1 The p.d. across a resistor is 12 V. The power dissipated is 6.0 W.

Which statement is correct?

A The charge passing through the resistor in one second is 2.0 coulomb.
B The resistor transfers 6.0 joule for each coulomb passing through the resistor.
C The resistor transfers 12 joule in 2.0 second.
D The resistor dissipates 6.0 joule when the current is 2.0 ampere.

Your answer

[1]

2 A copper wire is connected across a cell. The conduction electrons within the copper wire move.

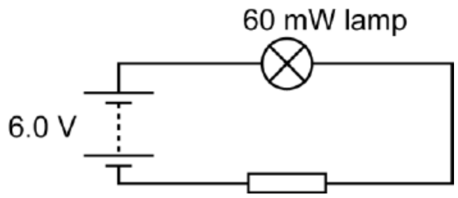
Which statement is correct about these electrons?

A They drift towards the negative end of the cell.
B They have random speeds because of collisions with other electrons.
C They travel through the wire at the speed of light.
D They collide with vibrating copper ions.

Your answer

[1]

3(a) A battery is connected in series with a lamp and a resistor as shown.



The battery has e.m.f. 6.0 V and negligible internal resistance. The potential difference across the lamp is 2.4 V and it dissipates 60 mW. The resistor has cross-sectional area of 2.0 mm^2. The number density of charge carriers (free electrons) within the resistor is 1.4×10^{25} m^{-3}.

Calculate the resistance *R* of the resistor.

R = ____________________ Ω **[3]**

(b) Calculate the mean drift velocity *v* of the free electrons within the resistor.

v = ____________________ m s^{-1} **[3]**

(c) The number density of the free electrons in the connecting wires is greater than that of the resistor. The connecting wires have the same diameter as the resistor. State and explain whether the mean drift velocity of the free electrons would be smaller, the same, or larger than your value in **(b)**.

____

____

____ **[2]**

4 Fig. 19 shows a photocell.

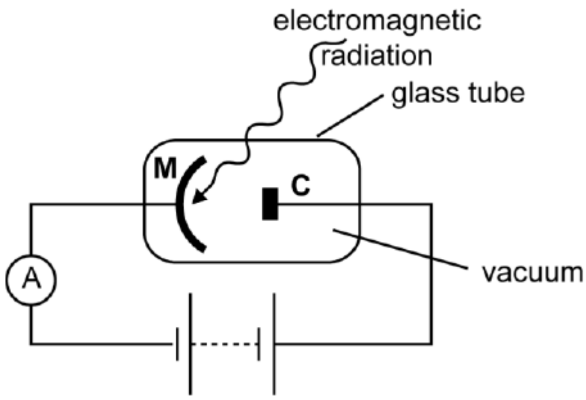


Fig. 19

When the metal **M** is exposed to electromagnetic radiation, photoelectrons are ejected from the surface of the metal. These photoelectrons are collected at the electrode **C** and the sensitive ammeter indicates the presence of a tiny current.

The work function of the metal **M** is 2.3 eV.

The incident electromagnetic radiation has wavelength 5.1×10^{-7} m.

The ammeter reading is 0.24 μA.

Calculate the number of photoelectrons reaching **C** in a time of 5.0 s.

number = ____________________ **[3]**

5 A small heater is connected to a power supply. The power supply is switched on for 100 s. The current in the heater is 3.0 A and it dissipates 1200 J of thermal energy.

What is the potential difference across the heater?

A 0.25V
B 4.0V
C 12V
D 300V

Your answer

[1]

6 A filament lamp X is part of an electrical circuit. The circuit has a battery of electromotive force (e.m.f.) 6.0 V and negligible internal resistance. The potential difference across the lamp can be increased **continuously** from 0 to 6.0 V. This potential difference is measured using a voltmeter.
The lamp glows brightly at 6.0 V.

(i) Draw a circuit diagram for this electrical arrangement.

[2]

(ii) Describe and explain the variation of the resistance of this lamp as the potential difference across it is changed from 0 to 6.0 V.

-- **[4]**

(iii) The filament lamp X is now connected in a different circuit as shown in Fig. 16.

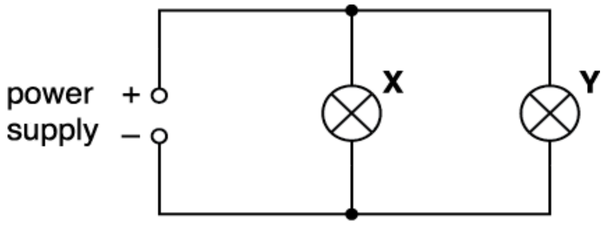


Fig. 16

The power dissipated in X is three times more than the power dissipated in the filamentlamp Y. The filament wire of lamp X has a diameter half that of lamp Y.

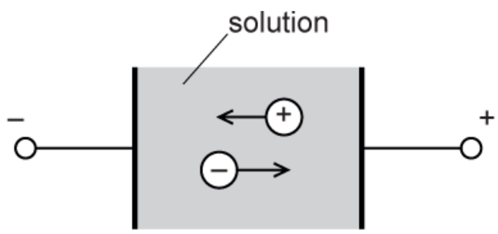
The filament wires of X and Y are made of the same material and are at the same temperature.

Calculate the ratio

$$\frac{\text{mean drift velocity of charge carriers in lamp } \mathbf{X}}{\text{mean drift velocity of charge carriers in lamp } \mathbf{Y}}.$$

ratio = ____________________________ **[3]**

7 The diagram below shows the motion of positive and negative particles in a conducting solution.



Which statement is correct?

A The current in the solution is zero.

B The conventional current is to the left.

C The positive particles are always protons.

D The negative particles are always electrons.

Your answer [1]

8 One million electrons travel between two points in a circuit.
The **total** energy gained by the electrons is 1.6×10^{-10} J.

What is the potential difference between the two points?

A 1.6×10^{-16} V

B 1.6×10^{-4} V

C 1.0×10^{3} V

D 1.0×10^{9} V

Your answer [1]

9 A small thin rectangular slice of semiconducting material has width *a* and thickness *b* and carries a current *I*. The current is due to the movement of electrons. Each electron has charge –*e* and mean drift velocity *v*.
A uniform magnetic field of flux density *B* is perpendicular to the direction of the current and the top face of the slice as shown in Fig. 2.1.

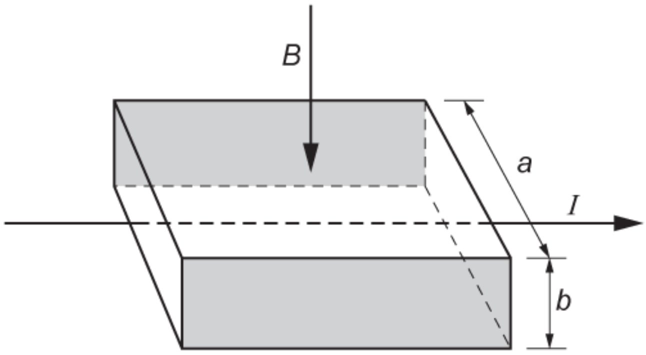


Fig. 2.1

Here are some data for the slice in a particular experiment.

number of conducting electrons per cubic metre, $n = 1.2 \times 10^{23}\ m^{-3}$

$a = 5.0$ mm

$b = 0.20$ mm

$I = 60$ mA

$B = 0.080$ T

Use this data to calculate

(i) the mean drift velocity *v* of electrons within the semiconductor

v = ____________________ $m\ s^{-1}$ **[3]**

(ii) the potential difference *V* between the shaded faces of the slice.

