8 An active temperature sensor produces an emf $\mathcal{E}$ which depends on temperature. The points in Fig. 8.1 show how the emf varies with temperature. A straight line fitting the data up to 40 °C has been added to the graph.

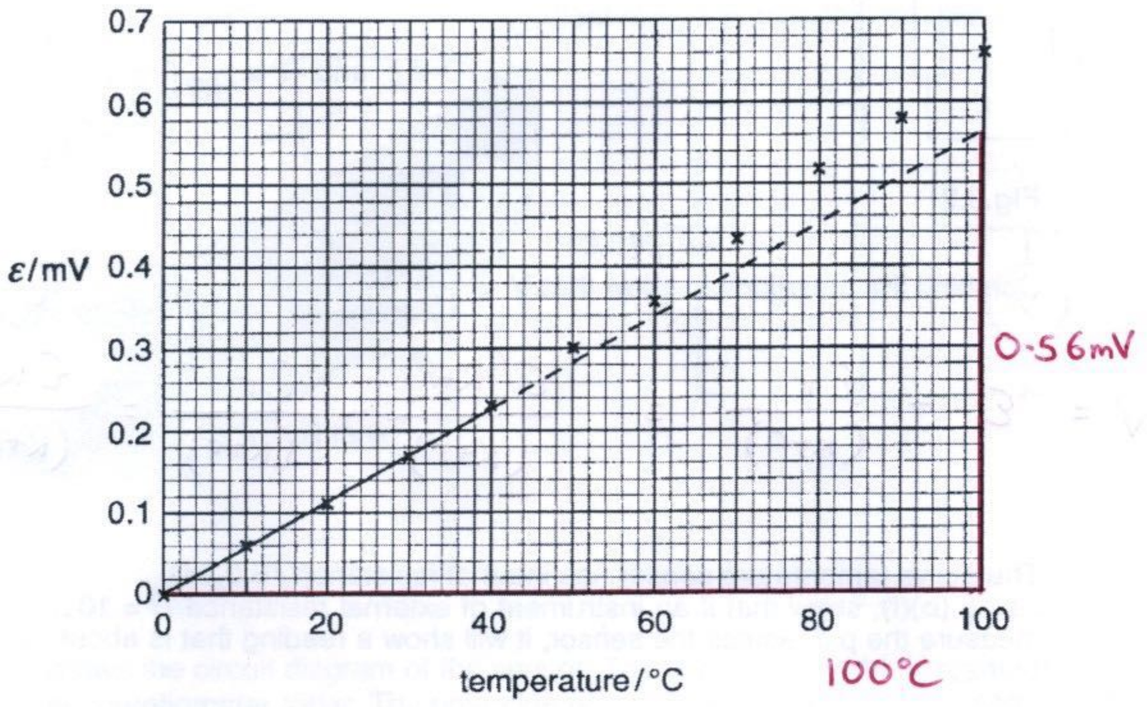


Fig. 8.1

(a) (i) Describe the relationship between the emf $\mathcal{E}$ and the temperature in °C shown by all the data points of Fig. 8.1.

(directly) proportional up to 40°C
then gradient increases

[2]

(ii) Estimate the **sensitivity** of the temperature sensor in the range 0 °C to 40 °C from the data points in Fig. 8.1.
Use units of μV °C^{-1} for the sensitivity.
Make your method of estimating the sensitivity clear.

$$\text{sensitivity} = \frac{\Delta\mathcal{E}}{\Delta T} = \frac{0{\cdot}56\times10^{-3}}{100} = 5{\cdot}6\times10^{-6}\ \text{V}^\circ\text{C}^{-1}$$

sensitivity = 5·6 μV °C^{-1} [2]

(b) **(i)** Fig. 8.2 shows an active sensor of internal resistance r producing an emf $\mathcal{E}$ connected to an external resistance R.

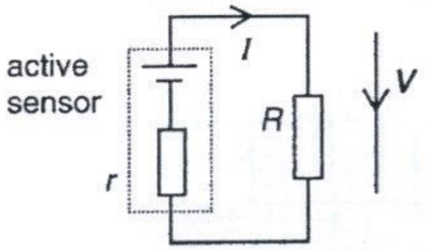


Fig.8.2

The p.d. V across the sensor, and the current I in the circuit are given by the equations

$$V = \mathcal{E} - Ir \quad \text{and} \quad I = \frac{\mathcal{E}}{(R+r)}.$$

Combine the equations to show that $V = \dfrac{\mathcal{E}R}{(R+r)}$.

$$V = \mathcal{E} - \frac{\mathcal{E}r}{(R+r)} = \frac{\mathcal{E}(R+r)}{(R+r)} - \frac{\mathcal{E}r}{(R+r)} = \frac{\mathcal{E}R}{(R+r)}$$

[2]

(ii) The active temperature sensor has internal resistance $r = 0.2\,\Omega$.
Using **(b)(i)**, show that if an instrument of external resistance $R = 10\,\Omega$ is used to measure the p.d. across the sensor, it will show a reading that is about 98% of the emf $\mathcal{E}$.

$$V = \mathcal{E}\frac{R}{(R+r)} = \mathcal{E}\frac{10}{10+0.2} = 0.98\,\mathcal{E}$$

ie 98%

[2]

(c) Instruments available to measure the output from the temperature sensor are given in the table below.

instrument	full scale deflection	sensitivity	internal resistance
moving coil meter MCM	300 mm	$10\,\mu V\,mm^{-1}$	$10\,\Omega$
cathode ray CRO oscilloscope	100 mm	$1.0\,mV\,mm^{-1}$	$25\,M\Omega$
digital voltmeter	$200\,\mu V$	$0.1\,\mu V$ steps	$2.0\,M\Omega$

The most suitable of these instruments to use for this sensor in the temperature range 0 to 100 °C is the **moving coil meter**.
Give **two** reasons why the **moving coil meter** is the most suitable, using the data in the table.

Digital voltmeter only reads up to 200μV and 0.7mV needed
CRO only has deflection of ~ 0.7mm at 0.7mV
MCM has low error ~2% and can give good deflection ~ 70mm.

[2]

[Total: 10]

8 This question is about a sensing system to monitor the oil-level in a domestic oil tank. Fig. 8.1 shows a cylindrical tank of oil.

