Catholic Junior College

JC2 Block Test

Higher 2

Topics: Gravitational Field, Oscillations, Wave Motion, Superposition, Thermal Physics, Electric Fields, Current of Electricity and D.C. circuits

CANDIDATE NAME	**MARK SCHEME**
CLASS	**2T**

PHYSICS **9749**

Section A: Multiple Choice Questions **5 March 2024**

Section B: Structured Questions **2 hours**

Additional Material: Multiple Choice Answer Sheet

INSTRUCTIONS

Write your name and tutorial group on this cover page.

FOR SECTION A

Write and shade your name, NRIC/FIN number and HT group on the Answer Sheet (OMR sheet).
Write in soft pencil.
Do not use staples, paper clips, highlighters, glue or correction fluid.

There are a total of **15 Multiple Choice Questions (MCQs)** in this paper.
For each question, there are four possible answers, **A, B, C** and **D**. Choose the **one** you consider correct and record your choice in **soft pencil** on the Answer Sheet (OMR sheet) provided.

FOR SECTION B

Write in dark blue or black pen in the spaces provided. **[PILOT FRIXION ERASABLE PENS ARE NOT ALLOWED]**
You may use a soft pencil for any diagrams, graphs or rough working.
Do not use highlighters, glue or correction fluid.

Answer all questions.
You are advised not to spend more than 30 minutes on Section A.

FOR EXAMINER'S USE		
SECTION A		/ 15
SECTION B		
Q1		/ 12
Q2		/ 8
Q3		/ 17
Q4		/ 9
Q5		/ 14
GRAND TOTAL		/ 75

This document consists of **32** printed pages and **zero** blank page.

PHYSICS DATA:

speed of light in free space	c	=	3.00×10^{8} m s^{-1}
permeability of free space	μ_0	=	$4\pi \times 10^{-7}$ H m^{-1}
permittivity of free space	ε_0	=	8.85×10^{-12} F m^{-1}
			$\approx (1/(36\pi)) \times 10^{-9}$ F m^{-1}
elementary charge	e	=	1.60×10^{-19} C
the Planck constant	h	=	6.63×10^{-34} J s
unified atomic mass constant	u	=	1.66×10^{-27} kg
rest mass of electron	m_e	=	9.11×10^{-31} kg
rest mass of proton	m_p	=	1.67×10^{-27} kg
molar gas constant	R	=	8.31 J K^{-1} mol^{-1}
the Avogadro constant	N_A	=	6.02×10^{23} mol^{-1}
the Boltzmann constant	k	=	1.38×10^{-23} mol^{-1}
gravitational constant	G	=	6.67×10^{-11} N m^{2} kg^{-2}
acceleration of free fall	g	=	9.81 m s^{-2}

PHYSICS FORMULAE:

uniformly accelerated motion	s	=	$ut + \frac{1}{2}at^2$
	v^2	=	$u^2 + 2as$
work done on / by a gas	W	=	$p\,\Delta V$
hydrostatic pressure	P	=	$\rho g h$
gravitational potential	ϕ	=	$-\dfrac{Gm}{r}$
temperature	T/K	=	$T/{}^{\circ}C + 273.15$
pressure of an ideal gas	p	=	$\dfrac{1}{3}\dfrac{Nm}{V}\langle c^2\rangle$
mean translational kinetic energy of an ideal gas molecule	E	=	$\dfrac{3}{2}kT$
displacement of particle in s.h.m.	x	=	$x_0 \sin \omega t$
velocity of particle in s.h.m.	v	=	$v_0 \cos \omega t$
		=	$\pm\,\omega\sqrt{x_0^{\,2} - x^2}$
electric current	I	=	$Anvq$
resistors in series	R	=	$R_1 + R_2 + \ldots$
resistors in parallel	$1/R$	=	$1/R_1 + 1/R_2 + \ldots$
electric potential	V	=	$\dfrac{Q}{4\pi\varepsilon_o r}$
alternating current / voltage	x	=	$x_0 \sin \omega t$
magnetic flux density due to a long straight wire	B	=	$\dfrac{\mu_o I}{2\pi d}$
magnetic flux density due to a flat circular coil	B	=	$\dfrac{\mu_o NI}{2r}$
magnetic flux density due to a long solenoid	B	=	$\mu_o nI$
radioactive decay	x	=	$x_0 \exp(-\lambda t)$
decay constant	λ	=	$\dfrac{\ln 2}{t_{\frac{1}{2}}}$

Section A

Shade your answers on the OMR sheet.

1 A satellite is in orbit above a planet at a height of 42000 km. The radius of the planet is 4600 km. The orbital period of the satellite is 24 hours.

What is the mass of this planet?

A	1.3×10^{24} kg	**B**	3.7×10^{24} kg	**C**	5.9×10^{24} kg	**D**	8.0×10^{24} kg

L2 **Answer: D**

Gravitational force provides for centripetal force,

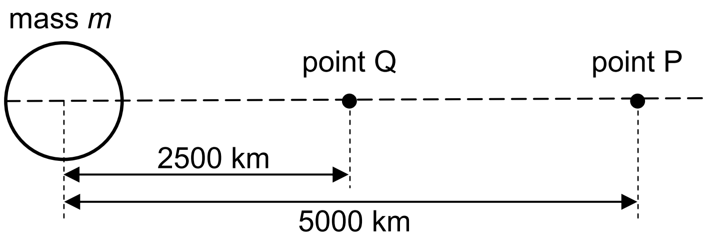
$$\frac{GMm}{r^2} = mr\omega^2 = mr\left(\frac{2\pi}{T}\right)^2$$

$$M = \frac{r^3(2\pi)^2}{GT^2} = \frac{\left[(4600+42000)\times 10^3\right]^3 \times (2\pi)^2}{(6.67\times 10^{-11})(24\times 60\times 60)^2}$$

$$= 8.0 \times 10^{24} \text{ kg}$$

A: miss out power of 2 for 2π – 1.3 × 10^{24} kg
B: miss out power of 3 for orbital radius – 3.7 × 10^{9} kg
C: mistake height as orbital radius – 5.9 × 10^{24} kg

2 A mass m is isolated in space. Point P is 5000 km from the centre of mass m and has a gravitational potential of −1000 J kg^{-1}. Point Q is 2500 km from the centre of mass m.



When a small test mass is moved from point P to point Q, what is the increase in gravitational potential experienced by the test mass?

A	+1000 J kg^{-1}	**B**	−1000 J kg^{-1}	**C**	+3000 J kg^{-1}	**D**	−3000 J kg^{-1}

L2 **Answer: B**

$$\phi_{initial} = -\frac{GM}{r_{initial}} = -1000 \text{ J kg}^{-1}$$

$$\Delta\phi = -\frac{GM}{r_{\text{final}}} - \left(-\frac{GM}{r_{\text{initial}}}\right) = -GM\left(\frac{1}{r_{\text{final}}} - \frac{1}{r_{\text{initial}}}\right) = -GM\left(\frac{1}{0.5r_{initial}} - \frac{1}{r_{initial}}\right) = -\frac{GM}{r_{initial}} = -1000 \text{ J kg}^{-1}$$

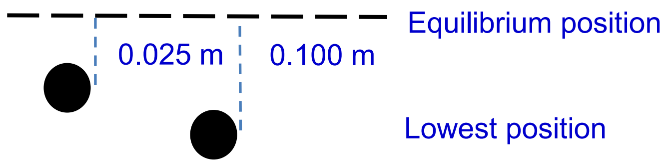
A: wrong sign
C/D: wrongly included power of 2 for radius.

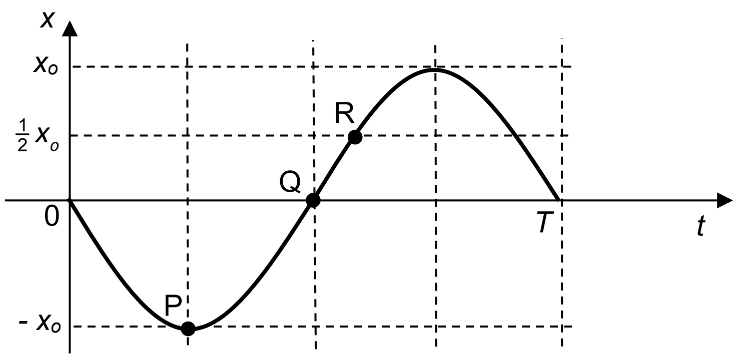
3 The displacement x of a body of mass 0.020 kg in simple harmonic motion varies with time t according to the equation

$$x = 5.0 \text{ x } 10^{-3} \sin(6\pi t)$$

where x is in metres and t in seconds.

	What is the maximum restoring force on the body?							
	A	0.00189 N	**B**	0.0355 N	**C**	0.0942 N	**D**	1.78 N
L2	**Answer: B** Maximum restoring force = $ma_{max} = m\omega^2 x_0 = 0.020(6\pi)^2(0.0050) = 0.0355\ N$							

4	While travelling on a level road, a small car passes over a speed bump and experiences rapid vertical oscillations. The amplitude of the oscillations is 0.100 m, and its angular frequency is 8.72 rad s^{-1}. What is the shortest time taken for the car to move from its lowest point to a point 0.0250 m below its equilibrium position during its oscillations?							
	A	0.0290 s	**B**	0.151 s	**C**	1.66 s	**D**	8.66 s
L2	**Answer: B**  Taking vectors below the equilibrium position to be negative Since the starting point is at lowest position $x = -x_o \cos \omega t$ $-0.025 = -0.100 \cos(8.72\ t)$ $t = 0.151$ s ***Note: use radian mode for calculation***							

5	The graph below shows how the displacement *x* of a body varies with time *t* when it is oscillating with simple harmonic motion.  Which statement about the body is false?	
	A	The kinetic energy of the body is a minimum at P.
	B	The kinetic energy of the body is a maximum at Q.
	C	The kinetic energy of the body at R is half the maximum kinetic energy.
	D	The kinetic energy of the body at R is 0.75 times the kinetic energy at Q.
L2	**Answer: C** At the amplitude positions (e.g. P), the speed is at its minimum and hence the kinetic energy is at its minimum. → option A is true.	

