{72}{6} = 12$$

$$A_2 = 12\,A_1$$

$$\frac{\pi d_2^{\,2}}{4} = 12\frac{\pi d_1^{\,2}}{4}$$

$$d_2^{\,2} = 12 \times 1.5^2$$

$$d_2 = 5.20 \text{ cm}$$

Diameter of large piston = 5.20 cm

Formative Practice 2.5

1. Archimedes' principle states that an object which is partially or fully immersed in a fluid will experience a buoyant force equal to the weight of fluid displaced.
2. Buoyant force, $F_B = \rho V g$
   $= 1\,050 \times 3.8 \times 10^{-2} \times 9.81$
   $= 391.4$ N
3. Weight of block $= mg$
   $= 0.48 \times 9.81$
   $= 4.71$ N

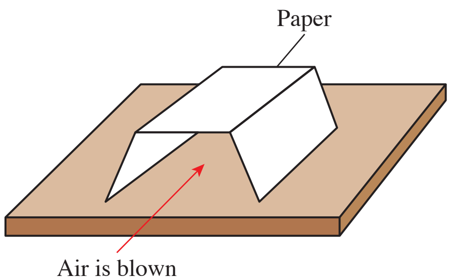
   Buoyant force, $F_B = \rho V g$
   $= 1\,000 \times 5.0 \times 10^{-4} \times 9.81$
   $= 4.91$ N

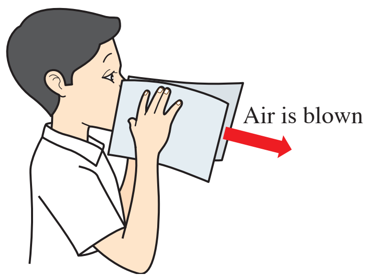
   Buoyant force > Weight of block

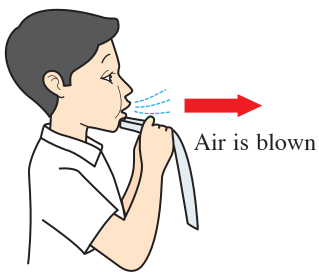
   The block will move up with an acceleration.

Formative Practice 2.6

1. Bernoulli's principle states that when the velocity of the flow of a fluid increases, the pressure in the fluid decreases.
2.







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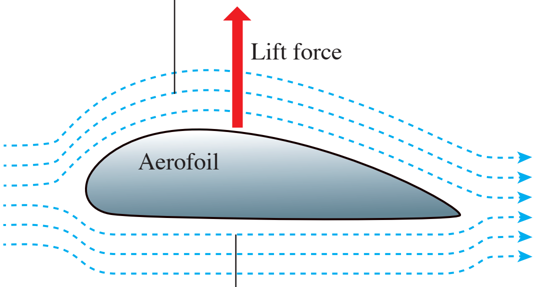
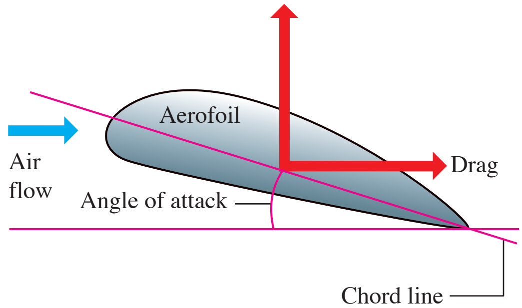
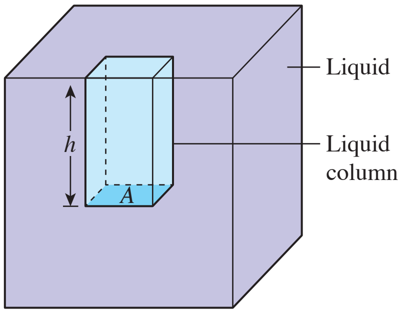




The shape of the aerofoil causes air to flow:
– at high velocity above the upper section of the wing of the aircraft
– at lower velocity below the lower section of the wing of the aircraft
According to Bernoulli's principle:
– above the upper section of the wing is a region of low air pressure
– below the lower section of the wing is a region of high pressure
– this difference in air pressure produces a resultant force upwards to lift the aircraft into the air
The wing is inclined to produce an angle of attack:
– the flow of air below the wing experiences an action force and is deflected
– the wing experiences a reaction force that contributes to the lift force

Summative Practice

1. (a) Consider a liquid column in a container
Height of liquid column = h
Area of the base of liquid column = A
Density of liquid = ρ



Pressure on the base of the liquid column is due to the weight of the liquid column.
Volume of liquid column, $V = Ah$
Mass of liquid column, $m = Ah\rho$
Weight of liquid column, $W = Ah\rho g$

Pressure on the base of liquid column, $P = \dfrac{\text{Weight of liquid column}}{\text{Surface area}}$

$$P = \frac{Ah\rho g}{A}$$
$$P = h\rho g$$

(b) $P = h\rho g$
$= 24 \times 1\ 120 \times 9.81$
$= 2.64 \times 10^5$ Pa

2. (a) *A* and *B* are at the same level in a stationary liquid.
(b) Density of liquid $X = \rho$
Pressure at A = pressure at B
$36.0 \times \rho \times g = 35.0 \times 1\ 000 \times g$
$\rho = 972$ kg m^{-3}

3.

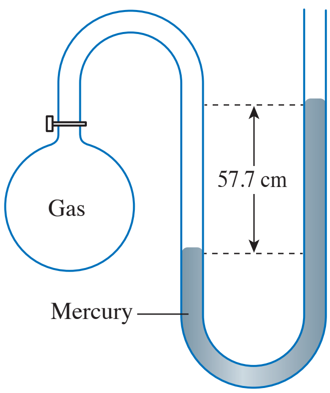
	Pressure in liquid	**Atmospheric pressure**
Similarities	Due to the weight of the fluid column acting on the surface below it.	
	Acts in all directions	
	Does not depend on surface area	
	Depends on density	
	Depends on gravitational acceleration	
Difference	Increases with depth	Decreases with altitude

4. (a) Pressure at point X = atmospheric pressure
Pressure at point $Y = 0$
(b) Since point X and point Z are at the same level,
Pressure at point X = pressure at point Z
Pressure at point X = atmospheric pressure, and
Pressure at point Z = pressure due to mercury column + 0
Atmospheric pressure = pressure due to mercury column
Therefore, the height of the mercury column, h is a measure of atmospheric pressure.
(c) Atmospheric pressure = 756 mm Hg = 0.756 m Hg
Atmospheric pressure $= 0.756 \times 13\ 600 \times 9.81$
$= 100\ 862$ Pa

5. Difference between the pressure of the compressed air and atmospheric pressure $= 180 - 103$
$= 77$ kPa
$= 77\ 000$ Pa

$h\rho g = 77\ 000$
$h \times 13\ 600 \times 9.81 = 77\ 000$
$h = 0.577$ m
$h = 57.7$ cm

Difference in height between the two mercury columns in the manometer = 57.7 cm



6. (a) Diameter of master cylinder = 0.8 cm

Cross-sectional area of master cylinder $= \frac{\pi \times 0.8^2}{4}$

$= 0.50\ \text{cm}^2$

Pressure $= \frac{400}{0.50}$

$= 800\ \text{N cm}^{-2}$

(b) Pascal's principle

(c) Cross-sectional area of slave cylinder $= \frac{\pi \times 2.5^2}{4}$

$= 4.91\ \text{cm}^2$

Braking force = pressure × surface area

$= 800 \times 4.91$

$= 3\ 928$ N

7. Mass of wooden block $= 3.24 \times 10^{-3} \times 920 = 2.98$ kg

Weight of wooden block $= 2.98 \times 9.81 = 29.23$ N

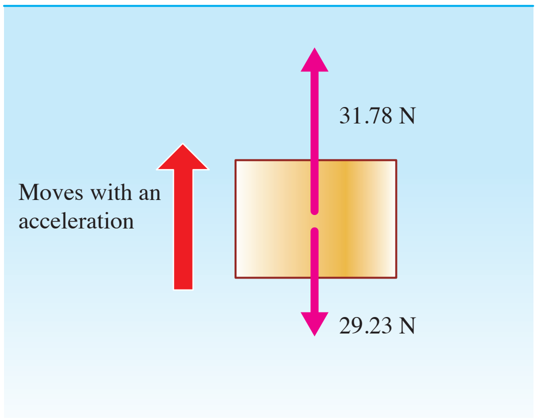
Buoyant force $= 3.24 \times 10^{-3} \times 1\ 000 \times 9.81$

$= 31.78$ N

Buoyant force > weight of block

There is a resultant force upwards

The block moves up with an acceleration



8. (a) The handle of the lever is pulled to the right.

An input force acts on the small piston.

The input force produces a pressure on the hydraulic oil.

Valve *A* opens, valve *B* closes.

Pressure is transmitted to the large piston.

A larger output force moves the large piston upwards.

The handle of the lever is pulled to the left.

Valve *A* closes, valve *B* opens.