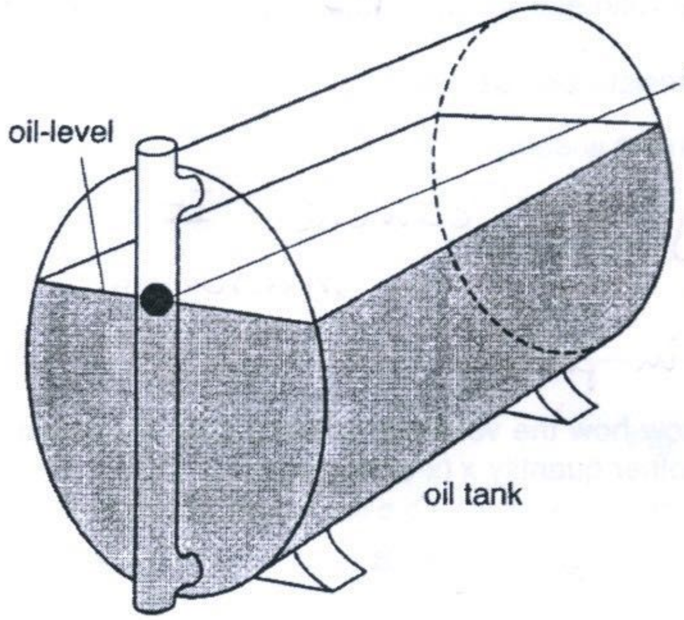


Fig. 8.1

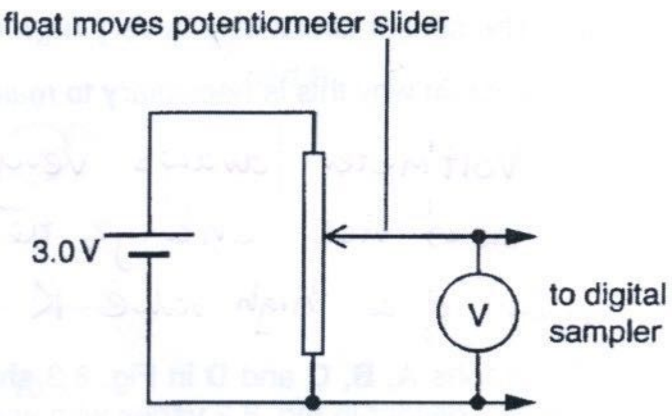


Fig. 8.2

Fig. 8.2 shows the circuit diagram of the sensor. The float rising and falling with the oil-level, moves the potentiometer slider. The potentiometer is **linear**. The voltmeter reads 0.0 V when the tank is empty and 3.0 V when it is full.

(a) **(i)** The voltage from the sensor is sampled digitally using a 3 bit sample.

Show clearly that 8 distinct levels can be represented by a 3 bit sample.

$N = 2^b = 2^3 = 8$

[1]

(ii) Show that the smallest change in voltage that can be represented by a 3 bit sample in this system is about 0.4 V.

8 levels gives 7 intervals

$3.0\text{V}/7 = 0.43\text{V}$

[1]

(b) A radio transmitter sends a signal from the sensor to a receiver in the house. The wavelength of the signal is 0.68 m.

Calculate the frequency of this radio signal.

speed of electromagnetic waves $c = 3.0 \times 10^8 \text{ m s}^{-1}$

$c = f\lambda \quad \therefore f = c/\lambda = \dfrac{3\times10^8}{0.68}$

frequency = 4.4×10^8 Hz [2]

(c) The oil tank in Fig. 8.1 is a horizontal cylinder holding 1200 litres when full.

(i) State the reading on the voltmeter when the volume of oil in the tank is 600 litres.

reading on the voltmeter = ...1.5......V [1]

(ii) The sensor circuit uses a very **high** resistance voltmeter.

Explain why this is necessary to maintain linearity.

Voltmeter draws very little current. It does not change the p.d. it is measuring. (Adding a high value R in parallel has little effect) [2]

(d) The graphs **A, B, C** and **D** in Fig. 8.3 show how the voltmeter reading from the **linear** potential divider in Fig. 8.2 varies with another quantity x (x-axis).

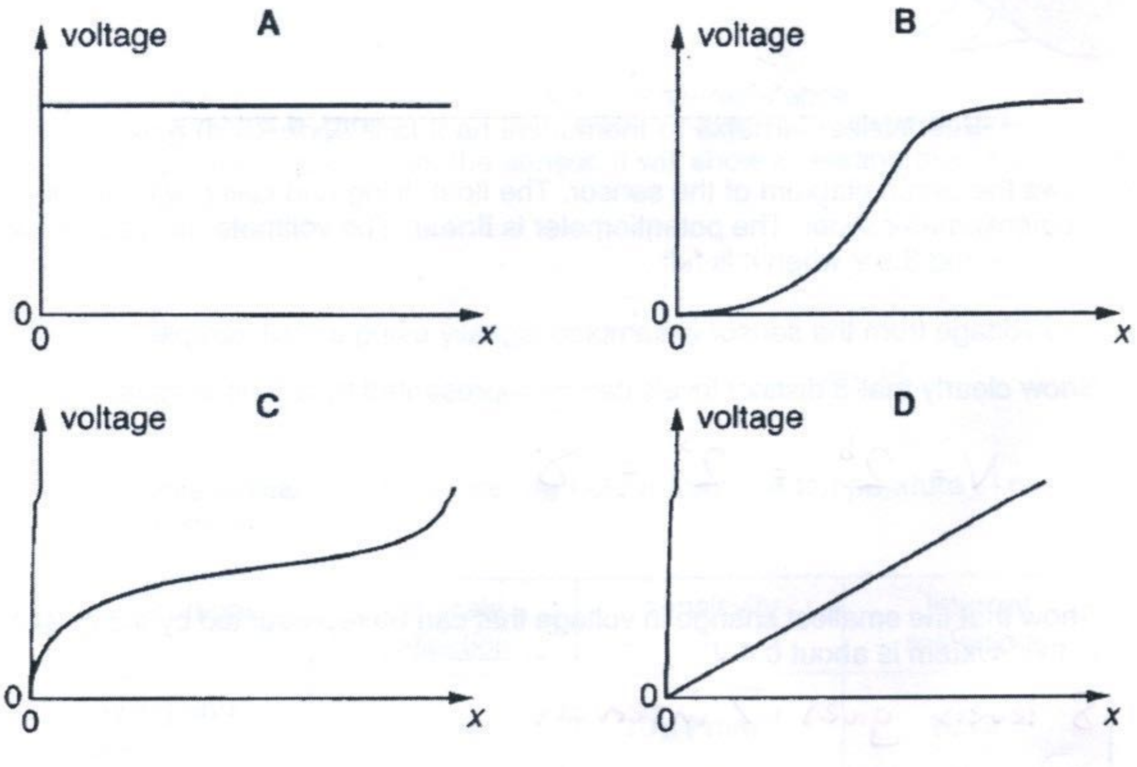


Fig. 8.3

Choose the graph that best represents how the reading on the voltmeter varies with

