Cambridge IGCSE™

CANDIDATE NAME

CENTRE NUMBER

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PHYSICS **0625/41**

Paper 4 Theory (Extended) **May/June 2020**

1 hour 15 minutes

You must answer on the question paper.

No additional materials are needed.

INSTRUCTIONS

- Answer **all** questions.
- Use a black or dark blue pen. You may use an HB pencil for any diagrams or graphs.
- Write your name, centre number and candidate number in the boxes at the top of the page.
- Write your answer to each question in the space provided.
- Do **not** use an erasable pen or correction fluid.
- Do **not** write on any bar codes.
- You may use a calculator.
- You should show all your working and use appropriate units.
- Take the weight of 1.0 kg to be 10 N (acceleration of free fall = 10 m/s^2).

INFORMATION

- The total mark for this paper is 80.
- The number of marks for each question or part question is shown in brackets [ ].

This document has **16** pages. Blank pages are indicated.

[Turn over

1   An aeroplane of mass 2.5×10^5 kg lands with a speed of 62 m/s, on a horizontal runway at time $t = 0$. The aeroplane decelerates uniformly as it travels along the runway in a straight line until it reaches a speed of 6.0 m/s at $t = 35$ s.

   (a) Calculate:

   (i) the deceleration of the aeroplane in the 35 s after it lands

   deceleration = ... [2]

   (ii) the resultant force acting on the aeroplane as it decelerates

   force = ... [2]

   (iii) the momentum of the aeroplane when its speed is 6.0 m/s.

   momentum = ... [2]

   (b) At $t = 35$ s, the aeroplane stops decelerating and moves along the runway at a constant speed of 6.0 m/s for a further 15 s.

   On Fig. 1.1, sketch the shape of the graph for the distance travelled by the aeroplane along the runway between $t = 0$ and $t = 50$ s. You are **not** required to calculate distance values.
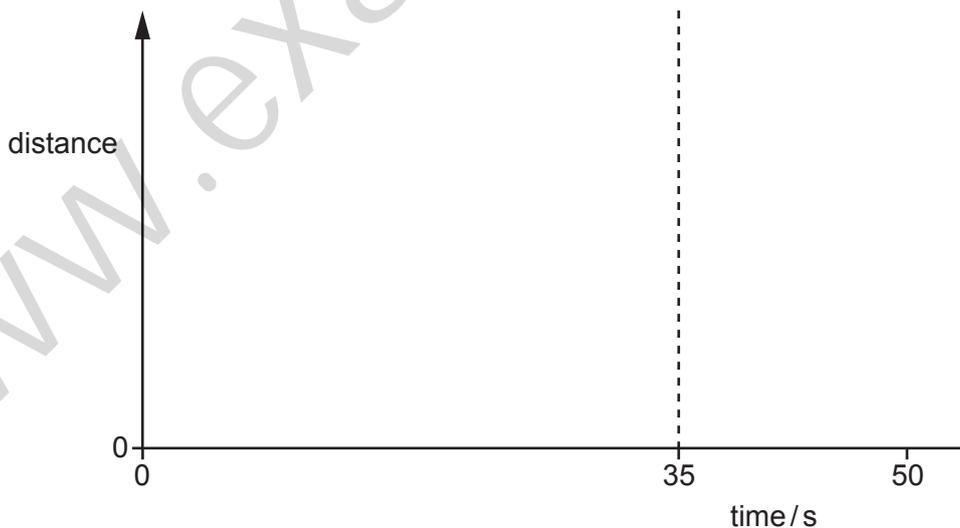

Fig. 1.1

[3]

(c) As the aeroplane decelerates, its kinetic energy decreases.

Suggest what happens to this energy.

....

.... [1]

[Total: 10]

Question no. 1

(a)(i) Deceleration of the aeroplane

The aeroplane lands with an initial speed of **62 m/s** and slows down uniformly to a final speed of **6.0 m/s** in **35 s**.

For uniform acceleration (or deceleration), the acceleration is given by:

change in velocity ÷ time taken.

Change in velocity
= final velocity − initial velocity
= 6.0 − 62
= −56 m/s

Acceleration
= −56 ÷ 35
= −1.6 m/s²

The negative sign shows the aeroplane is slowing down, so the **magnitude of the deceleration** is:

Deceleration = 1.6 m/s²

(a)(ii) Resultant force acting on the aeroplane

Newton's second law states that the resultant force acting on an object is equal to the **rate of change of momentum**, or equivalently **mass × acceleration**.

Mass of aeroplane = 2.5×10^5 kg
Deceleration = 1.6 m/s²

Resultant force
= mass × acceleration
= $2.5 \times 10^5 \times 1.6$
= 4.0×10^5 N

This force acts **opposite to the direction of motion**, causing the aeroplane to slow down.

Resultant force = 4.0 × 10⁵ N

(a)(iii) Momentum of the aeroplane at 6.0 m/s

Momentum is given by:

momentum = mass × velocity

Momentum
= $2.5 \times 10^5 \times 6.0$
= 1.5×10^6 kg m/s

Momentum = 1.5 × 10⁶ kg m/s

(b) Distance–time graph from t = 0 s to t = 50 s

You are **not required to calculate distances**, only to sketch the **shape** of the graph.

Key ideas to use:

- The **gradient of a distance–time graph represents speed**.
- From **0 to 35 s**, the aeroplane is **decelerating**, so its speed is decreasing.
- From **35 to 50 s**, the aeroplane moves at a **constant speed of 6.0 m/s**.

Shape of the graph:

- From **t = 0 to t = 35 s**:
    o The graph starts at the origin.
    o It is a **curve with decreasing gradient** (steep at first, then becoming less steep), because the speed is decreasing uniformly.
- At **t = 35 s**:
    o The gradient is **still positive and not zero**, because the aeroplane is still moving.
    o There is **no sudden change in gradient**.
- From **t = 35 to t = 50 s**:
    o The graph becomes a **straight line with constant positive gradient**, showing constant speed.

Correct sketch (distance–time):