At the equilibrium position (e.g. Q), the speed is the maximum and hence the kinetic energy is at its maximum. → option B is true.

$$Kinetic\ Energy = \frac{1}{2}m\omega^2(x_0^2 - x^2)$$

$$Maximum\ Kinetic\ Energy = Total\ Energy\ of\ oscillation = \frac{1}{2}m\omega^2 x_0^2$$

When we substitute $\frac{x_0}{2}$ into the equation for kinetic energy, we see that the kinetic energy is ¾ (= 0.75) of the maximum kinetic energy. → option D is true, and option C is false.

6 A point source emits 60 W of sound uniformly in all directions. A small microphone of area 7.5×10^{-5} m^2 detects the sound at 5.0 m from the source.

What is the power received by the microphone?

A	1.4×10^{-5} W	**B**	1.4×10^{-4} W	**C**	9.0×10^{-4} W	**D**	1.4×10^{-1} W

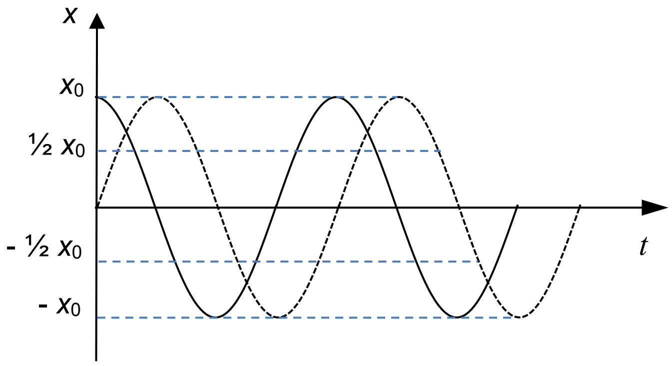
L2 **Answer: A**

Intensity of wave at distance r from source = $\frac{\text{Power of source}}{\text{Surface area of spherical wavefront}}$

Intensity at 5.0 m = $\frac{60}{4\pi(5.0)^2} = 0.19099$ Wm^{-2}

Hence, power received by microphone = $0.19099 \times 7.5 \times 10^{-5} = 1.4 \times 10^{-5}$ W

7 Two identical vertical spring-mass systems execute simple harmonic motion of the same amplitude and frequency. The graph below shows the variation of the displacement x of the masses with time t.



What is the phase difference between them?

A	90°	**B**	120°	**C**	135°	**D**	150°

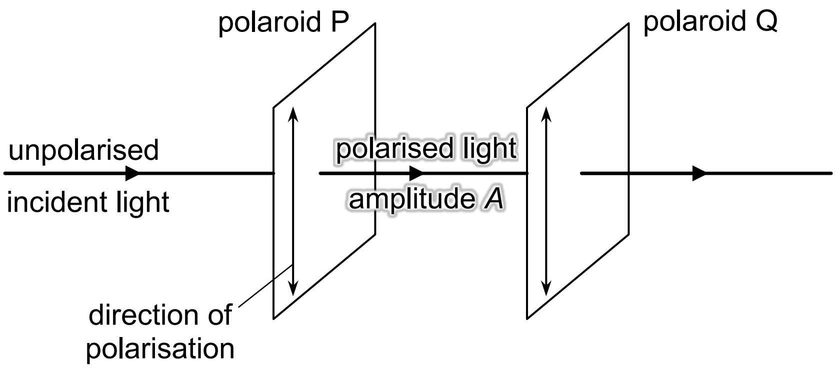
L1 **Answer: A**

The masses are one quarter a period apart.

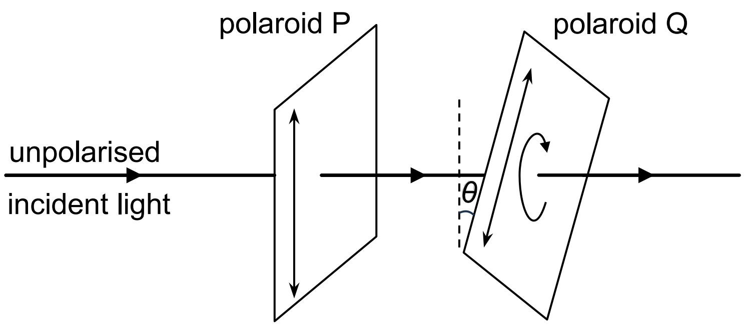
$\Delta\theta = \frac{\Delta t}{T} \times 360°$,

$\Delta\theta = \frac{1}{4} \times 360° = 90°$

8 Two sheets of polaroid, P and Q, are placed so that their polarising directions are parallel and vertical, as shown below. A parallel beam of light passes through polaroid P. The beam after passing through polaroid P has amplitude *A*. The beam then passes through polaroid Q.



Polaroid Q is now rotated about the axis of the light beam, as shown below.



What is the smallest angle θ through which Q must be rotated for the amplitude of the emergent beam from Q to be reduced to ½ *A*?

A	30°	**B**	45°	**C**	60°	**D**	90°

L1 **Answer: C**

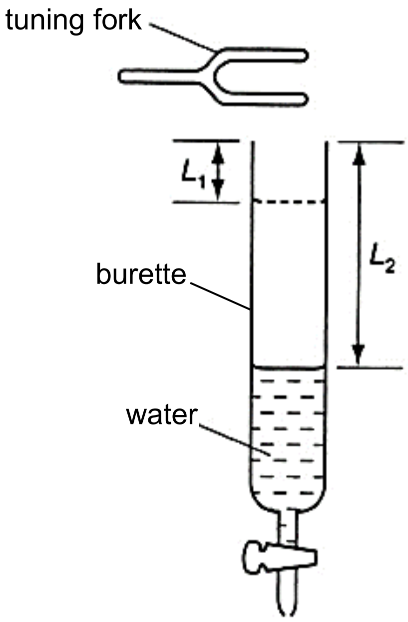
The amplitude of the polarized beam transmitted through polaroid Q is given by:

$$A_T = A \cos\theta$$

From here,

$$\tfrac{1}{2} A = A \cos\theta$$
$$\theta = 60°$$

9	A tuning fork is made to vibrate above a burette filled with water. The water is allowed to run out of the tube. A loud sound is heard when the length of the air column is L_1 = 18 cm and again when the length is L_2 = 45 cm.



What is the wavelength of the sound in the air column?

A	27 cm	**B**	54 cm	**C**	60 cm	**D**	72 cm

L2 **Answer: B**

Note that since (18 cm x 3) ≠ 45 cm,
End correction at the open end is NOT negligible and must be accounted for.

Let c be the end correction.

At first resonance: $L_1 + c = \frac{1}{4}\lambda$ ——-(1)
At second resonance: $L_2 + c = \frac{3}{4}\lambda$ ——-(2)

(2) − (1):
$L_2 - L_1 = \frac{1}{2}\lambda$
$45 - 18 = \frac{1}{2}\lambda$
$\lambda = 54$ cm

10	A beam of white light was projected onto a diffraction grating with 400 lines per mm. How many orders of the entire visible spectrum (400 nm to 700 nm) can be produced using this grating? (Do not count the zeroth order.)

A	3	**B**	4	**C**	6	**D**	7

L2 **Answer: A**

Diffraction grating equation
$d \sin\theta = n\lambda$

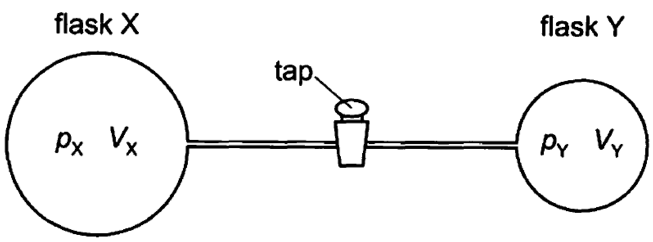
"How many orders" implies MAXIMUM number of orders → assume $\theta = 90^{o}$

"entire spectrum" → since the LONGEST wavelength diffracts the most, the LEAST number of orders of the LONGEST wavelength light can be seen on the screen, thus it is the limiting factor!

Use d sin θ = nλ
Where
d = (1 x 10^{-3}) / 400 = 0.0000025 m
θ = 90º
λ = 700 x 10^{-9} m

n = 3.6
→ n = 0, 1, 2, 3 are visible
→ maximum number of orders that can be seen, excluding zeroth order = 3

11 Some ideal gas is contained in two flasks X and Y. The flasks are connected by a tube of negligible volume that is fitted with a tap, as shown.



With the tap closed, the pressure and volume of the gas in flask X are p_X and V_X respectively. In flask Y, the gas has pressure p_Y and volume V_Y. The temperature of the gas in both flasks is *T*.

The tap is opened. After some time, the temperature of the gas returns to *T*.

Which expression gives the final pressure of the gas in the flasks after opening the tap once the temperature has returned to *T*?

A	$\dfrac{p_X V_X + p_Y V_Y}{V_X + V_Y}$
B	$\dfrac{1}{2}\dfrac{p_X V_X + p_Y V_Y}{V_X + V_Y}$
C	$\dfrac{(p_X + p_Y)V_X V_Y}{V_X + V_Y}$
D	$\dfrac{(p_X - p_Y)(V_X - V_Y)}{V_X + V_Y}$

L2 **Answer: A**

No. of moles of gas in X, $n_x = \frac{p_x V_x}{RT}$

No. of moles of gas in Y, $n_y = \frac{p_y V_y}{RT}$

When the tap is opened, the gas from both flasks are mixed, but the total number of moles of gas is unchanged and given by,

$$n = n_x + n_y$$

Let *p* be the final pressure of the gas, and $V = (V_X + V_Y)$ be the total volume.

$$\frac{pV}{RT} = \frac{p_x V_x}{RT} + \frac{p_y V_y}{RT}$$

$$pV = p_x V_x + p_y V_y$$

$$p(V_x + V_y) = p_x V_x + p_y V_y$$

$$p = \frac{p_x V_x + p_y V_y}{V_x + V_y}$$

12 A school laboratory has dimensions 12 m by 10 m by 3 m. The laboratory contains air of molar mass 0.029 kg, at an atmospheric pressure of 1.0×10^5 N m^{-2}. The air has a density of 1.2 kg m^{-3}.

What is the root-mean-square speed of the gas molecules in the air?