(i) the **depth of oil** in the tank (x-axis) ......D......[1]

(ii) the **volume of oil** in the tank (x-axis). ......C......[1]

tank is cylindrical

[Total: 9]

10 A battery is being tested. Fig. 10.1 shows the battery connected to a variable load resistor **R** and two meters.

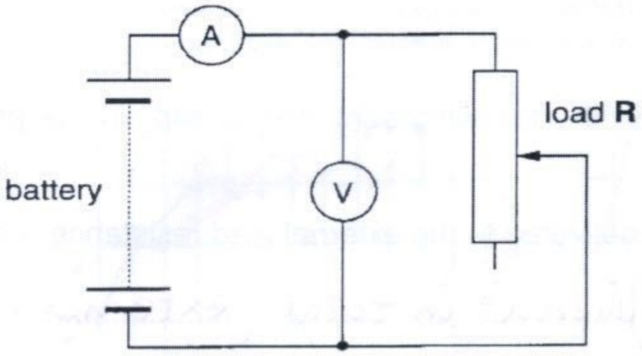


Fig. 10.1

Fig. 10.2 is a plot of the p.d. *V* across the battery against the current *I*, as **R** is varied.

Fig. 10.2

(a) **(i)** Draw the line of best fit on Fig. 10.2. [1]

(ii) Use your line of best fit to

1. estimate the e.m.f. $\mathcal{E}$ of the battery $\mathcal{E}$ = 6·0 V [1]

2. calculate the internal resistance *r* of the battery. Show your working clearly.

* $V = -rI + \mathcal{E}$ grad $= \frac{\Delta y}{\Delta x} = \frac{6{\cdot}0}{2{\cdot}0} = 3{\cdot}0\,\Omega$

$y = mx + c$

$\therefore$ gradient $= -r$

r = 3·0 Ω [3]

* from $V = \mathcal{E} - Ir$

(b) When the equation $V = \mathcal{E} - Ir$

is multiplied throughout by the current I, an equation for the power, IV, delivered to the load resistance is

$$IV = I\mathcal{E} - I^2 r.$$

Complete the gaps in the following sentence to explain the physical meaning of the second equation.

The electrical power delivered to the external load resistance is equal to

the power ......delivered in total (external + internal)...... minus

the power ......delivered to the internal resistance...... [2]

(c) **(i)** Using point **M** on Fig. 10.2, where $I = 1.0$ A and p.d. $V = 3.0$ V, calculate

1. the resistance of the variable load resistor **R**

$R = V/I = 3.0/1.0$ $R =$ ......3.0...... Ω [1]

2. the power dissipated in **R**.

$P = IV = 3.0 \times 1.0$ power = ...3.0...... W [1]

(ii) The efficiency of a battery under load can be defined as follows

$$\text{efficiency} = \frac{\text{useful power}}{\text{total power}}.$$

Calculate the efficiency of the battery operating at point **M** on the graph.

$$\text{eff} = \frac{IV}{I\mathcal{E}} = \frac{1.0 \times 3.0}{1.0 \times 6.0} = 0.5 = 50\%$$

efficiency = ...50%...... [1]

(iii) Choose **one** other data point from the graph Fig. 10.2.

Show that the power dissipated in **R** at this point is smaller than the power at point **M**, calculated in **(c)(i)**.

1.6 A & 1.2 V → $1.6 \times 1.2 = 1.9$ W < 3.0 W

or alternative point

[1]

[Total: 11]

9 This question is about a data-logger that runs on a battery supply.

(a) Sensors monitor the environment. They produce potential differences which are recorded by the data-logger. An analogue p.d. from a sensor is shown in Fig. 9.1.

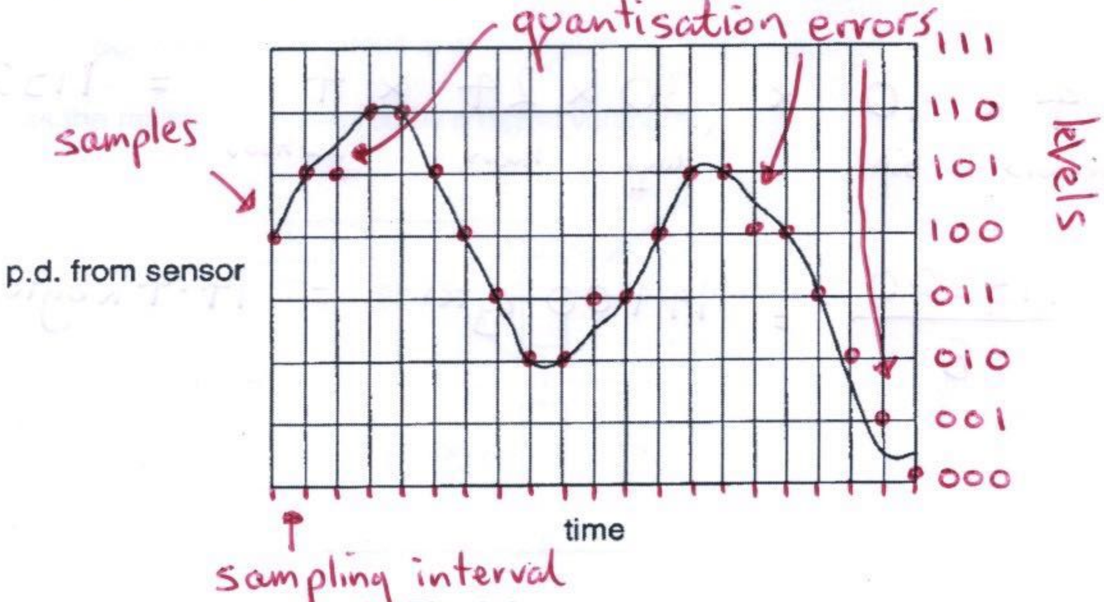


Fig. 9.1

The p.d.s are converted from analogue to digital form inside the data-logger.