V = ____________________ V **[1]**

10 Fig. 6.1 shows a single photomultiplier tube and its internal components. The tube can detect gamma photons in high-energy physics experiments.

A single gamma photon incident on the scintillator crystal generates many photons of blue light. These visible light photons travel to the photocathode where they are converted into photoelectrons. The number of electrons is then multiplied in the photomultiplier tube with the help of electrodes called dynodes. A short pulse of electric current is produced at the output end of the photomultiplier tube.

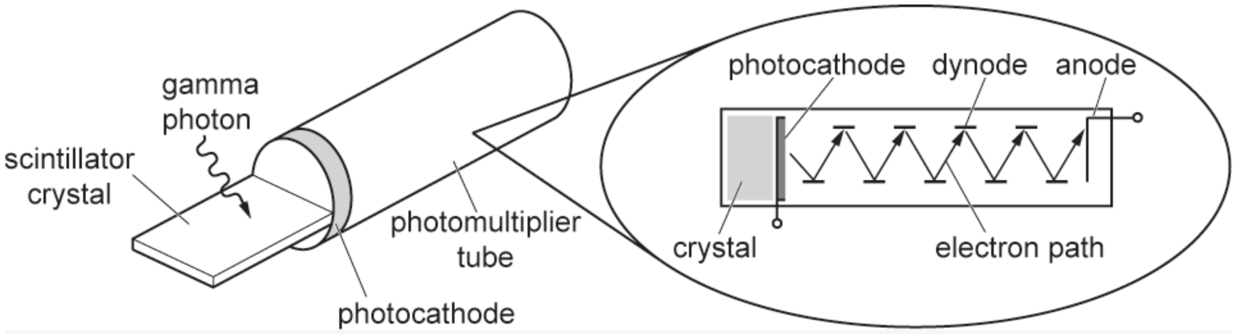


Fig. 6.1

The photocathode is coated with potassium which has a work function of 2.3 eV. Each emitted photoelectron is accelerated by a potential difference of 100 V between the photocathode and a metal plate, called the first dynode.

(i) Show that the maximum kinetic energy of an emitted electron at the photocathode is very small compared to its kinetic energy of 100 eV at the first dynode.

[1]

(ii) 2000 photoelectrons are released from the photocathode. Each photoelectron has enough energy to release four electrons from the first dynode at the collision. These four electrons are then accelerated to the next dynode where the process is repeated. There are 9 dynodes in the photomultiplier tube. The total number of electrons collected at the anode for each photoelectron is 4^9.

The pulse of electrons at the anode lasts for a time of 2.5×10^{-9} s.

Calculate the average current due to this pulse.

average current = ... A **[3]**

11 Which electrical quantity has S.I. units ampere-second (A s)?

A charge

B current

C resistance

D potential difference

Your answer ☐ **[1]**

12(a)

Derive the S.I. base units for resistance.

base units: .... **[2]**

(b) Fig. 16.1 shows the *I-V* characteristics of two electrical components **L** and **R**.

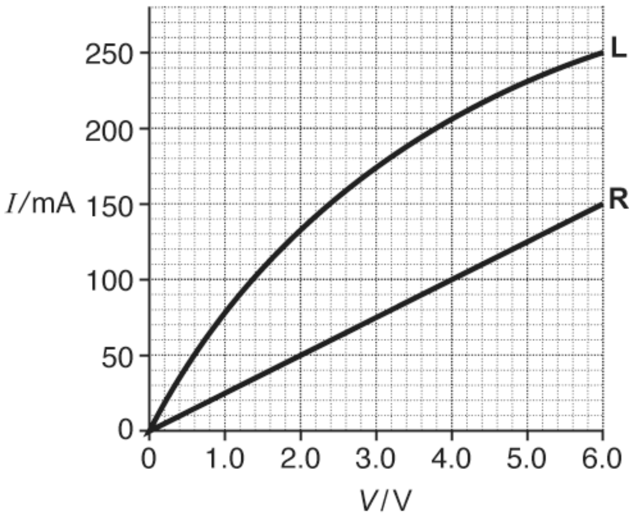


Fig. 16.1

The component **L** is a filament lamp and the component **R** is a resistor.

(i) Show that the resistance of **R** is 40 Ω.

(ii) Fig. 16.2 shows the components **L** and **R** connected in series to a battery of e.m.f. 6.0 V.

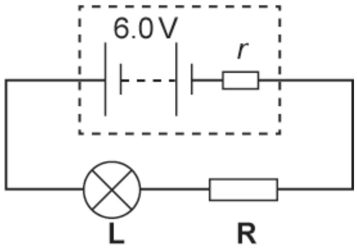


Fig. 16.2

The resistor **R** is a cylindrical rod of length 8.0 mm and cross-sectional area 2.4×10^{-6} m^2. The current in the circuit is 100 mA.

1 Use Fig. 16.1 to determine the internal resistance *r* of the battery.

r = ... Ω **[3]**

2 Calculate the resistivity ρ of the material of the resistor **R**.

ρ = ... Ω m **[2]**

3 There are 6.5×10^{17} charge carriers within the volume of **R**.

Calculate the mean drift velocity v of the charge carriers within the resistor **R**.

v = ... m s^{-1} **[3]**

13 Which law indicates that charge is conserved?

A Lenz's law

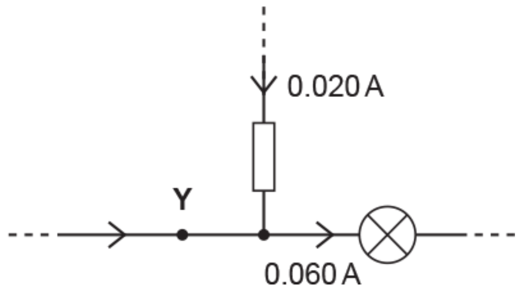
B Coulomb's law

C Kirchhoff's first law

D Faraday's law of electromagnetic induction

Your answer [1]

14 Part of an electric circuit is shown below.



The direction of all the currents and the magnitude of two currents are shown.

How many electrons pass through the point **Y** in 10 s?

A 1.25×10^{18}

B 2.50×10^{18}

C 3.75×10^{18}

D 5.00×10^{18}

Your answer [1]

15 Wires **P** and **Q**, made from the same metal, are connected in **parallel** across a cell of negligible internal resistance.

The table shows some data.

Wire	Length of wire	Diameter of wire	Mean drift velocity of electrons in the wire / mm s^{-1}
P	*L*	*d*	0.60
Q	3*L*	2*d*	*v*

What is the mean drift velocity v of the electrons in wire **Q**?

A 0.15 mm s^{-1}

B 0.20 mm s^{-1}

C 0.30 mm s^{-1}

C 0.60 mm s^{-1}

Your answer **[1]**

16(a) A 150 W heater constructed from nichrome wire is switched on for 5.0 hours.

The wire has a cross-sectional area of 4.1×10^{-9} m^2.
The current in the wire is 1.5 A.
The number density of charge carriers in nichrome is 7.9×10^{28} m^{-3}.

Calculate

(i) the resistance R of the heater

R = ... Ω **[2]**

(ii) the number N of electrons passing through the heater in 5.0 hours

N = ... **[2]**

(iii) the mean drift velocity v of the electrons (charge carriers) in the heater.

v = ... ms^{-1} **[2]**

(b) Nichrome is a metal. Silicon is a semiconductor.