A	410 m s^{-1}	**B**	500 m s^{-1}	**C**	50000 m s^{-1}	**D**	61000 m s^{-1}

L2 **Answer: B**

$$\frac{1}{2}mv_{r.m.s.}^2 = \frac{3}{2}nRT = \frac{3}{2}pV$$

$$v_{r.m.s.} = \sqrt{\frac{3p}{\left(m/V\right)}} = \sqrt{\frac{3p}{\rho}} = \sqrt{\frac{3(1.0\times10^5)}{1.2}} = 500 \text{ m s}^{-1}$$

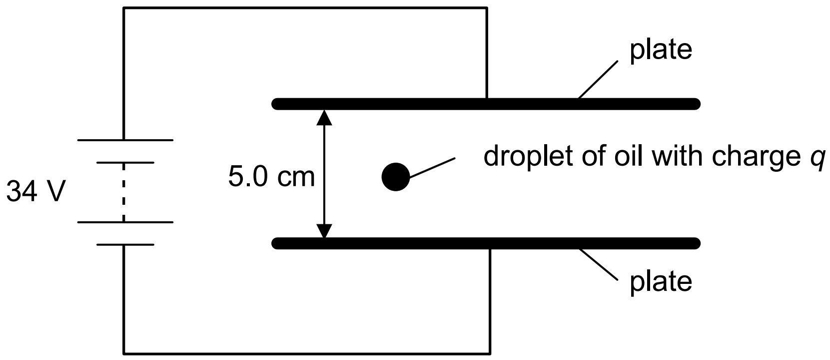
OR

$$p = \frac{1}{3}\frac{Nm}{V}v_{r.m.s.}^2 = \frac{1}{3}\rho v_{r.m.s.}^2$$

$$v_{r.m.s.} = \sqrt{\frac{3p}{\rho}} = \sqrt{\frac{3(1.0\times10^5)}{1.2}} = 500 \text{ m s}^{-1}$$

A: Miss out 3/2 fraction – 410 m s^{-1}
C: Miss out 3/2 fraction and wrongly use m = 0.029 kg – 50 000 m s^{-1}
D: Wrongly use m = 0.029 kg – 61 000 m s^{-1}

13 A droplet of oil of mass 0.21 g is held in equilibrium between two horizontal parallel charged plates as shown. The droplet of oil has a charge q. The parallel plates are fixed with a separation of 5.0 cm and a potential difference of 34 V is applied across the plates.



What is the electric field strength experienced by the droplet of oil?

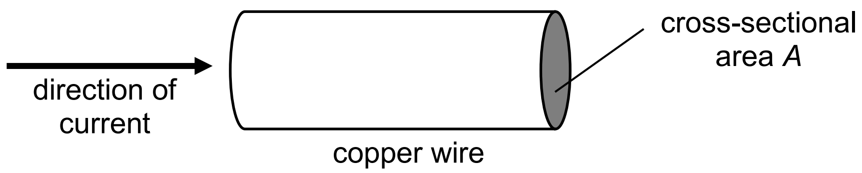
A	0.070 N C^{-1}	**B**	34 N C^{-1}	**C**	680 N C^{-1}	**D**	1.6×10^4 N C^{-1}

L1 **Answer: C**

$$E = \frac{\Delta V}{\Delta d} = \frac{34}{0.050} = 680 \text{ N C}^{-1}$$

A: Wrongly use weight of oil droplet times ΔV – 0.070
D: Wrongly use V/m – 1.6×10^4

14 An electric current $I = 4.0$ A flows through a cylindrical shaped copper wire as shown. The wire has a cross-sectional area A = 4.0×10^{-6} m^2.



Given that the number of free electrons per cubic metre for copper is 8.6×10^{28}, what is the drift velocity of electrons through the copper wire?

A	1.2×10^{-23} m s^{-1}	**B**	7.3×10^{-5} m s^{-1}
C	8.5×10^{-3} m s^{-1}	**D**	2.2×10^{5} m s^{-1}

L2 **Answer: B**

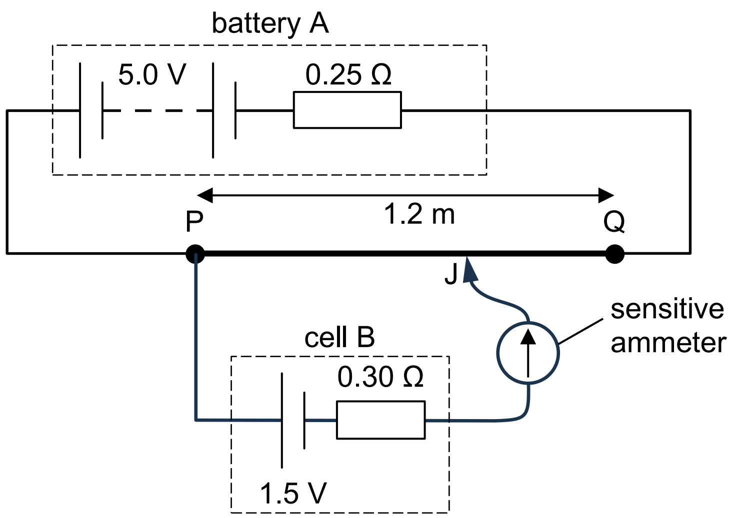
$$I = Avnq$$

$$v = \frac{I}{Anq} = \frac{4.0}{(4.0 \times 10^{-6})(8.6 \times 10^{28})(1.60 \times 10^{-19})}$$

$$= 7.3 \times 10^{-5} \text{ m s}^{-1}$$

A: Wrongly omitting charge of electron – 1.2×10^{-23}
C: Wrongly take square root – 8.5×10^{-3}
D: Wrongly use *v=IAnq* – 220000

15 A battery A with internal resistance 0.25 Ω is connected in series with a uniform resistance wire PQ as shown. Resistance wire PQ has a length of 1.2 m and a resistance of 3.0 Ω. A cell B and a sensitive ammeter is connected to points P and J on the resistance wire.



The ammeter reads zero. What is the length PJ?

A	0.32 m	**B**	0.35 m	**C**	0.36 m	**D**	0.39 m

L2	**Answer: D** $V_{PQ} = \frac{3.0}{3.0+0.25} \times 5.0 = 4.6154\text{ V}$ $V_{PJ} = \frac{\ell_{PJ}}{\ell_{PQ}} \times V_{PQ}$ $1.5 = \frac{\ell_{PJ}}{1.2} \times 4.6154$ $\ell_{PJ} = 0.39\text{ m}$ A: Wrongly take length of PQ as 1m – 0.32 m B: Wrongly take V_{PJ} = (3/3.3)×1.5 V – 0.35 m C: Wrongly miss out internal resistance of A – 0.36 m

Section B

Answer all questions in the answer spaces provided in this paper.

1 Coherent light of wavelength 590 nm is incident normally on a double slit, as illustrated in Fig. 1.1.

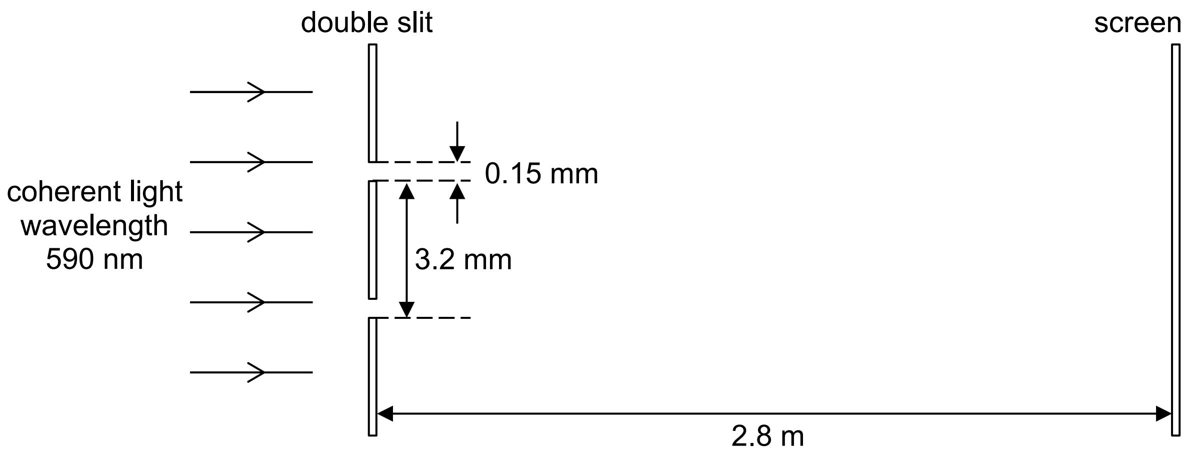


Fig. 1.1 (not to scale)

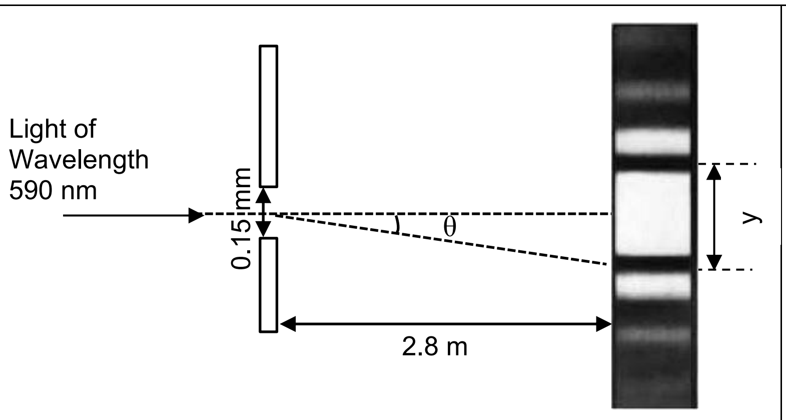
Both slits in the double-slit arrangement are rectangular with a width of 0.15 mm. The separation of the two slits is 3.2 mm.

A screen is placed parallel to the plane of the double slit at a distance of 2.8 m from the double slit.

(a) Initially, one of the two slits is covered.

Calculate the width of the central bright maximum formed on the screen by diffraction through the uncovered slit.

