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Centre number

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Surname

*StemUp Model Solution*

Forename(s)

Candidate signature

I declare this is my own work.

# AS PHYSICS

## Paper 1

Wednesday 14 May 2025

Morning

Time allowed: 1 hour 30 minutes

### Materials

For this paper you must have:

- a pencil and a ruler
- a scientific calculator
- a Data and Formulae Booklet
- a protractor.

### Instructions

- Use black ink or black ball-point pen.
- Fill in the boxes at the top of this page.
- Answer **all** questions.
- You must answer the questions in the spaces provided. Do not write outside the box around each page or on blank pages.
- If you need extra space for your answer(s), use the lined pages at the end of this book. Write the question number against your answer(s).
- Do **all** rough work in this book. Cross through any work you do not want to be marked.
- Show **all** your working.

### Information

- The marks for questions are shown in brackets.
- The maximum mark for this paper is 70.
- You are expected to use a scientific calculator where appropriate.
- A Data and Formulae Booklet is provided as a loose insert.

| For Examiner's Use |      |
|--------------------|------|
| Question           | Mark |
| 1                  |      |
| 2                  |      |
| 3                  |      |
| 4                  |      |
| 5                  |      |
| 6                  |      |
| 7                  |      |
| <b>TOTAL</b>       |      |



J U N 2 5 7 4 0 7 1 0 1

Answer **all** questions in the spaces provided.

0 1

Hydrogen has three naturally occurring isotopes. One of these isotopes is hydrogen-3 ( ${}^3_1\text{H}$ ).

0 1 . 1

Calculate the specific charge of a nucleus of hydrogen-3.

[2 marks]

$$\text{specific charge} = \text{charge} / \text{mass}$$

$$\text{charge of nucleus} = +1e = 1.60 \times 10^{-19} \text{ C}$$

$$\text{mass} = 3 \text{ nucleons} = 3 \times 1.67 \times 10^{-27} = 5.01 \times 10^{-27} \text{ kg}$$

$$\text{specific charge} = 1.60 \times 10^{-19} / 5.01 \times 10^{-27}$$

$$\text{specific charge} = 3.19 \times 10^7 \text{ C kg}^{-1}$$

$$\text{specific charge} = \underline{3.19 \times 10^7} \text{ C kg}^{-1}$$

0 1 . 2

The specific charge of the hydrogen-3 nucleus is less than the specific charges of the nuclei of the other two isotopes.

Suggest why.

[2 marks]

All three isotopes are hydrogen, so their nuclei have the same charge

(one proton, +1e).

The other two isotopes (hydrogen-1 and hydrogen-2) have fewer

neutrons, so fewer nucleons and a smaller mass, so their charge/mass

ratio is greater.



Kaons (K) and pions ( $\pi$ ) are produced when a beam of antiprotons is incident on a sample of hydrogen gas.

One reaction that occurs is



0 1 . 3

Deduce, with reference to appropriate conservation laws, the quark structure of the  $K^0$  produced in this reaction.

[3 marks]

*Strong interaction, so strangeness is conserved.  $K^- = s + \text{anti-}u$  ( $S = -1$ ),  $\pi^+ = u + \text{anti-}d$  ( $S = 0$ ).*

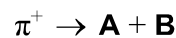
*Strangeness:  $0 + 0 \rightarrow (-1) + 0 + S$ , so  $K^0$  has  $S = +1$ : it has an anti-strange quark.*

*$K^0$  is neutral (charge conserved), so the other quark is  $d$ .*

quark structure =  $d \bar{s}$

0 1 . 4

One possible decay of a  $\pi^+$  particle is



where **A** is a charged lepton.

Suggest, with reference to appropriate conservation laws, the name of **A** and the name of **B**.

[2 marks]

*Charge must be conserved:  $+1 \rightarrow (+1) + 0$ , so A must be a positive lepton: a positron.*

*Lepton number must be conserved:  $0 \rightarrow (-1) + (+1)$ , so B has  $L_e = +1$  and no charge: an electron neutrino.*

name of **A** positron ( $e^+$ )

name of **B** electron neutrino ( $\nu_e$ )



0 2

An optical fibre consists of a glass core surrounded by cladding.

Monochromatic light enters the glass core of the optical fibre from air.

