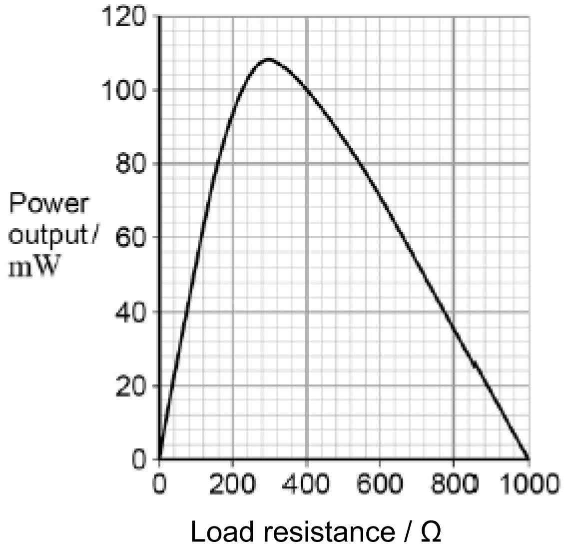
1 **Figure 1** shows data for the variation of the power output of a photovoltaic cell with load resistance. The data were obtained by placing the cell in sunlight. The intensity of the energy from the Sun incident on the surface of the cell was constant.

Figure 1



(a) Use data from **Figure 1** to calculate the current in the load at the peak power.

(3)

(b) The intensity of the Sun's radiation incident on the cell is 730 W m $^{-2}$. The active area of the cell has dimensions of 60 mm × 60 mm.

Calculate, at the peak power, the ratio $\frac{\textit{electrical energy delivered by the cell}}{\textit{energy arriving at the cell from the Sun}}$

(3)

(c) The average wavelength of the light incident on the cell is 500 nm. Estimate the number of photons incident on the active area of the cell every second.

(2)

(d) The measurements of the data in **Figure 1** were carried out when the rays from the sun were incident at 90° to the surface of the panel. A householder wants to generate electrical energy using a number of solar panels to produce a particular power output.

Identify **two** pieces of information scientists could provide to inform the production of a suitable system.

____

____

____

____

____

____

(2)

(Total 10 marks)

2 In each of the following circuits the battery has negligible internal resistance and the bulbs are identical.

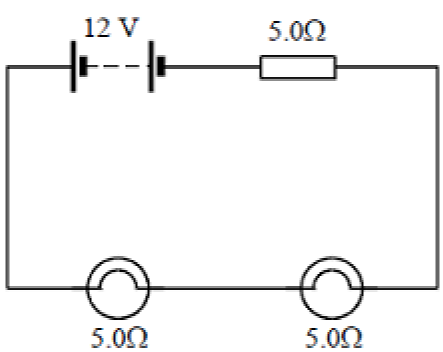


Figure 1

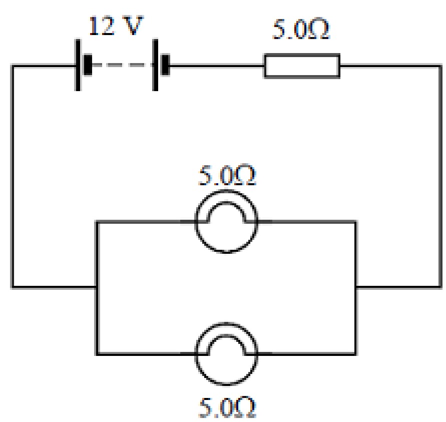


Figure 2

(a) For the circuit shown in **Figure 1** calculate

(i) the current flowing through each bulb,

____

____

(ii) the power dissipated in each bulb.

____

____

(2)

(b) In the circuit shown in **Figure 2** calculate the current flowing through each bulb.

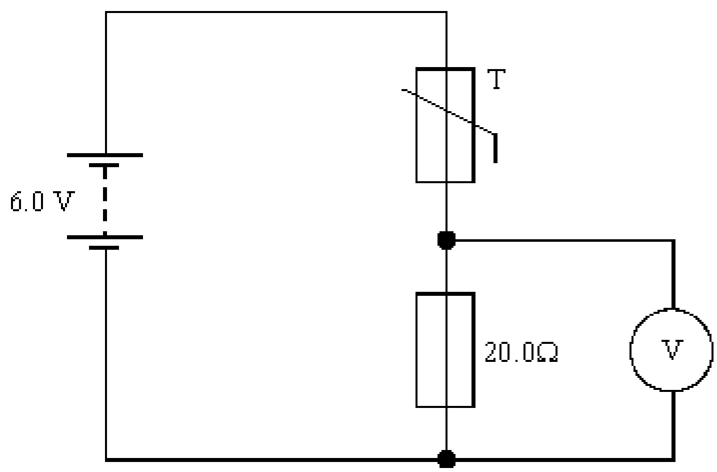
(3)

(c) Explain how the brightness of the bulbs in **Figure 1** compares with the brightness of the bulbs in **Figure 2**.