Distance–time graph (shape) from t = 0 to 50 s
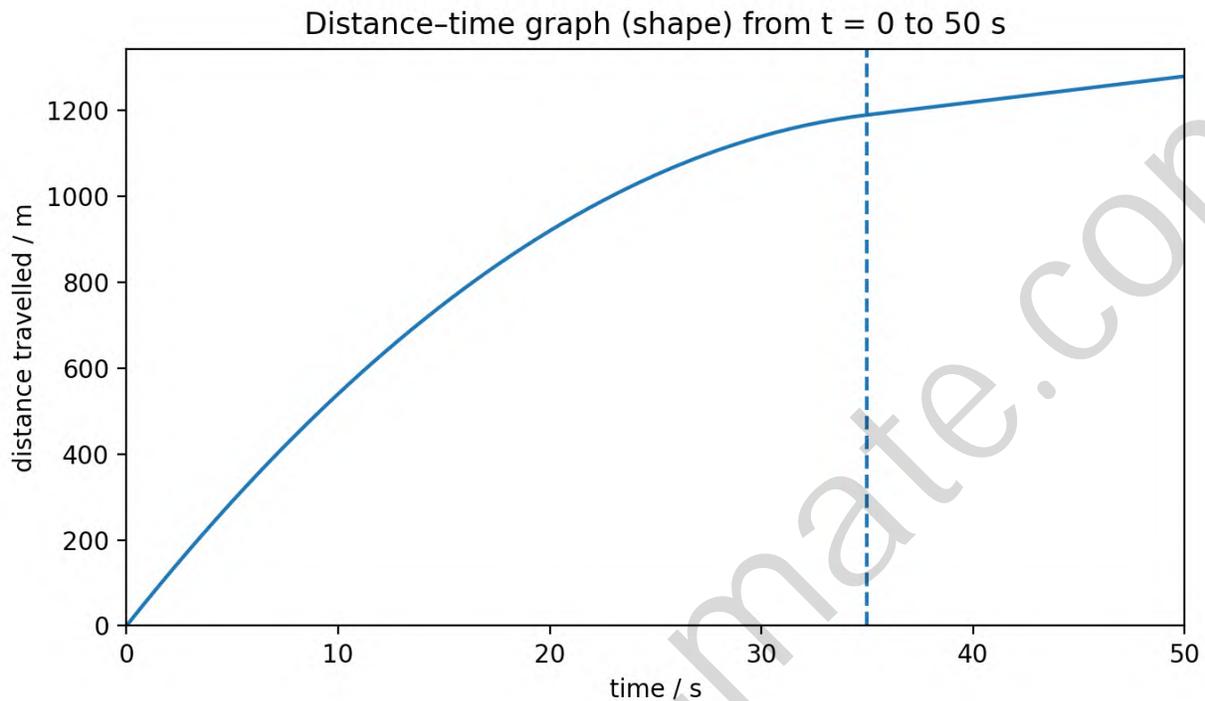
(Any smooth curve of decreasing gradient up to 35 s, followed by a straight line, gains full marks.)

(c) What happens to the kinetic energy?

As the aeroplane decelerates, its kinetic energy decreases because work is done against resistive forces.

This kinetic energy is mainly:

- **Converted into thermal energy** due to friction and air resistance, especially in the **brakes, tyres, and surrounding air**
- Some energy also becomes **kinetic energy of the air** due to turbulence and drag

The kinetic energy is dissipated mainly as thermal energy in the brakes, tyres, and air.

2 Fig. 2.1 is the extension–load graph for a light spring S.
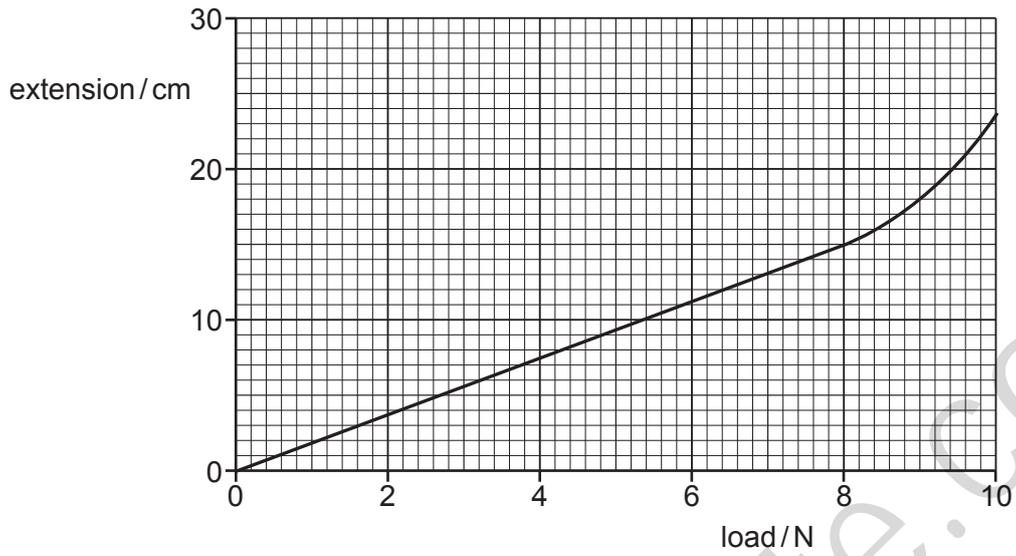
Fig. 2.1

(a) State the range of loads for which S obeys Hooke's law.

from .... to .... [1]

(b) Using information from Fig. 2.1, determine the spring constant k of spring S.

k = ... [2]

(c) A second spring, identical to spring S, is attached to spring S. The two springs are attached to a rod, as shown in Fig. 2.2. A load of 4.0 N is suspended from the bottom of spring S. The arrangement is in equilibrium.
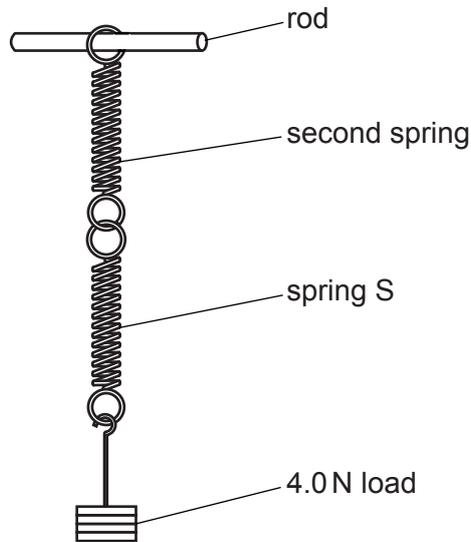
Fig. 2.2

(i) State the name of the form of energy stored in the two springs when they are stretched.

.... [1]

(ii) Determine the extension of the arrangement in Fig. 2.2.

extension = ... cm [1]

(iii) The load is carefully increased to 6.0 N in total.

Calculate the distance moved by the load to the new equilibrium position as the load increases from 4.0 N to 6.0 N.

distance moved = ... [1]

[Total: 6]

Question no. 2

(a) Range of loads for which spring S obeys Hooke's law

A spring obeys **Hooke's law** when its **extension is directly proportional to the applied load**. On an extension–load graph, this corresponds to the region where the graph is a **straight line passing through the origin**.

From Fig. 2.1, the graph is a straight line starting from **0 N** and remains linear up to a load of **8.0 N**. Beyond 8.0 N, the graph curves, showing that extension is no longer proportional to load.

Therefore, spring S obeys Hooke's law from 0 N to 8.0 N.

(b) Determination of the spring constant k of spring S

The spring constant k is defined by the equation:

load = k × extension

so,

k = load / extension

From the straight-line (Hooke's law) region of Fig. 2.1, a convenient point to use is:

- Load = **8.0 N**
- Extension = **15 cm**, which is **0.15 m**

Substituting these values:

k = 8.0 / 0.15

This gives:

k ≈ 53 N m^{-1}

(Equivalently, this may be stated as **0.53 N cm^{-1}**, which is also acceptable.)

(c)(i) Form of energy stored in the stretched springs

When a spring is stretched and remains within its elastic limit, the energy stored is **elastic potential energy**.

Therefore, the energy stored in the two stretched springs is elastic potential energy.