The large piston stays at the same position.

Hydraulic oil flows from the reservoir into the small cylinder.

This process is repeated so that the large piston is moved a little at a time.

(b) • Lever: Design *X* is better than design *Y*.

A longer lever enables a larger input force to be exerted on the small piston.

• Cross-sectional area of small piston and large piston: Design *Y* is better than design *X*.

Output force, $F_2 = \frac{A_2}{A_1} \times F_1$

A_2 = cross-sectional area of large piston

A_1 = cross-sectional area of small piston

F_1 = input force

Design *Y* has larger A_2 and a smaller A_1 to give a larger multiplying factor $\frac{A_2}{A_1}$

- Volume of oil reservoir: Design X is better than design Y
  Design X has a larger volume of oil. More oil can be moved from the small cylinder to the large cylinder. The load on the large piston can be lifted to a greater height.

(c) Suggested design:
- Longer lever
- Smaller cross-sectional area for the small piston
- Larger cross-sectional area for the large piston
- Oil reservoir with a larger volume

9. (a) Archimedes' principle states that an object which is partially or fully immersed in a fluid will experience a buoyant force equal to the weight of fluid displaced.

(b) The balloon is stationary, that is the forces acting on the balloon are in equilibrium.
Resultant force on the balloon = 0.
Weight of balloon = buoyant force
According to Archimedes' principle, buoyant force = weight of air displaced
Therefore, weight of balloon = weight of air displaced

(c) When the flame of the burner is extinguished and the parachute valve is opened:
- part of the hot air in the balloon flows out through the valve
- temperature of the air in the balloon decreases
- cooler surrounding air flows into the balloon
- density of the balloon increases
- weight of the balloon increases

Since the weight of the balloon > buoyant force, there is a resultant force downwards
The balloon moves down until it reaches the ground.

10. (a) Pressure at point A < pressure at point B
because the depth of A is lower than B

(b) Pressure on the lower surface of the metal block > pressure on the upper surface of the metal block
Force on the lower surface of the metal block > force on the upper surface of the metal block
A resultant force acts upwards.
This resultant force is the buoyant force.

(c) Weight of block in air $= mg$
$= 0.050 \times 9.81$
$= 0.49$ N

When the metal block is in water:
Weight of metal block in water = 0.20 N
Apparent loss in weight of the metal block = 0.49 – 0.20
= 0.29 N
Buoyant force = apparent loss in weight of the metal block
= 0.29 N

Buoyant force, $F_B = \rho V g$,
ρ = density of water
V = volume of water displaced

$\rho V g = 0.29$
$1\,000 \times V \times 9.81 = 0.29$
$V = 2.96 \times 10^{-5}$ m^3

When the block is in oil:
Volume of oil displaced = volume of water displaced
$= 2.96 \times 10^{-5}$ m^3
Weight of metal block in oil = 0.25 N
Apparent loss in weight of the metal block = 0.49 – 0.25
= 0.24 N
Buoyant force = apparent loss in weight of the metal block
= 0.24 N

Buoyant force, $F_B = \rho Vg$,
ρ = density of oil
V = volume of oil displaced

$$\rho Vg = 0.24$$
$$\rho \times 2.96 \times 10^{-5} \times 9.81 = 0.24$$
$$\rho = 826.5 \text{ kg m}^{-3}$$

11. (a) Air flows at a lower velocity past the upper surface of the aerofoil to produce a region of high pressure.
Air flows at a higher velocity past the lower surface of the aerofoil to produce a region of low pressure.
The difference in pressure produces a resultant force downward.

(b) Air flows at a lower velocity past the upper surface of the car, producing a region of high pressure.
The space between the bottom of the car and the road is narrow.
Air flows at a higher velocity past the narrow space, producing a region of low pressure.
The difference in pressure produces a resultant force downward.

21st Century Challenge

12. (a) Weaknesses of the braking system of the car
- Brake pedal bar that is short and almost vertical
  Does not produce a large input force on the brake fluid in the master cylinder
- Air bubbles in the brake fluid
  Air can be compressed. The movement of the piston in the master cylinder produces a very small movement of the piston in the wheel cylinder
- The cross-sectional area of the wheel cylinder is almost the same as the cross-sectional area of the master cylinder.
  The multiplying factor is small. A large braking force cannot be produced.

(b) Suggested modifications:

Aspect	Suggestion	Explanation
(i) Characteristics of brake fluid	– Liquid with high boiling point – Low density – Liquid without rusting effect	Low rate of evaporation. Does not produce bubbles or vapour Can flow smoothly in the brake fluid lines Does not cause rusting of the brake fluid lines
(ii) Cross-sectional area of master cylinder	Smaller cross-sectional area	Produces a larger multiplying factor, and therefore a larger braking force
(iii) Cross-sectional area of wheel cylinder	Larger cross-sectional area	Produces a larger multiplying factor, and therefore a larger braking force
(iv) Length of brake pedal bar	Longer brake pedal bar	Produces a larger input force
(v) Additional design	A mechanical system or compressed air system between the brake pedal and master cylinder	Multiplies the force exerted by the foot of the driver so that a larger input force acts in the master cylinder

Chapter 3 Electricity

Formative Practice 3.1

1. A current is the rate of flow of charge in a conductor.
The potential difference is the work done to move one coulomb of charge between two points.

2. An electric field is the region around a charged particle where any electric charge in the region will experience an electric force.

3. Current, $I = 4.0 \times 10^{-2}$ A
Time, $t = 3$ h
$= 3 \times 60 \times 60$
$= 10\ 800$ s
$Q = ne$ and $It = ne$
$4.0 \times 10^{-2}(10\ 800) = n(1.6 \times 10^{-19})$
Number of electrons, $n = 2.7 \times 10^{21}$ electron

4. (a) Time, $t = 1 \times 3\ 600$
$= 3\ 600$ s
Current, $I = 0.2$ A
Charge flow, $Q = It$
$= 0.2 \times 3\ 600$
$= 720$ C
(b) Potential difference, $V = 3.0$ V
Charge flow, $Q = 720$ C
Energy, $E = VQ$
$= 3.0 \times 720$
$= 2\ 160$ J

5. Charge flow, $Q = 900$ C
Time, $t = 10$ min
$= 10 \times 60$
$= 600$ s
Current, $I = \dfrac{Q}{t}$
$= \dfrac{900}{600}$
$= 1.5$A

Formative Practice 3.2

1. Wire length, cross-sectional area of wire, resistivity and temperature.

2. Wire length, $l = 50.0$ m
Cross-sectional area, $A = 2.5\ \text{mm}^2$
$= 2.5 \times 10^{-3} \times 10^{-3}\ \text{m}^2$
$= 2.5 \times 10^{-6}\ \text{m}^2$
Resistivity of copper, $\rho = 1.72 \times 10^{-8}\ \Omega$ m
$R = \dfrac{\rho l}{A}$
$= \dfrac{(1.72 \times 10^{-8})50}{2.5 \times 10^{-6}}$
$= 0.344\ \Omega$

Formative Practice 3.3

1. The electromotive force, e.m.f. is the energy transferred or work done by a source of electrical energy to move one coulomb of charge in a complete circuit.

2. The electromotive force, e.m.f. is the work done by a source of electrical energy to move one coulomb of charge in a complete circuit and its value is measured when the switch is open (open circuit) while potential difference is the work done to move one coulomb of charge between two points in the external circuit and its value is measured when the switch is closed (closed circuit).

3. The magnitude of the current is smaller.

4. The dry cells are connected in parallel.

Formative Practice 3.4

1. (a) Power, $P = 80$ W
Time, $t = 10$ s
Electrical energy, $E = Pt$
$= 80(10)$
$= 800$ J

(b) Power, $P = 80$ W
Time, $t = 2$ h
$= 2 \times 60 \times 60$
$= 7\ 200$ s
Electrical energy, $E = Pt$
$= 80(7\ 200)$
$= 576$ kJ

2. (a) Power, $P = 600$ W
Time, $t = 8$ h
Energy used = 0.6 kW × 8 h
= 4.8 kWh
Unit cost = RM0.30
Cost of energy used = 4.8 × 0.30
= RM1.44

(b) Power, $P = 1$ kW
Time, $t = 0.5$ h
Energy used = 1 kW × 0.5 h
= 0.5 kWh
Unit cost = RM0.30
Cost of energy used = 0.5 × 0.30
= RM0.15

Summative Practice

1. – The filament lamps require high resistance to produce light.
– The coiled filament causes the wire length to increase.
– The resistance is directly proportional to the length of the wire.
– The longer the filament wire, the higher the resistance.
– The higher the resistance, the brighter the lamp.