(2)

(Total 7 marks)

3 The circuit shown in the diagram below can be used as an electronic thermometer. The battery has negligible internal resistance.



The reading on the digital voltmeter can be converted to give the temperature of the thermistor T which is used as a temperature sensor.

(a) Explain why the reading on the voltmeter increases as the temperature of the thermistor increases.

(2)

(b) When the thermistor is at 80.0 °C the voltmeter reading is 5.0 V. Show that the resistance of the thermistor at this temperature is 4.0 Ω.

(1)

(c) When the thermistor is at 20.0 °C its resistance is 24.5 Ω. Calculate the reading on the voltmeter.

Voltmeter reading ____________________

(2)

(d) The battery is replaced with another having the same emf but an internal resistance of 3.0 Ω.

(i) Calculate the new voltmeter reading when the thermistor temperature is 80.0 °C.

Voltmeter reading ____________________

(2)

(ii) State and explain the effect, if any, on the measured temperature when the thermistor is at 20.0 °C.

____

____

____

____

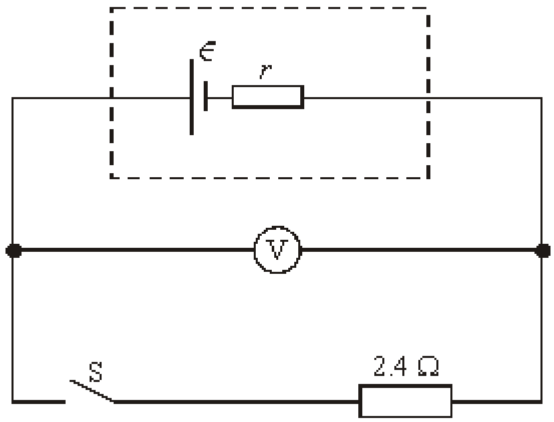
____

____

(1)

(Total 8 marks)

4 In the circuit shown the battery has emf ϵ and internal resistance *r*.



(a) (i) State what is meant by the emf of a battery.

(ii) When the switch S is open, the voltmeter, which has infinite resistance, reads 8.0 V. When the switch is closed, the voltmeter reads 6.0 V. Determine the current in the circuit when the switch is closed.

(iii) Show that $r = 0.80\ \Omega$.

(4)

(b) The switch S remains closed. Calculate

(i) the power dissipated in the 2.4 Ω resistor,

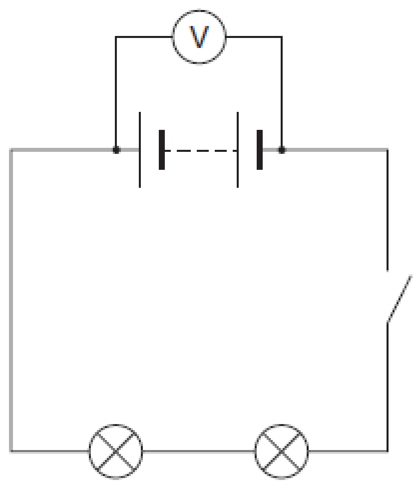
(ii) the total power dissipated in the circuit,

(iii) the energy wasted in the battery in 2 minutes.

____

(4)
(Total 8 marks)

5 The diagram shows an electrical circuit in a car. A voltmeter of very high resistance is used to measure the potential difference across the terminals of the battery.



(a) Define potential difference.

____

____

(1)

(b) Explain how and why the voltmeter reading changes when the switch is closed.

____

____

____

____

____

____

(3)
(Total 4 marks)

6 (a) (i) Give the equation which relates the *electrical resistivity* of a conducting material to its *resistance*. Define the symbols in the equation.

____

____

____

(ii) A potential difference of 1.5 V exists across the ends of a copper wire of length 2.0 m and uniform radius 0.40 mm. Calculate the current in the wire.

resistivity of copper = $1.7 \times 10^{-8}\ \Omega$ m

____

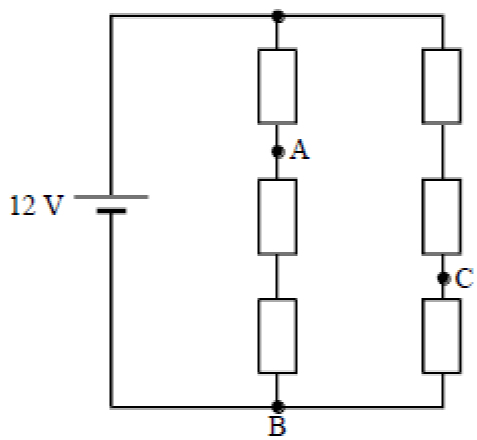
____

____

____

(5)

(b) In the circuit shown, each resistor has the same resistance. The battery has an e.m.f. of 12 V and negligible internal resistance.