(c)(ii) Extension of the arrangement in Fig. 2.2

In Fig. 2.2, **two identical springs are connected in series**, and a load of **4.0 N** is applied. In a series arrangement, **the same force acts through each spring**, and the **total extension is the sum of the extensions of the individual springs**.

From Fig. 2.1, a load of **4.0 N** produces an extension of **7.5 cm** in a single spring.

Since there are **two identical springs** in series:

Total extension = 7.5 cm + 7.5 cm = 15 cm

Therefore, the extension of the arrangement is 15 cm.

(c)(iii) Distance moved when the load increases from 4.0 N to 6.0 N

When the load increases, the system moves to a new equilibrium position. Because the springs obey Hooke's law in this range, **extension is proportional to load**.

From part (c)(ii), the total extension at **4.0 N** is **15 cm**. Increasing the load from **4.0 N to 6.0 N** represents an increase of **2.0 N**, which is **half of 4.0 N**.

Since extension is proportional to load:

Additional extension = 15 cm ÷ 2 = 7.5 cm

This additional extension is the **distance moved by the load**.

Therefore, the distance moved is 7.5 cm.

✅ **Final Answers Summary (for checking)**

- **(a)** from **0 N to 8.0 N**
- **(b) k ≈ 53 N m⁻¹**
- **(c)(i) elastic potential energy**
- **(c)(ii) 15 cm**
- **(c)(iii) 7.5 cm**

3 Fig. 3.1 shows gas trapped in the sealed end of a tube by a dense liquid.
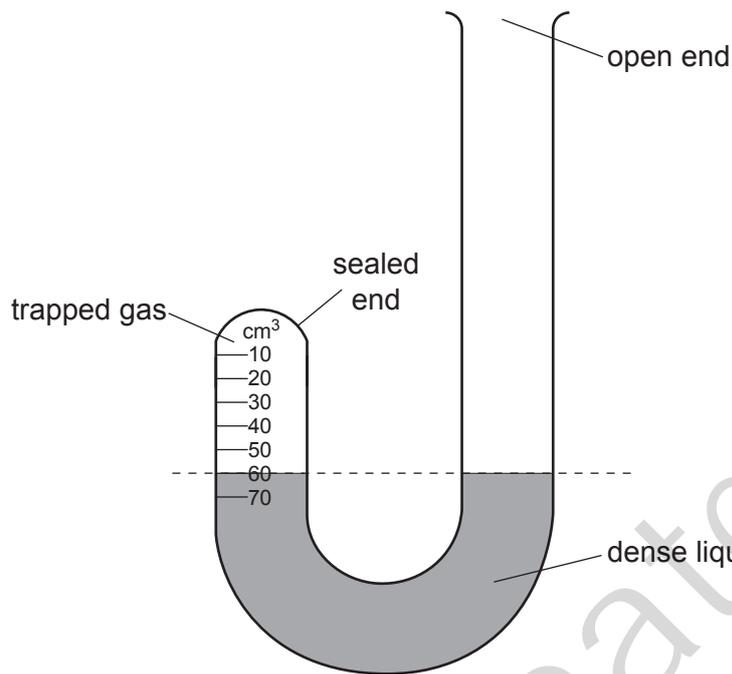

Fig. 3.1

The scale marked on the sealed end of the tube is calibrated to read the volume of gas trapped above the liquid surface. Fig. 3.1 shows that initially the volume V_1 of the gas is $60\,cm^3$.

The pressure of the atmosphere is $1.0 \times 10^5\,Pa$.

(a) State how Fig. 3.1 shows that the pressure of the trapped gas is equal to the pressure of the atmosphere.

....

.... [1]

(b) Explain, in terms of the momentum of its molecules, why the trapped gas exerts a pressure on the walls of the tube.

....

....

....

.... [3]

(c) More of the dense liquid is poured into the open end of the tube. The level of the liquid surface in both the sealed and the open ends of the tube rises as shown in Fig. 3.2. The temperature of the trapped gas and atmospheric pressure both remain constant.
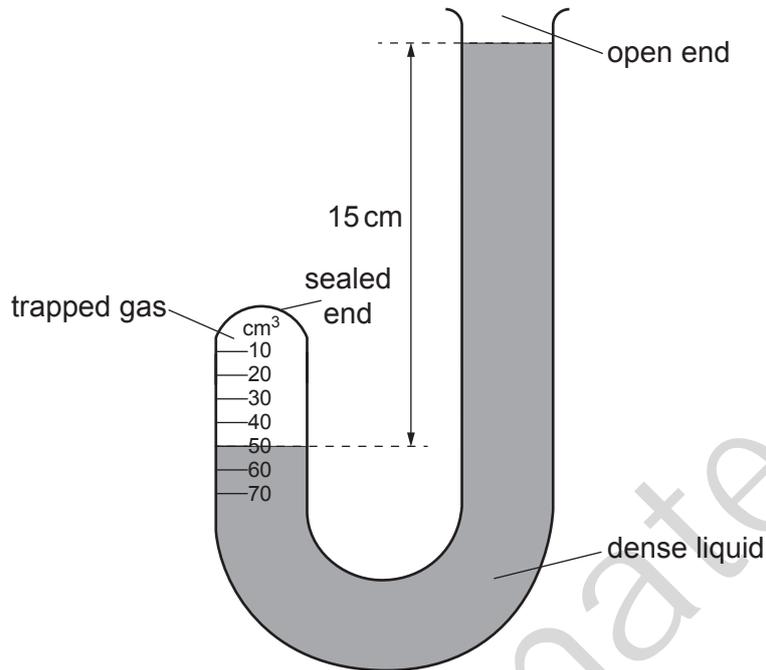
Fig. 3.2

(i) In the sealed end of the tube, the volume V_2 of the trapped gas is $50\,cm^3$. In the open end of the tube, the liquid surface is 15 cm above the new level in the sealed tube.

Calculate the pressure p_2 of the trapped gas.

pressure p_2 = ... [2]

(ii) Calculate the density of the liquid in the tube.

density = ... [2]

[Total: 8]

Question no. 3

(a) How Fig. 3.1 shows that the pressure of the trapped gas is equal to atmospheric pressure

Figure 3.1 shows that the **levels of the dense liquid in the sealed limb and the open limb are at the same horizontal level**. The liquid in the open limb is exposed to the **atmosphere**, so the pressure acting on it is the **atmospheric pressure**.

Because the liquid levels are equal, this shows that there is **no pressure difference between the two sides** at the same depth in the liquid. Therefore, the pressure exerted by the trapped gas on the liquid must be **equal to the atmospheric pressure**.

(b) Why the trapped gas exerts a pressure on the walls of the tube (in terms of momentum)

The trapped gas consists of molecules that are in **constant random motion**. These molecules **collide repeatedly with the walls of the tube**.

When a gas molecule strikes the wall, it **rebounds**, so its velocity changes direction. This means that the **momentum of the molecule changes**. A change in momentum requires a force, so the molecule exerts a **force on the wall**.

Because a very large number of molecules collide with the walls every second, these forces are **spread over the area of the walls**. The result is a steady **force per unit area**, which is the **pressure exerted by the gas**.