2. (a) (i) Resistance, $\frac{1}{R} = \frac{1}{3} + \frac{1}{3}$
$= \frac{2}{3}$
$R = \frac{3}{2}$
$= 1.5\ \Omega$

Effective resistance, $R = 3 + 1.5$
$= 4.5\ \Omega$

(ii) Potential difference, $V = 6$ V
Effective resistance, $R = 4.5\ \Omega$
Current, $I = \frac{V}{R}$
$= \frac{6}{4.5}$
$= 1.33$ A

(iii) Current, $I = 1.33$ A
Resistance, $R = 3\ \Omega$
Potential difference, $V = IR$
$= 1.33 \times 3$
$= 3.99$ V

(b) Bulb X is the brightest compared to bulb Y and bulb Z. Bulb Y and bulb Z have the same brightness.

(c) (i) Effective resistance, $R = 3 + 3$
$= 6\ \Omega$

(ii) Potential difference, V = 6 V
Effective resistance, $R = 6\ \Omega$

Current, $I = \dfrac{V}{R}$

$= \dfrac{6}{6}$

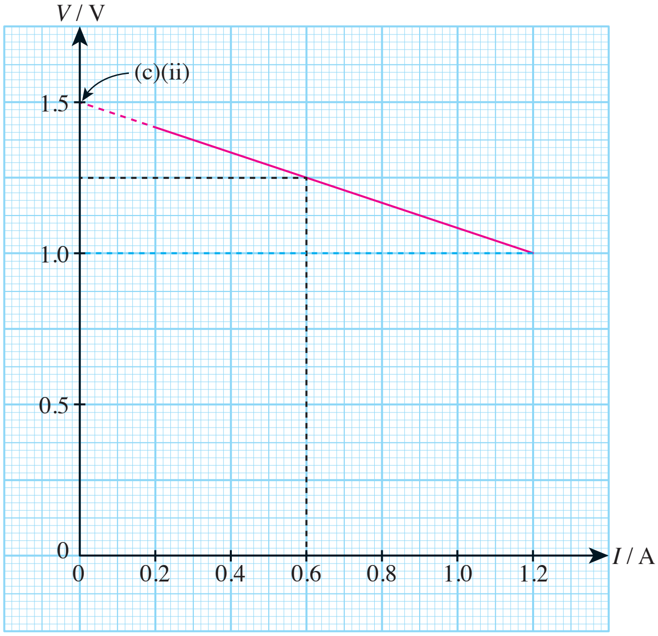
$= 1.0$ A

(iii) Current, $I = 1.0$ A
Resistance, $R = 3\ \Omega$
Potential difference, $V = IR$
$= 1 \times 3$
$= 3$ V

(d) Bulb X and bulb Y glow with equal brightness. Bulb Z does not light up.

3. (a) The electromotive force, e.m.f. is the energy transferred or work done by a source of electrical energy to move one coulomb of charge in a complete circuit.

(b)



(c) (i) V decreases linearly with I

(ii) From the graph above, $V = 1.5$ V

(iii) Electromotive force, e.m.f.

(d) Gradient, $m = \dfrac{1.0 - 1.5}{1.2 - 0}$
$= -\ 0.417\ \Omega$

Internal resistance, $r = -m$
$= -(-0.417)$
$= 0.417\ \Omega$

(e) – Make sure the connecting wires are tightly connected.
– Avoid parallax errors when taking ammeter and voltmeter readings.

4. (a) The resistivity of a conductor, ρ is a measure of a conductor's ability to oppose the flow of electric current.

(b) (i) The gradient of the lead wire graph is greater.

(ii) The resistivity of the lead wire is greater.

(c) – The greater the gradient of the graph, the greater the resistivity of the conductor.
– The gradient of the graph is directly proportional to the resistivity of the conductor.

5. (a) The fuse melts when the current exceeds the value of the fuse current, thereby disconnecting the circuit.
(b) A total of 1 500 J of electrical energy is consumed per second when connected to a 240 V power supply
(c)

Feature	Explanation
The heating element is nichrome	Nichrome has high resistivity
The heating wire has many turns of coil	It produces a high resistance
There are many fan blades	More hot air can be spread
A suitable fuse must have a current specification that is slightly higher than the current that goes into the air fryer	The current flowing through the air fryer is 6.25 A. Hence an 8 A fuse is suitable for use

(d) Air fryer *D* is the most suitable because it has a nichrome heating element, a heating wire with many turns of coil, a large number of fan blades and an 8 A fuse.

6. (a) The most suitable type of electric stove to be used must have four characteristics of the heater as follow:
– Metal resistivity at 20° C is high. Therefore, does not need a long wire to obtain the resistance required to make the stove heat up quickly.
– High thermal conductivity. Therefore, the stove will heat up quickly.
– High melting point. Therefore, it can withstand heat and the heater will not melt at high temperatures.
– Low oxidation rate. Therefore, it does not rust easily and is more durable.
(b) The type *R* of electric stove is the most suitable for use due to its high metal resistivity, high thermal conductivity, high melting point and low oxidation rate.

21st Century Challenge

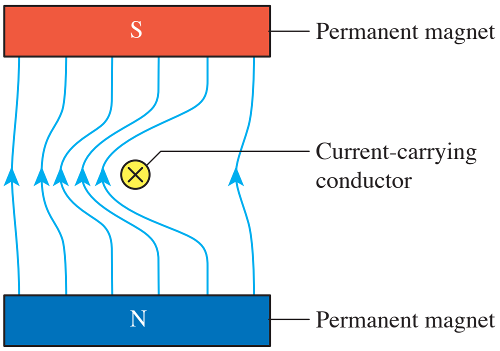
7.

Feature	Explanation
The heating wire has many turns of coil	Long wire, the resistance is high
Low density heating element material	Light
Small diameter of the heating wire	High resistance
The heating element is nichrome	High resistivity

Chapter 4 Electromagnetism

Formative Practice 4.1

1. A catapult field is a resultant magnetic field produced by the interaction between the magnetic field from a current-carrying conductor with the magnetic field from a permanent magnet.



2. (a) X to Y
   (b) The current in copper wire XY produces a magnetic field that superimposes with the magnetic field from the permanent magnet.
   The two magnetic fields combine to produce a catapult magnetic field.
   The catapult magnetic field exerts a force on wire XY and moves the wire.
   The direction of motion of wire XY is to the right.
3. Current in the coil, number of turns of the coil, strength of magnetic field
4. (a) Both consist of a coil and permanent magnets
   Brushed motor: The permanent magnet is stationary while the coil rotates
   Brushless motor: The coil is stationary while the magnet rotates
   (b) Lower level of operational sound
   Lower maintenance cost

Formative Practice 4.2

1. Electromagnetic induction is the production of an induced e.m.f. in a conductor when there is relative motion between the conductor and a magnetic field or when the conductor is in a changing magnetic field.
2. (a) Faraday's law states that the magnitude of induced e.m.f. is directly proportional to the rate of cutting of magnetic flux.
   (b) When a coil rotates and cuts magnetic field lines, an e.m.f. is induced in the coil. If the speed of rotation is increased, the rate of cutting of magnetic flux increases. According to Faraday's law, the induced e.m.f. increases.
3. (a) When the bar magnet moves towards the copper ring, magnetic field lines are cut by the ring. An induced e.m.f. is produced in the ring. This induced e.m.f. produces an induced current in the copper ring.
   (b) Anti-clockwise.
   (c) According to Lenz's law, the anti-clockwise current produces a magnetic north pole to oppose the motion of the bar magnet.
   This causes the motion of the bar magnet to be slowed down.

Formative Practice 4.3

1. The alternating voltage produces an alternating current in the primary coil.
   The alternating current produces a changing magnetic field.
   The magnetic field is linked to the secondary coil through the soft iron core.
   The changing magnetic field induces an alternating voltage in the secondary coil.
   The number of turns of the secondary coil is less than the number of turns of the primary coil.
   The voltage across the secondary coil is lower than the voltage across the primary coil.
   Therefore, the transformer steps down voltage.
2. (a) Efficiency, $\eta = \frac{\text{Output power}}{\text{Input power}} \times 100\%$

$$= \frac{V_S I_S}{V_P I_P} \times 100\%$$

$$= \frac{6 \times 4.80}{120 \times 0.25} \times 100\%$$

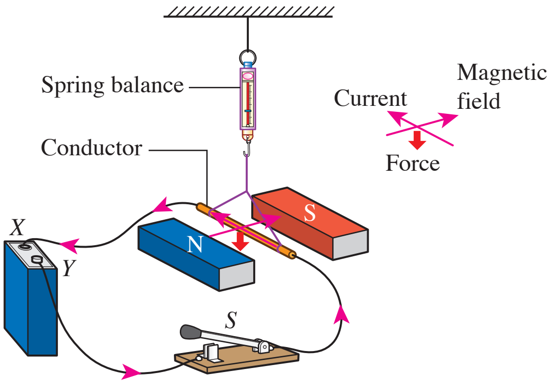
$$= 96.00\%$$

   (b) The resistance of the coil causes heating of the coil when a current flows through it. This results in energy loss in the form of heat.
   Hysteresis caused by the magnetisation and demagnetisation of the soft iron core results in energy loss in the form of heat.
3. The alternating current in the coil produces a changing magnetic field.
   The changing magnetic field induces eddy currents in the base of the pot.
   The eddy currents flow along a path of low resistance and heats up the base of the pot.
4. (a) Step-up transformer
   (b) Step-down transformer

Summative Practice

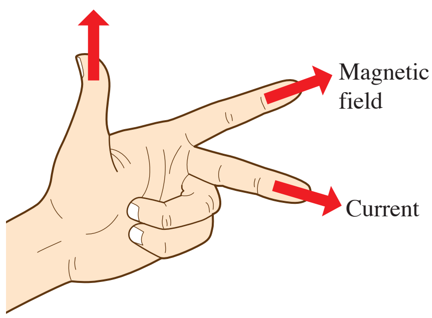
1. (a) *X*: negative, *Y*: positive, *P*: north, *Q*: south

(b) When switch *S* is turned on, current flows in the circuit from *Y* to *X*. The direction of the magnetic field from the permanent magnet is from north to south.
According to Fleming's left-hand rule, a force acts on the conductor in the downward direction.