0 2 . 1

What happens to the frequency of the light as it enters the glass core?

Tick (✓) **one** box.

[1 mark]

It decreases.

☐

It is unchanged.

☒

It increases.

☐

The refractive index of the glass core is 1.51

0 2 . 2

The critical angle at the core–cladding boundary is  $80.7^\circ$

Calculate the refractive index of the cladding.

[2 marks]

$$\sin \theta_c = n_2 / n_1$$

$$n_2 = n_1 \sin \theta_c = 1.51 \times \sin 80.7^\circ$$

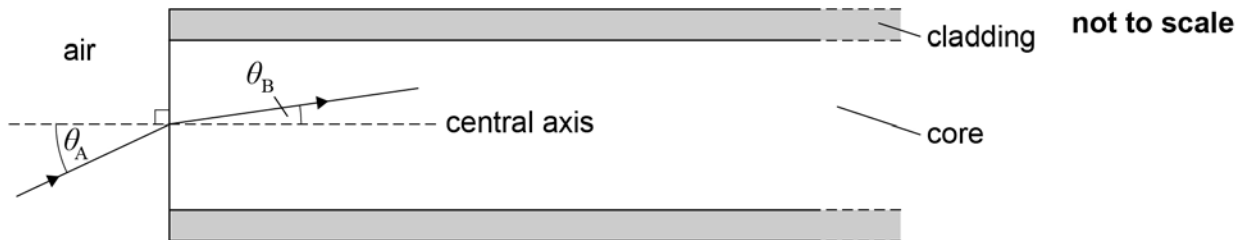
$$n_2 = 1.51 \times 0.987 = 1.490$$

refractive index of cladding = 1.49



**Figure 1** shows a ray of light that is incident on the centre of the core.  
At the air–core boundary, the angle of incidence of this ray is  $\theta_A$  and the angle of refraction is  $\theta_B$ .

**Figure 1**



When  $\theta_B$  is greater than  $9.3^\circ$ , the ray will **not** be transmitted through the optical fibre.

0 2 . 3

Calculate the maximum value of  $\theta_A$  for the ray to be transmitted through the optical fibre.

[2 marks]

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

$$1.00 \times \sin \theta_A = 1.51 \times \sin 9.3^\circ$$

$$\sin \theta_A = 1.51 \times 0.1616 = 0.244$$

$$\theta_A = 14.1^\circ$$

maximum value of  $\theta_A =$  14 °

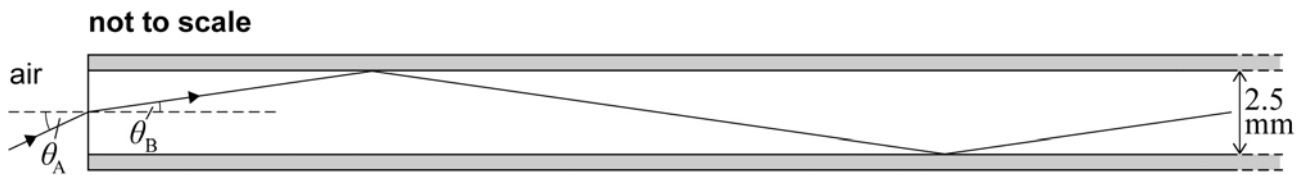
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0 2 . 4

**Figure 2** shows the path of a ray of light that enters at the centre of the straight optical fibre at a smaller value of  $\theta_A$ . Only the first two total internal reflections are shown.

**Figure 2**

The core has a diameter of 2.5 mm.

$\theta_B$  is now  $9.0^\circ$

$3.1 \times 10^4$  total internal reflections occur before the light leaves the optical fibre.

Calculate the time for the light to travel through the optical fibre.

refractive index of glass core = 1.51

[3 marks]

speed in core:  $v = c / n = 3.00 \times 10^8 / 1.51 = 1.99 \times 10^8 \text{ m s}^{-1}$

path between reflections =  $2.5 \text{ mm} / \sin 9.0^\circ = 15.98 \text{ mm}$

(from the centre to the first reflection = 7.99 mm)

total distance =  $3.1 \times 10^4 \times 15.98 \times 10^{-3} \text{ m} = 495 \text{ m}$

time = distance / speed =  $495 / 1.99 \times 10^8$

time =  $2.49 \times 10^{-6} \text{ s}$

time =  $2.5 \times 10^{-6}$  s

8



0 3

A fluorescent tube contains a low-pressure gas consisting of mercury atoms.