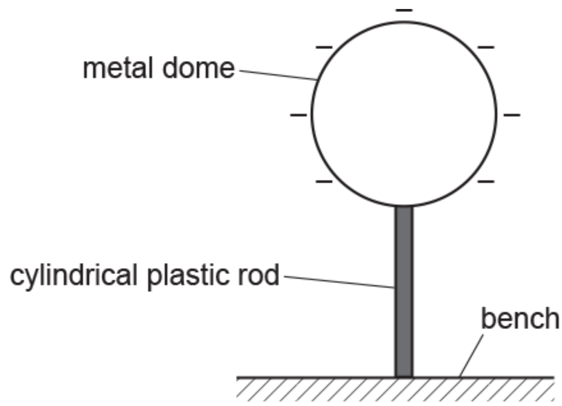
State how the number density of charge carriers n and the resistivity ρ of silicon compare with that of nichrome.

n ....

ρ ....

[2]

17 A spherical metal dome shown below is charged to a potential of –12 kV.



The dome is supported by a cylindrical plastic rod. The radius of the dome is 0.19 m.

(i) Show that the magnitude of the total charge Q on the dome is 2.5×10^{-7} C.

[2]

(ii) The dome discharges slowly through the plastic rod.
It takes 78 hours for the dome to completely discharge.

1 Show that the mean current I in the plastic rod is about 9×10^{-13} A.

[2]

2 The average potential difference across the plastic rod during discharge is 6000 V.
The rod has cross-sectional area 1.1×10^{-4} m^2 and length 0.38 m.

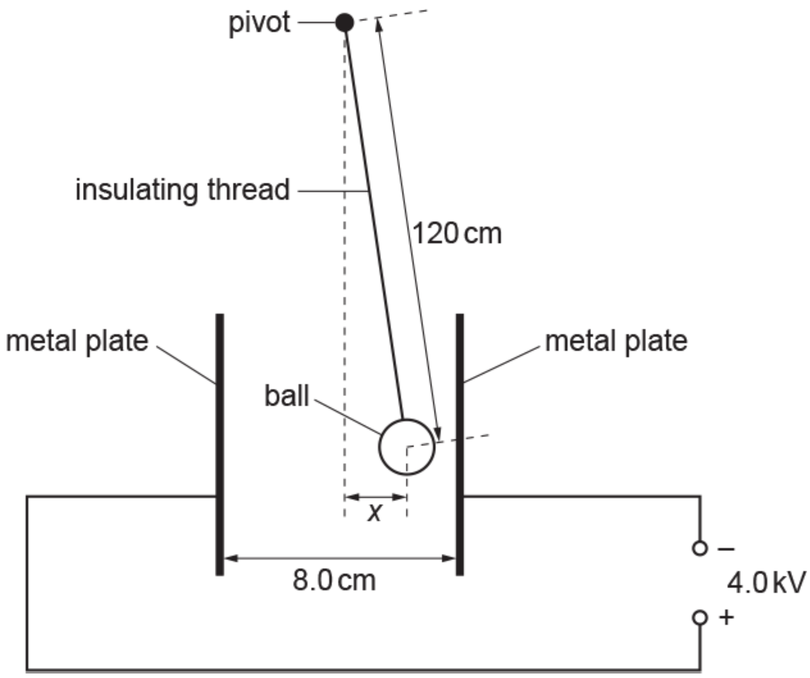
Calculate the resistivity ρ of the plastic.

ρ = ... Ωm **[3]**

18(a) A ball coated with conducting paint has weight 0.030 N and radius 1.0 cm. The ball is suspended from an insulating thread. The distance between the pivot and the centre of the ball is 120 cm.

The ball is placed between two vertical metal plates. The separation between the plates is 8.0 cm. The plates are connected to a 4.0 kV power supply.

The ball receives a positive charge of 9.0 nC when it is made to touch the positive plate. It then repels from the positive plate and hangs in equilibrium at a displacement *x* from the vertical, as shown below. The diagram is **not** drawn to scale.



(i) Show that the electric force acting on the charged ball is 4.5×10^{-4} N.

[2]

(ii) Draw, on the diagram above, arrows which represent the **three** forces acting on the ball. Label each arrow with the name of the force it represents.

[2]

(iii) By taking moments about the pivot, or otherwise, show that x = 1.8 cm.

[2]

(b) The ball is still positively charged.

The plates are now moved slowly towards each other whilst still connected to the 4.0 kV power supply. The plates are stopped when the separation is 5.0 cm.

Explain the effect that this has on the deflection of the ball and explain why the ball eventually starts to oscillate between the plates.

[4]

(c) When the ball oscillates between the plates, the current in the external circuit is 3.2×10^{-8} A.

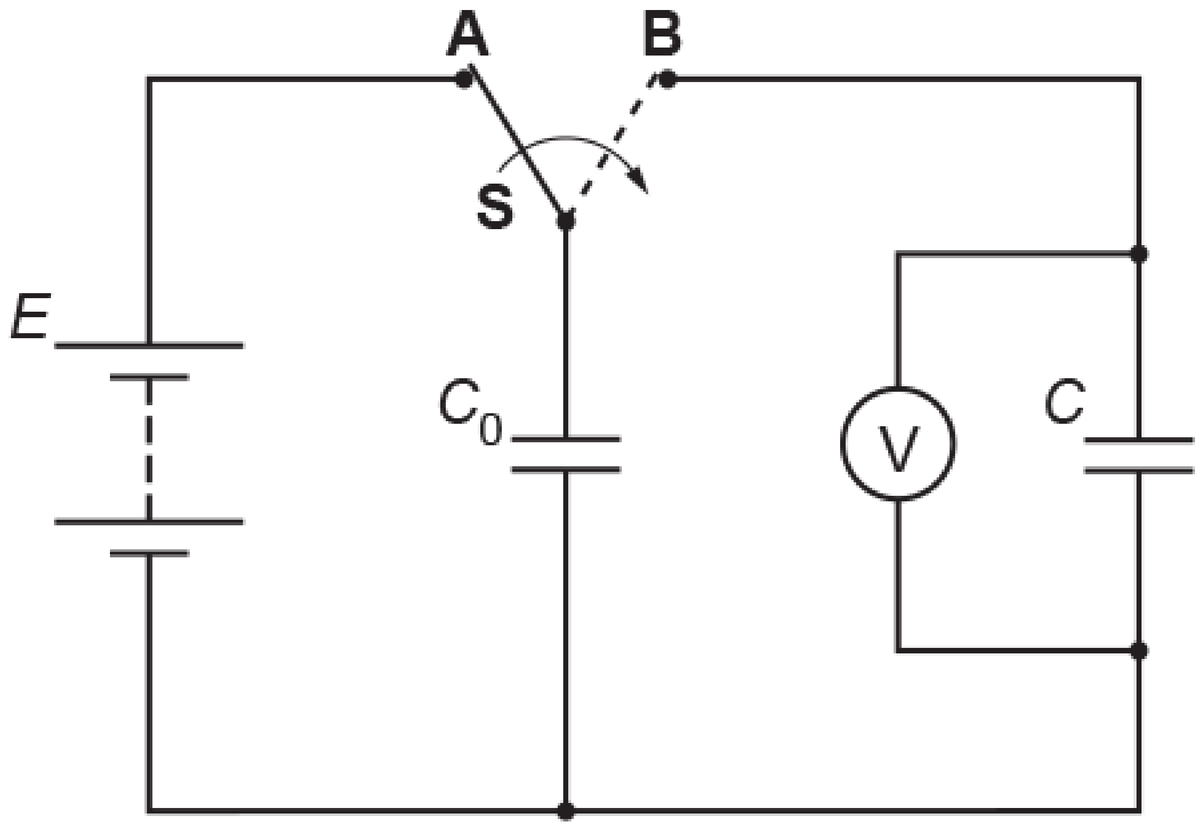
A charge of 9.0 nC moves across the gap between the plates each time the ball makes one complete oscillation.