(i) Calculate the potential difference between A and B.

____

____

(ii) Calculate the potential difference between B and C.

____

____

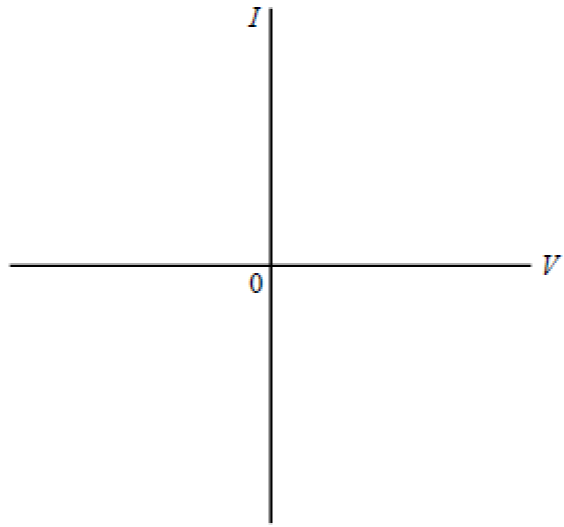
(iii) A high resistance voltmeter is connected between A and C. What is the reading on the voltmeter?

____

(5)
(Total 10 marks)

7 (a) Using the axes below, sketch the characteristic of a silicon semiconductor diode for forward bias and reverse bias.

Indicate approximate values on the voltage axis.



(4)

(b) Describe, with reference to the characteristic you have drawn, how the resistance of the diode changes with the voltage across the diode.

___

___

___

___

(3)

(Total 7 marks)

8 Scientists have suggested that carbon dioxide emissions produced by power stations in the European Union could be reduced considerably if high temperature superconductors were used instead of ordinary conductors to improve the efficiency of power plants.

(a) Explain what is meant by a superconductor.

___

___

(2)

(b) Explain why the use of superconductors would improve the efficiency of power stations and hence reduce carbon dioxide emissions.