(c) Increase the current by adding another dry cell in series.
Replace the permanent magnet with a stronger permanent magnet.

2. Fore finger: Direction of magnetic field
Middle finger: Direction of current
Thumb: Direction of force



3. (a) Induced current is the current produced in a conductor when there is relative motion between the conductor and a magnet that causes the conductor to cut magnetic field lines.

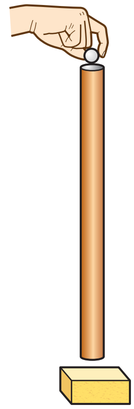
(b) *X*: north pole
Y: south pole

(c) Figure (a): Direction of motion of magnet to the left
Figure (b): Direction of motion of magnet to the right

(d) Increase the number turns of the solenoid
Increase the speed of motion of the magnet

4.
$$V_S I_S = V_P I_P$$
$$6 \times I_S = 240 \times 0.18$$
$$I_S = 7.2 \text{ A}$$
The loss of energy from the transformer can be neglected, that is the transformer is ideal.

5. The copper tube is held vertically with a piece of sponge below it.
Release the metal balls one by one to fall through the copper tube onto the sponge.
The ball that takes a shorter time to fall onto the sponge is the steel ball.
The ball that takes a longer time to fall onto the sponge is the neodymium magnet ball.
When the neodymium magnet ball falls, magnetic field lines cut the copper tube.
Eddy currents are induced in the copper tube.
According to Lenz's law, the eddy currents will produce a magnetic field that opposes the motion of the neodymium ball.
Since the neodymium magnet is a strong magnet and copper is a good conductor.
The eddy currents produce a strong magnetic field. Therefore, the fall of the neodymium magnet ball is slowed down.



6. (a) Induced current is produced in the solenoid.
The motion of the bar magnet towards the solenoid causes the cutting of magnetic field lines by the solenoid.
An e.m.f. is induced across the solenoid.
When the switch is turned on, the induced e.m.f. produces an induced current in the solenoid.
(b) The motion of the block will experience a deceleration.
According to Lenz's law, the induced current produces a magnetic pole at the end of the solenoid that is the same as the pole of the bar magnet so that the motion of the bar magnet is opposed.
(c) Electromagnetic braking is more effective than braking that uses frictional force.
– does not need human action to activate the braking process
– does not need electric power to produce a braking force
– the magnitude of the braking force is controlled by factors such as the strength of the magnet and number of turns of the solenoid, that is factors that can be fixed during the construction of the system.

7. (a)
$$V_S I_S = V_P I_P$$
$$12 \times I_S = 240 \times 0.125$$
$$I_S = 2.5 \text{ A}$$
(b) The transformer is ideal

8. Efficiency, $\eta = \dfrac{\text{Output power}}{\text{Input power}} \times 100\%$
$$= \frac{V_S I_S}{V_P I_P} \times 100\%$$
$$= \frac{48 \times 0.6}{12 \times 4.0} \times 100\%$$
$$= 60.00\ \%$$
– Use laminated soft iron core
– The secondary coil is wound on top of the primary coil

21st Century Challenge

9.

Problem	Suggestion for improvement	Explanation
Slow speed of rotation	Add more turns to the coil	The magnitude of the force on the coil is increased
	Use stronger permanent magnets	The magnitude of the force on the coil is increased
	Use finer copper wire to construct the coil	The coil will not be too heavy although the number of turns has increased
Speed of rotation of the disc cannot be controlled	Connect a rheostat in the circuit	The current in the coil can be adjusted. Therefore, the magnitude of the force that rotates the coil can be controlled. Hence, the speed of rotation can be controlled.

Rotation of the disc is not smooth	Prepare four sets of coils wound on a soft iron core and a commutator with eight parts	The coil experiences a force that is more uniform
Dry cell loses its power quickly	Connect a few similar dry cells in parallel	The total internal resistance of the dry cell is reduced

Chapter 5 Electronics

Formative Practice 5.1

1. (a) Thermionic emission is the emission of electrons from a heated metallic surface. The cathode rays are high-speed electron beams in a vacuum tube.
(b) Cathode rays are negatively charged, possess momentum and kinetic energy, move in straight lines and can be deflected by electric fields and magnetic fields.

2. (a) (i) Heats the cathode to a high temperature
(ii) Emits electrons (thermionic emission)
(iii) Accelerates the electron beam until it reaches a high velocity
(iv) Produces light spots when high-velocity electron beams hit the fluorescent screen
(b) So that the electrons do not collide with the air molecules.

3. (a) Uniform acceleration
(b) Electrical potential energy is converted into kinetic energy of electron
(c) $eV = \frac{1}{2}mv^2_{max}$
that is e = charge of an electron (1.6×10^{-19} C)
V = potential difference between cathode and anode
m = mass of electron (9.1×10^{-31} kg)
v_{max} = maximum velocity of electron

4. $v = \sqrt{\frac{2eV}{m}}$

$= \sqrt{\frac{2 \times 1.6 \times 10^{-19} \times 800}{9.1 \times 10^{-31}}}$

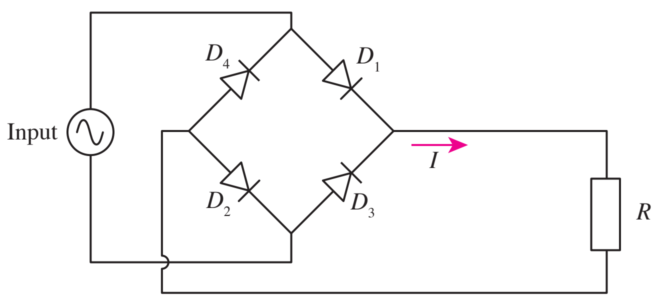
$= 1.68 \times 10^7$ m s^{-1}

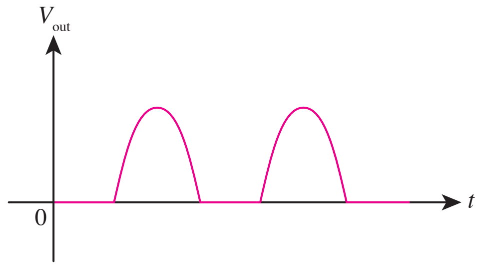
The electron velocity will be doubled if the potential difference is increased by four times.

Formative Practice 5.2

1. (a) An electronic component which allows electric current to flow in one direction only.
(b) A situation when the positive terminal of a dry cell is connected to the anode of diode and the negative terminal is connected to the cathode of diode, enabling electric current to flow in a circuit.
(c) Conversion of an alternating current to a direct current.

2.



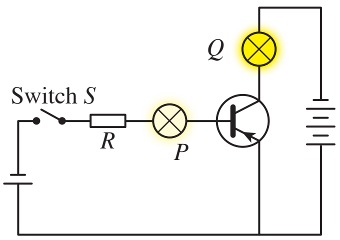


3. (a) Capacitor
(b) The capacitor is connected in parallel with the load.
When the potential difference increases, the capacitor will be charged and energy is stored in the capacitor. When the potential difference decreases, the capacitor will be discharged so that the output current does not fall to zero value. The energy stored in the capacitor will maintain the potential difference across the resistor. From the shape of the smoothed output wave, it shows that the capacitor functions as a current smoother.

Formative Practice 5.3

1. (a) pnp transistor
(b) Supply charge carriers to the collector

2. (a) *A* is the base circuit and *B* is the collector circuit.
(b) The current flowing through bulb *P* is very small.
(c)



3. Potential difference, $V_0 = 6$ V
Resistance, $R = 10$ kΩ
Potential difference across *XY*, $V_{XY} = 5.5$ V

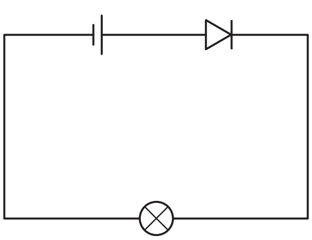
$$V_{XY} = \frac{10}{10 + R_T} \times 6$$

$$5.5 = \frac{10}{10 + R_T} \times 6$$

$$\text{Thermistor resistance, } R_T = \frac{60}{5.5} - 10$$
$$= 10.9 - 10$$
$$= 0.9 \text{ k}\Omega$$

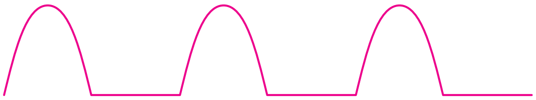
Summative Practice

1. (a)

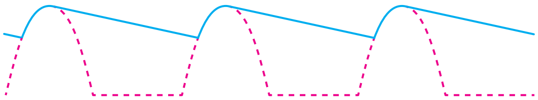


(b) The bulb does not light up because the diode is a in reverse biased state.