Calculate the frequency f of the oscillations of the ball.

f = ... Hz **[2]**

19(a) The diagram below shows a circuit containing two capacitors which are both initially uncharged. The battery has e.m.f. E and negligible internal resistance.

The switch **S** is first moved to position **A** until the capacitor of capacitance C_0 is fully charged.



The switch **S** is then moved to position **B**. The initial charge stored by the capacitor of capacitance C_0 is shared between the two capacitors.
The final reading on the voltmeter is V.

Show that $V = \frac{C_0}{C + C_0} E$.

[2]

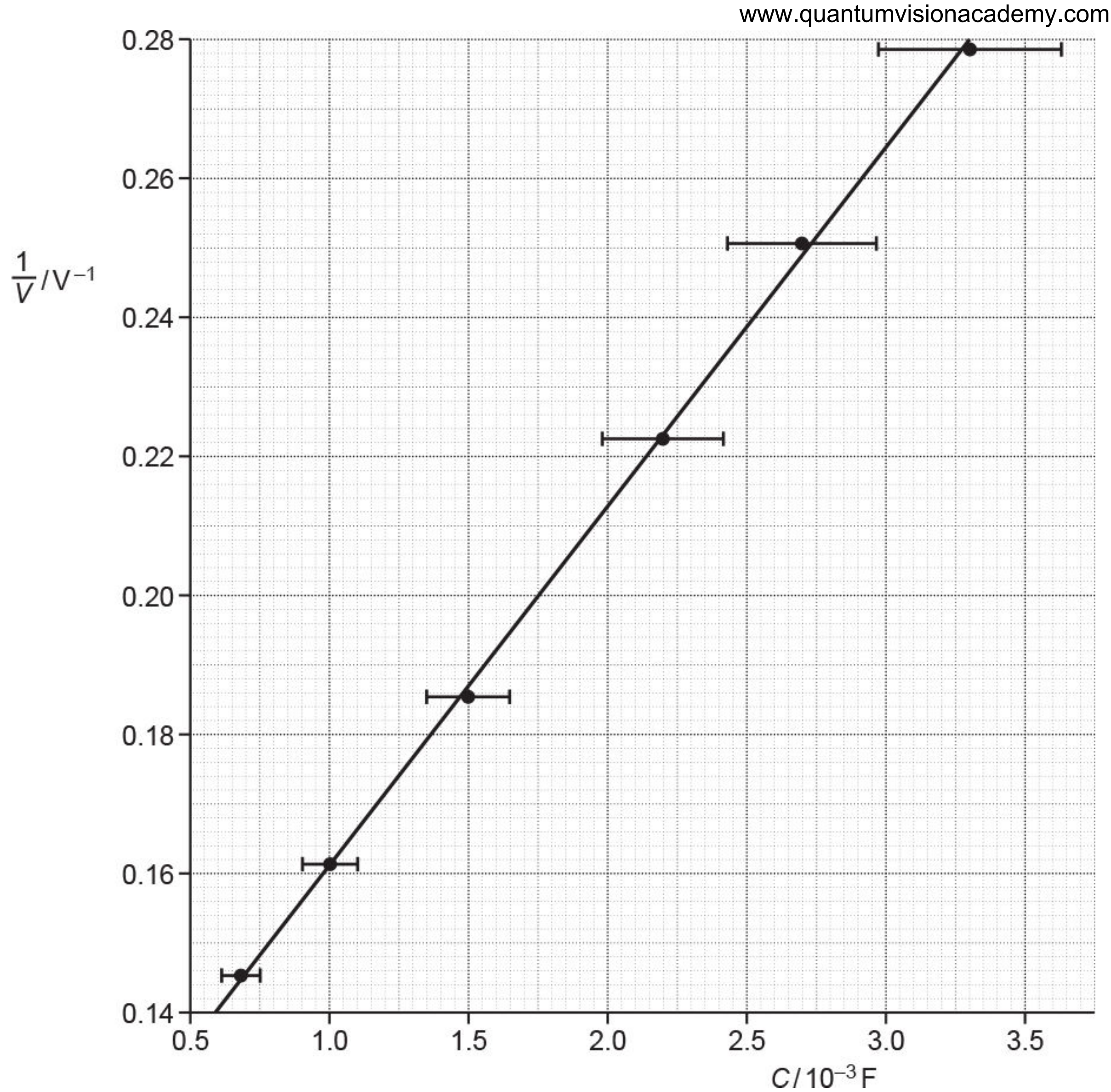
(b) A student wants to determine the values of E and C_0 by repeating the experiment above and measuring the potential difference (p.d.) V for a selection of capacitors of capacitance C.

The student decides to plot a graph of $\frac{1}{V}$ against C.

(i) Use the expression in **(a)** to show that the graph should be a straight line of gradient $\frac{1}{C_0E}$ and y-intercept $\frac{1}{E}$.

[1]

(ii) The data points, error bars and the line of best fit drawn by the student are shown in the graph below.



The gradient of the line of best fit is 51 V^{-1} F^{-1}. The value of E is 9.1 V.

Determine the value of C_0 in millifarads (mF). Write your answer to 2 significant figures.

C_0 = ... mF **[2]**

(iii) Draw on the graph a straight line of worst fit.

Use this line to determine the absolute uncertainty in your value of C_0. Write your answer to an appropriate number of significant figures.

absolute uncertainty = ... mF **[4]**

(c) The experiment is repeated with a resistor of resistance 10 kΩ placed in series between **S** and the capacitor of capacitance C_0.

State with a reason what effect, if any, this would have on the experiment.

[1]

20 This question is about the Sun and its radiation.

* A student attends a lecture about the Sun and makes the following notes.

1. The Sun loses more than 4×10^9 kg of its mass every second to maintain its luminosity.
2. Treating hydrogen nuclei (protons) as an ideal gas, a temperature of 10^{10} K provides a kinetic energy of about 1 MeV, which is necessary for fusion.
3. However, the Sun's core temperature is only 10^7 K, so the chance of protons fusing on collision is very small. This explains why the Sun has such a long lifetime.

Explain the principles of physics which are involved in each of the three points.
You should include relevant formulae, but no numbers or calculations are required.

[6]

21 This question is about investigations involving an electromagnetic wave.

A vertical transmitter aerial emits a **vertically polarised** electromagnetic wave which travels towards a vertical receiver aerial. The wavelength of the wave is 0.60 m.

Fig. 5.1 shows a short section of the oscillating electric field of the electromagnetic wave.