___

___

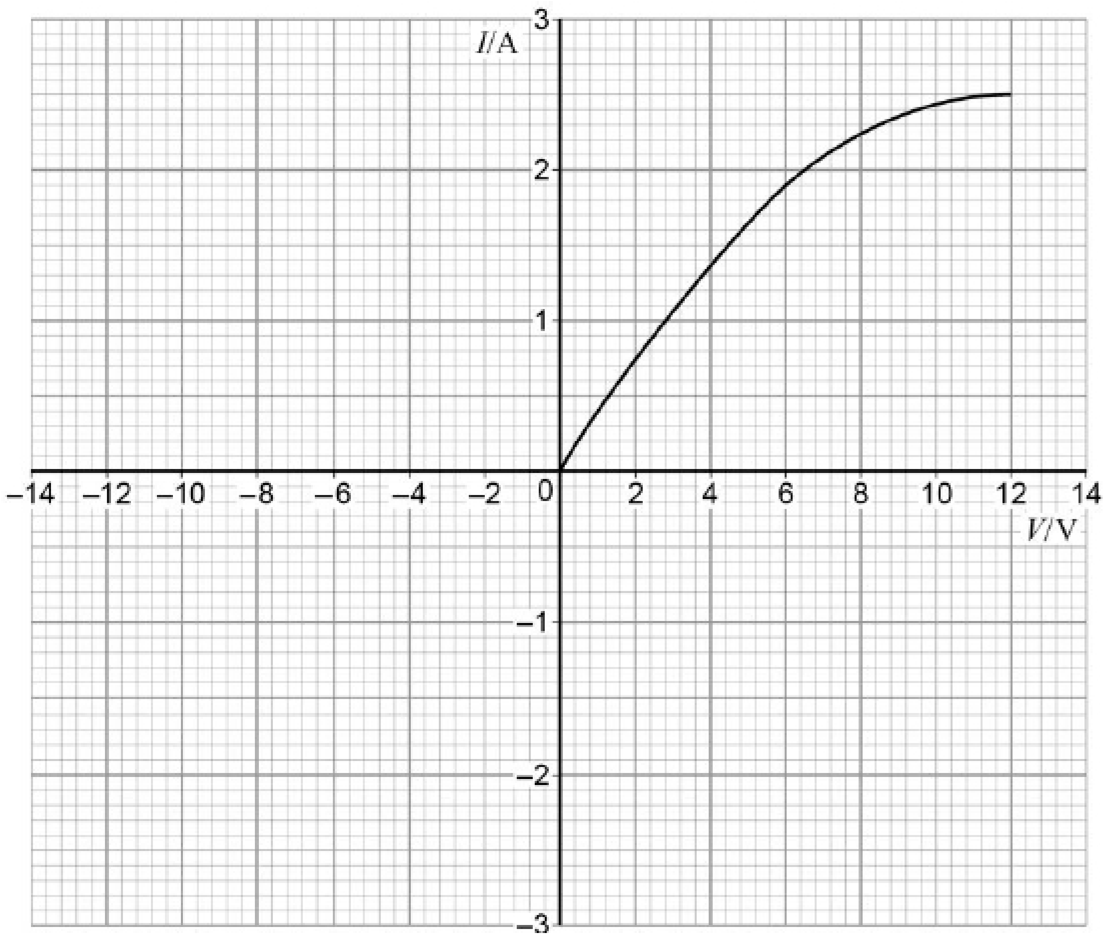
___

(2)

(Total 4 marks)

9 **Figure 1** shows the current–voltage ($I–V$) characteristic of the lamp used in a car headlight up to its working voltage.

Figure 1



(a) Draw on **Figure 1** the characteristic that would be obtained with the connections to the supply reversed.

(2)

(b) Lamps are marked with their working voltage and the power used at this voltage.
For example, a lamp for use in a torch may be marked 2.5 V 0.3 W.

Deduce the marking on the lamp for the car headlight.

lamp marking =______ V ______ W

(2)

(c) Determine the resistance of the lamp when the potential difference (pd) across it is half the working voltage.

resistance ___________________ Ω

(1)

(d) Explain, without further calculation, how the resistance of the lamp varies as the voltage across it is increased from zero to its working voltage.

____

____

____

____

____

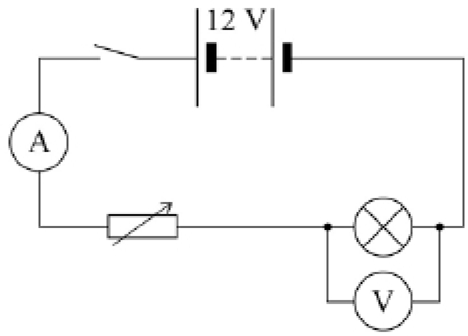
____

____

(3)

(e) A student suggests that the circuit shown in **Figure 2** is suitable for collecting data to draw the *I*−*V* characteristic of the lamp up to its working voltage. The maximum resistance of the variable resistor is 6.0 Ω and the internal resistance of the power supply is 2.0 Ω. The resistance of the ammeter is negligible.

Figure 2



Discuss the limitations of this circuit when used to collect the data for the characteristic.

____

____

____

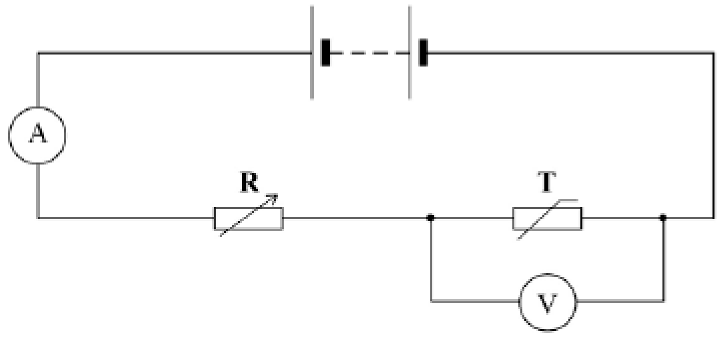
____

(2)

(Total 10 marks)