L2 Solution:



M1

Using single-slit diffraction equation:
b sin θ = m λ were m: order of intensity *minima*
$(0.15 \times 10^{-3}) \sin \theta = (1)(590 \times 10^{-9})$
θ = 0.22536°

M2
(for use of tan, and, correct numerator = ½ width)

From diagram above,

$$\tan\theta = \frac{\frac{y}{2}}{2.8}$$

A1

$$\tan 0.22536° = \frac{\frac{y}{2}}{2.8}$$

Width, y = 0.0220268 m = **0.022 m** (2 s.f.)

width = …………………….……………… m [4]

Examiners' Comments:

- A significant number of candidates used Young's double-slit equation, although light is passing through 1 slit only.
- Some candidates had unclear working; they did not show why $\frac{\lambda}{b} \approx \frac{\frac{y}{2}}{D}$.
- Several candidates gave the final answer as half of the actual width.

(b) State the *Rayleigh criterion* for the resolution of two images.

……………………………………………………………………………………………… [2]

L1 Rayleigh's criterion states that the images of two sources are ***just*** distinguishable if **B1**

the **central maximum** of **one diffraction pattern** lies on the **first minimum** of the **other diffraction pattern**. **B1**

A-level marking points:

- **'just distinguishable' / 'just seen as separate' [do not use 'just resolved']**
- **'diffraction pattern' [do not use 'image' or simply 'pattern']**
- **'central maximum of one' 'lies on' 'first minimum of the other'**

Examiners' Comments:

- Common A-level question but not well answered. Many candidates left this question unanswered too.

- Many candidates did not hit the A-level marking points highlighted in Red above.

(c) Both slits in the double slit are now uncovered.

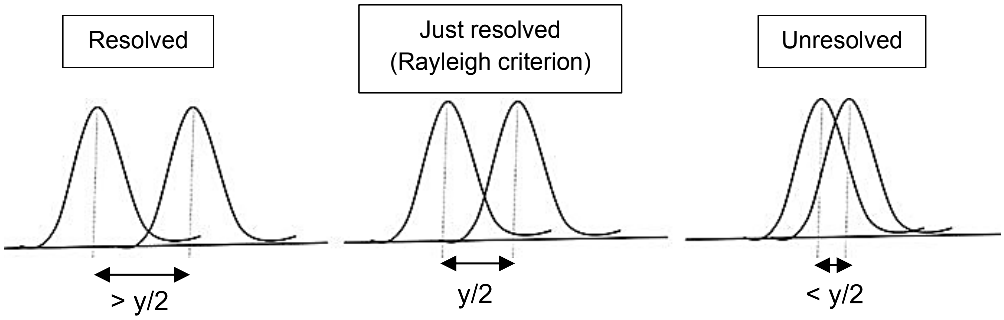
Use the Rayleigh criterion to explain whether the diffraction patterns produced by the two slits are seen on the screen as being separate.

.... [3]

L3

To check if the 2 diffraction patterns due to the double slits are distinguishable using Rayleigh criterion, we need to know the separation between the central maxima of the 2 diffraction patterns…how can we know this? → What information is given in the question & what have we derived in the earlier part(s)?

- ➔ Separation between the 2 central maxima equals to the separation of the double slits = 3.2 mm
- ➔ What is the distance between the central maximum of one & the first minimum of the other? → Draw out the 2 diffraction patterns as shown below to visualise. → distance equals HALF the width of the central maximum fringe found in (a) = y/2 = 0.0220268 m / 2 = 11.0 mm
- ➔ So are the 2 diffraction patterns distinguishable? → No, because 3.2 mm is smaller than 11.0 mm. The 2 diffraction patterns overlap to a large extent and hence not distinguishable.



where y: width of the central maximum of a single slit diffraction pattern, calculated in (a).

Solution:

Using (a), **distance between the central maximum of one diffraction pattern and the first minimum of the other equals to 0.0220268 m / 2 = 11.0 mm**. **B1**

The **separation between the central maxima of the two slits' diffraction patterns in Fig. 1.1 is 3.2 mm**. **B1**

The **separation of 3.2 mm is <u>very much smaller than</u> the separation of 11.0 mm required for the two diffraction patterns to be distinguishable by Rayleigh criterion**. The two diffraction patterns overlap to too large an extent and **will <u>not</u> be seen as being separate**. **B1**

Examiners' Comments:

- **This question is similar to A-level 2019 P3 Q8**.
- Majority of the candidates found this question challenging. Many did not attempt the question too.
- Candidates need to make clear the significance of the slits separation (3.2mm) in relation to Rayleigh's Criterion, i.e. relate 3.2mm to the separation between the central maxima of the two diffraction patterns, not simply repeat that 3.2mm is the slits separation which is given in the question.

(d) Calculate the width of a fringe produced by the interference of light passing through the uncovered double slit.

fringe width = …………………….……………… m [2]

L2

$$x = \frac{\lambda D}{a} = \frac{(590 \times 10^{-9})(2.8)}{(3.2 \times 10^{-3})}$$ **C1**

$= 5.1625 \times 10^{-4} =$ **5.2×10^{-4} m** **A1**

Examiners' Comments:

- Most candidates recalled the Young's double-slit formula and many obtained full credit.
- However there were a significant number of candidates who recalled the Young's formula but did not recall the meaning of 'x' and 'a' correctly. **Common mistakes include substituting a=0.15mm instead of a=3.2mm, or using a=(3.2-0.15)mm.**

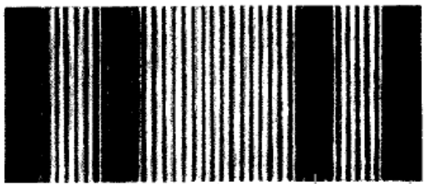
(e) Use your answers to **(a)** and **(d)** to estimate, to one significant figure, the number of double-slit fringes observed in the central bright maximum produced by diffraction at one of the slits.

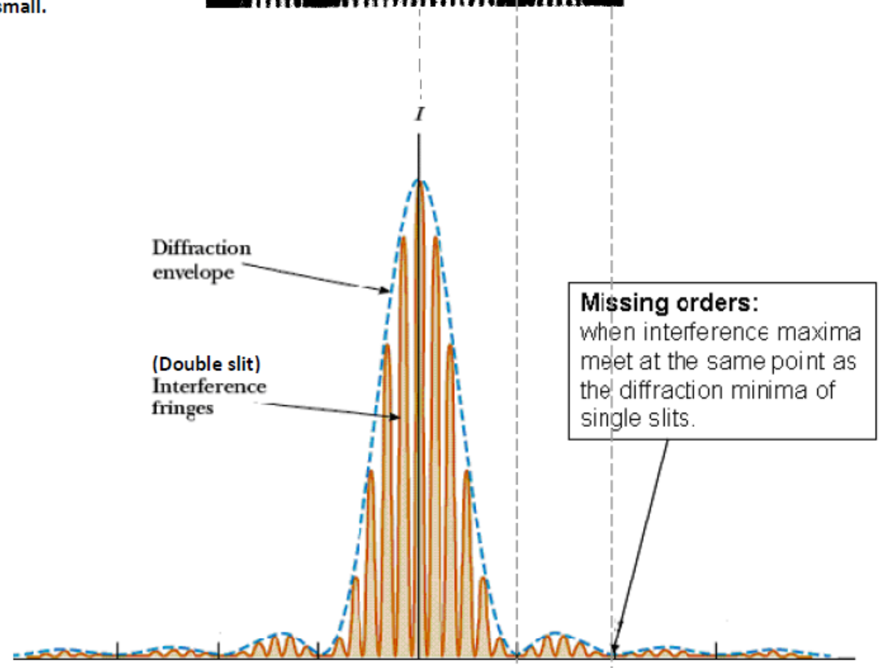
number = …………………….……………… [1]

L2

Recall the following diagram from your Module Notes:

(a) Photograph of the double slit interference fringes seen on the screen when the slits are not infinitesimally small.





(b) Plot of intensity against distance from the central maxima.
The figure shows the combined effects of double slit interference and single slit diffraction. Notice how the diffraction pattern acts as an 'envelope' and controls the intensity of the regularly spaced interference maxima.

Is the question asking for number of bright fringes or dark fringes or both? → both.

Solution:

Total number of <u>bright & dark</u> fringes within the central maximum diffraction envelope

		= 0.0220268 / (5.1625 x 10^{-4}) = 42.6 = **40 (Round DOWN to 1 sig. fig.)** ***Answer should be rounded DOWN not up.*** ***And should be expressed to 1 sig. fig. only.*** ***The following are not acceptable e.g. 42, 43, ..***	**B1**
		Examiners' Comments: • Many candidates obtained ECF for this part. However many also left this part blank or put in a random value as the answer without showing how it is derived from parts (a) and (b).	

[Total: 12]

2 A receiver aerial is placed between a transmitter emitting radio waves at a single fixed frequency and a metal sheet, as shown in Fig. 2.1. The radio waves undergo π radians phase change upon reflection at the metal sheet.

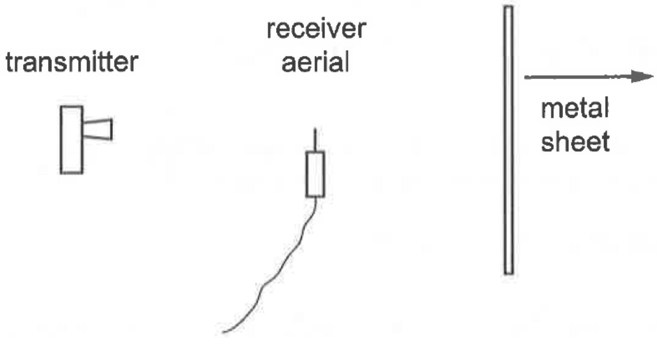


Fig. 2.1

The metal sheet is moved away from the receiver aerial by distance *h*. The variation of the intensity detected by the receiver aerial with *h* is shown in Fig. 2.2.