(i) Describe, using Fig. 9.1, the process of converting an analogue signal to digital form. Adding annotation to Fig. 9.1 will be useful in your answer.

The analogue signal is sampled at regular intervals. The p.d. from the sensor is measured to the nearest level. That level is represented by a binary number.

[3]

(ii) Each analogue sample is converted into a 10 bit number (10 bits per sample).

Calculate the number of alternative levels that the converter can resolve.

$N = 2^b = 2^{10} = 1024$

number of levels = ...1024...... [1]

(iii) The signal voltage ranges from 0 V to 9.0 V.
Show that the voltage resolution is about 9 mV.

$\text{resolution} = \frac{\text{range}}{\text{intervals}} = \frac{9.0}{1023} = 8.80 \times 10^{-3}\,\text{V} \approx 9\,\text{mV}$

(intervals ↑ no. of levels − 1)

[2]

(b) The data-logger records 10 bits per sample from four sensors.
Samples are taken every 15 minutes ($\frac{1}{4}$ hour).
The data-logger is to collect data for 30 days unattended.

Show that the memory capacity that the data-logger needs to record all the data is greater than 10 kbytes.

$4 \times 10 \times 30 \times 24 \times 4 = 115200$ bits

sensors, bits, days, hours, per hour

$\frac{115200}{8} = 14400$ bytes $= 14.4$ kbytes

[2]

(c) The battery in the data-logger can deliver a total charge of 500 C.
A current of 20 mA is needed to run the four sensors.
The memory circuit draws a negligible current from the battery.

Show that the battery **cannot** run the sensors for 30 days non-stop, so that the sensor circuits need to be switched off between readings.

$Q = It = 20 \times 10^{-3} \times 30 \times 24 \times 3600$

$= 20 \times 10^{-3}\,A \times 2.59 \times 10^{6}\,s$

$= 5.2 \times 10^{4}\,C$ way too big

OR

$t = \frac{Q}{I} = \frac{500\,C}{20 \times 10^{-3}\,A} = 25000\,s$

$= 6.9$ hrs

[3]

4 Fig. 4.1 shows a light sensing circuit using an LDR, a fixed resistor of resistance 220 Ω and a 6.0 V battery.

The battery in the potential divider circuit is of negligible internal resistance.

The p.d. across the resistor is measured by a digital voltmeter.

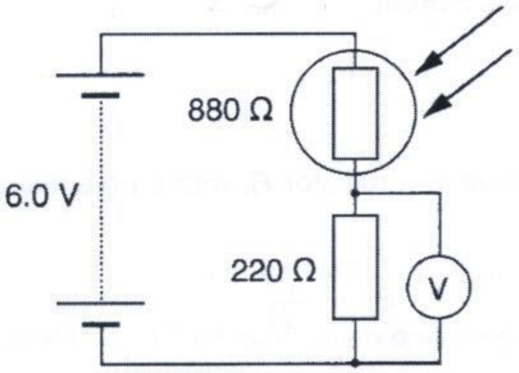


Fig. 4.1

In bright daylight, the resistance of the LDR is 880 Ω.

(a) Calculate the ratio = $\frac{\text{p.d across resistor}}{\text{p.d. across LDR}}$. $= \frac{220}{880} = \frac{1}{4}$

ratio = 1 : 4 [1]

(b) Calculate the voltmeter reading in bright daylight.

$6\text{V} \times \frac{220}{220+880} = 1.2\text{V}$

p.d. = 1.2 V [2]

1 Here is a list of four units for physical quantities.

C $\quad$ $C\,s^{-1}$ $\quad$ $J\,s^{-1}$ $\quad$ V

From the list

(a) write down the unit for electric potential difference ......V......

(b) write down a unit for electric current. ......Cs^{-1}...... [2]

6 The electrical power *P* dissipated in a resistor *R*, with a potential difference *V* across it, can be calculated using

$$P = \frac{V^2}{R}.$$

Here is a list of multiplying factors.

$\times 2$ $\quad$ $\times \frac{1}{2}$ $\quad$ $\times 4$ $\quad$ $\times \frac{1}{4}$ $\quad$ $\times 1$

Choose the factor that best completes each of the two statements given below.

(a) When resistance *R* is kept constant, and the p.d. *V* is halved,

the power *P* will be multiplied by ......$\times\frac{1}{4}$...... [1]

(b) When p.d. *V* is kept constant, and the resistance *R* is halved,

the power *P* will be multiplied by ......$\times 2$...... [1]

5 Here are two relationships for electrical components.

$P = I\,V$ $\quad$ $V = I\,R$

(a) **Show how** to combine these two relationships to produce an equation for the electrical power *P* in terms of the current *I* and resistance *R* only.

$P = IV$ and since $V = IR$, $P = IIR = I^2R$

[1]

(b) Complete the following statement.

When the current is doubled in a constant resistance, the power dissipated is increased

by a factor of ......4...... . [1]

8 This question is about the heated **front windscreen** of a car.
The heater consists of resistance wires which are embedded in the glass.

(a) The power of the heater needs to be 180W for satisfactory de-misting.

A car battery of negligible internal resistance supplies 12V to operate the heated screen.

(i) Calculate the current required to deliver a power of 180W.

P = IV ∴ I = P/V = 180W/12V

current = 15 A [2]

(ii) Show that the resistance of the heater when operating is about 1 Ω.

R = V/I = 12V/15A = 0·80Ω

[2]

(b) The heater consists of 200 wires inside the glass.
These wires are connected in parallel to the 12V supply as shown in Fig. 8.1.

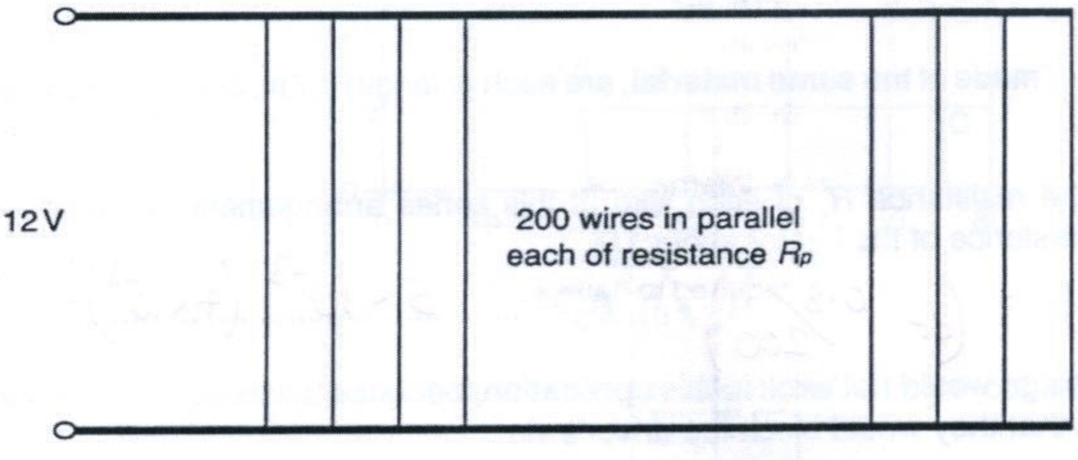


Fig. 8.1

Each of the 200 wires has a length of 0.70 m and resistance R_p of 160 Ω.