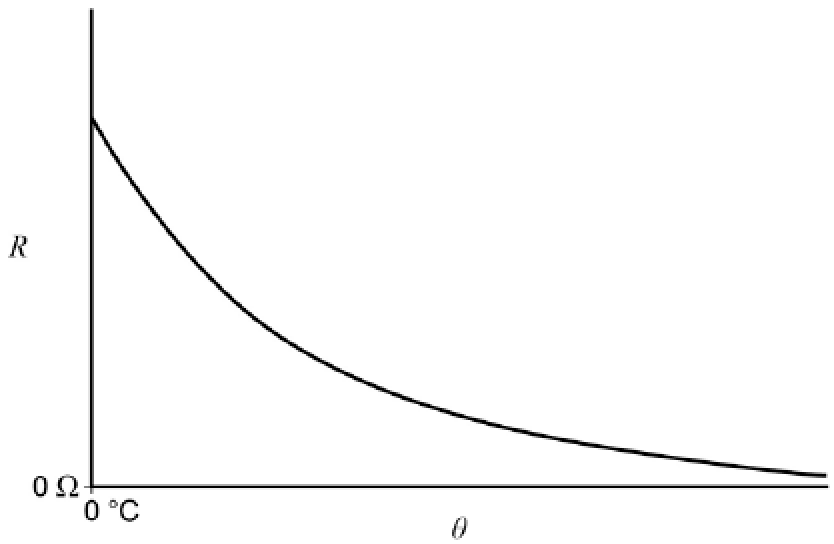
10 **Figure 1** shows a circuit including a thermistor **T** in series with a variable resistor **R**. The battery has negligible internal resistance.

Figure 1



The resistance–temperature (R–θ) characteristic for **T** is shown in **Figure 2**.

Figure 2



(a) The resistor and thermistor in **Figure 1** make up a potential divider.

Explain what is meant by a potential divider.

____

____

____

(1)

(b) State and explain what happens to the voltmeter reading when the resistance of **R** is increased while the temperature is kept constant.

____

____

____

____

____

____

(3)

(c) State and explain what happens to the ammeter reading when the temperature of the thermistor increases.

____

____

____

____

(2)

(d) The battery has an emf of 12.0 V. At a temperature of 0 °C the resistance of the thermistor is 2.5×10^3 Ω.

The voltmeter is replaced by an alarm that sounds when the voltage across it exceeds 3.0 V.

Calculate the resistance of R that would cause the alarm to sound when the temperature of the thermistor is lowered to 0 °C.

resistance = ____________________ Ω

(2)

(e) State **one** change that you would make to the circuit so that instead of the alarm coming on when the temperature falls, it comes on when the temperature rises above a certain value.

___

___

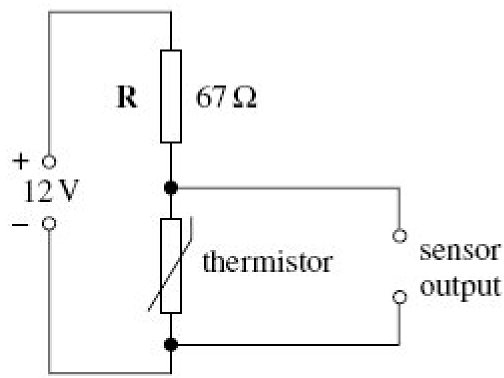
___

(1)

(Total 9 marks)

11 **Figure 1** shows a circuit that can be used to sense temperature changes. Sensing is possible because the potential difference across the thermistor changes as the temperature changes.

Figure 1



The power supply has a negligible internal resistance and the resistor **R** has a resistance of 67 Ω.

(a) When the thermistor is at a high temperature the potential difference across it is 4.5 V.

(i) Calculate the potential difference across **R**.

___

___

potential difference ___________________ V

(1)

(ii) Calculate the current in the circuit.

___

___

___

current ___________________ A

(2)

(b) (i) The temperature of the thermistor changes to 25 °C and its resistance becomes 360 Ω.

Show that the potential difference across the thermistor at 25 °C is about 10 V.

____

____

____

____

(3)

(ii) Calculate the power dissipated in the resistor **R** when the thermistor temperature is 25 °C, giving an appropriate unit for your answer.

____

____

____

____

____

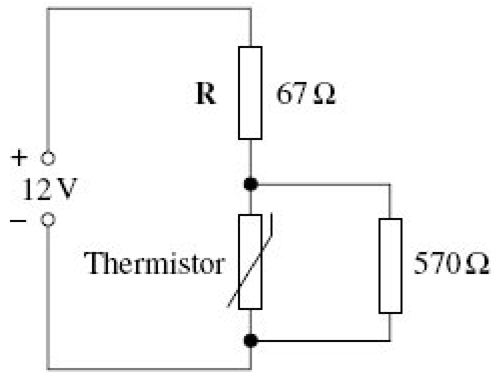
____

power dissipated ____

(4)

(c) The circuit is modified as shown in **Figure 2**. A resistor of resistance 570 Ω is connected in parallel with the thermistor.

Figure 2



For the circuit in **Figure 2** calculate the current in the 67 Ω resistor when the thermistor temperature is 25 °C.

____

____

____

____

____

current in 67 Ω resistor ____________________ A

(4)

(d) Explain, in terms of charge carriers, why the resistance of the thermistor decreases as the temperature rises.

