Answer **all** the questions.

SECTION A

1 Here is a list of electrical SI units.

A **C** **S** **V** **W** **Ω**

Choose from the list the correct SI unit for each of the following combinations of physical quantities.

$\frac{\text{energy}}{\text{time}}$ ......W...... $P = E/t$

$\frac{\text{current}}{\text{voltage}}$ ......S...... $G = I/V$

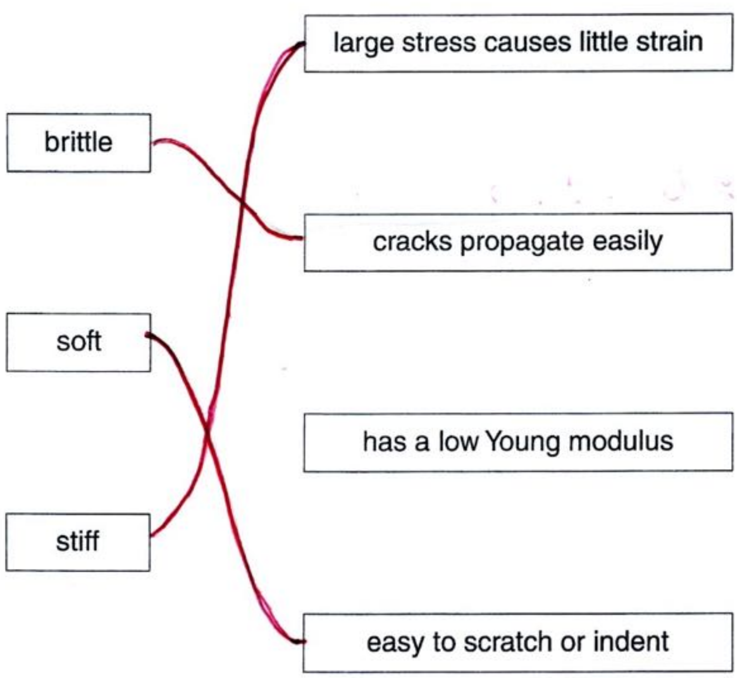
$\frac{\text{charge}}{\text{time}}$ ......A...... $I = Q/t$

[3]

2 Here is a list of mechanical properties and possible descriptions of them.

Draw a straight line from each property to the correct description.

property **description**



[2]

3 Fig. 3.1 shows the frequency spectrum of four radio signals labelled **A**, **B**, **C** and **D**.

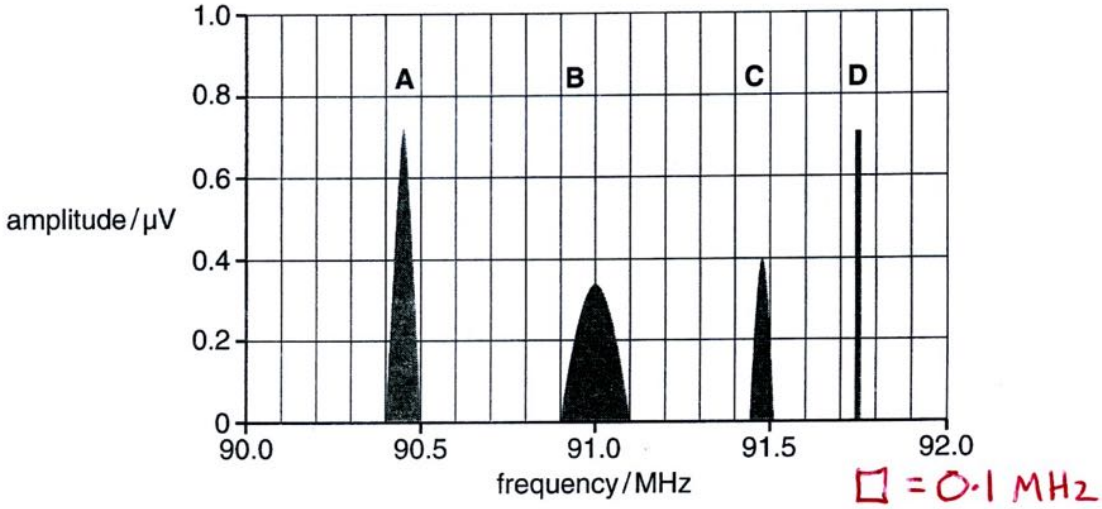


Fig. 3.1

(a) State which signal has:

the smallest wavelength ....D.......... highest f $c = f\lambda$

the smallest bandwidth. ....D..........