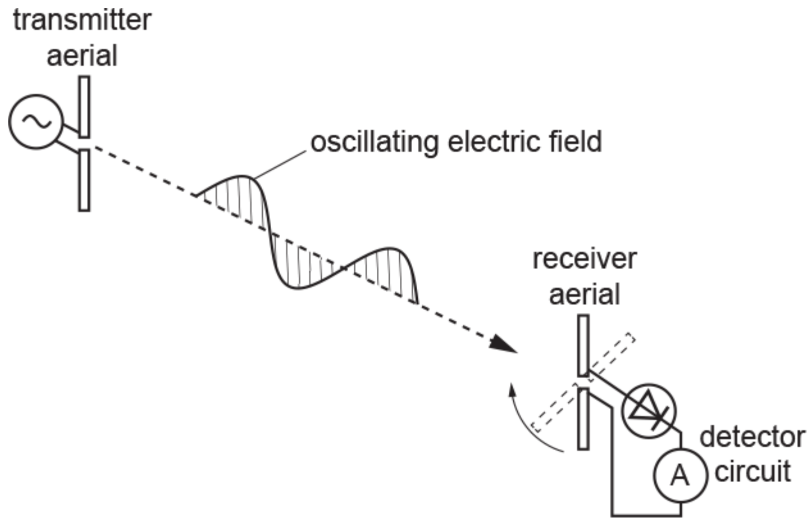


Fig. 5.1

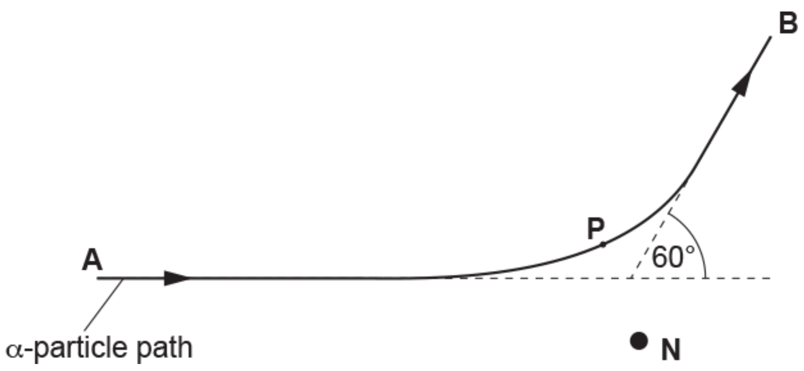
Suggest why the diode in **Fig. 5.1** is necessary for an ammeter to detect a signal at the receiver aerial.

--- **[1]**

22 A beam of α-particles is incident on a thin gold foil. Most α-particles pass straight through the foil. A few are deflected by gold nuclei.

The diagram shows the path of one α-particle which passes close to a gold nucleus **N** in the foil. The α-particle is deflected through an angle of 60° as it travels from **A** to **B**.

P marks its position of closest approach to the gold nucleus.



The distance between **P** and **N** is 6.8×10^{-14} m.

Calculate the magnitude of the electrostatic force *F* between the α-particle $({}^{4}_{2}He)$ and the gold nucleus $({}^{197}_{79}Au)$ when the α-particle is at **P**.

F = ... N **[4]**

23 Which sequence shows the materials arranged in the order of increasing number density of charge carriers?

increasing number density ⟶

A conductor, insulator, semiconductor

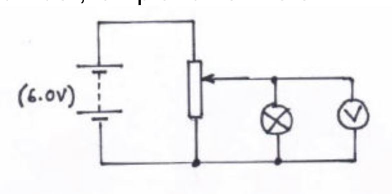
B conductor, semiconductor, insulator

C insulator, semiconductor, conductor

D semiconductor, insulator, conductor

Your answer [ ] **[1]**

END OF QUESTION PAPER

Question			Answer/Indicative content	Marks	Guidance
1			C	1	
			Total	1	
2			D	1	
			Total	1	
3	a		current = $\frac{0.060}{2.4}$ or current = 0.025 (A)	C1	
			$R = \frac{6.0 - 2.4}{0.025}$	C1	
			R = 140 (Ω)	A1	**Note** answer to 3 sf is 144 Ω
	b		$I = Anev$ and $A = 2.0 \times 10^{-6}$ (m^2)	C1	
			$0.025 = 2.0 \times 10^{-6} \times 1.4 \times 10^{25} \times 1.60 \times 10^{-19} \times v$	C1	**Allow** any subject Possible ecf
			$v = 5.6 \times 10^{-3}$ (m s^{-1})	A1	
	c		The current is constant, therefore $v \propto n^{-1}$.	M1	
			The mean drift velocity is therefore smaller.	A1	
			Total	8	
4			$Q = It$ and $e = 1.6 \times 10^{-19}$ (C)	C1	
			number of electrons = $0.24 \times 10^{-6} \times 5.0/1.6 \times 10^{-19}$	C1	
			number of electrons = 7.5×10^{12}	A1	
			Total	3	
5			B	1	
			Total	1	
6		i	Correct circuit with a battery, potential divider, lamp and voltmeter. 	B1	

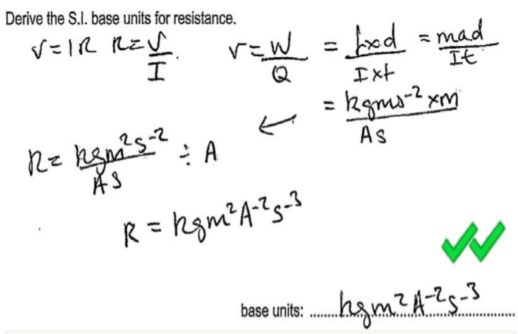
Mark Scheme

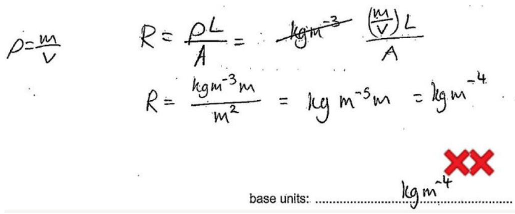
Question			Answer/Indicative content	Marks	Guidance
		i	Correct symbols used for all components.	B1	**Allow**: A cell symbol for a battery
		ii	Description: The temperature of the filament increases. (AW)	B1	
		ii	The resistance of the lamp increases	M1	
		ii	from a non-zero value of resistance.	A1	**Allow** 'when cold the resistance is small'
		ii	Explanation: Resistance increases because electrons/charge carriers make frequent collisions with ions. (AW)	B1	
		iii	($P = VI$) current in **X** is 3 times the current in **Y** Or area of **X** is 4 times smaller than area of **Y**	C1	**Allow** other correct methods.
		iii	$I = Anev$ and ratio = $\frac{3}{0.25}$	C1	
		iii	ratio = 12	A1	
			Total	**9**	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
7			B	1	Examiner's Comment All questions showed a positive discrimination, and the less able candidates could access the easier questions. The questions in Section A require careful reading and execution. Underlining or circling key information may help. Candidates are reminded not to use highlighter pens for this purpose. There is ample space for jotting down ideas and key equation, but it is best to do calculations on calculators to save time. Questions **1, 3,10** and **14** proved to be particularly straightforward, allowing most of the candidates to demonstrate their knowledge and understanding of physics. At the other end of the scale, Questions **5, 9,** and **15** proved to be more challenging. • Question **5** was on the superposition of waves and the relationship intensity∞ amplitude^2. The amplitude of the resultant wave is 0.4*a* and therefore the intensity of resultant wave must be 0.16*I*. The most popular distractors were **B** and **C**. Less than half of the candidates got the correct answer of **A**. • Question **9** was about doubling the separation between two oppositely charged parallel plates. The only correct statement is **D**. Electric field strength is p.d. divided by the distance between the plates. Since both quantities double, the electric field strength, must remain the same. • Question **15** was about refraction and the equation nsinη = constant at the boundary between two materials. The ratio *n*1/*n*2 = sin80°/sin90° = 0.98; the correct is **B**. The most popular distractor was **C**, which was the inverse of the correct answer.
			Total	1	
8			C	1	
			Total	1	