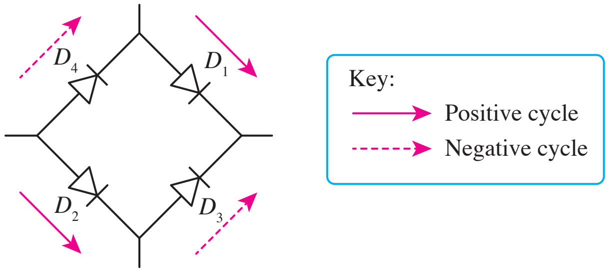
2. (a)



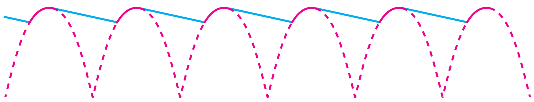
(b)



3. (a)

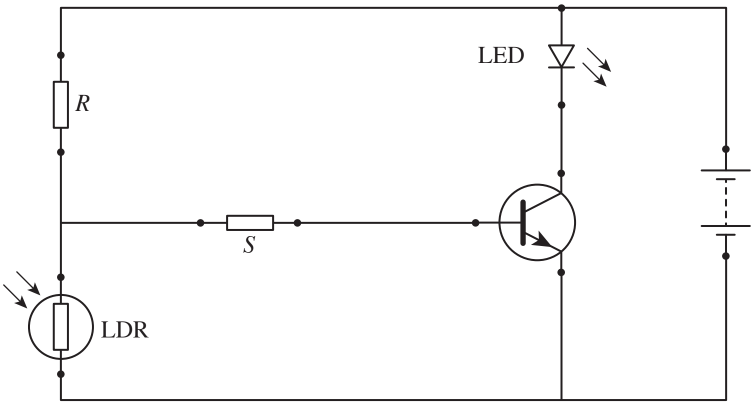


(b) The capacitor acts as a current smoother



(c) Half-wave rectification will occur

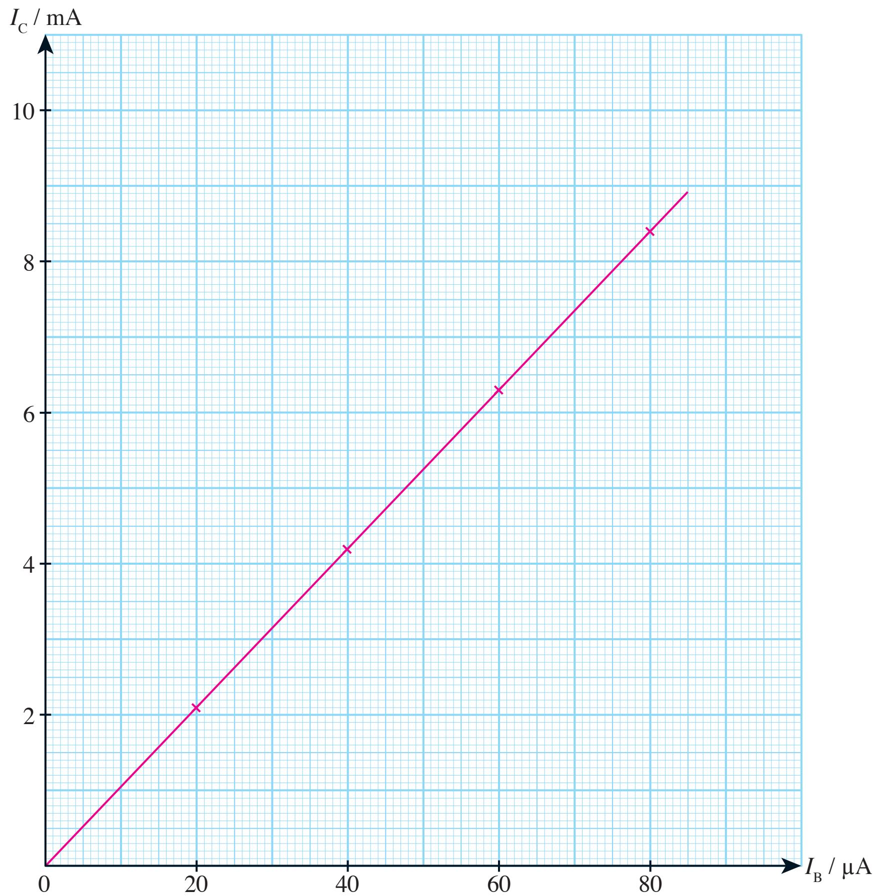
4. (a)



(b) Under bright conditions, LDR resistance becomes low.
Therefore, the voltage across LDR decreases but the voltage across R is increased. The I_B is low and the transistor is turned off. The I_C will be low and the LED will not light up.

(c) Replace LED with an alarm, replace resistor with a thermistor and the LDR with a resistor.

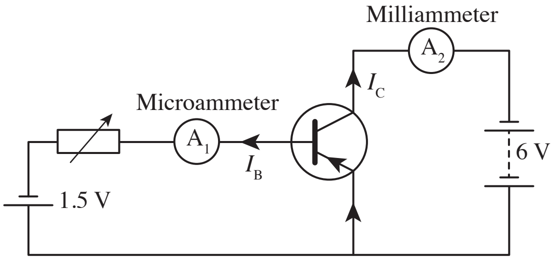
5. (a)



(b) (i) I_C is directly proportional to I_B. The graph of I_C against I_B shows a straight line passing through the origin with a positive gradient.

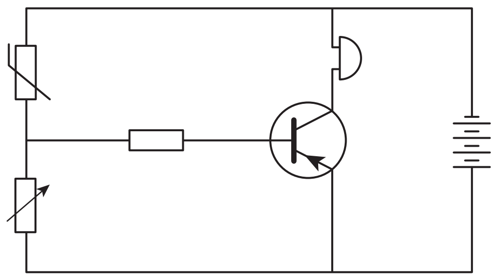
(ii) – Transistors play a role as current amplifiers.
– The graph has a positive gradient and is a straight line, so the collector current changes proportionally with the base current.
– The gradient of the graph is 105, thefore the amplification factor is 105.

(c)



21st Century Challenge

6. (a)



(b)

	Component	Suitability
A	Battery	A transistor only functions in a direct current power supply (negative terminals are shown above because a pnp transistor is used)
B	Electric bell	To produce a sound in the event of a fire
C	Thermistor	Its resistance will decrease when the surrounding temperature increases
D	Resistor	Acts as a protector / limiter of current to the very thin base of the transistor
E	Rheostat	The resistance of a rheostat can be initially adjusted according to the surrounding temperature in order to supply a suitable voltage across it to turn on the transistor in an emergency situation

Chapter 6 Nuclear Physics

Formative Practice 6.1

1. (a) $^{228}_{89}\text{Ac}$

(b) $^{4}_{2}\text{He}$

(c) $^{1}_{0}n$

2. $238 = 4(x) + 0\ (y) + 206$

$x = 8$

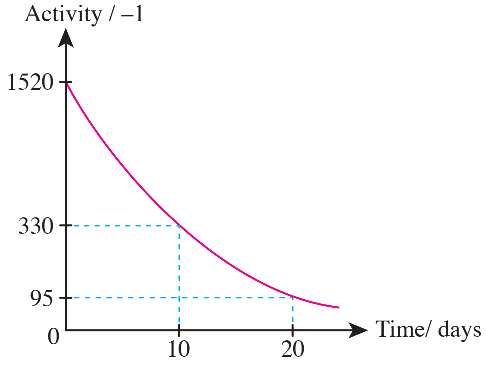
$92 = 2(x) - 1(y) + 8$

$y = 6$

The number of particles that are emitted is 8 α-particles and 6 β-particles.