____

____

____

____

____

____

____

(3)
(Total 17 marks)

Mark schemes

1 (a) Peak power = 107 / 108 mW and load resistance = 290 / 310 Ω ✓ 1

Use of power = I^2R with candidate values✓ 1

0.0186 – 0.0193 A ✓ 1

(b) Area of cell = 36 x 10^{-4} m^2 and solar power arriving = 730 × (an area)✓ 1

$\frac{0.108}{2.63}$ seen✓ 1

0.041 (correct answer only; lose if ratio given unit) ✓ 1

(c) energy of one photon = $\frac{hc}{\lambda}$ = 4.0 ×10^{-19}J✓ 1

Number of photons = $\frac{730 \times 36 \times 10^{-4}}{4.0 \times 10^{-19}}$ = 6.6 × 10^{18} s^{-1}✓ 1

(d) **Two** from

Intensity of the sun at the Earth's surface
Average position of the sun
Efficiency of the panel
Power output of 1 panel
Weather conditions at the installation=
✓✓

Allow other valid physics answers= 2

[10]

2 (a) (i) $I = \frac{12}{15}$ = 0.80 A **(1)**

(ii) $P = (0.80)^2 \times 5$ = 3.2 W **(1)** (allow e.c.f. from (a)(i)) **(2)**

(b) $I_{tot} = \frac{12}{7.5}$ **(1)** = 1.60 (A) **(1)**

$I = \frac{1.6}{2}$ = 0.80 (A) **(1)** (allow e.c.f. from I_{tot}) **(3)**

(c) same brightness **(1)**
because same current **(1)**
[or an answer consistent with their current values]

(2)

[7]

3 (a) as the temperature of T increases its resistance decreases /more charge carriers are released

B1

increasing the current in the circuit /changing the ratio of resistance/reducing pd across T

B1

(so that so that the pd across the resister increases)

2

(b) T/ 20.0 = 1.0/5.0 **OR** 5.0/6.0 = 20/(20+T) **OR** equivalent
(Therefore T = 4.0 ohms)

Note T = (1/5)20 just ok but T = 20/5 not enough

M1

1

(c) Use of Vout = $R_1/(R_1 + R_2) \times V_{in}$ **OR** I = 6/44.5 = 0.135 A

C1

V = 2.7 V

A1

2

(d) (i) V/6.0 = 20.0/(20.0+4.0+3.0) **OR** I = 0.222 A

C1

V = 4.4V

A1

2

(ii) The measure temperature would be lower because the pd across the resistor would be less *(ie 2.53V)*

B1

1

[8]

4 (a) (i) energy changed to electrical energy per unit charge/coulomb passing through
[or electrical energy produced per coulomb or unit charge]
[or pd when no current passes through/or open circuit] **(1)**

(ii) $I = \frac{6}{2.4} = 2.5$ A **(1)**

(iii) (use of $\in = I(R + r)$ gives) $\in = V + Ir$ and $8 = 6 + Ir$ **(1)**

substitution gives 8 – 6 = 2.5r **(1)** (and $r = 0.8\ \Omega$)

4

(b) (i) (use of $P = I^2R$ gives) $P_R = 2.5^2 \times 2.4 = 15$ W

[or $P = VI$ gives $P = 6 \times 2.5 = 15$ W] **(1)**

(allow C.E. for value of *I* from (a))

(ii) $P_T = 15 + (2.5^2 \times 0.8)$ **(1)**

= 20 (W) **(1)**

(allow C.E. for values of P_R and I)

(iii) $E = 5 \times 2 \times 60 = 600$ J **(1)**

(allow C.E. for value of P from (i) and P_T from (ii))

4

[8]

5 (a) work done per unit charge

Allow V=W/Q if W and Q defined

1

(b) Voltmeter reading / terminal pd drops
Battery has internal resistance
pd occurs within battery / 'lost volts' within battery / emf is shared between internal and external resistances

3

[4]

6 (a) (i) resistivity defined by $\rho = \frac{RA}{l}$ **(1)**

symbols defined $\frac{RA}{l}$

(ii) $R = \frac{\rho l}{A} = \frac{1.7 \times 10^{-8} \times 2}{\pi(0.4 \times 10^{-3})^2}$ **(1)**

$= 0.068\ (\Omega)$ **(1)** $(0.0676\ \Omega)$

$I = \frac{1.5}{0.068} = 22$ A **(1)** (22.2 A)

(allow e.c.f. from value of R)

(5)