Figure 3 shows the four lowest energy levels of a mercury atom.

Figure 3

|         |       |                                    |
|---------|-------|------------------------------------|
| $n = 4$ | _____ | $-2.56 \times 10^{-19} \text{ J}$  |
| $n = 3$ | _____ | $-5.92 \times 10^{-19} \text{ J}$  |
| $n = 2$ | _____ | $-8.80 \times 10^{-19} \text{ J}$  |
| $n = 1$ | _____ | $-16.64 \times 10^{-19} \text{ J}$ |

A mercury atom inside the fluorescent tube is in its ground state  $n = 1$

An electron is travelling inside the tube. The electron has a kinetic energy of  $13.10 \times 10^{-19} \text{ J}$  when it collides with the mercury atom.

As a result of the collision, the mercury atom is excited to its  $n = 3$  energy level. Immediately after the collision, the electron is moving with a speed that is smaller than before the collision.

Assume that the kinetic energy of the mercury atom does not change.

0 3

. 1

Calculate the de Broglie wavelength of this electron immediately after the collision.

[4 marks]

$$\text{energy absorbed by atom} = 16.64 - 5.92 = 10.72 \times 10^{-19} \text{ J}$$

$$E_k \text{ of electron after} = 13.10 - 10.72 = 2.38 \times 10^{-19} \text{ J}$$

$$E_k = \frac{1}{2}mv^2: v = \sqrt{(2 \times 2.38 \times 10^{-19} / 9.11 \times 10^{-31})}$$

$$v = 7.23 \times 10^5 \text{ m s}^{-1}$$

$$\lambda = h / mv = 6.63 \times 10^{-34} / (9.11 \times 10^{-31} \times 7.23 \times 10^5)$$

$$\lambda = 1.01 \times 10^{-9} \text{ m}$$

$$\text{de Broglie wavelength} = \underline{1.01 \times 10^{-9}} \text{ m}$$

Question 3 continues on the next page

Turn over ►



The excited mercury atoms inside the fluorescent tube can emit photons of ultraviolet light, each of energy  $7.83 \times 10^{-19}$  J.

**0 3 . 2** Calculate, in nm, the wavelength of a photon with this energy.

**[2 marks]**

$$E = hf \text{ and } c = f\lambda, \text{ so } E = hc / \lambda \text{ and } \lambda = hc / E$$

$$\lambda = (6.63 \times 10^{-34} \times 3.00 \times 10^8) / 7.83 \times 10^{-19}$$

$$\lambda = 2.54 \times 10^{-7} \text{ m} = 254 \text{ nm}$$

wavelength = 254 nm

**0 3 . 3** The fluorescent tube has an input power of 18 W.

82% of the input power is converted into ultraviolet photons, each of energy  $7.83 \times 10^{-19}$  J.

Calculate the number of these photons emitted in one second.

**[2 marks]**

$$\text{power converted to UV} = 0.82 \times 18 = 14.76 \text{ W (14.76 J per second)}$$

$$\text{number per second} = 14.76 / 7.83 \times 10^{-19}$$

$$= 1.89 \times 10^{19}$$

number of photons =  $1.9 \times 10^{19}$



0 3 . 4

Explain how the coating of the fluorescent tube emits white light.

In your answer you should:

- describe the processes that take place in the coating
- suggest why there are many more visible photons than ultraviolet photons emitted by the tube.

[4 marks]

*UV photons emitted by the mercury atoms are absorbed by atoms in the coating.*

*Each absorbed photon excites an electron in a coating atom to a higher energy level. The electron then de-excites, returning to lower levels and emitting a photon each time it drops, often in several steps via intermediate levels.*

*The energy level differences in the coating are smaller than the UV transition energy in mercury, so the emitted photons have less energy, lower frequency and longer wavelength: visible light.*

*There are many different possible transitions in the coating, giving photons of many wavelengths across the visible spectrum, which together appear as white light.*

*Since the electron returns in several steps, one UV photon absorbed can produce several lower-energy visible photons, so many more visible photons than UV photons are emitted.*

12

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State the principle of moments.