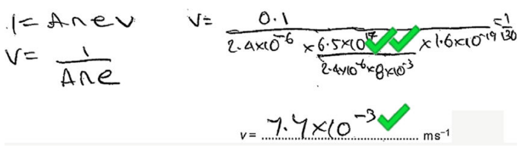
Question			Answer/Indicative content	Marks	Guidance
9		i	I = nAev; $v = 60 \times 10^{-3}/1.2 \times 10^{23} \times 1.6 \times 10^{-19} \times 5.0 \times 0.2 \times 10^{-6}$ v = 3.1 (m s^{-1})	C1 C1 A1	**allow** any subject
		ii	$V = 80 \times 10^{-3} \times 3.1 \times 5.0 \times 10^{-3}$ $= 1.2 \times 10^{-3}$ (V)	A1	**ecf (b)(i); allow** 1.2 mV; 1.3×10^{-3} (V) **Examiner's Comments** This exercise of choosing a formula, substituting values in correct units and evaluating was done well with about three quarters of the candidates gaining full marks.
			Total	4	
10		i	2.76 – 2.3 = 0.46 eV (so only 0.5% of energy/AW)	B1	**allow** 2.8 – 2.3 = 0.5 eV and 3.0 – 2.3 = 0.7 eV possible **ecf** from **(b)**
		ii	$n = 2000 \times 4^9$ (= 5.24×10^8) Q = ne = 8.4×10^{-11} (C) $I = 8.4 \times 10^{-11} / 2.5 \times 10^{-9}$ average current = 0.034 (A)	C1 C1 A1	**allow ecf** for wrong n **allow** 34 m(A); answer is 1.7×10^{-5} A if 2000 omitted (2/3) **Examiner's Comments** Almost all of the candidates attempted this last section of the paper with some success. In part (i) most candidates showed that they understood the theory behind the question and subtracted the appropriate two numbers from part (b) to gain the mark. Part (ii) was done well with a significant number obtaining the correct answer. Another large group forgot that 2000 electrons were released and performed the calculation for only a single electron being multiplied up and so forfeited the final mark.
			Total	4	
11			A	1	
			Total	1	

Question			Answer/Indicative content	Marks	Guidance
12	a		$(R = \frac{V}{I} = \frac{W}{QI}\ ;\ \ Q = It)$ charge → A s **or** energy → kg m s^{-2} × m **or** kg m^2 s^{-2} (base units) kg m^2 A^{-2} s^{-3}	 C1 A1	**Allow** other correct methods **Allow** *Q* or *C* **or** coulomb for 'charge'; *E* **or** *W* **or** joule **or** J **or** work done for 'energy' **Allow** 1 mark for J s^{-1} A^{-2} **Allow** $\frac{\text{kg m}^2}{\text{A}^2\,\text{s}^3}$ **or** kg m^2 /(A^2 s^3) **Not** kg m^2 / A^2 / s^3 **or** kg m^2 / s^3 / A^2 <u>Examiner's Comments</u> This was a challenging question, which provided the ideal opportunity for top-end candidates to use a variety of methods to get the correct S.I. base units of kg m^2 A^{-2} s^{-3} for resistance. A significant number of candidates secured 1 mark for a partial answer with either charge → A s, or energy → kg m^2 s^{-2}. The rules for exponents were a bit perplexing for the low-scoring candidates. Many also misunderstood S.I. units. Exemplar 4  This exemplar illustrates a flawless answer from a top-end candidate. The equations are clear to see and follow. The units of each physical quantities are clearly identified and the appropriate S.I. units for the quantities have been

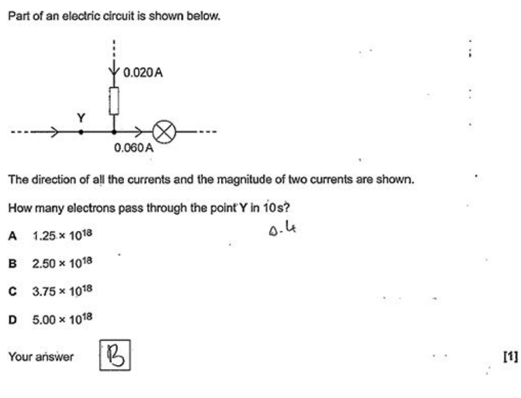
Question			Answer/Indicative content	Marks	Guidance
					successfully manipulated to give the correct answer. Compare this with the exemplar below which illustrates a common misconception. **Exemplar 5**  This exemplar illustrates a common error made by some candidates across the ability spectrum.  The resistivity ρ in the equation for resistance has been mistaken for density (which unfortunately has the same label). There can be no credit for wrong physics. It is vital to know your equations. **Key:**  **Misconception**

Question			Answer/Indicative content	Marks	Guidance
	b	i	$(R =) \frac{6.0}{0.150}$ R = 40 Ω	M1 A0	**Allow** any correct value of V (± 0.1 V) divided by the correct value of I (± 10 mA) from the straight line for **R** Examiner's Comments The majority of the candidates scored 1 mark here for clearly using the graph to show the resistance of **R** to be 40 Ω. Most used a data point from the straight line. A significant number also used the idea that the gradient of the straight line is equal to the inverse of the resistance. However, candidates are reminded that resistance is equal potential difference divided by current, but in this context of a straight line through the origin, determining resistance from the gradient was allowed. Of course, determining the gradient of a curve is simply incorrect physics for determining resistance.
		ii	(V_L =) 1.4 (V) **or** (V_R =) 4.0 (V) **or** (R_T =) 6.0/0.1 (Ω) ($V_{terminal}$ =) 5.4 (V) **or** (V_r =) 0.6 (V) **or** (r =) 60 – 54 (Ω) r = 6.0 (Ω)	C1 C1 A1	**Allow** full credit for other correct methods Possible ECF from **(i)** **Allow** ± 0.1 V for the value of p.d. from the graph **Note** getting to this stage will also secure the first C1 mark **Allow** 1 SF answer here without any SF penalt Examiner's Comments This was a discriminating question with many of the top-end candidates effortless getting the correct answer of 6.0 Ω for the internal resistance r. The most common error was omitting the resistance of the filament lamp in the calculation. This gave an incorrect value of 20 Ω for the internal resistance. Candidates doing this still managed to pick up 1 mark for the total resistance of 60 Ω.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iii	$\rho = \frac{40 \times 2.4 \times 10^{-6}}{8.0 \times 10^{-3}}$ (Any subject)	C1	**Allow** ECF
			ρ = 0.012 (Ω m)	A1	**Allow** 1 mark for either 0.018 for using 60 Ω, 0.016(2) for using 54 Ω or for 0.0018 for 6.0 Ω <u>Examiner's Comments</u> The success in this question depended on understanding the term *n* in the equation *I* = *Anev* given in the Data, Formulae and Relationship booklet. A significant number of candidates took *n* to be the total number of charge carriers within the volume of **R**, instead of the number of charge carriers per unit volume (number density). Those who appreciated this had no problems coping with prefixes and powers of ten. The correct answer was 7.7 × 10^{-3} m s^{-1}. Using 6.5 × 10^{17} for the number density, gave an answer of 4.0 × 10^{5} m s^{-1}; examiners credited 1 mark for this incorrect answer, mainly for the manipulating and using the equation *I* = *Anev*. **Exemplar 6**  This exemplar illustrates a perfect answer from a C-grade candidate. The equation has been rearranged correctly and the substitution is all correct and easy to follow. The number density *n* has not been calculated separately – it forms an integral part of the whole calculation. The one big benefit of this is that you do not end up with rounding errors. A decent technique demonstrated here. All correct for 3 marks.