The material of the wire has resistivity $\rho = 6.0 \times 10^{-7}\,\Omega\,m$.

Calculate the **diameter** of the wire.

$R = \frac{\rho L}{A} = \frac{6\times10^{-7}\times0.7}{A} = 160\,\Omega$ ✓

$\therefore A = \frac{6\times10^{-7}\times0.7}{160} = 2.625\times10^{-9}\,m^2$ ✓

$A = \pi r^2 \quad \therefore d = 2\sqrt{\frac{A}{\pi}} = 2\times\sqrt{\frac{2.625\times10^{-9}}{\pi}} =$ ✓✓

diameter = 5.78×10^{-5} m [4]

(c) An alternative design has a heater of the **same power** rating. The wires are connected in **series** as shown in Fig. 8.2.

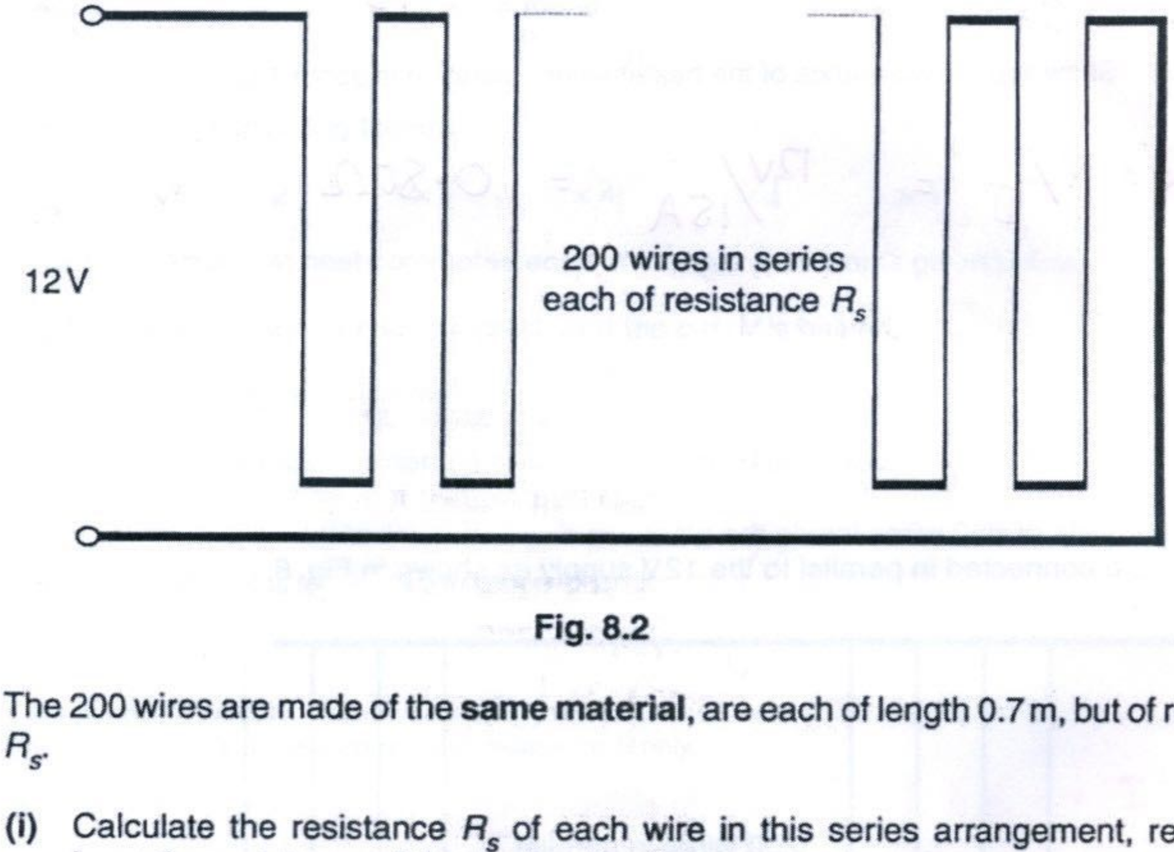


Fig. 8.2

The 200 wires are made of the **same material,** are each of length 0.7 m, but of resistance R_s.

(i) Calculate the resistance R_s of each wire in this series arrangement, required to keep the resistance of the heater about 1 Ω.

$R = 1/200 =$ (or $0.8/200$) R_s = 5×10^{-3} (4×10^{-3}) Ω [1] ✓

(ii) This series design would not work in this application, because the wires would have to be so thick that they would block the driver's vision.

Justify this statement.

Since $R = \frac{\rho L}{A}$ & ρ & L are fixed & R must be very small A must be v large.

[4]

$A = \rho L/R = 6\times10^{-7}\times0.7/0.004 = 1.05\times10^{-4}\,m^2$ ✓

$\therefore d = 1.2\,cm$

June 2002

10 A solar cell generates electrical power in constant bright sunlight.
A circuit is required to measure the p.d. and current delivered into a variable load resistor.

(a) Complete the circuit in Fig. 10.1 showing the connection of a variable load resistor and a voltmeter to measure the output p.d. across the load.