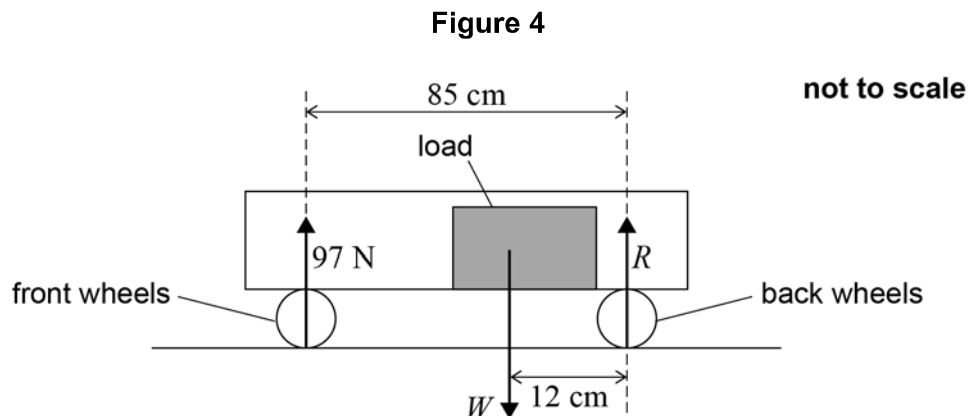
**[2 marks]**

*For a body in equilibrium, the sum of the clockwise moments about any point is equal to the sum of the anticlockwise moments about the same point.*

**Question 4 continues on the next page****Turn over ►**

0 4 . 2

**Figure 4** shows a trolley at rest on a horizontal surface. A load is fixed to the base of the trolley.



Assume that the forces in **Figure 4** are coplanar.

The distance between the centre of the front wheels and the centre of the back wheels is 85 cm.

The total reaction force at the front wheels is 97 N and the total reaction force at the back wheels is  $R$ .

The trolley and load have a total weight  $W$ .

The perpendicular distance between the lines of action of the forces  $W$  and  $R$  is 12 cm.

Calculate  $R$ .

**[3 marks]**

*Take moments about the line of action of  $W$ :*

*distance from 97 N force to  $W$  =  $85 - 12 = 73$  cm*

*anticlockwise moment = clockwise moment*

$$97 \times 73 = R \times 12$$

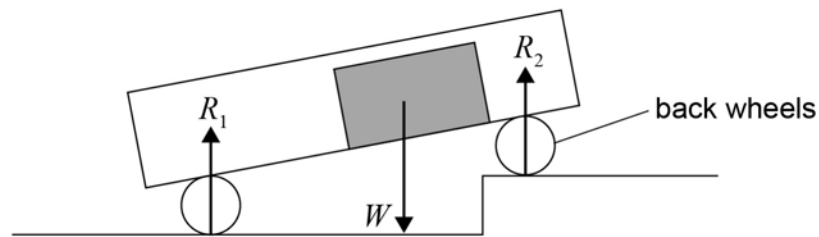
$$R = 97 \times 73 / 12 = 590 \text{ N}$$

$$R = \underline{\quad 590 \quad} \text{ N}$$



**Figure 5** shows the trolley after its back wheels have been lifted onto a step. The trolley is stationary.

**Figure 5**



0 4 . 3

When the back wheels are on the step, the moment of  $W$  about the centre of the back wheels is less than that in **Figure 4**.

Explain why.

[1 mark]

*The perpendicular distance between the line of action of  $W$  and the centre of the back wheels has decreased (the trolley is tilted).*

0 4 . 4

Deduce how the magnitude of  $R_1$  in **Figure 5** compares with the value of 97 N in **Figure 4**.

[3 marks]

*$R_1$  is the same as 97 N; its magnitude does not change.*

*Still in equilibrium, so about the back wheel the clockwise moment of  $R_1$  equals the anticlockwise moment of  $W$ .*

*Tilting decreases the perpendicular distances from the back wheel to the lines of action of both  $R_1$  and  $W$ , by the same factor, so  $R_1$  has the same magnitude.*