(b) (i) $\text{pd}_{AB} = \frac{2}{3} \times 12 = 8$ V **(1) (1)**

(ii) $\text{pd}_{BC} = (\frac{1}{3} \times 12) = 4$ V **(1)**

(iii) pd_{AC} = potential at A – potential at C **(1)**

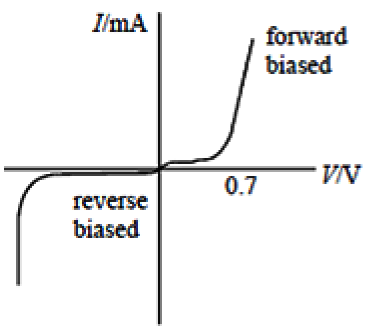
= (8 – 4) = 4 V **(1)**

(allow e.c.f. from (i) and (ii))

(5)

[10]

7 (a)



forward bias:
zero current rising gradually **(1)**
sharp increase at ≈ 0.7 V **(1)**

reverse bias:
zero or slightly less than zero current **(1)**

sharp negative increase at breakdown **(1)**
breakdown value >50 V indicated **(1)**

4

(b) forward bias: high resistance (initially gives small current) **(1)**
at ≈ 0.7 V, resistance decreases rapidly (current increases) **(1)**

reverse bias: high resistance (gives ≈ zero or slightly negative current) **(1)**
at breakdown, resistance ≈ zero (and very large current) **(1)**

3

The Quality of Written Communication marks are awarded for the quality of answers to this question.

[7]

8 (a) superconductor has zero resistance/resistivity (**not** very little)

B1

when at (condone below) the **transition temperature**
(not critical or low)

B1

2

(b) no/less/lower **power/energy lost** (in conducting wires)

B1

less fuel needed (so less CO_2 emitted to produce the required power)

B1

2

[4]

9 (a) correct general shape ✓

accurate plotting to within $\frac{1}{2}$ square ✓

2

(b) 12 (V) ✓, 30 (W) ✓

2

(c) $R = \left(\frac{6}{1.9}\right) = 3.2\ (\Omega)$ ✓

1

(d) Resistance increases ✓

Temperature increases ✓

More collisions / interaction of electrons with lattice ions ✓

Condone 'atoms', 'molecule'.

*Do **not** allow electron−electron collisions.*

3

(e) Can attain neither maximum nor minimum voltage ✓

Explanation of either maximum OR minimum ✓

2

[10]

10 (a) A combination of resistors in series connected across a voltage source (to produce a required pd) ✓

Reference to splitting (not dividing) pd

1

(b) When R increases, pd across R increases ✓

Pd across R + pd across T = supply pd ✓

So pd across T / voltmeter reading decreases ✓

Alternative:

Use of $V = \dfrac{R_1 \times V_{tot}}{R_1 + R_2}$ ✓

V_{tot} and R_2 remain constant ✓

So V increases when R_1 increases ✓

3

(c) At higher temp, resistance of T is lower ✓

1

So circuit resistance is lower, so current / ammeter reading increases ✓

1

(d) Resistance of T = 2500 Ω

Current through $T = V / R = 3 / 2500 = 1.2 \times 10^{-3}$ A ✓

(Allow alternative using $V_1/R_1 = V_2/R_2$)

pd across R = 12 − 3 = 9 V

The first mark is working out the current

1

Resistance of $R = V / I = 9 / 1.2 \times 10^{-3} = 7500$ Ω✓

The second mark is for the final answer

1

(e) Connect the alarm across R instead of across T ✓

allow: use a thermistor with a ptc instead of ntc.

1

[9]

11 (a) (i) pd across resistor = 12 – 4.5 = 7.5 V

C1

1

(ii) I = (answer to (a) (i))/67 (allow 12/7.5/4.5 for this mark)

C1

0.110/0.112 (A)

A1

2

(b) (i) *360 + 67 (= 427) seen*

C1

$V = 12 \times 360/(360 + 67)$

C1

10.1 V

A1

3

(ii) substitution $P = V^2/R$ allow 360 Ω/67 Ω;
10 V, 10.1 V, 1.9 V, 2 V

C1

$1.9^2/67$

C1

0.053

C1

W or J s^{-1}

A1

4

(c) $1/R = 1/570 + 1/360$

C1

220 [Ω]

C1

total $R = 287\ \Omega$

C1

42/41.7 mA $4.2 \times 10^{-2}/4.17 \times 10^{-2}$

A1

4

(d) extra charge carriers released as temperature rises

B1

increased thermal agitation of atoms resists flow of charge carriers

B1

1st effect overwhelms 2nd

A1

3

[17]

Examiner reports

3 Another difficult question when judged by the candidates. responses: more candidates failed to score on this question than any other. The calculations proved to be beyond most candidates. abilities.

Many good answers to part (a) were seen, and the better candidates scored on part (b) as well, although the idea of *showing* something mathematically is unfamiliar with many.