Question			Answer/Indicative content	Marks	Guidance
		iv	$n = \frac{6.5 \times 10^{17}}{2.4 \times 10^{-6} \times 0.008}$ or $n = 3.385 \times 10^{25}$ (m^{-3})	C1	
			$v = \frac{0.100}{2.4 \times 10^{-6} \times 3.385 \times 10^{25} \times 1.60 \times 10^{-19}}$ (Any subject)	C1	**Note** do not penalise again for the same POT error
			$v = 7.7 \times 10^{-3}$ ($m\ s^{-3}$)	A1	**Allow** 1 mark for $4(.0) \times 10^5$ ($m\ s^{-1}$); $n = 6.5 \times 10^{17}$ used
			Total	11	
13			c	1	<u>Examiner's Comments</u> This was a well-answered question with most candidates correctly recalling that charge is conserved according to Kirchhoff's first law. A significant number of candidates distracted towards **B**; perhaps because of the unit of charge is the coulomb.
			Total	1	

Question			Answer/Indicative content	Marks	Guidance
14			B	1	<u>Examiner's Comments</u> This was not an easy question, but most candidates did extremely well in this multi-step calculation. The directions of the currents are important. The current at **Y** and the current in the resistor, must add up to 0.060 A. The charge passing point **Y** in a time of 10 s can be calculated using $\Delta Q = I\Delta t$ and finally the number of electrons can be determined by dividing the charge passing through **Y** by the elementary charge *e.* Therefore number of electrons = $\frac{(0.060-0.020)\times 10}{1.60\times 10^{-19}} = 2.50 \times 10^{18}$ The key, correct answer, is **B**. The most popular distractor was **C**, in which a current of 0.060 A is assumed; the rest of the distractors were equally favourable. **A** was the answer for a current of 0.020 A and **D** was the answer for a current of 0.080 A. It is worth mentioning that most of the candidates just wrote down the correct answer in the box, without any calculations. On the surface, this looks reckless, but it is an excellent strategy if the numbers are being punched into the calculator correctly. The exemplar 1 below shows a typical correct answer, with numbers jotted down for visual help. **Exemplar 1**  Part of an electric circuit is shown below. The direction of all the currents and the magnitude of two currents are shown. How many electrons pass through the point Y in 10 s? 0.4 **A** 1.25×10^{18} **B** 2.50×10^{18} **C** 3.75×10^{18} **D** 5.00×10^{18} Your answer B **[1]** The candidate has the correct current at **Y**.

Question			Answer/Indicative content	Marks	Guidance
					Without the 0.040 A, the answer would have led to one of the distractors. It is worth pointing out that the final step of the calculation must have been done directly on the calculator. An excellent time-saving approach.
			Total	1	
15			B	1	**Examiner's Comments** This was a question on combining together three important expression in the topic of electricity; $V = IR$, $R = \rho L/A$ and $I = Anev$. On top of this, there was the additional information that **P** and **Q** were in parallel and hence the potential difference across each wire was the same. The mean drift velocity v of the electrons is given by the expression $v = \frac{V}{ne\rho L} \propto \frac{1}{L}$. The cross-sectional area A, and hence the diameter d of the wire has no effect on v. The relationship above implies that for wire **Q**, $v = \frac{1}{3} \times 0.60 = 0.20$ mm s^{-1}. The correct answer is **B**. All the distractors were equally popular. About a third of the candidates, mostly from the very top end of the ability range, were successful in this very demanding question.
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
16	a	i	$R = \frac{150}{1.5^2}$ 67 Ω	C1 A1	**Allow** $V = \frac{150}{1.5} = 100\text{ V}$ <u>and</u> $R = \frac{100}{1.5}$
		ii	Q = 1.5 × 5.0 × 60 × 60 or 27000 $N = \frac{1.5 \times 5.0 \times 60 \times 60}{1.6 \times 10^{-19}}$ =1.7 x 10^{23}	C1 A1	**Note** use of 150 (W) does not score 1.7 × 10^{25} 1.68 × 10^{23} 4.7 × 10^{19} scores one mark **Not** 1.7 × 10^{25} (uses 150 W)
		iii	$v = \frac{1.5}{7.9 \times 10^{28} \times 4.1 \times 10^{-9} \times 1.6 \times 10^{-19}}$ 0.029 (m s^{-1})	C1 A1	
	b		Silicon will have a smaller number density, ORA Silicon will have a larger resistivity, ORA	B1 B1	**Allow** semiconductor for silicon; metal for nichrome <u>Examiner's Comments</u> High achieving candidates found this question straightforward. Some candidates on (a)(iii) used *N* instead of *n.* Part (b) caused the most difficulty with candidates either using 150 W rather than 0.150 kW or changing the time to seconds. **Misconception** The worst acceptable line is either the steepest line that passes within all the error bars or the shallowest error line that passes within all the error bars.
			Total	**8**	

Question			Answer/Indicative content	Marks	Guidance
17		i	$12000 = \frac{Q}{4\pi\varepsilon_0 r}$ $12000 = \frac{Q}{4\pi\varepsilon_0 \times 0.19}$ $Q = 2.5(4) \times 10^{-7}$ (C)	C1 C1 A0	**Allow** $E = (V/d =)\ 6.316 \times 10^4$ and **C1** $E = 6.316 \times 10^4 = \frac{Q}{4\pi\varepsilon_0 \times 0.19^2}$ **C1**
		ii	1 $t = 78 \times 3600$ $(I =) \frac{2.5 \times 10^{-7}}{78 \times 3600}$ $I = 8.9 \times 10^{-13}$ (A) 2 $(R =) \frac{6000}{9.0 \times 10^{-13}}$ **or** 6.7×10^{15} (Ω) **or** $V = IR$ and $R = \frac{\rho L}{A}$ $\frac{6000}{9.0 \times 10^{-13}} = \frac{\rho \times 0.38}{1.1 \times 10^{-4}}$ $\rho = 1.9 \times 10^{12}$ (Ω m)	C1 C1 A0 C1 C1 A1	There is no ECF from **(b)(i)** **Note** 2.54×10^{-7} gives an answer 9.0×10^{-13} A There is no ECF from **(b)(ii)1** **Take** 12000 V as **TE** for this C1 mark, then ECF **Note** 8.9×10^{-13} (A) gives an answer 2.0×10^{12} (Ω m)
			Total	7	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
18	a	i	$F = QE = QV / d$ **or** $E = 5(.0) \times 10^{4}$ (Vm^{-1}) $F = 9.0 \times 10^{-9} \times 4000 / 8.0 \times 10^{-2}$ (= 4.5×10^{-4} N)	C1 A1	$F = 5.0 \times 10^{4} \times 9.0 \times 10^{-9}$ <u>Examiner's Comments</u> Many lower ability candidates did not appreciate the uniform nature of the electric field between the plates and attempted to use Coulomb's Law.
		ii	weight; arrow vertically downwards tension; arrow upwards in direction of string electric (force); arrow horizontally to the <u>right</u> (not along dotted line)	B1 x 2	All correct, 2 marks; 2 correct, 1 mark 1 mark maximum if more than 3 arrows are drawn **Ignore** position of arrows **Allow** W **or** 0.030(N) (**not** gravity or g) **Allow** T **Allow** F **or** E or 4.5×10^{-4}(N) or electrostatic **Ignore** repulsion or attraction **Not** electric field / electric field strength / electromagnetic <u>Examiner's Comments</u> Most candidates scored a mark for showing the weight and tension forces accurately. Only a small proportion labelled the electric force arrow correctly and drew it as clearly perpendicular to the plates. **AfL** Do not use the word 'gravity' in place of 'weight'