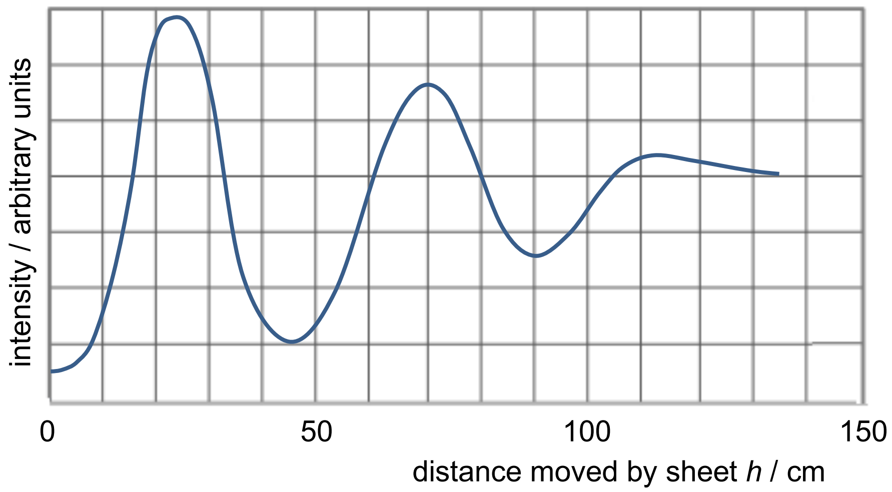


Fig. 2.2

(a) A minimum intensity is detected when *h* = 0.

State the phase difference, in radians, between the direct wave from the transmitter and the reflected wave at the receiver aerial when *h* = 0.

phase difference = ... rad [1]

	L1	Destructive interference occurs at the position of the aerial when *h* = 0. This implies that the two waves arrive in antiphase at the aerial, thus phase difference equals to **π radians**.	**B1**
		Examiners' Comments: • Generally not well done. • Candidates will need to note that for minimum intensity, destructive interference takes place and that the waves will meet at antiphase, with a phase difference of π radians.	
	(b)	Explain why as *h* increases, the intensity detected by the antenna alternates between maximum and minimum.	
		....	[3]
	L2	**As *h* increases, the path difference between the direct and reflected radio waves increases and alternates between an integer multiple of a wavelength, and, an odd integer multiple of half a wavelength**. Since the radio waves undergo π radians phase change upon reflection, **Whenever the path difference equals zero or an integer multiple of a wavelength, the two waves arrive in antiphase at the aerial and undergo destructive interference, giving rise to an intensity minimum.** **Whenever the path difference equals an odd integer multiple of half a wavelength, the two waves arrive in phase at the aerial and undergo constructive interference, giving rise to an intensity maximum.** **B1** for relating h to path difference. **B1** for stating that when the 2 waves arrive in phase they interfere constructively, and, when arrive in antiphase they interfere destructively. **B1** for correct values of path difference stated in each case. *No mark for the point that radio waves undergo π radians phase change upon reflection since it is given in the question.* ***It is to be taken note that the metal sheet is the one that is moving while the receiver is stationary.***	**B1** **B1** **B1**
		Examiners' Comments: • Generally not well done. • Many candidates visualized the scenario as the formation of a stationary wave. • Answer related to this question should be contextualized in terms of the question phrasing. As h changes, the distance that the direct wave travels to the receiving aerial does not change, but the distance that the reflected wave travels after undergoing the reflection from the metal sheet changes. As a result, the path difference varies and so does the phase difference between the two waves when they meet at the receiving aerial.	
	(c)	Explain why as *h* increases, the intensity of the minimum increases.	
		....	[2]
	L2	The **reflected wave has a smaller amplitude** than the wave directly from the transmitter. **The *difference* in their amplitudes increases with *h***. Hence **when the direct and the reflected waves superpose in *antiphase*, the resultant displacement is *non-zero and is greater* as *h* increases**.	**B1** **B1**
		Examiners' Comments:	

		• Generally not well done. • Candidates to note the decrease in amplitude of waves as they travel further and further away from the source. As a result, when both waves undergo destructive interference, the resultant amplitude will be non-zero.	
		Extension Question: Explain why as *h* increases, the intensity of the maximum decreases.	
		Solution: While the amplitude of the wave directly from the transmitter remains constant, the amplitude of the reflected wave decreases as h increases. Hence when the two waves superpose in phase, the resultant displacement decreases as h increases.	
	(d)	Use Fig. 2.2 to estimate, to one significant figure in cm, the wavelength of the radio wave.	
		wavelength = ……………………………… cm	[2]
	L3	***Successive minima*** detected when **path difference <u>changes by</u> one wavelength**. Likewise, ***successive maxima*** detected when **path difference <u>changes by</u> one wavelength.** **λ = change in** path difference when the plate moves a distance that results in successive minima/maxima detected = **2 x change in h** Using successive minima when *h* = 0 and *h* = 45 cm, **λ = 2 x change in h** **= 2 (45 cm) = <u>90 cm (Round off to 1 sig. fig.)</u>** OR A **stationary wave** is formed between the transmitter and the metal sheet. **Maximum intensity detected indicates an antinode in the stationary wave at the aerial. Minimum intensity indicates a node.** **Internodal distance is 45 cm.** **Wavelength λ = 2 x 45 cm = <u>90 cm (Round off to 1 sig. fig.)</u>**	**M1** **A1**
		Examiners' Comments: • **This question is similar to Alevel 2014 P1 Q22 and 2019 P1 Q18.** • Generally not well done. • Candidates to note that a change in path difference of one wavelength corresponds to a position experiencing minimum intensity twice, detecting one minimum intensity to a maximum and then back to a minimum. Therefore, visualizing how the reflected wave is travelling, this one wavelength is equal to twice the distance moved by the metal sheet.	

[Total: 8]

3	**(a)**	Define *electric field strength*.	
		………………………………………………………………………………………	[2]
	L1	The electric field strength at a point in an electric field is the **<u>electric</u> force <u>per</u> unit <u>positive</u> charge** acting on a **stationary small test charge** placed at that point.	**B1** **B1**
		Examiners' Comments: • Several candidates referred to electric force on a 'mass' or per unit 'mass'. • Some candidates omitted per unit 'positive' charge. • Some candidates stated 'on a charge' rather than 'per unit'.	

- Most candidates did not mention 'stationary small test charge'.
- Some candidates stated the definition for 'electric field' instead of 'electric field strength'.
- Some candidates confused with the definition of 'electric potential' and referred to work done by external agent from infinity.

(b) A charged solid metal sphere A is isolated in vacuum. The variation with distance *x* from the centre of sphere A of the electric field strength *E* is shown in Fig. 3.1.

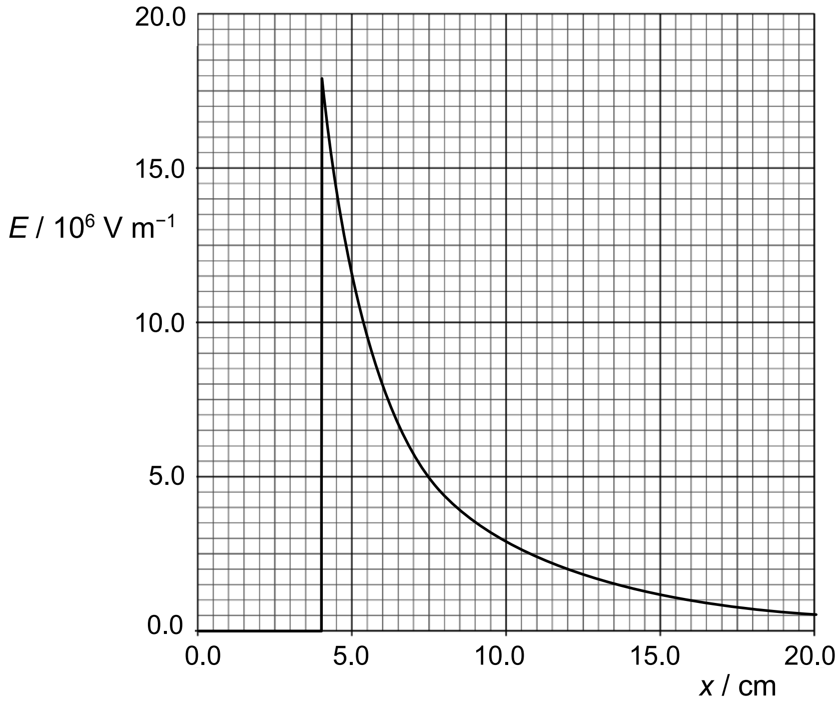


Fig. 3.1

(i) Explain why the electric field strength is zero for certain values of *x*.

.... [1]

L2 Mobile electrons within the charged metal sphere are in equilibrium at steady-state, **net force** on **all mobile charge carriers (mobile electrons)** within the sphere is **zero**.
Hence electric field strength has to be zero within the sphere. **B1**

Examiners' Comments:

- Very few concise answers state the redistribution of charges until the charge carriers experiences no net force, therefore field strength is zero.
- Several answers did not even state that only for metal sphere, the field strength in the metal sphere is zero. If it is a plastic sphere, such a statement would not make sense on its own yet.
- Many answers engage in circular argument, stating that there is no field for certain values of *x*, which is a rephrase of the question instead of providing a step-by-step reasoning to reach the conclusion.

(ii) Using Fig. 3.1, state the radius of the sphere A.

radius = ... cm [1]

L1 Radius = **4.0 cm** **B1**

Since electric field strength within a metal sphere is zero, the region of E=0 ends at 4.0 cm and beyond that will be outside of the sphere.

			Examiners' Comments: • Majority of the answers were acceptable.	
		(iii)	Using Fig. 3.1, determine the magnitude of the charge of sphere A.	
			charge = ………………………… C	[2]
		L2	From the graph, at x = 4.0 cm, E = 18.0 × 10^6 V m^{-1} $E = \frac{Q}{4\pi\varepsilon_0 r^2}$ $18.0 \times 10^6 = \frac{Q_A}{4\pi(8.85 \times 10^{-12})(0.040)^2}$ $Q_A = 3.20 \times 10^{-6}$ C	**M1** **A1**
			Examiners' Comments: • Common errors include not squaring the separation or read off the graph as a V against r graph. • Plenty of answers did not consider units in the graph, i.e. 10^6 is often missing for the vertical axis and cm ignored in the horizontal axis.	

(c) Another charged solid metal sphere B is placed with a centre-to-centre separation of 25 cm from sphere A as shown in Fig. 3.2. Both metal spheres are isolated in vacuum.