(c)(i) Calculation of the pressure p_2 of the trapped gas

When more dense liquid is added, the **temperature of the trapped gas remains constant**, so the gas undergoes an **isothermal change**. Under these conditions, **Boyle's law applies**, meaning that pressure is inversely proportional to volume.

Initially:

- the pressure p_1 of the gas is equal to atmospheric pressure, which is **1.0×10^5 pascals**

- the initial volume V_1 is **60 cubic centimetres**

After adding the liquid:

- the new volume V_2 is **50 cubic centimetres**

Using Boyle's law in words:
initial pressure multiplied by initial volume equals final pressure multiplied by final volume.

So the new pressure p_2 is calculated by multiplying the initial pressure by the ratio of the initial volume to the final volume:

$p_2 = 1.0 \times 10^5 \times 60 \div 50$

This gives:

$p_2 = 1.2 \times 10^5$ pascals

(c)(ii) Calculation of the density of the liquid

In Fig. 3.2, the liquid level in the open limb is **15 centimetres higher** than the liquid level in the sealed limb. This shows that the pressure of the trapped gas is **greater than atmospheric pressure**.

The pressure difference is found by subtracting atmospheric pressure from the trapped gas pressure:

pressure difference = $1.2 \times 10^5 - 1.0 \times 10^5$
pressure difference = **2.0×10^4 pascals**

This pressure difference is caused by the **column of dense liquid**, so it is equal to the product of the liquid's density, gravitational field strength, and height of the column.

The height of the liquid column is **15 centimetres**, which is **0.15 metres**, and the gravitational field strength is taken as **10 metres per second squared**.

Rearranging to find density and substituting the values:

density = $2.0 \times 10^4 \div (0.15 \times 10)$

This gives:

density = 1.3 × 10⁴ kilograms per cubic metre

✅ **Final answers**

- **Pressure p_2 = 1.2 × 10⁵ pascals**
- **Density of the liquid = 1.3 × 10⁴ kilograms per cubic metre**

4 Water has a specific heat capacity of 4200 J / (kg °C) and a boiling point of 100 °C.

(a) State what is meant by *boiling point*.

....

.... [1]

(b) A mass of 0.30 kg of water at its boiling point is poured into a copper container which is initially at 11 °C. After a few seconds, the temperature of the container and the water are both 95 °C.

(i) Calculate the energy transferred from the water.

energy transferred = ... [2]

(ii) Calculate the thermal capacity of the copper container.

thermal capacity of the copper container = ... [2]

(iii) Water from the container evaporates and the temperature of the remaining water decreases slowly.

Explain, in terms of molecules, why evaporation causes the temperature of the remaining water to decrease.

....

....

....

.... [3]

[Total: 8]

Question no. 4

(a) Boiling point

The **boiling point** of a substance is the **temperature at which the liquid changes into a gas (boils)** (for a given external pressure, usually atmospheric pressure).

(b)(i) Energy transferred from the water

The water cools from **100 °C to 95 °C**, so the temperature drop is:

ΔT = 100 − 95 = 5 °C

Energy transferred from the water:
Energy = m c ΔT
= 0.30 × 4200 × 5
= 0.30 × 21000
= **6300 J**

So, the **energy transferred from the water = 6300 J**.

(b)(ii) Thermal capacity of the copper container

The copper container warms from **11 °C to 95 °C**, so:

ΔT (container) = 95 − 11 = 84 °C

Assuming the energy lost by the water is gained by the container (over these few seconds), the container gains **E = 6300 J**.

Thermal capacity, C, is:
C = E / ΔT
= 6300 / 84
= **75 J °C⁻¹** (to 2 s.f.)

So, the **thermal capacity of the copper container = 75 J °C⁻¹**.

(b)(iii) Why evaporation makes the remaining water cool (molecular explanation)

In liquid water, molecules have a **range of kinetic energies**. During evaporation, the molecules that escape from the surface are usually the **more energetic (faster) molecules**, because they have enough energy to **overcome the attractive forces** (intermolecular forces) holding them in the liquid.

To break away, they must do **work against these attractive forces**, which requires energy. This energy comes from the water itself, so when the highest-energy molecules leave, the **average kinetic energy of the remaining molecules decreases**. Since temperature is a measure of the **average kinetic energy of the molecules**, the **temperature of the remaining water falls**.

5 The distance between the centre of a thin converging lens and each principal focus is 5.0 cm.

(a) Describe what is meant by the term *principal focus* for a thin converging lens.

....

....

.... [2]

(b) The lens is used as a magnifying glass to produce an image I of an object O.

(i) Underline the terms that describe the nature of the image produced by a magnifying glass. [2]

diminished   **enlarged**   **inverted**   **real**   **same size**   **upright**   **virtual**

(ii) Fig. 5.1 is a full-scale diagram of the lens and the image I.
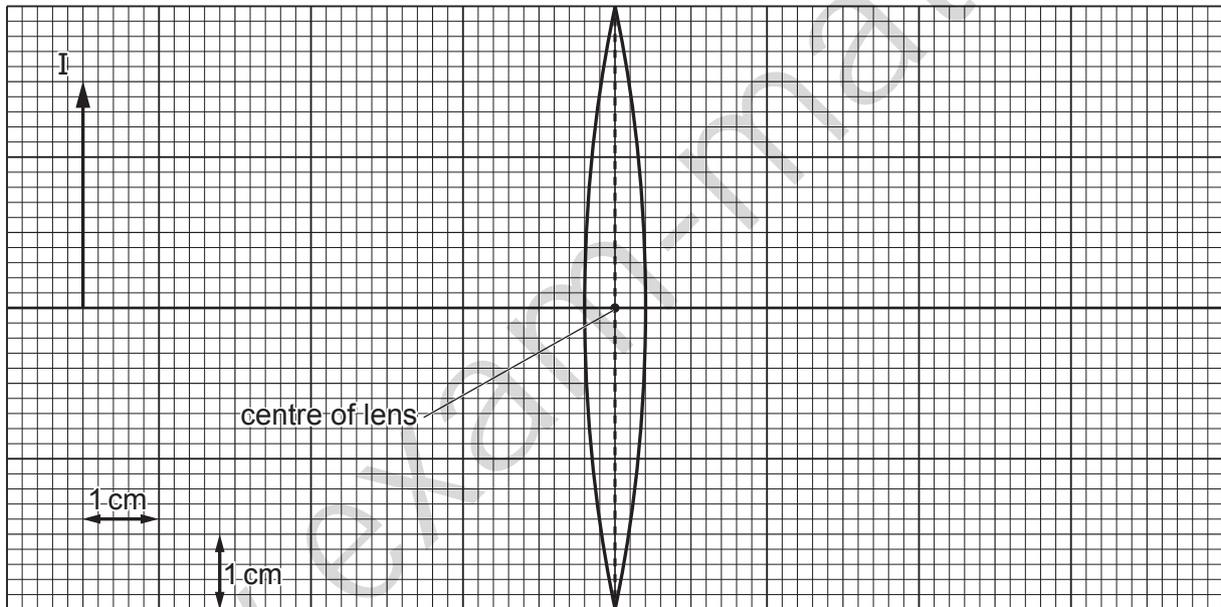

Fig. 5.1 (full-scale)

1. On Fig. 5.1, mark both principal focuses and label each of them F. [1]

2. By drawing on Fig. 5.1, find the position of object O and add object O to the diagram. [3]

(iii) Using Fig. 5.1, determine the distance of object O from the centre of the lens.

distance = ... [1]

[Total: 9]

Question no. 5

(a) Principal focus of a thin converging lens

For a **thin converging lens**, the **principal focus** is the **point on the principal axis** where **rays that are incident on the lens parallel to the principal axis converge (meet) after refraction by the lens**.
(Equivalently, it is the point on the principal axis from which rays would appear to **emerge parallel** after passing through the lens, if the light is travelling in the opposite direction.)