3. (a) $\frac{1\,520}{95} = 16 = 2^4$, 4 half-lives = 20 days, half-life = 5 days

(b)



Formative Practice 6.2

1. Nuclear fission is a nuclear reaction in which a heavy nucleus splits into two or more lighter nuclei and releases a large amount of energy. Nuclear fusion is a nuclear reaction in which two small and light nuclei fuse to form a heavier nucleus while releasing a large amount of energy.
2. In a nuclear reactor, a uranium-235 nucleus is bombarded by a neutron to form the uranium-236 nucleus which is unstable. The unstable uranium-236 nucleus will split to produce lighter and more stable nuclei such as barium-141 and krypton-92 as well as three new neutrons. The three neutrons released will then bombard three other uranium-235 nuclei to form three heavy unstable uranium-236 nuclei. These unstable uranium-236 nuclei will undergo nuclear fission which in turn produce other neutrons that enable the subsequent nuclear fission. The nuclear energy produced increases with the increasing number of fissions of nuclei.
3. In a nuclear reactor, fissions occurs when uranium-235 nuclei are bombarded by neutrons to form a chain reaction. The resulting nuclear energy boils water to become steam. High pressure steam is channeled to rotate the turbine. Rotating turbines with switch on dynamos that generate electrical energy.
4. $E = mc^2$
   $E = 0.19585 \times 1.66 \times 10^{-27} \times (3.0 \times 10^8)^2$
   $= 2.9260 \times 10^{-11}$ J
   $= 2.93 \times 10^{-11}$ J

Summative Practice

1. (a) A radioactive decay is a random and spontaneous process by which an unstable nucleus will decay by emitting radioactive radiation to become a more stable nucleus.
   (b) The half life, $T_{\frac{1}{2}}$ is the time taken for a sample of radioactive nuclei to decay to half of its initial number.
   (c) Nuclear energy is the energy produced by reactions in atomic nuclei.
2. (a) X is the helium nucleus or α-particle, Y is γ-ray.
   (b) 3 α-particles and 2 β-particles are released.
3. (a) $100\% \xrightarrow{1} 50\% \xrightarrow{2} 25\% \xrightarrow{3} 12.5\% \xrightarrow{4} 6.25\% \xrightarrow{5} 3.125\% \xrightarrow{6} 1.5625\% \xrightarrow{7} 0.78125\%$
   Total time = 7 × 1.6 s
   = 11.2 s

   (b) $n = \frac{8\ 000}{1\ 600}$
   $= 5$

   $\frac{N}{N_0} = \left(\frac{1}{2}\right)^5 = 0.03125$

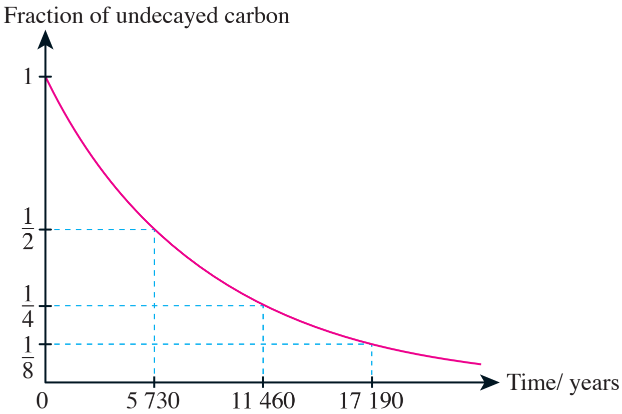
   Change the fraction into percentage = 0.03125 × 100%
   = 3.125%

   so after $5T_{\frac{1}{2}}$, only 3.125% of the sample remains.
4. (a) A is the older sample. The ratio of uranium-238 to plumbum-206 is smaller.
   (b) Suppose that during the rock formation, only uranium-238 was trapped. The oldest rock formed on Earth is about 4.28 billion years. The half-life of uranium-238 is 4.5 billion years. Therefore, the decay process of uranium-238 in a rock sample has gone through less than one half-life. Hence, less than half of the uranium-238 nuclei in the sample of rock had decayed to form lead-206 nuclei. So the number of lead-206 nuclei cannot be more than the remaining uranium-238 nuclei.
5. (a) $n = \frac{17\ 190}{5\ 730}$
   $= 3$

   $1 \xrightarrow{1} \frac{1}{2} \xrightarrow{2} \frac{1}{4} \xrightarrow{3} \frac{1}{8}$

   After 1.719×10^4 years, $\frac{1}{8}$ of carbon-14 in the sample has not decayed.

(b)



6. (a) Nuclear fusion

$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n$ + energy

(b) Mass defect, m = (4.00260 +1.00866) – (2.01410 + 3.01605)

= 0.01889 amu

The nuclear energy that is released

$= 0.01889 \times 1.66 \times 10^{-27} \times (3.00 \times 10^{8})^{2}$

$= 2.82 \times 10^{-12}$ J

7. (a) $235 = 4(x) + 0(y) + 207$

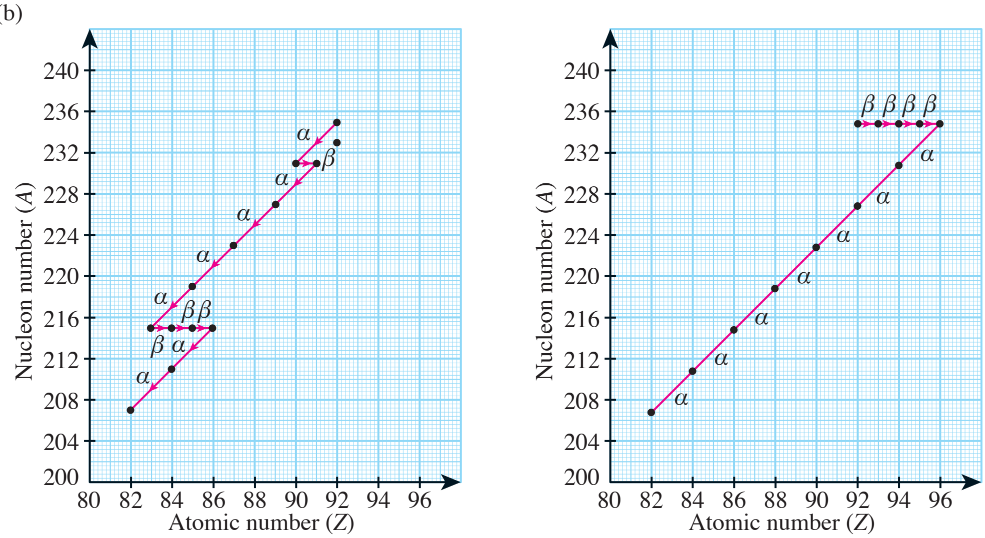
$x = 7$

$92 = 2(x) - 1(y) + 82$

$y = 4$

7 α-particles and 4 β-particles are emitted.

(b)



Note: Any relevant graph is accepted

8. (a) The chain reaction resulting from neutron bombardment on the uranium-235 nuclei produces a large amount of nuclear energy in the reactor.

(b) Heat energy boils the cold water. The high pressure steam produced is capable of rotating a turbine at extremely high speed.

(c) The rotation of a turbine will enable the dynamo to generate electricity by electromagnetic induction.

(d) After passing the turbines, the steam will be cooled by large amounts of water from lakes or ponds. Part of the heat generated through the steam cooling process is released through the cooling tower. A nuclear reactor needs to have a complete cooling system that is in good working condition. A faulty cooling system can cause a reactor core meltdown and lead to a serious radioactive leakage disaster.

21st Century Challenge

9.

Suggestion	Characteristics	Justification
Location	By the sea or near abundance of natural water sources	• Abundance of water to function as cooling agents.
Walls of reactor core	Made of thick lead metal	• Prevents radioactive radiation from escaping into the environment
Walls of reactor building	Built of thick concrete	• Prevents radioactive radiation from escaping into the environment
Cooling agent	Water to act as cooling agent	• Water has a high specific heat capacity. • It can absorb large amounts of heat with a small rise in temperature.
Energy control methods	Boron control rod	• The reactor core is equipped with control rods to control the chain reaction. • The control rods will absorb excess neutrons produced from the nuclear fission.
	Graphite moderator	• The moderator slows down the neutrons to ensure a continuous nuclear fission in the reactor core.
Waste management	Disposal and storage facility site for radioactive waste material is developed	• Radioactive waste materials are buried at disposal and storage facility site at a certain depth. This facility site is situated far from residential areas depending on the type of radioactive waste.
Safety precautions	Safety precautions and work procedures in accordance to International Atomic Energy Agency (IAEA) standards	• To ensure the safety of mankind and the environment

Chapter 7 Quantum Physics

Formative Practice 7.1

1. Speed of light in vacuum, $c = 3.00 \times 10^8$ m s^{-1}

Wavelength, $\lambda = 10$ nm

$= 10 \times 10^{-9}$ m

Planck's constant, $h = 6.63 \times 10^{-34}$ J s

Frequency, $f = \frac{c}{\lambda}$

$= \frac{3.00 \times 10^8}{10 \times 10^{-9}}$

$= 3.0 \times 10^{16}$ Hz

Energy, $E = hf$

$= (6.63 \times 10^{-34})(3.0 \times 10^{16})$

$= 1.99 \times 10^{-17}$ J

2. Photon power, $P = 50$ W
Planck's constant, $h = 6.63 \times 10^{-34}$ J s
Frequency of green light, $f = 5.49 \times 10^{14}$ Hz
$P = nhf$
Number of photons emitted per second, $n = \dfrac{P}{hf}$

$$= \frac{50}{(6.63 \times 10^{-34})(5.49 \times 10^{14})}$$

$$= 1.37 \times 10^{20} \text{ s}^{-1}$$

3. (a) de Broglie wavelength,

$$E = \frac{1}{2}mv^2$$

$$mv = \sqrt{2mE}$$

$$\lambda = \frac{h}{mv}$$

$$= \frac{h}{\sqrt{2mE}}$$

$$= \frac{6.63 \times 10^{-34}}{\sqrt{2(9.11 \times 10^{-31})(50 \times 1.60 \times 10^{-19})}}$$

$$= 1.74 \times 10^{-10} \text{ m}$$

(b) Electron diffraction

Formative Practice 7.2

1. Emission of electrons from a metal surface when shone on by light of a certain frequency.

2. Yes. The number of photoelectrons emitted depends on the number of photons that arrive on the metal surface.

3. – The higher the frequency of the light photons, the higher the kinetic energy of the photoelectrons emitted from the metal surface.
– The minimum frequency of light needed for a metal to emit electrons is the threshold frequency, f_0 for the metal.
– The kinetic energy of photoelectrons does not depend on the intensity of light.
– Photoelectrons are emitted instantaneously when shone on by light.