9

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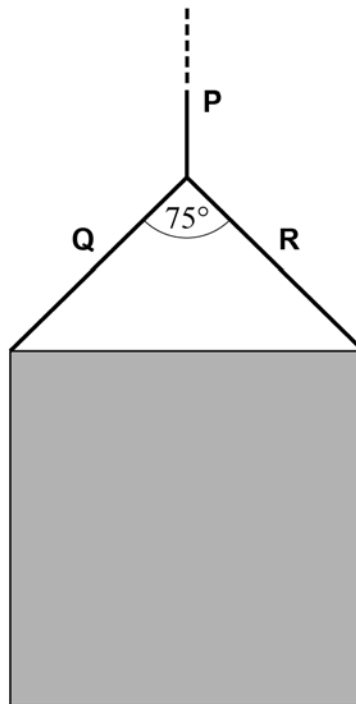
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0 5

**Figure 6** shows a stationary lift suspended using three steel cables **P**, **Q** and **R**. The centre of mass of the lift is vertically below cable **P**.

Figure 6



The mass of the lift is 850 kg.

The angle between **Q** and **R** is  $75^\circ$

**Q** and **R** each have an unstretched length of 2.0 m.

The cross-sectional area of each cable is  $1.4 \times 10^{-4} \text{ m}^2$ .

The Young modulus of the steel is  $2.1 \times 10^{11} \text{ Pa}$ .

0 5 . 1

Determine the extension of **Q**.

[4 marks]

$$W = mg = 850 \times 9.81 = 8340 \text{ N}$$

$$\text{vertically: } 2T \cos 37.5^\circ = 8340, \text{ so } T = 5260 \text{ N}$$

$$E = TL / A\Delta L, \text{ so } \Delta L = TL / AE$$

$$\Delta L = (5260 \times 2.0) / (1.4 \times 10^{-4} \times 2.1 \times 10^{11})$$

$$\Delta L = 3.58 \times 10^{-4} \text{ m}$$

$$\text{extension} = \underline{3.6 \times 10^{-4}} \text{ m}$$

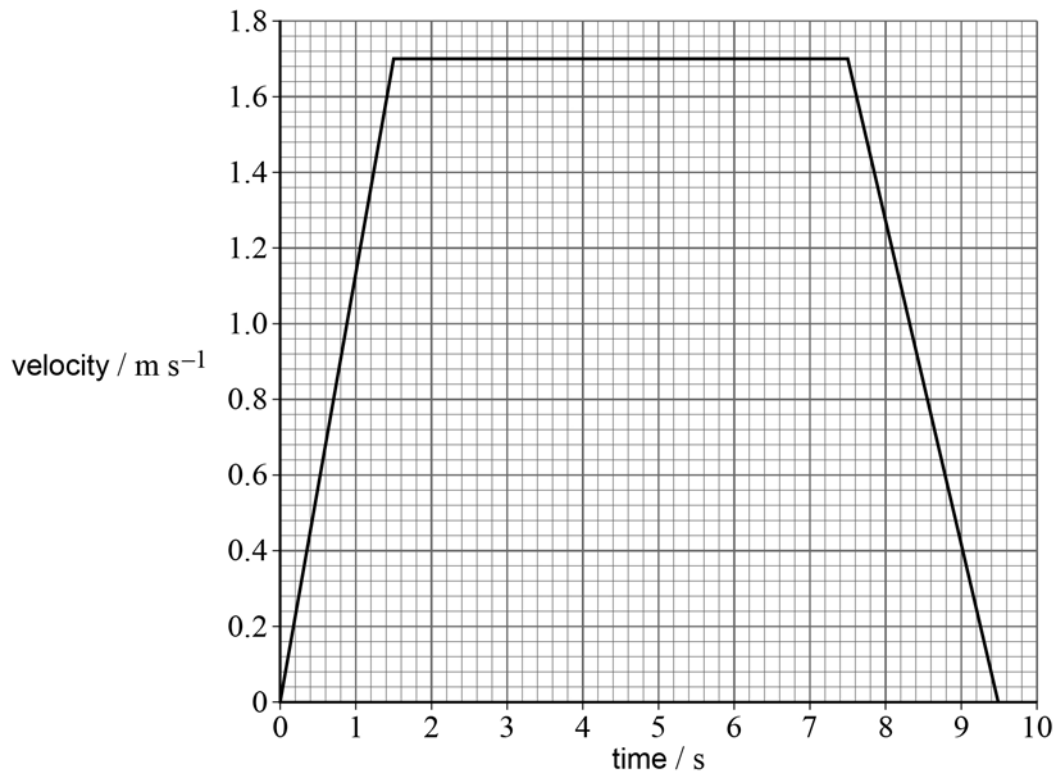
Question 5 continues on the next page

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Figure 7 is a velocity–time graph for the lift as it travels upwards from ground level.