## (b)(i) Nature of the image formed by a magnifying glass

A magnifying glass is a converging lens used with the object **inside the focal length**, so the image is **upright**, **virtual**, and **enlarged**.

So you underline: **enlarged**, **upright**, **virtual**.

(b)(ii) Marking the foci and locating the object on Fig. 5.1

- The focal length is 5.0 cm, so each principal focus **F** must be marked **5.0 cm to the left and 5.0 cm to the right of the optical centre**, on the **principal axis**.
- To find the object position **O** (since the image **I** is given and is virtual), you use **reverse ray tracing**:
    1. Draw a straight line from the **top of image I** through the **centre of the lens** (a ray through the optical centre is undeviated).
    2. Draw a line from the **top of image I** towards the **far principal focus**; when it reaches the lens, draw the refracted part **horizontal (parallel to the axis)** back towards the object side.
       The intersection of the two construction lines gives the **top of the object O**, and the base of O lies on the principal axis.

Here is the **completed, labelled diagram (real image)** showing **both foci F**, the **construction lines**, and the **object O**:

centre of lens

1 cm
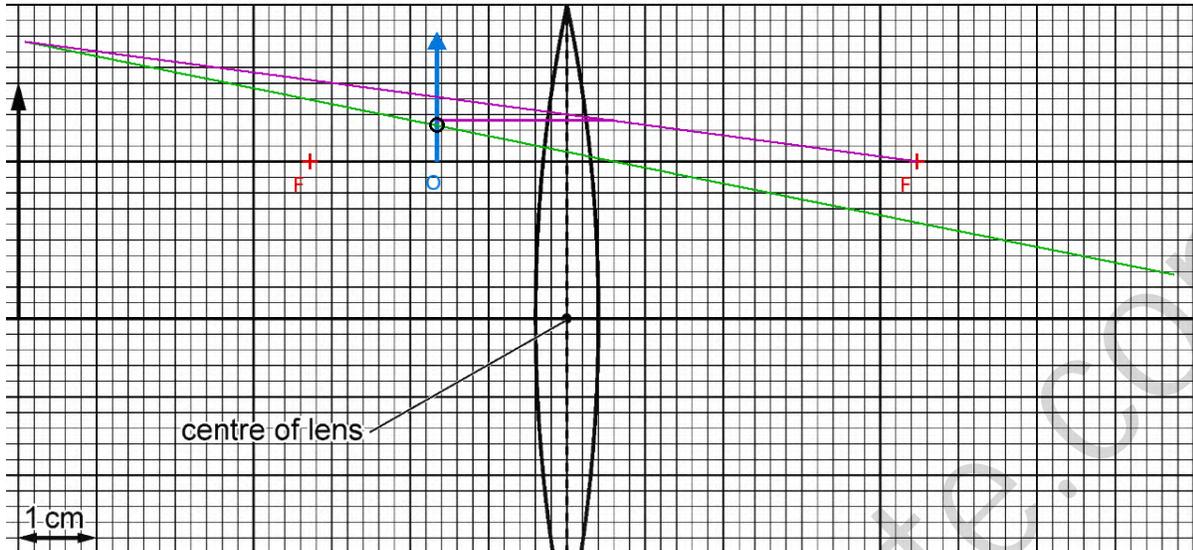
(b)(iii) Distance of the object from the centre of the lens

From the full-scale diagram, the object is about **2.9 cm** from the lens centre (any value in the range **2.7 cm to 3.1 cm** is accepted).

So, **distance = 2.9 cm**.

6 The speed of sound in air is 340 m / s.

(a) Calculate the range of wavelengths for sounds that are audible by a healthy human ear.

wavelengths range from .... to .... [2]

(b) Sound waves are longitudinal waves.

Describe how a longitudinal wave differs from a transverse wave.

....

....

....

.... [3]

(c) Fig. 6.1 shows a band in front of a building.

Fig. 6.1

The drum produces a low frequency sound. Other musical instruments produce a high frequency sound. These sounds are equally loud.

A young man at the side of the building hears the drum but not the high frequency sounds from the other musical instruments.

Explain why this happens.

....

....

.... [3]

[Total: 8]

Question no. 6

(a) Range of wavelengths audible to a healthy human ear

For sound waves, **wavelength is related to speed and frequency** by the equation **wavelength = speed ÷ frequency**.

A healthy human ear can hear frequencies from **20 Hz to 20 000 Hz**.
The speed of sound in air is given as **340 m s⁻¹**.

For the **highest audible frequency (20 000 Hz)**, the wavelength is smallest:

- wavelength = 340 ÷ 20 000
- wavelength = **0.017 m**

For the **lowest audible frequency (20 Hz)**, the wavelength is largest:

- wavelength = 340 ÷ 20
- wavelength = **17 m**

Therefore, the wavelengths of audible sound range from 0.017 m to 17 m.

(b) Difference between a longitudinal wave and a transverse wave

In a **longitudinal wave**, such as sound, the particles of the medium **vibrate parallel to the direction of wave travel (energy transfer)**. This motion produces alternating regions of **compressions**, where particles are close together, and **rarefactions**, where particles are further apart.

In contrast, in a **transverse wave**, the particles of the medium **vibrate perpendicular to the direction of wave travel**. The energy moves forward, but the particle motion is at right angles to this direction, forming crests and troughs.

The key difference is therefore the direction of particle vibration relative to the direction of wave propagation.