[2]

(b) Estimate the bandwidth in Hz of signal **B**.

bandwidth = ...0.2×10^6.... Hz **[1]**

or 2×10^5

$91.1 - 89.9 = 0.2$ MHz

4 The world's smallest conducting 'wire' has been made by depositing a single layer of phosphorus atoms on an insulating silicon surface. The conductor is 4 atoms wide and 20 atoms long as shown in Fig. 4.1.

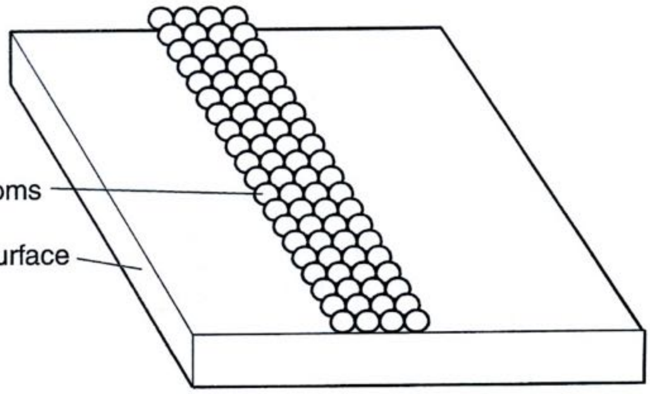


Fig. 4.1

(a) Calculate the width of the conductor in metres.   nano = 10^{-9}

diameter of phosphorus atom = 0.38 nm

$4 \times 0.38 \times 10^{-9} =$

width = 1.52×10^{-9} m **[1]**

(b) Assume that the conductor is a rectangular block.

Show that the conductance of this length of conductor is about 25 μS.

conductivity of phosphorus on this scale = $3.3 \times 10^5\,\text{S m}^{-1}$.

$$G = \frac{\sigma A}{L} = \frac{3.3 \times 10^5 \times 1.52 \times 10^{-9} \times 0.38 \times 10^{-9}}{20 \times 0.38 \times 10^{-9}}$$

$$= 25.1 \times 10^{-6}\ \text{S} \quad \text{or} \quad 25.1\ \mu\text{S}$$

[2]

5 **(a)** The focal length *f* of a converging lens can be estimated simply by measuring the distance *v* from the lens to the image that it forms of a distant window.

Use the lens equation

$$1/f = 1/v - 1/u$$

to explain why the approximation $f \approx v$ is appropriate in this case.

If object distance u is very large then $1/u \approx 0$

$\therefore 1/f \approx 1/v$ and $f \approx v$

[1]

(b) A digital camera is used to take a picture of an object 15 m away.
The image is formed on its CCD 3.5 mm from the lens.

(i) Estimate the power of the lens.

$P = \frac{1}{f} \approx \frac{1}{v} = 1/3.5\times10^{-3}$

power = 286 D **[1]**

(ii) The CCD of the camera is 2.0 mm wide as shown in Fig. 5.1.

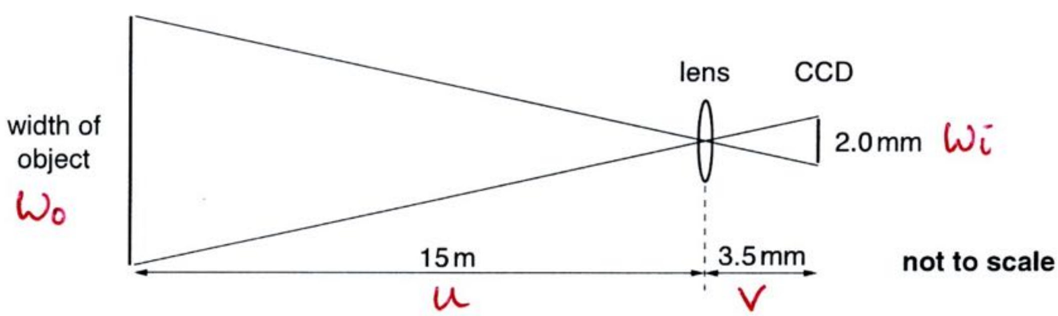


Fig. 5.1

The image just fills the width of the CCD. Calculate the width of the object.