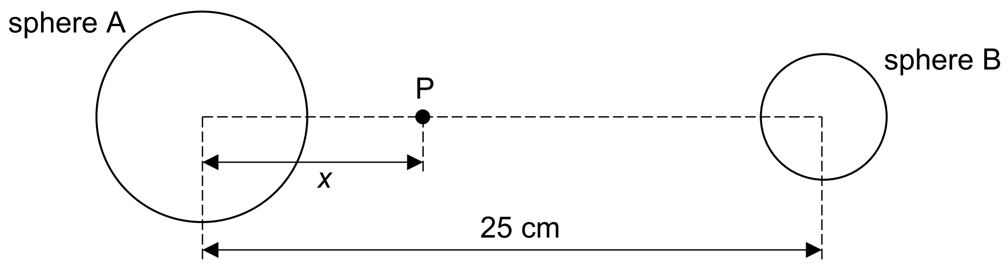


Fig. 3.2 (not to scale)

Point P is a point on the line joining the centres of the two spheres. Point P is a distance x from the centre of sphere A.

The variation with distance x from the centre of sphere A of the electric potential V due to both spheres is shown in Fig. 3.3.

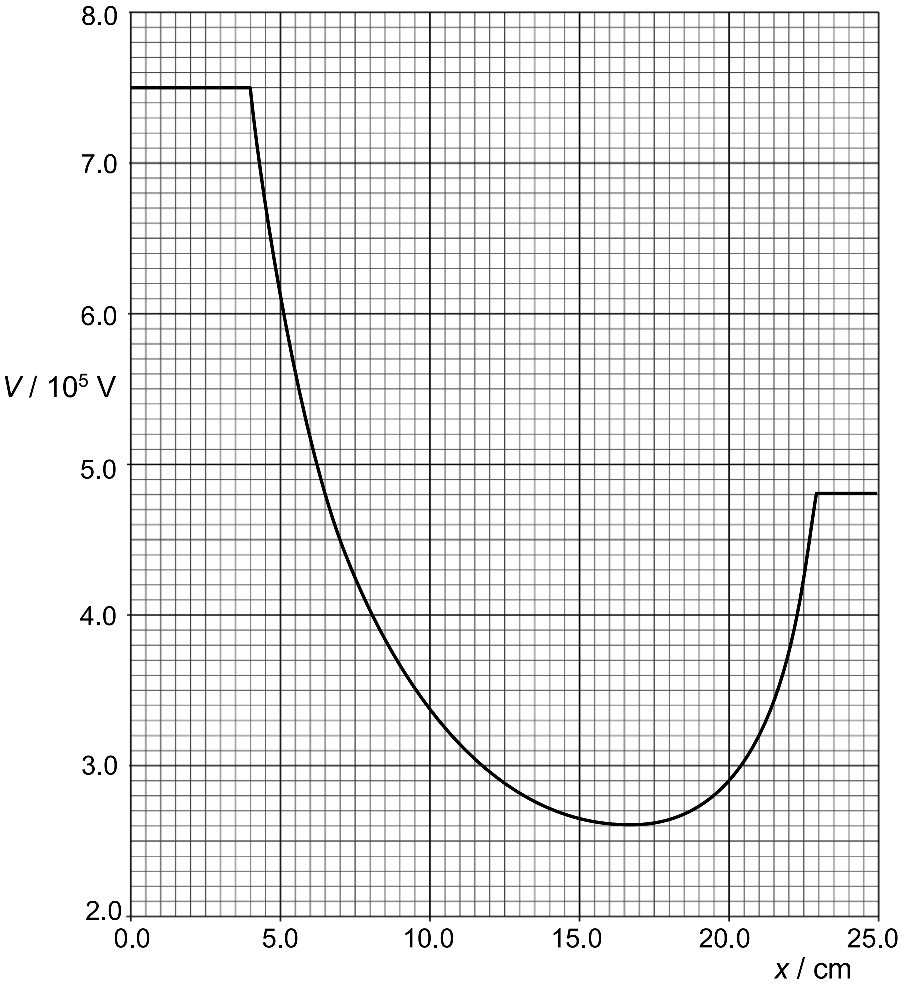
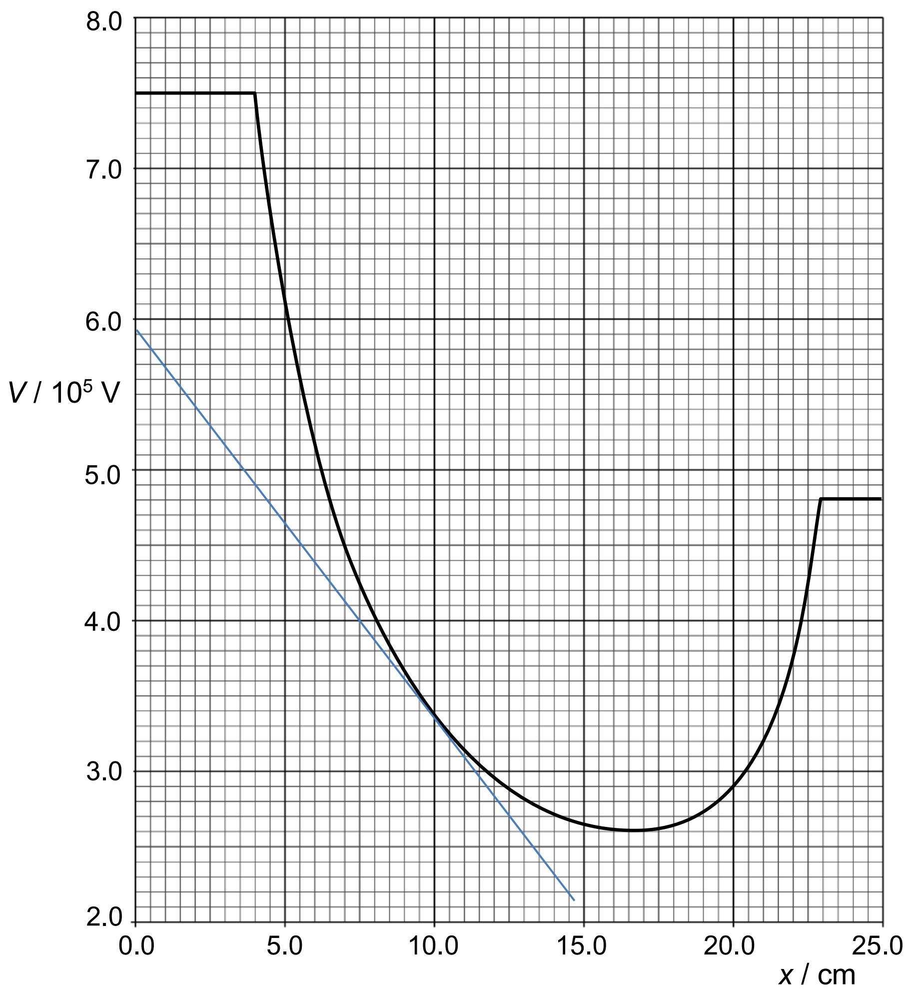


Fig. 3.3

		(i)	State and explain whether the spheres have charges of the same, or opposite, sign.	
			....	[1]
		L2	Since the **surface** of both spheres are at **positive potential**, the charges are of the **same sign.** OR Since the **potential at every point** between the 2 spheres is **positive**, **both spheres are positively charge, hence same sign**. OR Since the potential is **non-zero everywhere between the 2 spheres**, the spheres **cannot be of opposite signs and must be of same sign**.	**B1**
			Examiners' Comments: • Cancellation of answers from opposite to same, and vice versa was common in this question. More often, the cancellation happens when at the later part of the question, students found the answers contradictory to their answers here and decided to change. Students are advised that the order of the question matters, that in this case, students should be able to deduce the charge based on the data given up to this point in the question without working through the rest of the question.	

			• Less ideal answers merely describe the graphs but not the exact features that are confirmative of charges of the same sign, such as "there exist a null point"; "one charge potential is higher than the other"; the potential decreases then increases". Students are advised to be precise in their responses, for example, if we are to explain why an animal is a zebra, we do not just mention it has eyes, nose and ears, but to go straight to the point that it must have at least black and white stripes.	
		(ii)	Using the charge of sphere A found in **(b)(iii)**, determine the charge of sphere B.	
			charge = ... C	[2]
		L2	From the graph, at x = 4.0 cm, V = 7.5 × 10^5 V $V = \frac{Q_A}{4\pi\varepsilon_0 r_A} + \frac{Q_B}{4\pi\varepsilon_0 r_B}$ $7.5\times10^5 = \frac{3.20\times10^{-6}}{4\pi(8.85\times10^{-12})(0.040)} + \frac{Q_B}{4\pi(8.85\times10^{-12})(0.25-0.040)}$ $Q_B = 7.1595\times10^{-7} = 7.2\times10^{-7}\text{C}$	M1 A1
			Examiners' Comments: • This question is badly done. • Many answers did not realise that the graph in Fig. 3.3 is the **resultant** potential of both charge A and B, often missing a second term in the equation. • Concerning numbers of answers equated potential as equivalent to potential energy. • Some incorrect application stated that the potentials are the null point is equal, not realizing that for null point, it is the electric field strengths that are equal and opposite.	
		(iii)	State and explain the direction of the electric field at point P, where x = 10.0 cm.	
			....	[2]
		L2	Since the electric field strength is equal to **negative of the electric potential gradient,** the negative potential gradient implies that the **electric field strength acts in the direction away from sphere A** (***or*** **towards sphere B**).	M1 A1
			Examiners' Comments: • There were many guess works in this question, stating either towards A or towards B. Very field answers gave satisfactory explanation. • As the data Fig. 3.3 is provided, there is no error carry forward. All answers must be based on the data provided but not based on own incorrect interpretation of the question. • The best answers consider the relationship, E = -dV/dr, stating that the gradient is negative, this the E is positive, pointing towards B. • Many answers beat around the bush, describing the trend in Fig. 3.3. without exact feature that determines the direction of the electric field strength.	
		(iv)	Use Fig. 3.3 to determine the magnitude of the electric force on an electron placed at point P, where x = 10.0 cm.	
			magnitude of electric force = ... N	[3]
		L2	From the graph, at x = 10 cm, determine the gradient (Mark for construction of tangent at x = 10 cm. Tangent drawn should be long enough and 2 coordinates chosen to calculate gradient should be far apart enough.)	B1



			magnitude of $F = qE$ $= q\left\lvert\frac{dV}{dr}\right\rvert = q \times \lvert\text{gradient at } x = 10 \text{ cm}\rvert$ $= \left(1.60 \times 10^{-19}\right)\left\lvert\frac{(5.80 - 2.20) \times 10^{5}}{(0 - 14.5) \times 10^{-2}}\right\rvert$ $= 3.9274 \times 10^{-13} = 3.93 \times 10^{-13}$ N	M1 A1

			Examiners' Comments:
			• This question proved to be the most challenging to students.
			• Very few correct answers recognize that there are two forces acting on an electron. Majority of the answers did not even consider the charge of an electron.
			• Common errors include:
			  o Finding the force between charge A and B placed at 25 cm;
			  o Finding the force between charge A and B placed at 10 cm;
			  o Finding just the force of charge A on electron only or just the force of charge B on an electron.
			• Students are advised that should there be a graph given on a graph grid, there is a high chance of
			  o Reading values off a graph;
			  o Calculate gradient;
			  o Finding area under graph.	