(c) Why the young man hears the drum but not the high-frequency sounds

Diffraction

Light has a very small wavelength, so only very small objects or gaps can effect its direction. The wall blocks the light and the person can't see round the corner.
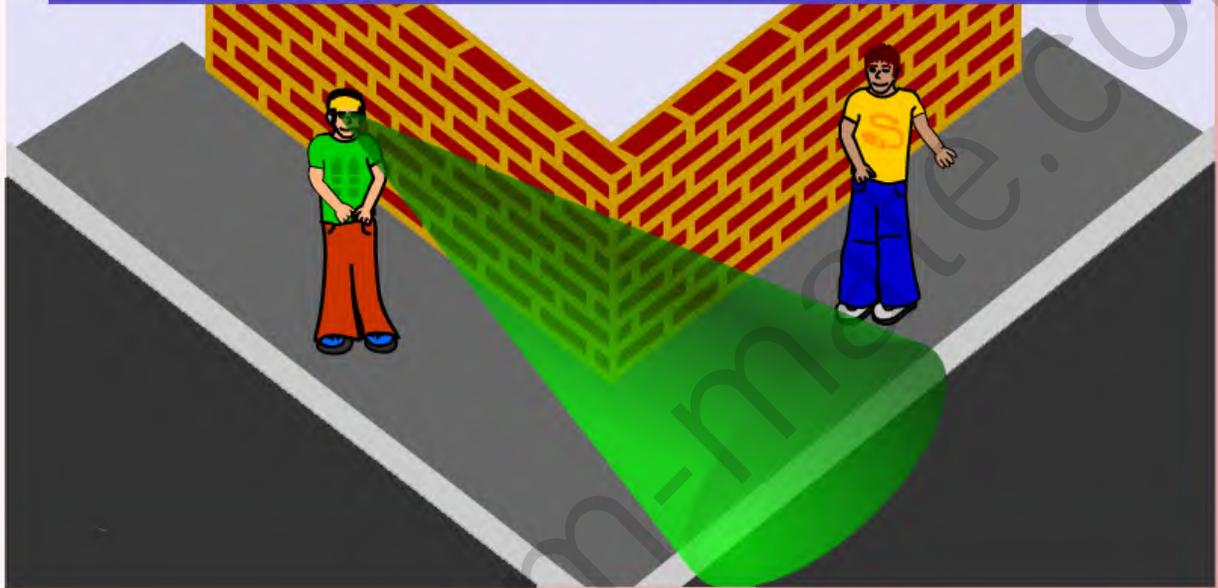
This effect occurs because of **diffraction**.

The drum produces a **low-frequency sound**, which has a **long wavelength**. The other instruments produce **high-frequency sounds**, which have **shorter wavelengths**. Diffraction is **more significant when the wavelength of a wave is comparable to or larger than the size of the obstacle**.

Because the drum sound has a **longer wavelength**, it **diffracts more strongly around the edge of the building**, allowing the sound waves to bend and spread into the region where the young man is standing. As a result, he can hear the drum even though it is not in his direct line of sight.

The high-frequency sounds have **shorter wavelengths**, so they **diffract much less**. These sound waves travel mainly in straight lines and do not bend around the building effectively, so they do not reach the young man.

Therefore, the young man hears the drum because low-frequency (long-wavelength) sound diffracts more than high-frequency (short-wavelength) sound.

7 An electromagnet consists of a solenoid X that is made of copper wire. The solenoid contains an iron core.

(a) Explain why:

(i) the structure of copper makes it a suitable material for the wire

....

....

.... [2]

(ii) iron is a suitable material for the core of an electromagnet.

....

....

.... [2]

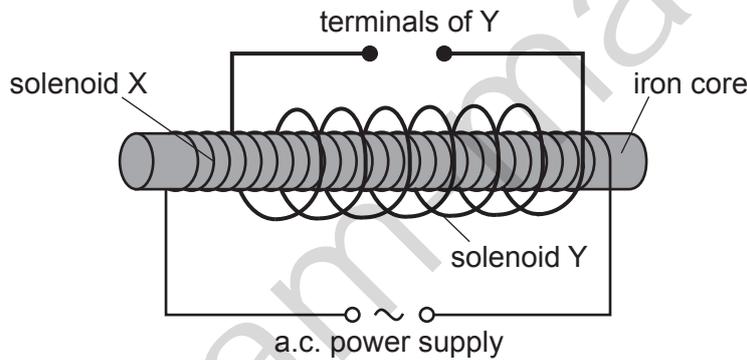**(b)** Fig. 7.1 shows the electromagnet inside a second solenoid Y.

Fig. 7.1

(i) Describe and explain what happens in solenoid Y when solenoid X is connected to an alternating current (a.c.) power supply.

....

....

....

.... [3]

(ii) A switch and a lamp are connected in series with the terminals of solenoid Y. When the switch is closed, the lamp lights up at normal brightness.

Describe and explain what happens to the current in solenoid X when the switch is closed.

....

....

.... [2]

[Total: 9]

Question no. 7

(a)(i) Explain why the structure of copper makes it suitable for the wire

Copper has a metallic structure in which **positive metal ions are arranged in a lattice** and there is a "sea" of **delocalised (free) electrons** moving throughout the metal. When a potential difference is applied, these **free electrons drift easily** through the copper, so charge is transported readily. Therefore, copper is a **good electrical conductor**, making it suitable for carrying the current needed to produce a strong magnetic field in the solenoid.

(a)(ii) Explain why iron is a suitable material for the core of an electromagnet

Iron is a **magnetic (ferromagnetic) material** with magnetic domains that can align when placed in an external magnetic field. When current flows in the solenoid, the magnetic field produced causes the domains in the iron core to **align easily**, so the core becomes strongly magnetised and the magnetic field in the solenoid is greatly increased.

Also, iron is a **temporary magnetic material** (it is **easily demagnetised**). When the current is switched off, the domains quickly become randomly oriented again, so the core loses most of its magnetism. This is ideal for an electromagnet because it can be **turned on and off**.

(b)(i) Describe and explain what happens in solenoid Y when solenoid X is connected to an a.c. power supply

When solenoid **X** is connected to an **a.c. supply**, the current in X **continually changes direction and magnitude**. Therefore, the magnetic field produced by X (and the magnetic flux in the iron core linking Y) is **alternating / changing**.

Because the magnetic flux linkage through solenoid **Y** is changing, an e.m.f. is produced across Y by **electromagnetic induction** (Faraday's law). Since the flux is alternating, the

induced e.m.f. is also **alternating**, so there is an **alternating p.d. between the terminals of Y** (and an a.c. current would flow in Y if the circuit is completed).

(b)(ii) A lamp is connected to Y and lights normally. Describe and explain what happens to the current in X when the switch is closed

When the switch is closed, the lamp forms a load on the secondary circuit, so current flows in **Y** and electrical power is delivered to the lamp. To supply this power, more energy must be transferred from the a.c. source driving **X**, so the **current in solenoid X increases**.

This happens because the secondary current produces a magnetic effect that opposes the original change (Lenz's law), so the primary draws extra current from the supply to maintain the alternating flux and provide the **power used in Y / the lamp**.

8 The power supply used in an electric vehicle contains 990 rechargeable cells each of electromotive force (e.m.f.) 1.2 V.

The cells are contained in packs in which all the cells are in series with each other. The e.m.f. of each pack is 54 V.

(a) Calculate the number of packs in the power supply.

number of packs = ... [2]

(b) When in use, each pack supplies a current of 3.5 A.

(i) Calculate the rate at which each cell is transferring chemical energy to electrical energy.

rate of energy transfer = ... [2]

(ii) The packs are connected in parallel to supply a large current to drive the electric vehicle.

Explain why it is necessary to use thick wires to carry this current.

....

....

....

.... [3]

[Total: 7]

Question no. 8

(a) Number of packs in the power supply

Each rechargeable cell has an **e.m.f. of 1.2 V**.
Within each pack, the cells are connected **in series**, so their e.m.f.s add together.