Figure 7



0 5 2

Determine the gravitational potential energy gained by the lift during the first 1.5 s of the motion.

$\Delta h = \text{area under graph from 0 to 1.5 s}$

[3 marks]

$$\Delta h = \frac{1}{2} \times 1.5 \times 1.7 = 1.275 \text{ m}$$

$$\Delta E_p = mg\Delta h = 850 \times 9.81 \times 1.275$$

$$\Delta E_p = 1.06 \times 10^4 \text{ J}$$

gravitational potential energy =  $1.1 \times 10^4$  J



0 5 . 3

**Q** and **R** are connected to **P** as shown in **Figure 6**.Determine the tension in **P** during the last 2.0 s of the motion.**[3 marks]**

$$\text{In the last 2.0 s: } a = \Delta v / \Delta t = (0 - 1.7) / 2.0 = -0.85 \text{ m s}^{-2}$$

(deceleration of  $0.85 \text{ m s}^{-2}$ , so resultant force is downwards)

$$F = ma: mg - T = m \times 0.85$$

$$T = 850 \times 9.81 - 850 \times 0.85 = 8340 - 723$$

$$T = 7620 \text{ N}$$

tension = 7600 N

Question 5 continues on the next page

Turn over ►



After 4.0 s of the motion, the lift is moving at a constant velocity and has travelled 5.5 m from ground level. An object becomes detached from the underside of the lift.

0 5 . 4

Determine the velocity of the object when it reaches ground level.

[3 marks]

*The object leaves the lift moving at  $1.7 \text{ m s}^{-1}$  upwards.*

*Taking downwards as positive:  $u = -1.7 \text{ m s}^{-1}$ ,  $a = 9.81 \text{ m s}^{-2}$ ,  $s = 5.5 \text{ m}$*

$$v^2 = u^2 + 2as = (-1.7)^2 + 2 \times 9.81 \times 5.5$$

$$v^2 = 2.89 + 107.9 = 110.8$$

$$v = 10.5 \text{ m s}^{-1} \text{ (downwards)}$$

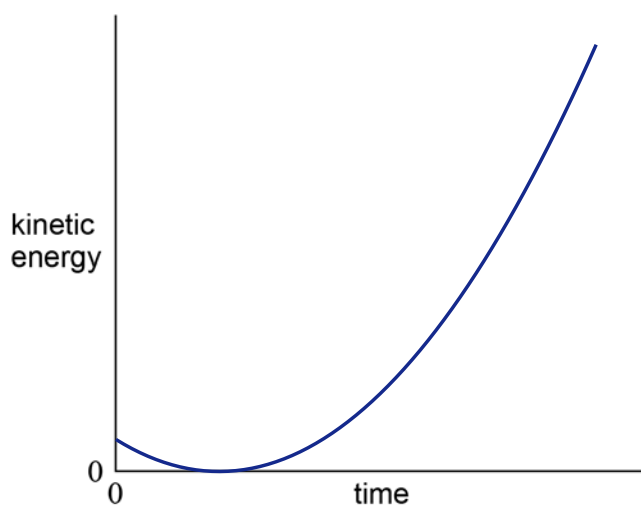
velocity = 11 (downwards)  $\text{m s}^{-1}$

0 5 . 5

Sketch on **Figure 8** the variation with time of the kinetic energy of the object from when it becomes detached until it hits the ground. No calculations are required.