		(v)	An electron is initially at rest a long distance from spheres A and B. The electron approaches the spheres and passes between the two spheres.	

			Calculate the minimum speed of the electron as it crosses the line joining the centres of the two spheres.	
			speed = ... m s^{-1}	[2]
		L3	At a long distance away, assume at infinite distance away, the potential will be zero. The minimum speed is achieved when the electron passes the point of **minimum potential** on the graph as the change in electric potential energy in the process would be the lowest. By conservation of energy, the electron loses electric potential energy and gains kinetic energy. Gain in kinetic energy = loss in electric potential energy $\frac{1}{2}mv^2 - 0 = q\left(V_{\text{initial}} - V_{\text{final}}\right)$ $\frac{1}{2}\left(9.11\times10^{-31}\right)v^2 = \left(-1.60\times10^{-19}\right)\left(0-2.60\times10^{5}\right)$ $v = 3.02\times10^{8}$ m s^{-1}	M1 A1
			Examiners' Comments: • Generally not well done. • Candidates to note the energies transformation of the electron as it gets attracted to the two positively charged spheres and make use of the conservation of energy to solve.	
		(vi)	Suggest why the answer in **(c)(v)** is not possible.	
			....	[1]
		L3	It exceeds the speed of light.	B1
			Examiners' Comments: • Generally not well done. • The answer is dependent on what candidates wrote for part (v).	

[Total: 17]

4 The *I*-*V* characteristic graph for a thermistor shown in Fig. 4.1.

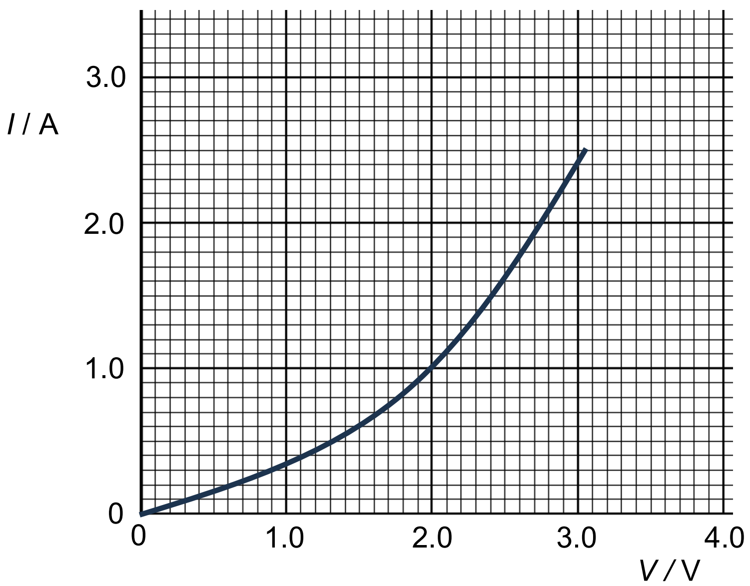


Fig. 4.1

	(a)	Explain why the resistance of the thermistor decreases when the temperature of the thermistor increases.	
		…………………………………………………………………………………………	[3]
L2		As the temperature of the thermistor increases, the number of free mobile charge carriers per unit volume increases, thus resistance decreases sharply. Moreover, the amplitude of vibration of the atomic core increases, the resistance increases. The effect of more free mobile charge carriers decreasing the thermistor resistance is larger than the increase in resistance due to the atomic vibrations. Thus, overall resistance of the thermistor decreases.	**B1** **B1** **B1**
		Examiners' Comments: • Most students ended up describing how resistance is decreasing by looking at the curvature of the graph. Should be explaining why resistance drops instead. • Some students get 1 mark for mentioning increase in frequency of collision due to more vigorous vibration of ions.	

(b) In an attempt to obtain the graph in Fig. 4.1 for the thermistor, a student set up a circuit as shown in Fig. 4.2.

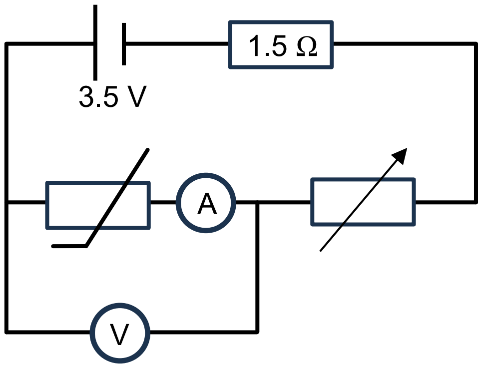


Fig. 4.2

A cell of e.m.f. 3.5 V with negligible internal resistance is connected to the thermistor, a 1.5 Ω fixed resistor and a variable resistor.

When the variable resistor has a resistance value of 2*R*, the thermistor has a resistance value of *R*. The potential difference across the variable resistor is 2.0 V.

	(i)	Determine the value of *R*.	
		R = ………………………… Ω	[2]
L1		By the potential divider principle, $\frac{2R}{2R+R+1.5}\times 3.5=2.0$ $3.5R=3R+1.5$ $0.5R=1.5$ $R=3.0\ \Omega$	**M1** **A1**
		Examiners' Comments: • A few students wrongly see this as a parallel circuit. Note that the ideal voltmeter is not drawing current. The same current flows through all 3 components (1.5Ω resistor, variable resistor and thermistor)	

			• Many students did not read the question carefully and mistakenly wrote 2.0V as the potential difference (p.d.) of thermistor. • Some students tried to calculate the total current in the circuit but didn't use the total resistance when applying *V=IR*.	
		(ii)	Use Fig. 4.1 to determine the current passing through the thermistor.	
			current = ………………………….. A	[2]
	L2		By the potential divider principle, the **potential difference across the thermistor is,** $\frac{3}{6.0+3.0+1.5}\times 3.5 = 1.0\,\mathbf{V}$ **From Fig. 4.1, the current passing through the thermistor is <u>0.35 A</u>.** (by calculation, the theoretical answer = 0.33 A)	M1 A1
			Examiners' Comments: • **Note that this question says: "Use Fig. 4.1" so you are forced to use this method.** • While there are some error carried forward, full marks couldn't be award since the method used was wrong to start with. • **Note that the values from the graph should be read to the nearest ½ smallest square on the graph. In this case, to the nearest 0.05 A. Hence, it is not acceptable for some students to read 0.34A or 0.33A from the graph.**	
		(iii)	The variable resistor has a resistance between zero to 10 Ω. Explain, using appropriate calculations, why the circuit shown in Fig. 4.2 is inappropriate for determining the graph of Fig. 4.1.	
			…………………………………………………………………………………………	[2]
	L3		The thermistor is in series with the fixed resistor, the variable resistor and the cell. **The resistance of the variable resistor of 10 Ω is not high enough, resulting in not achieving low p.d. across thermistor as shown in Fig. 4.1.** **In fact, looking at a point on the graph in Fig. 4.1, (0.6 V, 0.2 A), the p.d. across the fixed resistor is 1.5 x 0.2 = 0.3 V, and the p.d. across the variable resistor would have to be 3.5 – 0.6 – 0.3 = 2.6 V. The resistance required would be 2.6 / 0.2 = 13 Ω which is larger than the maximum resistance of 10 Ω.** Marks scheme: 1 mark – describe that the components are in series or the variable resistor's resistance of 10 Ω is not high enough to achieve low current and p.d. values across the thermistor. 1 mark – show quantitatively using a data point that on Fig. 4.1 that require a higher resistance than 10 Ω.	 B1 B1
			Examiners' Comments: • While this question is similar to Q12 of tutorial, most students left it blank or didn't know the requirement of this question. • Note that through practice, students can notice this style of questioning and recall to check that the range of V permissible by the setup is suitable to reproduce the graph provided. • Many students wrongly think that the resistance of thermistor is fixed at 3.0Ω! It varies with temperature and hence potential difference *V*!	