4. Light consists of discrete energy packets, when a photon hits a metal surface, all its energy will be transferred to an electron in the metal. With this, the photoelectron will be emitted instantanteously from the metal surface if the frequency of light is higher than the threshold frequency of the metal.

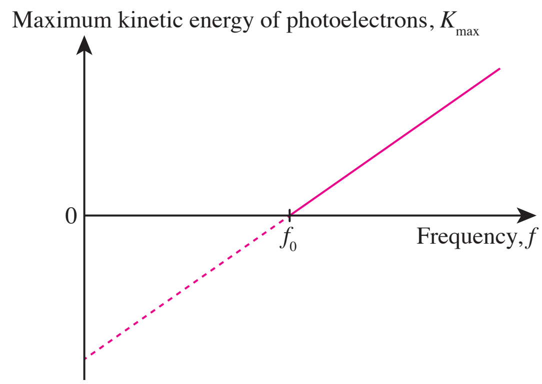
5. No. The intensity of light only affects the number of photons arriving on the metal per second (photon rate). The maximum kinetic energy of a photoelectron is influenced by the photon energy. Increasing the light intensity will not increase the kinetic energy of the photoelectrons.

Formative Practice 7.3

1. (a) $hf = W + \frac{1}{2}mv^2_{max}$

(b) (i) Work function, W is the minimum energy required for a photoelectron to be emitted from a metal surface.
(ii) Threshold frequency, f_0 is the minimum frequency for a light photon to produce photoelectric effect.
(iii) $W = hf_0$

2. (a)



(b) Gradient of the graph = Planck's constant, h
Graph intercept on the frequency axis = threshold frequency of the metal, f_0
Graph intercept on the K_{max} axis = work function of the metal, W

3. Work function, $W = 4.32 \times 10^{-19}$ J
Wavelength, $\lambda = 4 \times 10^{-7}$ m
Planck's constant, $h = 6.63 \times 10^{-34}$ J s
Speed of light in vacuum, $c = 3.00 \times 10^{8}$ m s^{-1}

$$hf = W + K_{max}$$

$$\text{then } c = \lambda f \text{ or } f = \frac{c}{\lambda}$$

So, $$\frac{hc}{\lambda} = W + K_{max}$$

$$K_{max} = \frac{hc}{\lambda} - W$$

$$= \frac{(6.63 \times 10^{-34})(3.00 \times 10^{8})}{4 \times 10^{-7}} - 4.32 \times 10^{-19}$$

$$= 6.53 \times 10^{-20} \text{ J}$$

Summative Practice

1. (a) A black body is an ideal body that is able to absorb all the electromagnetic rays that fall on it.
(b) Quantum of energy is a discrete packet of energy and not a continuous energy.

2. (a) Work function of sodium metal $= 2.28$ eV
$= 2.28 \times 1.60 \times 10^{-19}$
$= 3.65 \times 10^{-19}$ J

Photon energy of the red light $= \dfrac{hc}{\lambda}$

$$= \frac{(6.63 \times 10^{-34})(3.00 \times 10^{8})}{680 \times 10^{-9}}$$

$$= 2.93 \times 10^{-19} \text{ J}$$

Photoelectric effect does not occur because of the photon energy of the red light is lower than work function of sodium metal.

(b) Work function of sodium metal $= \dfrac{hc}{\lambda_0}$

Threshold wavelength, $\lambda_0 = \dfrac{hc}{W}$

$$= \frac{(6.63 \times 10^{-34})(3.00 \times 10^{8})}{3.65 \times 10^{-19}}$$

$$= 5.45 \times 10^{-7} \text{ m}$$

$$= 545 \text{ nm}$$

3. de Broglie wavelength, $\lambda_e = \dfrac{h}{p}$

$$= \frac{h}{\sqrt{2meV}},\ K = eV$$

$$590 \times 10^{-9} = \frac{6.63 \times 10^{-34}}{\sqrt{2 \times 9.11 \times 10^{-31} \times K}}$$

$$K = \frac{\left(\dfrac{(6.63 \times 10^{-34})}{590 \times 10^{-19}}\right)^2}{2 \times 9.11 \times 10^{-31}}$$

$$= 6.93 \times 10^{-25}\ \text{J}$$

4. (a) Momentum $= \dfrac{h}{\lambda}$

$$= \frac{6.63 \times 10^{-34}}{555 \times 10^{-9}}$$

$$= 1.19 \times 10^{-27}\ \text{kg m s}^{-1}$$

(b) $P = \dfrac{nhc}{\lambda}$

$$n = \frac{P\lambda}{hc}$$

$$= \frac{(5.00 \times 10^{-3})(555 \times 10^{-9})}{(6.63 \times 10^{-34})(3 \times 10^{8})}$$

$$= 1.40 \times 10^{16}\ \text{s}^{-1}$$

5. (a) Louis de Broglie hypothesised that particles such as electrons could have wave properties.

de Broglie wavelength, $\lambda_e = \dfrac{h}{p}$

p is the momentum of the electron

(b) Momentum of the electron, $p = \dfrac{h}{\lambda}$

$$= \frac{6.63 \times 10^{-34}}{1.00 \times 10^{-9}}$$

$$= 6.63 \times 10^{-25}\ \text{kg m s}^{-1}$$

(c) Velocity of the electron, $v = \dfrac{p}{m}$

$$= \frac{6.63 \times 10^{-25}}{9.11 \times 10^{-31}}$$

$$= 7.28 \times 10^{5}\ \text{m s}^{-1}$$

(d) $\lambda = \dfrac{h}{\sqrt{2mE}}$

$$\lambda^2 = \frac{h^2}{2mE}$$

Kinetic energy of the electron, $E = \dfrac{h^2}{2m\lambda^2}$

$$= \frac{(6.63 \times 10^{-34})^2}{2(9.11 \times 10^{-31})(1.00 \times 10^{-9})^2}$$

$$= 2.41 \times 10^{-19}\ \text{J}$$

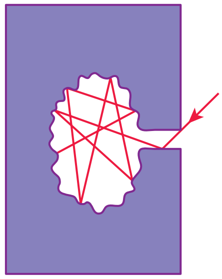
or

$$E = \frac{1}{2}mv^2$$

$$= \frac{1}{2}(9.11 \times 10^{-3})(7.28 \times 10^{5})^2$$

$$= 2.41 \times 10^{-19}\ \text{J}$$

6. (a) The rays of light that enter the large cavity will undergo repeated reflections on the inner walls of the cavity. At each reflection, part of the rays are absorbed by the inner walls of the cavity. Reflections continue to occur until all the rays are absorbed and none of them can leave the cavity. Thus, the cavity acts like a black body.



(b) As the temperature of the black body increases, the intensity of the radiation emitted increases rapidly. The intensity of the violet-blue rays increases more than the orange-yellow rays. Therefore, the black body is violet-blue at 9 000 K.

7. (a) $p = \dfrac{h}{\lambda}$

$= \dfrac{6.63 \times 10^{-34}}{800 \times 10^{-9}}$

$= 8.29 \times 10^{-28}$ kg m s^{-1}

(b) The energy carried by each photon, $E = \dfrac{hc}{\lambda}$

$= \dfrac{(6.63 \times 10^{-34})(3.00 \times 10^{8})}{800 \times 10^{-9}}$

$= 2.49 \times 10^{-19}$ J

(c) Number of photons per second, n

$P = \dfrac{nhc}{\lambda}$

$60 \times 10^{-3} = n(2.49 \times 10^{-19})$

$n = \dfrac{60 \times 10^{-3}}{2.49 \times 10^{-19}}$

$= 2.41 \times 10^{17}$ s^{-1}

(d) Total momentum per second = momentum of one photon × number of photons per second

$= 8.29 \times 10^{-28} \times 2.41 \times 10^{17}$

$= 2.0 \times 10^{-10}$ kg m s^{-2}

8.