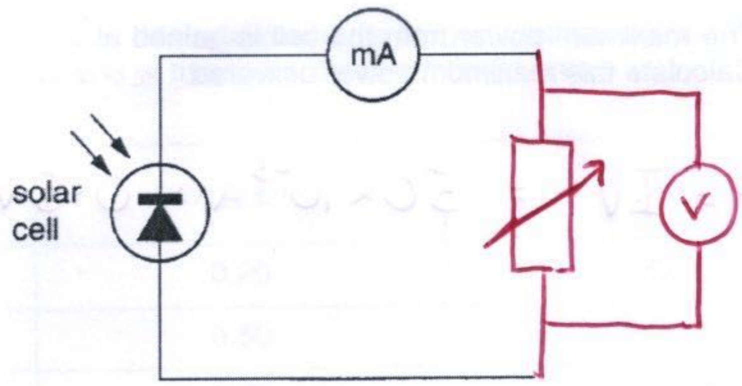


Fig. 10.1

[3]

The solar cell is placed in constant bright sunlight.
The graph in Fig. 10.2 shows this variation of p.d.

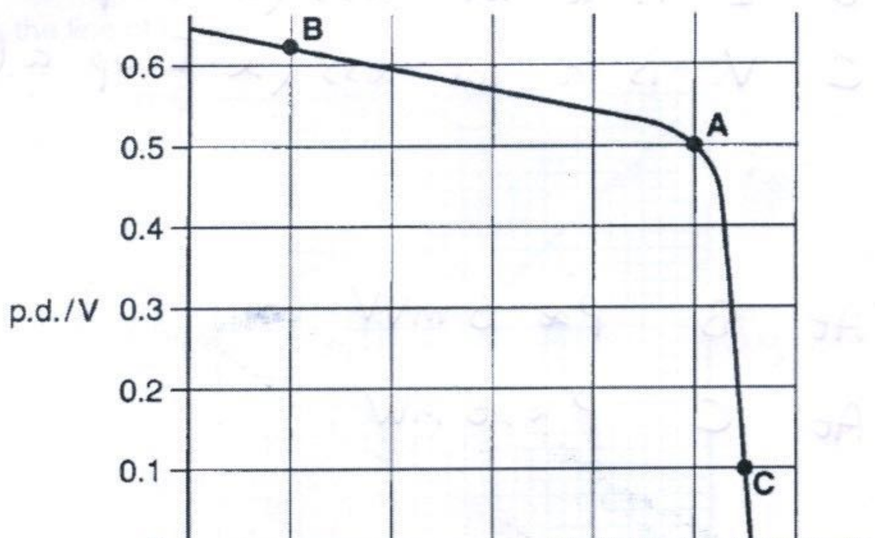


Fig. 10.2

(b) (i) Using the graph Fig. 10.2 describe how the p.d. of the solar cell varies, as more current is drawn from it.

p.d. drops as current increases. Rate of drop increases at current of 50mA

[2]

(ii) Suggest a reason for the variation you have described in **(b)(i)**.

Internal resistance of solar cell

[1]

(c) (i) The maximum power from the cell is gained at the point **A** indicated in Fig. 10.2. Calculate this maximum power delivered.

$P = IV = 50 \times 10^{-3} A \times 0.5 V =$

maximum power delivered = 0.025 W [3]

(ii) At both points **B** and **C** in Fig. 10.2, how do the values on the graph suggest that the power delivered is lower than at **A**?

At B I is a lot less (& V up a little)

At C V is a lot less (& I up a little)

[2]

OR

At B $P \approx 6$ mW

At C $P \approx 6$ mW

9 The conductance G of a wire is related to its length L and cross-sectional area A by the relationship

$$G = \frac{\sigma A}{L}$$

where σ is the electrical conductivity of the material.

(a) In an experiment to investigate this relationship, a student gathers the following data for wires of the same material and of the same cross-sectional area.

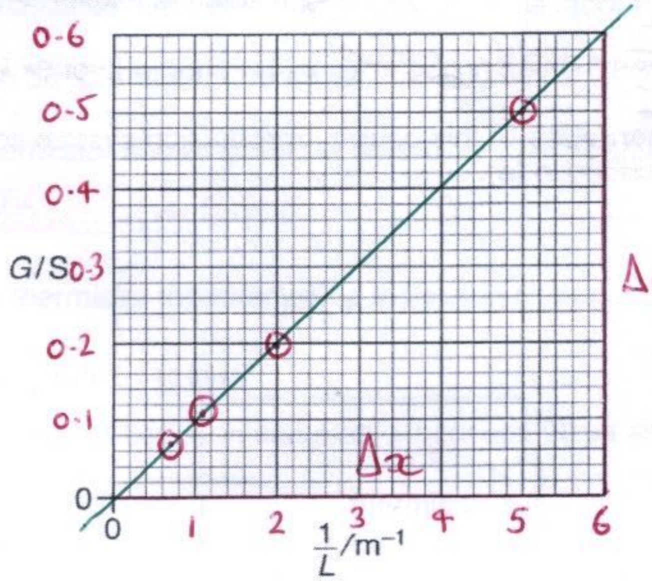
conductance G / S	length L / m	$\frac{1}{L}$ / m^{-1}
0.50	0.20	5.00
0.20	0.50	2.0
0.11	0.90	1.11
0.07	1.50	0.667

not $0.66\dot{6}$

(i) Complete the third column. [2]

(ii) Plot the data on a suitably scaled graph of G against $\frac{1}{L}$ below.

Draw the line of best fit.



[3]

(iii) Explain how your graph shows that G is **inversely proportional** to L.

Graph of G vs $\frac{1}{L}$ is a straight line ✓

through 0,0 (origin) ✓

[2]

(b) (i) Calculate the gradient of the graph, making your method clear.

$$\text{gradient} = \frac{\Delta y}{\Delta x} = \frac{\Delta G}{\Delta 1/L} = \frac{0.6}{6} = \underline{0.10\ \text{S m}}$$

↑ see red triangle on graph.

gradient = ...0·10...... S m [2]

(ii) Show that the conductivity of the material is about $4 \times 10^4\ \text{S m}^{-1}$.
Use your data from **(b)(i)**.