Question			Answer/Indicative content	Marks	Guidance
		iii	*W x* = *F l* 0.03 *x* = 4.5 x 10^{-4} x 120 **or** = 4.5 x 10^{-4} x 1.2 *x* = 1.8 cm **or** *x* = 0.018 m	M1 M1 A0	**Allow** any valid alternative approach e.g. M1 deflection angle θ = 1° M1 x = 120sinθ 1 mark for each side of the equation <u>Examiner's Comments</u> Although most candidates knew the principle of moments, many were unable to apply it correctly in this situation. More practice at this sort of question is recommended.
	b		Electric force/field (strength) increases Ball deflected further from vertical / moves to the right / touches negative plate Ball acquires the charge of the (negative) plate when it touches (Oscillates because) constantly repelled from (oppositely) charged plate	B1 B1 B1 B1	Must be clear which force is increasing Must have the idea of a repeating cycle <u>Examiner's Comments</u> The purpose of this question was to challenge the candidates to use their knowledge of electric fields in a novel practical situation. The word 'oscillate' confused many candidates, who tried to explain why the ball would perform simple harmonic motion.
	c		*I* = *Qf* **or** *Q* = *It* *f* = 3.2 x 10^{-8}/9.0 x 10^{-9} = 3.6 (Hz)	C1 A1	
			Total	12	

Question			Answer/Indicative content	Marks	Guidance
19	a		(initial charge) $Q = EC_0$ **or** (Q conserved so final) $Q = V(C + C_0)$ (as capacitors are in parallel) so $EC_0 = V(C + C_0)$ (and hence $V = C_0 E / (C + C_0)$)	M1 A1	At least one correct expression for Q for first mark The two correct expressions equated for the second mark **Examiner's Comments** Some candidates obtained $Q = EC_0$ by applying the definition of capacitance at A, but then did not realise that charge would be conserved on switching from A to B. Some chose the wrong formula for capacitors in parallel or attempted to use the potential divider equation.
	b	i	$1/V = 1/E + C/EC_0$ (and compare to $y = c + mx$)	B1	Mark is for rearrangement into linear equation **Examiner's Comments** Some candidates correctly took the reciprocal of both sides of the given equation but were then unable to show a rearrangement into the standard linear form. A common difficulty was an inability to expand the bracket in $\frac{1}{E} \times \frac{(C + C_0)}{C_0}$ to give $\frac{C}{EC_0} + \frac{C_0}{EC_0}$

Question			Answer/Indicative content	Marks	Guidance
		ii	$1/EC_0 = 51 = 1/(9.1\ C_0)$ giving $C_0 = 1/(51 \times 9.1)$ F C_0 = 2.2 (mF)	B1 B1	$C_0 = 2.1547 \times 10^{-3}$ F Answer must be correct, rounded correctly and given in mF Candidate's answer must be given to 2 SF <u>Examiner's Comments</u> Some candidates gave their response to 2 d.p. instead of to 2 s.f. as required.

Question			Answer/Indicative content	Marks	Guidance
		iii	(at least) one correct worst fit line drawn gradient calculated correctly using a large triangle uncertainty = C_0 – 1/(wfl gradient x 9.1) uncertainty given is to the same number of decimal places as C_0	B1 B1 B1 B1	Top and bottom points chosen must be from opposite extremes of uncertainty limits, accurate to within half a small square $\Delta x \geq 1.5 \times 10^{-3}$; **expect** 59±1 or 44±1 (**or** 0.059 **or** 0.044); **allow ECF** from poorly drawn line; readings must be accurate to within half a small square **ECF** from **b(ii)**; **expect** uncertainty of up to 0.4(mF) **ECF** from **b(ii)** **If** no value for C_0 given in b(ii), **allow** any answer given to 1dp <u>Examiner's Comments</u> Most candidates gained the mark for using a large triangle (spanning more than 1.5 on the x–axis) to determine the gradient of the worst-fit line. Lower ability candidates were unable to gain credit for finding the gradient of their line because they read the scales on the axes incorrectly. Candidates should take a ruler into the examination and be careful about the positioning of the ruler for drawing a worst-fit straight line. A worst-fit line should join opposite extremes of uncertainty limits and pass between all the uncertainty limits. The Practical Skills Handbook is helpful on this topic. Several candidates performed the unnecessary step of calculating the fractional (or percentage) uncertainty instead of using $\Delta C_0 = \pm \lvert C_{0\ best} - C_{0\ worst} \rvert$ directly.
	c		Only effect is to slow the charging and / or discharging (of capacitor(s)) <u>and so</u> the final charges are unchanged / the values for *V* are unchanged / the graph is unchanged / the gradient is unchanged / there is no effect on the experiment (results)	B1	**Allow** and so the experiment takes longer
			Total	10	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
20			**Level 3 (5 – 6 marks)** Clear expansion of three statements *There is a well-developed line of reasoning which is clear and logically structured. The information presented is clear, relevant and substantiated.* **Level 2 (3 – 4 marks)** Clear expansion of two statements **or** Limited attempt at all three *There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.* **Level 1 (1 – 2 marks)** Limited attempt at one or two statements *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** *No response or no response worthy of credit.*	B1 x 6	**Use level of response annotations in RM Assessor,** **e.g. L2 for 4 marks, L2^ for 3 marks, etc.** **Indicative scientific points may include:** **statement 1** • fusion reactions are occurring • which change H into He • and mass is lost which releases energy • energy released = $c^2\Delta m$ • Δm per second = luminosity / c^2 **statement 2** • average k.e. of each proton is $\frac{3}{2}kT$ • high T means protons are travelling at high speed • so fast enough to overcome repulsive forces • and get close enough to fuse • p.e. = $e^2/4\pi\varepsilon_0 r$ so T must be high enough for $\frac{3}{2}kT > e^2/4\pi\varepsilon_0 r$ • r is approximately 3fm **statement 3** • k.e. ∝ T so average energy at 10^7 K is only one thousandth of the average energy at 10^{10} K when protons might fuse • but M-B distribution applies so at the high energy end there will be a few p with enough energy • quantum tunnelling across potential barrier is possible • small probability of many favourable collisions to boost energy of p • 4 p must fuse to produce He; it is complicated process making probability of fusion much less • number of p in Sun is so huge that, even with such a small probability, 4 x 10^9 kg of p still interact s^{-1} • a larger probability means lifetime of the Sun would be shorter

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
					<u>Examiner's Comments</u> This was one of the two LoR questions. It required understanding of fusion, mass-energy equivalence, the Maxwell-Boltzmann distribution, and the relationship between mean kinetic energy and temperature for particles in an ideal gas. Responses to the following questions were being sought: 1. Why is the Sun losing mass? 2. Why is an extremely high temperature needed for fusion in stars? 3. Why does fusion occur in the Sun even though its temperature is 1,000 times less than that required by theory? Two dissimilar responses could score comparable marks if the criteria set out in the answer section of the marking scheme were met. Level 3 responses gave a clear answer to all three of the questions, whereas Level 2 responses generally had clear answers to only two. In Level 1, limited answers to only one or two of the above questions were given.
			Total	6	
21			the current (induced in the aerial) is alternating (5 × 10^8 times per second) (so the meter would register zero) / AW **or** the diode (half-)rectifies the current / changes the current (from a.c.) to d.c. / AW	B1	**Allow** 'a diode only lets current pass through in one direction' AW <u>Examiner's Comments</u> Allowing a mark for the diode only letting current pass in one direction enabled many candidates to score this mark. There was little mention of alternating current among the responses.
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
22			Q = 79e and q = 2e $F = (1/4\pi\varepsilon_0)Qq/r^2$ = 79 × 2 × $(1.6 \times 10^{-19})^2$/ [4π × 8.85 × 10^{-12} ×$(6.8 \times 10^{-14})^2$] = 7.9 (N)	C1 C1 C1 A1	**Apply ECF** for wrong charge(s), e.g. Q and / or q = e, or Q = 79 and / or q = 2, etc <u>Examiner's Comments</u> The most common error here was to use incorrect values for the charges on the two ions. Even so, most candidates were able to gain most of the marks with ECF.
			Total	4	
23			C	1	
			Total	1	