[2 marks]

**Figure 8**



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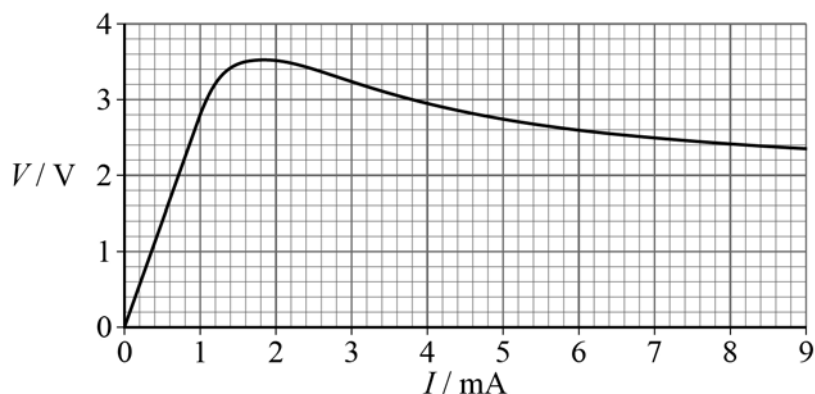
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0 6

**Figure 9** shows the variation of potential difference  $V$  with current  $I$  for a thermistor **T**.

**Figure 9**



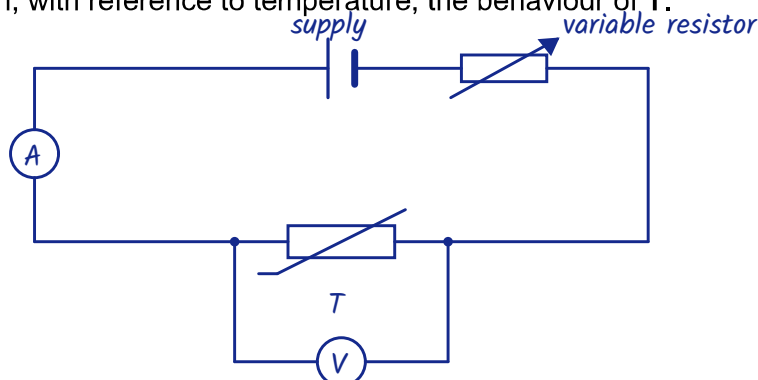
0 6 . 1

Discuss, for the range 0 to 9 mA, the characteristic of **T** shown by **Figure 9**.

In your answer you should:

- describe how to produce a characteristic experimentally
- describe, in terms of resistance, the behaviour of **T**
- explain, with reference to temperature, the behaviour of **T**.

**[6 marks]**



*Method: connect thermistor **T** in series with an ammeter (milliammeter) and a variable resistor, with a voltmeter connected in parallel across **T**, as in the circuit above.*

*Adjust the variable resistor to vary the current through **T** in steps from 0 to 9 mA. For each setting, wait for the readings to settle, then record the current  $I$  on the ammeter and the pd  $V$  across **T** on the voltmeter. Repeat and plot  $V$  against  $I$ .*



Behaviour: from 0 to about 1 mA the graph is a straight line through the origin, so  $V/I$  is constant and the resistance of  $T$  is constant (about 2.8 k $\Omega$ ).

Above about 1 mA,  $V$  increases by less than in proportion to  $I$ , so the resistance  $R = V/I$  decreases as the current increases.

After the peak at about 2 mA,  $V$  falls as  $I$  increases, so the resistance decreases rapidly at greater currents (at 9 mA,  $R = 2.35 / 0.009 \approx 260 \Omega$ ).

Explanation: at small currents the power dissipated in  $T$  ( $P = VI$ ) is very small, so the temperature of  $T$  stays constant and  $T$  behaves as an ohmic conductor with constant resistance.

As the current increases, the heating effect of the current increases, so  $T$  warms up and its temperature rises.

$T$  is an NTC thermistor: as its temperature increases, more charge carriers (electrons) are released, so its resistance decreases.

A greater current causes more heating and a higher temperature, so the resistance keeps decreasing, which is why the pd across  $T$  falls at the higher currents.

Question 6 continues on the next page

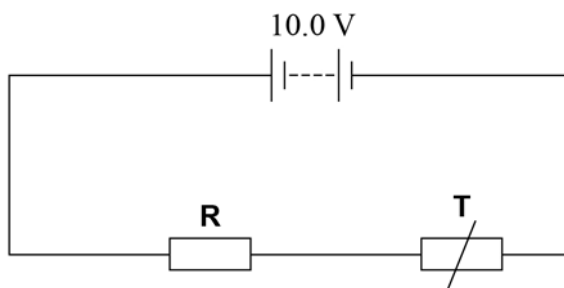
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**0 6 . 2** **Figure 10** shows thermistor **T** in series with a fixed resistor **R** and a battery.

The variation of  $V$  with  $I$  shown in **Figure 9** applies to **T** in this circuit.