Take the cross-sectional area A as $2.3 \times 10^{-6}\ \text{m}^2$.

$$G = \frac{\sigma A}{L} \quad \therefore \quad \sigma = \frac{GL}{A} = \frac{0.10}{2.3 \times 10^{-6}} = 4.3 \times 10^4\ \text{S m}^{-1}$$

$$\text{gradient} = \frac{\Delta G}{\Delta \frac{1}{L}} = GL$$

[2]

[Total: 11]

8 Fig. 8.1 shows how the resistance of a thermistor varies with temperature.

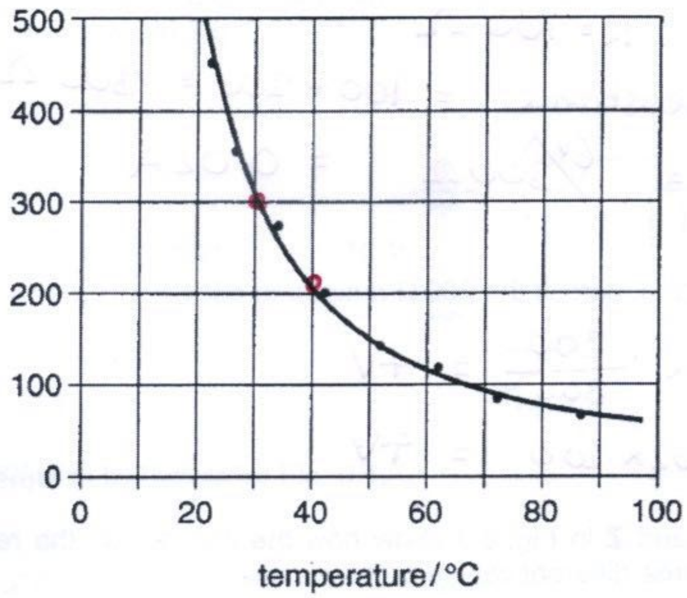


Fig. 8.1

(a) Complete the following description of the graph.

As the temperature of the thermistor rises, its resistance ....decreases

The change in resistance between 80 °C and 90 °C is about 15 Ω, the change in resistance between 30 °C and 40 °C is about .100 Ω. (± 10)

On Fig. 8.1, the thermistor shows **greatest** sensitivity to temperature change when the temperature is ....low....(~ 22°C) [3]

(b) Fig. 8.2 shows this thermistor together with a resistor in a temperature sensing potential divider circuit.

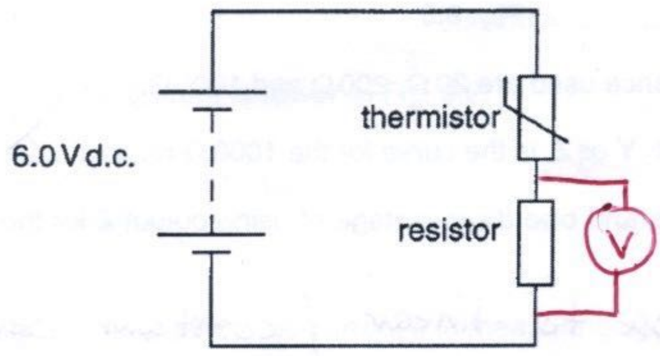


Fig. 8.2

(i) A voltmeter is to be connected to the circuit to indicate an **increasing** p.d. when the sensor detects an increasing temperature.

On Fig. 8.2, draw the circuit connections for a voltmeter to measure a p.d. that **rises** with increasing temperature. [1]

(ii) The value of the resistor in Fig. 8.2 is 200 Ω. The thermistor is at 65 °C.

Show that the current drawn from the 6.0 V supply is about 0.02 A.
Use data from Fig. 8.1.

At 65°C R = 100 Ω

∴ total resistance = 100 + 200 = 300 Ω

$I = V/R = 6V/300\Omega = 0.02A$

[3]

(iii) Calculate the p.d. across the 200 Ω resistor at 65 °C.

$V = 6V \times \frac{200}{300} = 4V$

OR $V = IR = 0.02 \times 200 = 4V$

p.d. across resistor = ...4.... V [1]

(c) The graphs **X, Y** and **Z** in Fig. 8.3 show how the p.d. across the resistor varies with temperature, for three different values of the resistor.

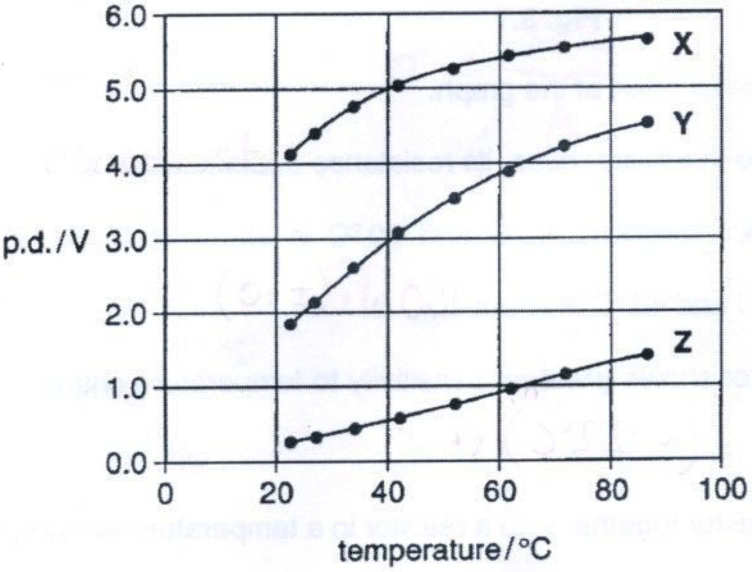


Fig. 8.3

(i) The values of resistance used are 20 Ω, 200 Ω and 1000 Ω.

State which graph, **X, Y** or **Z**, is the curve for the 1000 Ω resistor. ....X.... [1]

(ii) State **one** advantage and **one** disadvantage of using output **Z** for the temperature sensing circuit.

advantage close to linear / constant sensitivity

disadvantage low sensitivity

[2]

[Total: 11]

9 This question is about the resistances of ammeters and voltmeters.

(a) (i) A battery of emf 12.0 V and negligible internal resistance is connected to a resistor of resistance 2.5 Ω, as shown in Fig. 9.1.

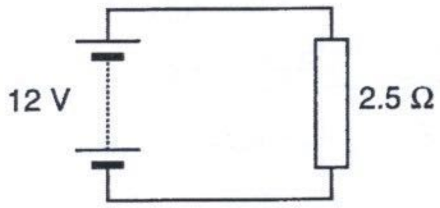


Fig. 9.1

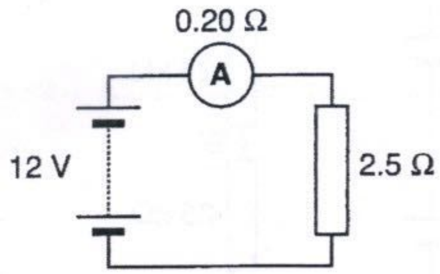


Fig. 9.2

Calculate the current in the circuit of Fig. 9.1.