The e.m.f. of one pack is given as **54 V**, so the number of cells in one pack is:

54 ÷ 1.2 = **45 cells per pack**

The total number of cells in the power supply is **990**, so the number of packs is:

990 ÷ 45 = **22**

Therefore, the number of packs in the power supply is 22.

(b)(i) Rate at which each cell transfers energy

The rate of transfer of energy is the **power**, given by:

power = e.m.f. × current

Each pack supplies a current of **3.5 A**. Because the cells in a pack are in **series**, the **same current flows through every cell**.

For one cell:

- e.m.f. = **1.2 V**
- current = **3.5 A**

Power = 1.2 × 3.5 = **4.2 W**

This means each cell transfers **4.2 joules of energy per second**.

The rate of energy transfer for each cell is 4.2 W (or 4.2 J s⁻¹).

(b)(ii) Why thick wires are necessary

The packs are connected **in parallel**, so the system supplies a **large total current** to drive the electric vehicle.

Thick wires are necessary because they have a smaller electrical resistance than thin wires. When a large current flows, energy is dissipated in the wires as thermal energy according to the effect of resistance.

Using thick wires:

- **reduces resistance**
- **reduces heating of the wires**
- **reduces energy loss as thermal energy**

As a result, the system is **more efficient** and there is **less risk of overheating, insulation melting, or fire**.

Therefore, thick wires are required to safely and efficiently carry the large current supplied by the battery packs.

9 **(a)** Describe how a digital signal differs from an analogue signal. You may draw a diagram.

....

....

.... [2]

(b) (i) In the appropriate box, draw the symbol for an AND gate and the symbol for an OR gate.

AND gate	OR gate

[1]

(ii) State how the behaviour of an AND gate differs from that of an OR gate.

....

.... [1]

(c) An arrangement of logic gates A, B and C is shown in Fig. 9.1. The arrangement has two inputs, X and Y and two outputs P and Q.
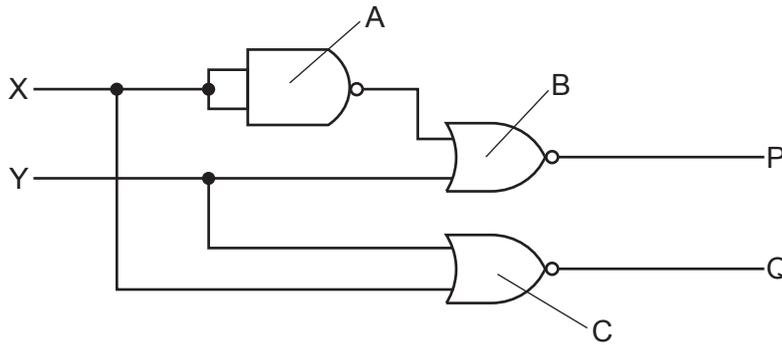
Fig. 9.1

Output P of logic gate B has logic state 1 (high).

(i) Determine the logic states of the two inputs of logic gate B.

upper input = ...

lower input = ...

[1]

(ii) Determine and explain the logic state of output Q.

....

....

....

....

logic state of Q = ... [3]

[Total: 8]

Question no. 9

(a) Difference between a digital signal and an analogue signal

A **digital signal** consists of **only two discrete voltage levels**, usually referred to as **logic 0 (low)** and **logic 1 (high)**. The signal **does not vary continuously**, but instead switches abruptly between these fixed levels. This makes digital signals suitable for use in logic circuits and computers, as each state can be clearly identified.

An **analogue signal**, in contrast, has a **continuously varying voltage** that can take **any value within a given range**. The voltage changes smoothly with time and directly represents the quantity being measured, such as sound intensity or temperature.
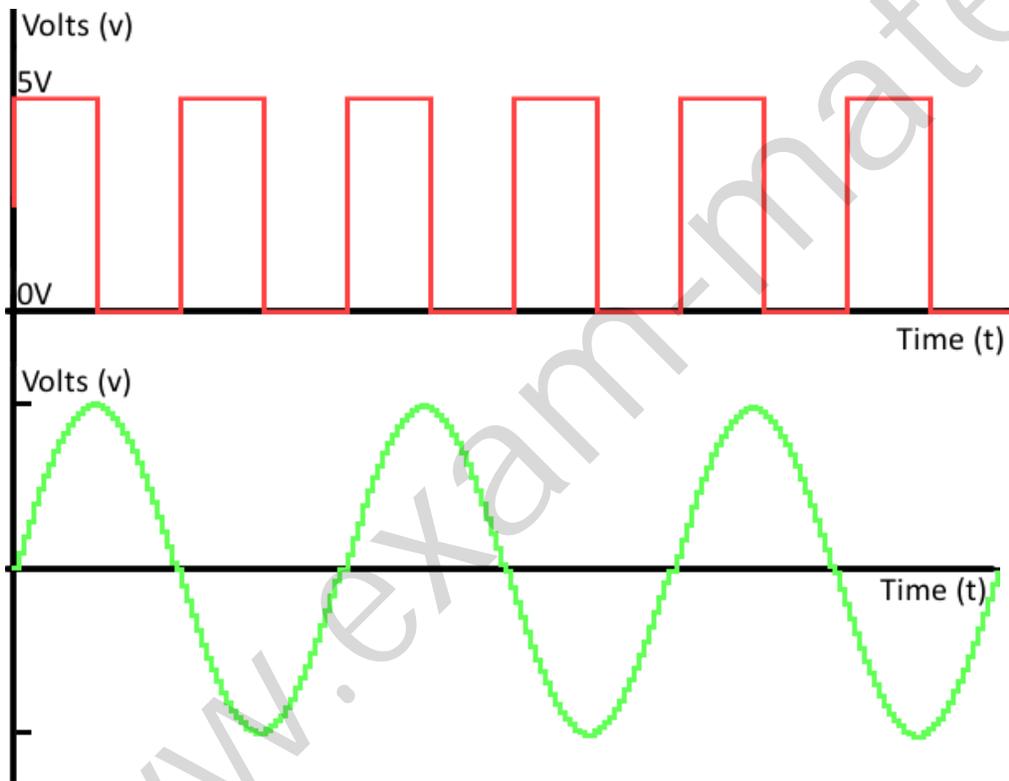
(b)(i) Symbols for an AND gate and an OR gate