It was quite clear that very few candidates understood what was being asked in part (d)(ii).

4 Candidates found this question very accessible and many gained full marks. In part (a) the meaning of emf seems to be reasonably well understood with most candidates opting for the voltage when no current passed through the circuit. Others defined it correctly in terms of energy per unit coulomb. There were, unfortunately, many candidates who, apparently, had not encountered the definition of emf and merely quoted electromagnetic force, or even tried to define it in terms of a force in the circuit. The calculation of the current in part (ii) was well done and in part (iii) correct substitution of values into the equation $\in = V + Ir$ gave $r = 0.80\ \Omega$.

Part (b) was involved with calculation of power and energy and although the majority of candidates obtained the correct answer for the power dissipated in the 2.4 Ω resistor, fewer had the correct answer for the total power dissipated in the circuit and a disappointing number had the correct value for the energy wasted the battery. The usual answer to the last part was to give the energy in the complete circuit. Whether this was due to inaccurate reading of the question or due to lack of understanding could not be decided.

5 (a) Barely 10% of students knew the definition of potential difference.

(b) This was poorly understood; just over 50% of students gained no credit here. Students who did identify that the voltmeter reading decreased hardly ever gave an accurate reason.

6 Giving the relevant equation for resistivity in part (a)(i) was straightforward for the majority of candidates. Errors were quite common however in the calculation in part (ii). The usual error occurred in calculating the area of cross-section, e.g. by omitting the π or the factor 10^{-3} or not squaring the radius. These errors however were allowed to be carried forward and credit was given for subsequent calculations and although it often resulted in currents of the order of 10^7 A very few candidates made any comment on this unlikely value.

Part (b) was probably the worst answered section in the paper and very few candidates gained full credit. The basic problem seemed to be that candidates were under the impression that the 12 V was somehow split, resulting in 6 V across each chain of three resistors. Thus answers of 4 V and 2 V respectively for parts (i) and (ii) were common. Many candidates attempted to calculate the various potential differences but their mathematics was so confused that it was difficult to decide what approach they were taking. Answers to part (iii) usually bore no relation to the previous answers and was very often a matter of guesswork.

7 Many of the silicon semiconductor diode characteristics presented in part (a) were poorly drawn and the examiners felt that although the candidate knew what the characteristic looked like, greater attention to detail and less sloppiness in drawing would have earned them many more marks. The main errors were in drawing the forward characteristic as a continuous smooth curve, without a sharp increase in current at 0.6 V or 0.7 V. In many cases the increasing current would be represented as a vertical line, whereas in practice the slope of the curve is large, but not infinite. In the reverse mode, the current would, very often, be shown as slightly positive, which was not accepted. Other points to note in the reverse mode is that the change to a large current at breakdown occurs sharply and then the curve may be drawn as a vertical line. When values of voltage were given, they were usually correct.

Part (b) in general was not well answered. Many candidates wrote at length on how the current varied with the voltage without once referring to the change in resistance, which was the purpose of the question. The terminology of many candidates was confusing with reference to 'negative voltages in the forward mode'.

8 (a) Many wrote vaguely of a superconductor having little or low resistance. Some thought the temperature had to reach absolute zero, while others thought the temperature had to be high for material to become a superconductor. The idea of a transition temperature was appreciated by a minority of the candidates.

(b) That a superconductor would reduce the power lost in conducting wires was generally well known. Why this reduces emissions was often poorly explained. Answers such as 'if less power is lost in conduction less electricity has to be produced' were common and some answers clearly gave the impression that candidates thought that the conductors themselves emitted the carbon dioxide.

11 The level of attainment in this question that tested the electrical areas of the specification was very poor. Some candidates are clearly not comfortable with even the simplest problems tested here.

The pd in part (a) (i) was correctly identified by most candidates.

Answers to part (a) (ii) were very mixed and in general poor. Explanations were not adequate and the application of $V = IR$ confused.

20% of candidates did not attempt part (b) (i) and only 10% gave completely accurate answers. Both the understanding and application of the potential divider by candidates as poor.

Again many used poor physics that did not relate to the circuit in part (b) (ii). There was a misunderstanding as to which pd to use in the equation.

One-fifth of candidates offered no explanations to part (c). The essence of the question was a computation of the total resistance of a parallel resistor network. About half of candidates were able to negotiate this with comfort, but the remainder were usually able to quote the appropriate equation but not to get further with it.

Only the more able candidates gave a complete picture of the situation in part (d). To gain full credit candidates needed to recognise both the change in atomic vibration and the increase in charge carrier density as a result of temperature increase, but then to go on to state that the second effect outweighs the first.