Wavelength, λ	**Photon energy, E**	**Region of the electromagnetic spectrum**
500 nm	2.5 eV (3.98×10^{-19}J)	Visible light
25 nm (2.49×10^{-8} m)	50 eV	Ultraviolet
40 µm (3.98×10^{-5} m)	5.0×10^{-21} J	Infrared

$E = \dfrac{hc}{\lambda}$

$= \dfrac{(6.63 \times 10^{-34})(3.00 \times 10^{8})}{500 \times 10^{-9}}$

$= 3.98 \times 10^{-19}$ J

$\lambda_1 = \dfrac{hc}{E}$

$= \dfrac{(6.63 \times 10^{-34})(3.00 \times 10^{8})}{50 \times 1.6 \times 10^{-19}}$

$= 2.49 \times 10^{-8}$ m

$\lambda_2 = \frac{hc}{E}$

$= \frac{(6.63 \times 10^{-34})(3.00 \times 10^{8})}{5.0 \times 10^{-21}}$

$= 3.98 \times 10^{-5}$ m

9. (a) $f_0 = \frac{c}{\lambda_0}$

$= \frac{3.00 \times 10^{8}}{1\ 110 \times 10^{-9}}$

$= 2.70 \times 10^{14}$ Hz

$W = hf_0$

$= (6.63 \times 10^{-34})(2.70 \times 10^{14})$

$= 1.79 \times 10^{-19}$ J

(b) At room temperature, the thermal energy is insufficient to release electrons in a photocell or to activate the photocell.

10. (a) $\lambda = \frac{h}{mv}$

$= \frac{6.63 \times 10^{-34}}{(5 \times 10^{-10})(0.4)}$

$= 3.32 \times 10^{-24}$ m

(b) No. The de Broglie wavelength of the sand is too short (10^{-24} m) compared to the size of the hole (1 mm). If the size of the hole is further reduced to approximate the order of the de Broglie wavelength, the sand will not be able to pass through it because the diameter of the sand is 0.07 mm.

11. (a) Work function, W

$$hf = W + K$$

$$\frac{hc}{\lambda} = W + K$$

$$\frac{(6.63 \times 10^{-34})(3.00 \times 10^{8})}{700 \times 10^{-9}} = W + K \quad ....(1)$$

$$\frac{(6.63 \times 10^{-34})(3.00 \times 10^{8})}{400 \times 10^{-9}} = W + 2K \quad ....(2)$$

$$2 \times (1) - (2): W = 2 \times \frac{(6.63 \times 10^{-34})(3.00 \times 10^{8})}{700 \times 10^{-9}} - \frac{(6.63 \times 10^{-34})(3.00 \times 10^{8})}{400 \times 10^{-9}}$$

$$= 7.10 \times 10^{-20} \text{ J}$$

(b) Threshold wavelength, λ_0

$\frac{hc}{\lambda_0} = W$

$\lambda_0 = \frac{(6.63 \times 10^{-34})(3.00 \times 10^{8})}{7.10 \times 10^{-20}}$

$= 2.80 \times 10^{-6}$ m

(c) de Broglie wavelength, λ_p

$\frac{hc}{\lambda} = W + K_{max}$

$K_{max} = \frac{hc}{\lambda} - W$

$= \frac{(6.63 \times 10^{-34})(3.00 \times 10^{8})}{131 \times 10^{-9}} - 7.10 \times 10^{-20}$

$= 1.48 \times 10^{-18}$ J

$\lambda_p = \frac{h}{\sqrt{2m_e K}}$

$= \frac{6.63 \times 10^{-34}}{\sqrt{2(9.11 \times 10^{-31})(1.48 \times 10^{-18})}}$

$= 4.04 \times 10^{-10}$ m

21st Century Challenge

12. (a) Based on Einstein's Photoelectric Equation,

$hf = W + K_{max}$

$hf = W + eV_s,\ W = \dfrac{hc}{\lambda_0}$

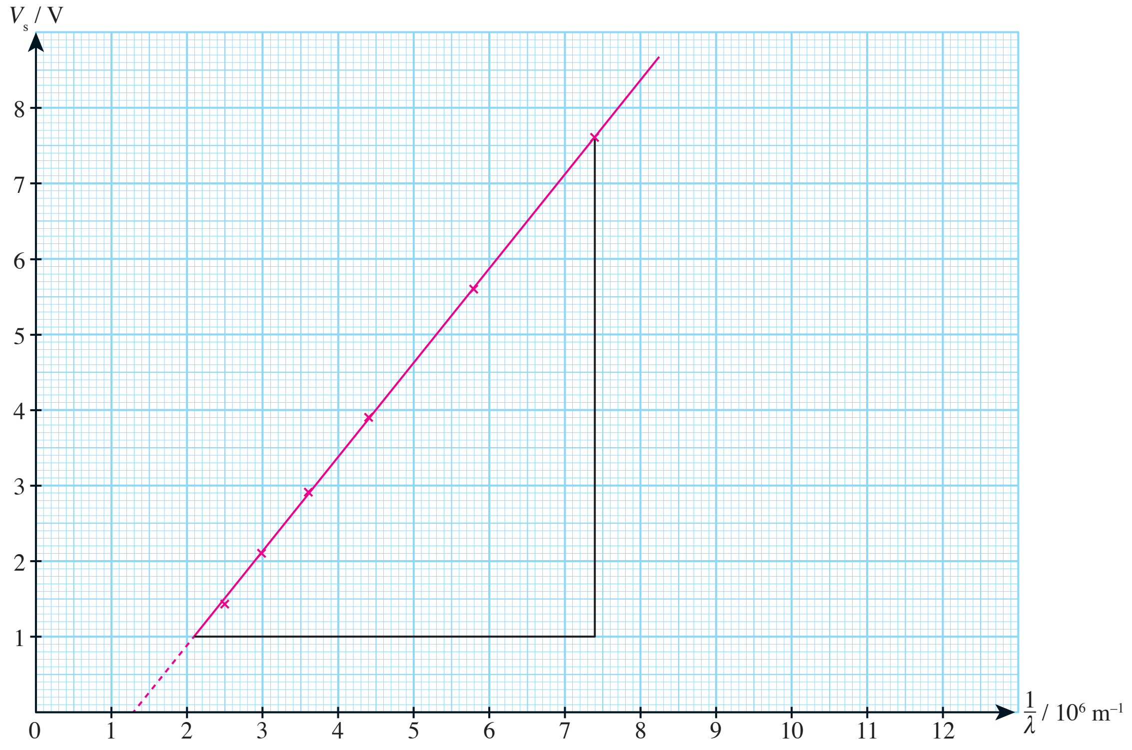
$\dfrac{hc}{\lambda} = \dfrac{hc}{\lambda_0} + eV_s$

$eV_s = h\left(\dfrac{c}{\lambda}\right) - h\left(\dfrac{c}{\lambda_0}\right)$

$V_s = \dfrac{hc}{e}\left(\dfrac{1}{\lambda} - \dfrac{1}{\lambda_0}\right)$

(b)

λ / nm	V_s / V	$\frac{1}{\lambda}$ / 10^6 m^{-1}
135	7.53	7.4
172	5.59	5.8
227	3.98	4.4
278	2.92	3.6
333	2.06	3.0
400	1.43	2.5



Gradient of graph, $m = \dfrac{7.53 - 1.00}{(7.4 - 2.1) \times 10^6}$

$= 1.23 \times 10^{-6}$ V m

$h = \frac{me}{c}$

$= \frac{(1.23 \times 10^{-6})(1.60 \times 10^{-19})}{3.00 \times 10^{8}}$

$= 6.56 \times 10^{-34}$ J s

Threshold wavelength, $\frac{1}{\lambda_0} = 1.3 \times 10^{6}$ m^{-1}

$\lambda_0 = 7.69 \times 10^{-7}$ m

Work function of $X = \frac{hc}{\lambda_0}$

$= \frac{(6.63 \times 10^{-34})(3.00 \times 10^{8})}{7.69 \times 10^{-7}}$

$= 2.59 \times 10^{-19}$ J

(c) $\frac{hc}{\lambda} = W + K_{max}$

$\lambda = \frac{hc}{W + K_{max}}$

$= \frac{(6.63 \times 10^{-34})(3.00 \times 10^{8})}{2.59 \times 10^{-19} + 10.0 \times 1.60 \times 10^{-19}}$

$= 8.37 \times 10^{-8}$ m

(d) $\lambda_e = \frac{h}{\sqrt{2mE}}$

$= \frac{6.63 \times 10^{-34}}{\sqrt{2(9.11 \times 10^{-31})(10.0 \times 1.60 \times 10^{-19})}}$

$= 3.88 \times 10^{-10}$ m

(e) For a night vision device, X should have a threshold wavelength longer than that of visible light ($4 \sim 7 \times 10^{-7}$ m).
X has a threshold wavelength of 7.69×10^{-7} m so it can be activated by radiation outside the wavelength of visible light and function in the dark.