$I = V/R = 12V/2.5\Omega =$

current = ...4.8...... A [1]

(ii) An ammeter of resistance 0.20 Ω is connected in series in the circuit as shown in Fig. 9.2 to measure this current.

1 Calculate the current in the circuit of Fig. 9.2 after the ammeter is added.

$I = V/R = 12V/(2.5+0.2)$

current = ...4.4...... A [2]

2 Explain why the current is **lower** in Fig. 9.2.

total resistance in circuit is higher

[1]

(iii) A good quality ammeter alters the current it is measuring by as little as possible.

Suggest the best value of the resistance of an ammeter to make it perfect.

Zero Ω

[1]

(b) A battery of emf 12.0V and negligible internal resistance is connected across two resistors in series as shown in Fig. 9.3.

Each resistor has a resistance of 25 kΩ.

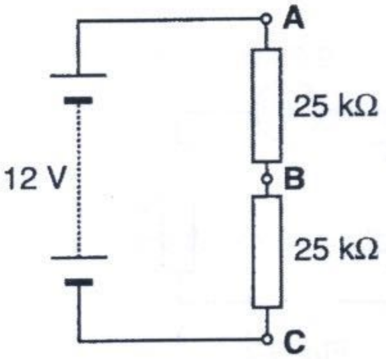


Fig. 9.3

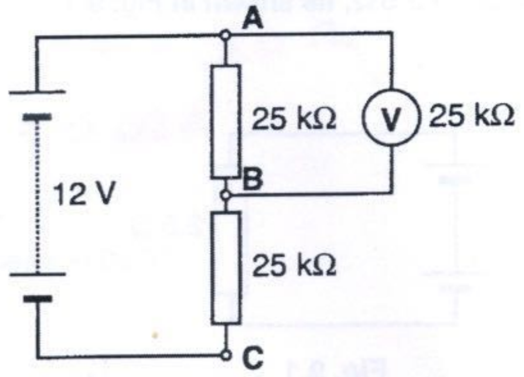


Fig. 9.4

(i) Explain why the potential difference V_{AB} between points **A** and **B** in Fig. 9.3 is 6.0V.

Resistors are same so p.d. is shared equally

[1]

(ii) A voltmeter of resistance 25 kΩ is now connected across **AB** as shown in Fig. 9.4, to measure V_{AB}.

1 Explain why two identical resistors connected in parallel have a combined resistance of **half** the value of one resistor on its own.

With 2 identical resistors in parallel the conductance will (double as double cross sectional area) so resistance must halve.

[1]

2 Calculate V_{AB} in the circuit of Fig. 9.4.

$$V = 12V \times \frac{12.5\,k\Omega}{25 + 12.5\,k\Omega} =$$

V_{AB} = ...4.0........ V [2]

3 Explain why V_{AB} is **lower** in the circuit in Fig. 9.4.

The voltmeter reduces the resistance of its half of the potential divider.

[1]

(iii) A good quality voltmeter alters the p.d. it is measuring by as little as possible.

Suggest the best value for the resistance of a voltmeter that makes it perfect.

As large as possible, ∞ Ω

[1]

7 An ion beam delivers a charge of 60 nC during a time of 30 s.

(a) Calculate the current carried by the beam.

$I = \frac{\Delta Q}{\Delta t} = \frac{60\,nC}{30\,s} = 2\,nA$

current = ...2.......... nA [1]

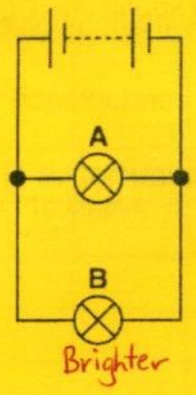
(b) Calculate the number of ions passing per second.

charge on each ion = 1.6×10^{-19} C

$2 \times 10^{-9}\,C / 1.6 \times 10^{-19}\,C/ion =$

number of ions per second = ...1.25×10^{10}.......... [2]

5 **(a)** To demonstrate some ideas in electricity, a teacher connects two different lamps **A** and **B** in parallel with a car battery as shown in Fig. 5.1.



$P = IV$

Fig. 5.1

Lamp **B** glows brighter than lamp **A**.

Complete the following sentences by adding one phrase from the list below.

greater than **equal to** **less than**

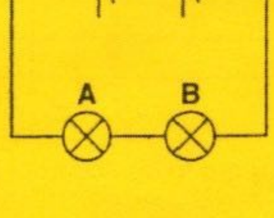
The current in lamp **B** is ....greater than.......... that in lamp **A**.

The p.d. across lamp **B** is ....equal to.......... that across lamp **A**. [2]

(b) The teacher then connects the lamps **A** and **B** in series with the car battery as shown in Fig. 5.2.

B has higher I ∴ lower R so in circuit 2 V is lower & P is lower

B is now dimmer.



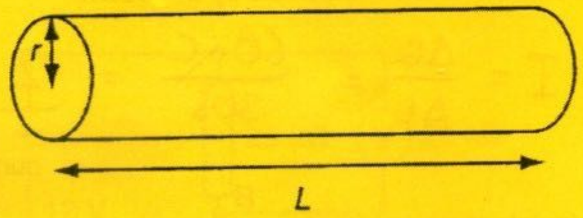
Which bulb is brighter? (1)

Explain. (2)

Fig. 5.2

3 This question is about the conductance G of a cylindrical wire given by the following equation.

$$G = \frac{\sigma A}{L} = \frac{\sigma \pi r^2}{L}$$



(a) State what the term πr^2 in the equation represents.

cross sectional area

[1]

(b) Here is a list of multiplying factors.

$\times 4$ $\qquad$ $\times 2$ $\qquad$ $\times 1$ $\qquad$ $\times \frac{1}{2}$ $\qquad$ $\times \frac{1}{4}$

Select the factor that best describes the variations given below.

If the length L of the wire is doubled, the conductance G will be ....1/2....

If the radius r of the wire is halved, the conductance G will be ....1/4....

[2]

1 Here is a list of electrical units.

$A\,s$ $\qquad$ $C\,s^{-1}$ $\qquad$ $J\,s^{-1}$ $\qquad$ $J\,C^{-1}$ $\qquad$ $V\,A^{-1}$

Choose the correct unit for

(a) electric current ....$C\,s^{-1}$....

(b) resistance ....$V\,A^{-1}$....

(c) potential difference. ....$J\,C^{-1}$....

[3]