Below are the **standard circuit symbols** used in logic diagrams.
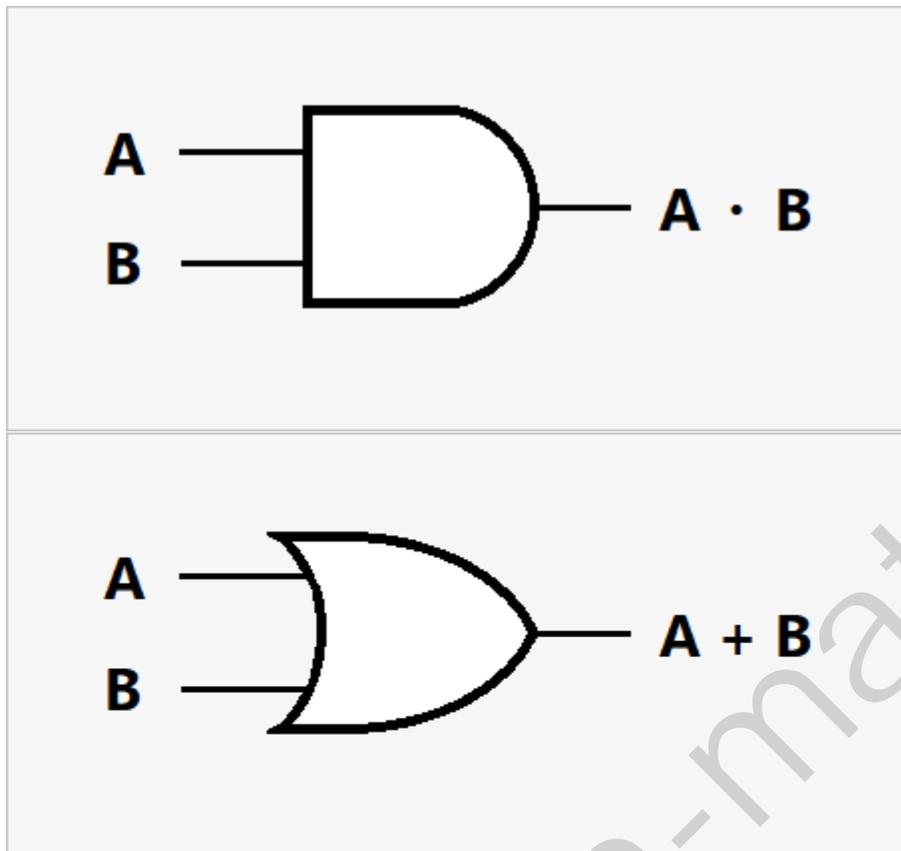
(b)(ii) Difference in behaviour between an AND gate and an OR gate

An **AND gate** produces an output of **logic 1 only when both inputs are logic 1**. If the inputs differ, or if either input is 0, the output is **logic 0**.

An **OR gate**, however, produces an output of **logic 1 whenever at least one input is logic 1**. Therefore, **when the two inputs differ**, the **AND gate gives 0**, whereas the **OR gate gives 1**.

(c) Logic circuit analysis

From the diagram, gates **B and C are NOR gates**, as indicated by the OR-gate shape with a **small circle at the output**. Gate **A is a NAND gate** with **both its inputs connected together**, meaning it acts as a **NOT gate**.
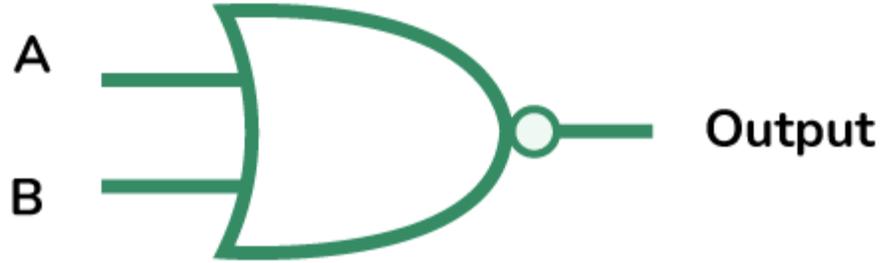
(c)(i) Logic states of the two inputs of logic gate B

The output **P of gate B is logic 1**.
A **NOR gate only produces logic 1 when both its inputs are logic 0**.

Therefore:

- **Upper input of B = 0**
- **Lower input of B = 0**

(c)(ii) Logic state of output Q

Since **both inputs to gate B are 0**, the output of **gate A must also be 0**, because gate A is a **NAND gate with identical inputs**, which inverts the input signal.

This means the input coming from gate A was **logic 1** before inversion, so the **signal feeding the lower part of the circuit is 1**.

For gate **C (a NOR gate)**:

- One of its inputs is **logic 1**.

A NOR gate produces **logic 0 if any input is 1**.

Therefore, **output Q is logic 0**.

Logic state of Q = 0

10 Fig. 10.1 represents a neutral atom of an isotope of element X.
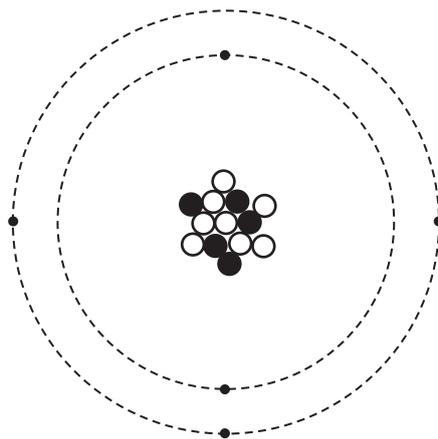
Fig. 10.1

(a) State **one** similarity between this atom and a neutral atom of a different isotope of element X.

....

.... [1]

(b) The isotope of element X is radioactive. It decays to form an isotope of element Y by emitting a β-particle.

(i) Using Fig. 10.1 deduce the nuclide notation for the isotope of Y produced by this decay.

nuclide notation: $^{......}_{......}Y$ [3]

(ii) β-particles ionise the air they pass through less strongly than the same number of α-particles.

Suggest why this is so.

....

....

.... [3]

[Total: 7]

Question no. 10

(a) One similarity

A neutral atom of a **different isotope of element X** has the **same number of protons** as this atom (because isotopes are the same element, so they have the same proton number).
Equivalently, because both atoms are **neutral**, they also have the **same number of electrons**.

(b)(i) Nuclide notation for Y after β decay

From Fig. 10.1, the atom has **5 electrons** (2 on the inner shell and 3 on the outer shell).
Since the atom is **neutral**, it must also have **5 protons**, so the **proton number Z = 5**.

Counting the particles in the nucleus in the diagram gives a total of **13 nucleons**, so the **mass number A = 13**.
So the isotope X is **13 over 5 X**.

In **β⁻ decay**, a neutron in the nucleus changes into a proton and an electron (the β particle) is emitted. This means:

- the **mass number A stays the same** (because a neutron becomes a proton: still one nucleon),
- the **proton number Z increases by 1** (because there is one extra proton).

So Y has:

- **A = 13**
- **Z = 6**

✅ **Nuclide notation for Y: 13 over 6 Y**

(b)(ii) Why β-particles ionise air less strongly than α-particles

β-particles are **much less strongly ionising** than α-particles mainly because they interact less powerfully with the electrons in air molecules.

Firstly, a β-particle has a charge of **–1e**, whereas an α-particle has a charge of **+2e**. The α-particle therefore produces a **stronger electrostatic force** on electrons in air molecules, so it is more likely to pull them out and cause ionisation.

Secondly, a β-particle has a **much smaller mass** than an α-particle, so for typical decay energies it travels **much faster**. Because it moves so quickly, it spends **less time close to each air molecule**, giving less opportunity to transfer energy and remove electrons.

As a result of these factors, β-particles produce **fewer ion pairs per unit distance** than α-particles, so their ionising effect is weaker.

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