**Figure 10**



The battery has an emf of 10.0 V and negligible internal resistance.

The current in **T** is 1.0 mA.

Determine the resistance of **R**.

**[3 marks]**

*From Figure 9, at  $I = 1.0 \text{ mA}$ ,  $V$  across  $T = 2.8 \text{ V}$*

*pd across  $R = 10.0 - 2.8 = 7.2 \text{ V}$*

*same current in  $R$  (series):  $R = V / I$*

$$R = 7.2 / 1.0 \times 10^{-3}$$

$$R = 7200 \, \Omega$$

resistance = 7200  $\Omega$



0 7 . 1

State what is meant by the threshold frequency of radiation in the photoelectric effect.

[2 marks]

*The threshold frequency is the minimum frequency of the incident radiation (photons) needed for photoelectrons to be emitted from the surface of the metal.*

*Below this frequency no electrons are emitted, however intense the radiation.*

When magnesium is illuminated with monochromatic electromagnetic radiation, photoelectrons are emitted.  
For this radiation, the maximum kinetic energy of the photoelectrons is  $5.47 \times 10^{-19} \text{ J}$  and the stopping potential is  $V_s$ .

0 7 . 2

Calculate  $V_s$ .

[1 mark]

$$eV_s = E_{k(max)}$$

$$V_s = 5.47 \times 10^{-19} / 1.60 \times 10^{-19} = 3.42 \text{ V}$$

$$V_s = \underline{\quad 3.42 \quad} \text{ V}$$

0 7 . 3

The radiation incident on the magnesium has a frequency of 1710 THz.

Calculate the work function of the magnesium.

[2 marks]

$$f = 1710 \text{ THz} = 1.71 \times 10^{15} \text{ Hz}$$

$$hf = \phi + E_{k(max)}, \text{ so } \phi = hf - E_{k(max)}$$

$$\phi = 6.63 \times 10^{-34} \times 1.71 \times 10^{15} - 5.47 \times 10^{-19}$$

$$\phi = 1.134 \times 10^{-18} - 5.47 \times 10^{-19} = 5.87 \times 10^{-19} \text{ J}$$

$$\text{work function} = \underline{\quad 5.87 \times 10^{-19} \quad} \text{ J}$$

Question 7 continues on the next page

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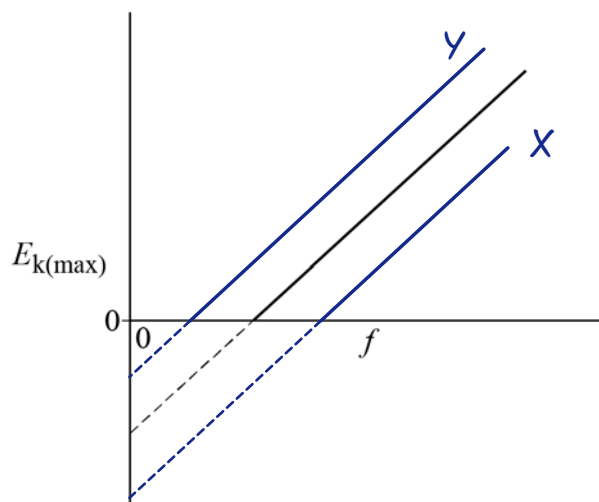


0 7 4

The frequency  $f$  of the electromagnetic radiation is varied.

**Figure 11** shows the variation of  $E_{k(\max)}$  with  $f$  for magnesium.

**Figure 11**



Metal **X** and metal **Y** are illuminated by radiation with the same range of frequencies as used for the magnesium.

Sketch, on **Figure 11**, graphs to show how  $E_{k(\max)}$  varies with  $f$  for **X** and for **Y**.

Label your graphs **X** and **Y**.

Go on to explain your reasoning.

work function of **X** > work function of magnesium > work function of **Y**

[3 marks]

*Both lines are parallel to the magnesium line (same gradient), because the gradient equals the Planck constant  $h$ , which is the same for all metals.*

*The intercept on the  $E_{k(\max)}$  axis is  $-\phi$ , so a larger work function gives a higher threshold frequency: X cuts the  $f$  axis to the right of magnesium and Y cuts it to the left (but above 0).*

8

**END OF QUESTIONS**



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