[Total: 9]

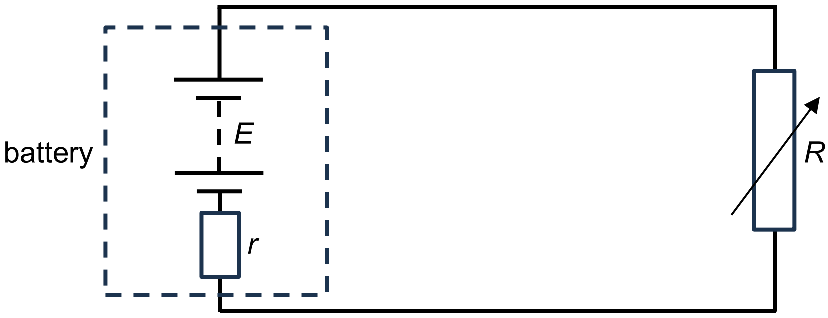
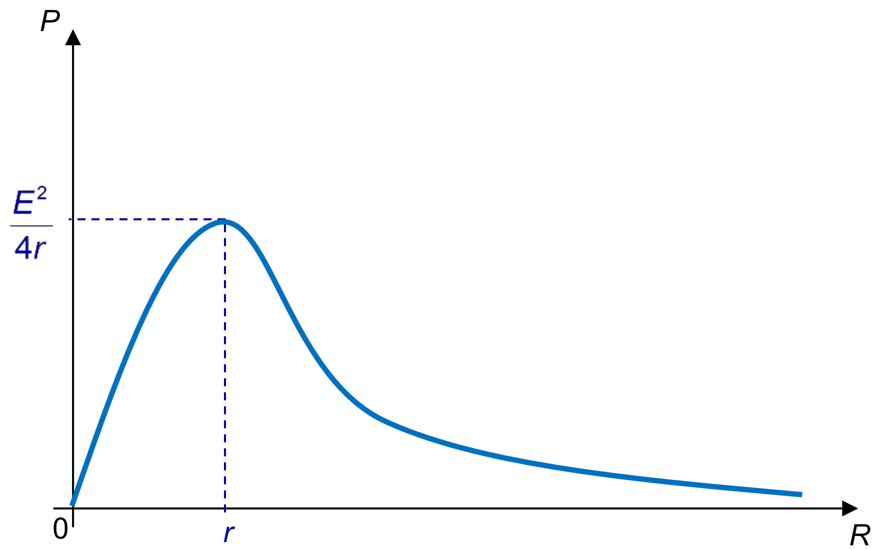
5	(a)	A battery of e.m.f. *E* and internal resistance *r* is connected to a load of variable resistance *R* as shown in Fig. 5.1.  **Fig. 5.1**		
		(i)	Derive an expression for the power *P* dissipated in the load resistor in terms of *E*, *r* and *R*.	
				[2]
	L2		The current flowing in the circuit is, $I = \frac{E}{R+r}$ Since electrical power dissipated in load with resistance *R*, $P = I^2 R$ $P = \left(\frac{E}{R+r}\right)^2 R$ $P = \frac{E^2 R}{R+r\ ^2}$	C1 A1
			Examiners' Comments: • Many candidates merely stated the expression without any logical deduction or explanation of their workings. • Some candidates were unable to derive the correct expression for the current flowing in the circuit. • A few candidates stated the final expression for the power *P* dissipated in the load resistor in terms of various incorrect and undefined physical quantities.	
		(ii)	On Fig. 5.2, sketch the variation of the power *P* dissipated in the load with resistance *R* of the load resistor. At the maximum of the curve, label the axes with appropriate expressions.	

Fig. 5.2

[3]

L2

Solution:



1 mark – general shape of graph (starts at 0 and have only one maximum) **B1**
1 mark – Labeling *r* at the horizontal axis for maximum power **B1**
1 mark – Correct expression $E^2/4r$ for maximum power **B1**

Examiners' Comments:

- Many candidates did not show correct understanding of the concept of the maximum power theorem and left this part of the question un-attempted.
- Some candidates sketched graphs of random shapes and did not obtain much credit for this part of the question.
- A group of candidates did not attempt to label the axes with the appropriate expressions.

(b) A battery has an e.m.f. 12.0 V and internal resistance 0.500 Ω. It is connected to a parallel arrangement of four lamps, as shown in Fig. 5.3.

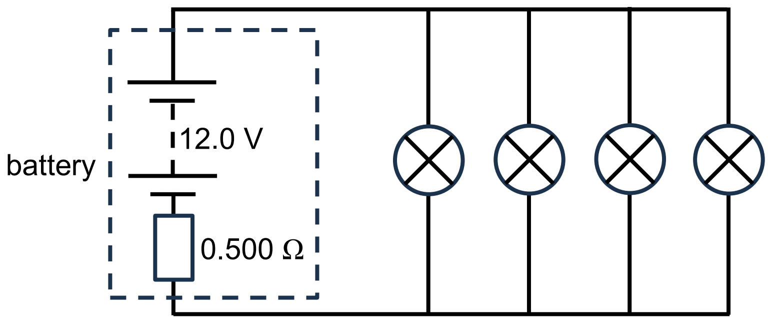


Fig. 5.3

Each lamp has a constant resistance of 30.0 Ω.

For the circuit as shown in Fig. 5.3, calculate

(i) the terminal potential difference of the battery,

terminal potential difference = ...V [2]

L2

The effective resistance R_{eff} of the four identical lamps each of 30.0 Ω:

$$R_{eff} = \frac{30.0}{4} = 7.50\ \Omega$$

By Potential Divider Principle, the p.d. across the four lamps which is also equal to the terminal p.d. of the battery is given by:

$$V = \frac{R_{eff}}{R_{eff} + r} \times E = \frac{7.50}{7.50 + 0.500} \times 12.0$$ **M1**

$$V = 11.25 = 11.3\ \text{V (3 s.f.)}$$ **A1**

Examiners' Comments:

- Many candidates did not understand the terminology 'terminal potential difference of the battery' correctly. Thus, they attempted to calculate the potential difference across the internal resistance of the battery instead.
- Some candidates were unable to calculate the effective resistance of the four lamps in parallel correctly.
- A small number of candidates wrongly assumed the potential difference across the four resistors as 12 V, which was the e.m.f. of the battery.

(ii) the total power dissipated in the four lamps,

power = ...W [2]

L1

$$P = \frac{V^2}{R} = \frac{11.25^2}{7.50}$$ **M1**

$$P = 16.875 = 16.9\ \text{W (3 s.f.)}$$ **A1**

Examiners' Comments:

- Many candidates did not realize that the potential difference across each resistor was the same as they were arranged in parallel with each other.
- Some candidates attempted to calculate the total power dissipated in the battery with reference to the e.m.f. of the battery of 12 V and total resistance of 8.00 Ω in the circuit.
- Some candidates attempted to find the current flow through each resistor by assuming it to be the same value as the current flow through the battery itself.

(iii) the efficiency, assuming that the total power dissipated in the lamps are useful power.

			efficiency = ……………………………%	[2]
	L2		The efficiency, $\eta = \dfrac{P_{load}}{P_{battery}} \times 100\% = \dfrac{16.875}{\dfrac{12.0^2}{0.500 + 7.50}} \times 100\%$ $\eta = 93.75\% = 93.8\%$ (3 s.f.)	**M1** **A1**
			Examiners' Comments: • Many candidates obtained full credit for this part of the question as they were able to deduce the correct expression. • Some candidates were unable to calculate the power dissipated by the battery correctly as they substituted wrong values of resistance in their workings. • A few candidates expressed their final answers for efficiency as a ratio instead of as percentage efficiency.	

(c) A student thinks that the brightness of the lamps in **(b)** would be increased by connecting an additional resistor in the circuit, placed so as to extract the maximum power from the battery.

The additional resistor may be placed as shown in Fig. 5.4(a) or in Fig. 5.4(b).

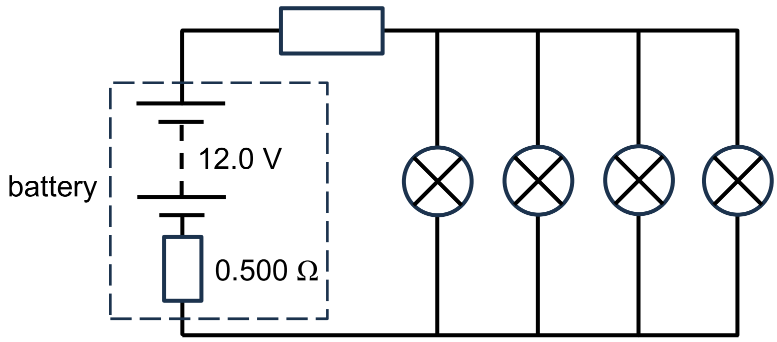


Fig. 5.4(a)

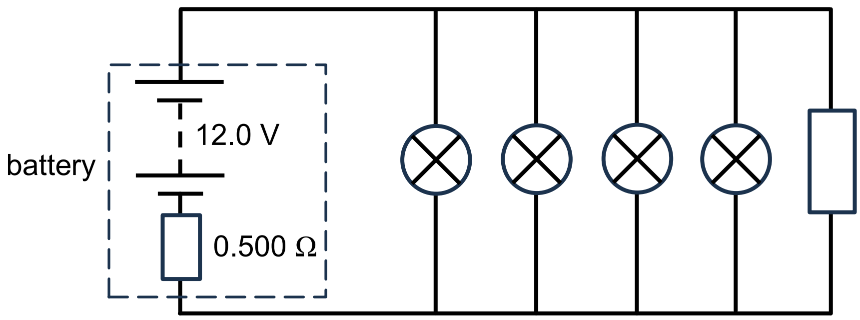


Fig. 5.4(b)

State and explain which of the two circuits, shown in Fig. 5.4(a) or Fig. 5.4(b), should the additional resistor be connected so as to extract the maximum power from the battery.

		…………………………………………………………………………………………	[3]
	L3	The circuit in <u>Fig. 5.4(b) should be used</u>. The <u>maximum power dissipated at the load</u> happens <u>when the effective resistance of the load is equal to the internal resistance of the battery</u>.	**A1** **M1**

		As the effective resistance of the lamps before placing the additional resistor of 7.50 Ω is higher than the internal resistance of 0.500 Ω, a decrease in the external resistance is required. Only when the additional resistor is placed parallel to the lamps, can the total resistance of the load decrease from 7.50 Ω to 0.500 Ω. Marks scheme: M1 marks must be attained for A1 mark to be awarded.	**M1**
		Examiners' Comments: • Most students managed to correct state that connecting the additional resistor in parallel to the lamps in Fig. 5.4(b) results in a lower resistance. • However, most students ended up using $P=IV=I^2R=V^2/R$ to explain but failed to notice that in every form, the variables have opposing changes (eg. *R* decreases but *I* increases. Hence we cannot use this to conclude. • Students need to read up on "maximum power theorem".	
		Extension Question: If the question is changed from *"...to extract **maximum power** from the battery"* to *"…to **increase the efficiency** of energy transfer from the battery to the load (additional resistor and lamps inclusive)"*, what would the answer be? Answer: The circuit in Fig. 5(a) should be used instead. When the additional resistor is connected as in Fig. 5(a), the total circuit resistance increases and the total current through the battery decreases, hence the power dissipated in the internal resistance of the battery decreases while the terminal p.d. across the battery increases. This increases the total power dissipated in the external load and hence increases the efficiency of energy transfer from the battery to the load (additional resistor and lamps inclusive).	

[Total: 14]

End of Paper