Make your method clear.

By similar triangles $\frac{15}{3.5\times10^{-3}} = \frac{\text{object width}}{2.0\times10^{-3}}$ $\therefore w_o = 15\times\frac{2}{3.5} =$

OR

magnification $= \frac{v}{u} = \frac{W_i}{W_o}$

width = 8.57 m **[2]**

$\therefore W_o = W_i \times \frac{u}{v} = 2\times10^{-3} \times \frac{15}{3.5\times10^{-3}} =$

6 Three temperature sensors **A**, **B** and **C** are plunged together into a hot water bath at time $t = 0$. Fig. 6.1 shows their responses over the first 15 seconds.

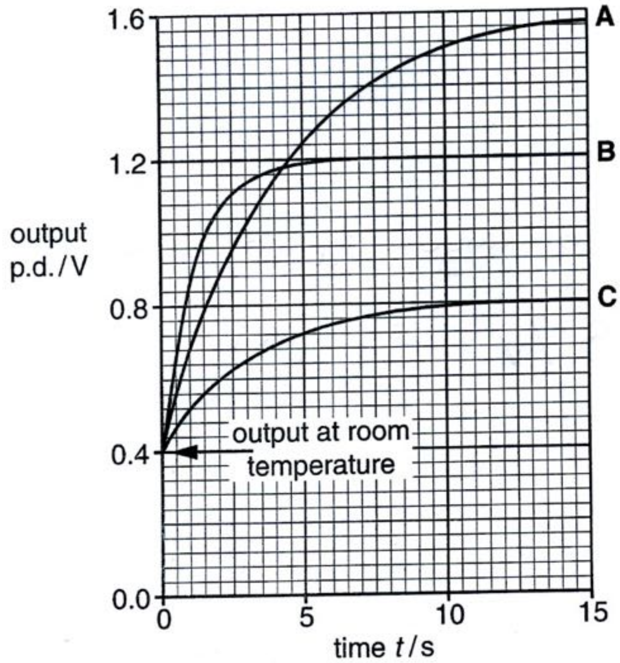


Fig. 6.1

(a) Sensor **A** has a longer response time than **B** or **C**.

Suggest **one** physical reason why.

Greater heat capacity
Lower thermal conductivity
Smaller surface area .... **[1]**

(b) State which sensor has the **largest** sensitivity. ....A......... **[1]**

(c) The water bath is 70 °C above room temperature.

Calculate the average sensitivity of sensor **B** in this temperature range.

1.2 − 0.4/70

sensitivity = ...0.0114......... V °C^{-1} **[2]**

7 A film soundtrack contains some random electrical noise. The soundtrack is to be sampled and digitised. The total variation of the analogue signal is 1000 times larger than the variation of the noise alone.

$$\frac{V_{total}}{V_{noise}} = 1000$$

(a) Calculate the largest number of bits it is worth using per sample.

$\log_2 1000 = 9.97$

number of bits = ...10...... **[2]**

(b) Explain why it is pointless to use more than this number of bits to digitise each sample.

With b > 10 there are more than 1000 levels so the size of each level ΔV is less than the noise. Some of the bits only store noise and no information **[2]**

8 A resistor of resistance *R* has a potential difference *V* across it.
The power dissipated in the resistor is *P*.

Here is a list of multiplying factors:

$P = I^2R = IV = V^2/R$

4 **2** **1** **½** **¼**

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 doubled,

the power *P* will be multiplied by ......4...... . **[1]**

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

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

SECTION B

9 Fig. 9.1 shows the stress versus strain graphs for glass and for epoxy resin up to their **breaking points**.

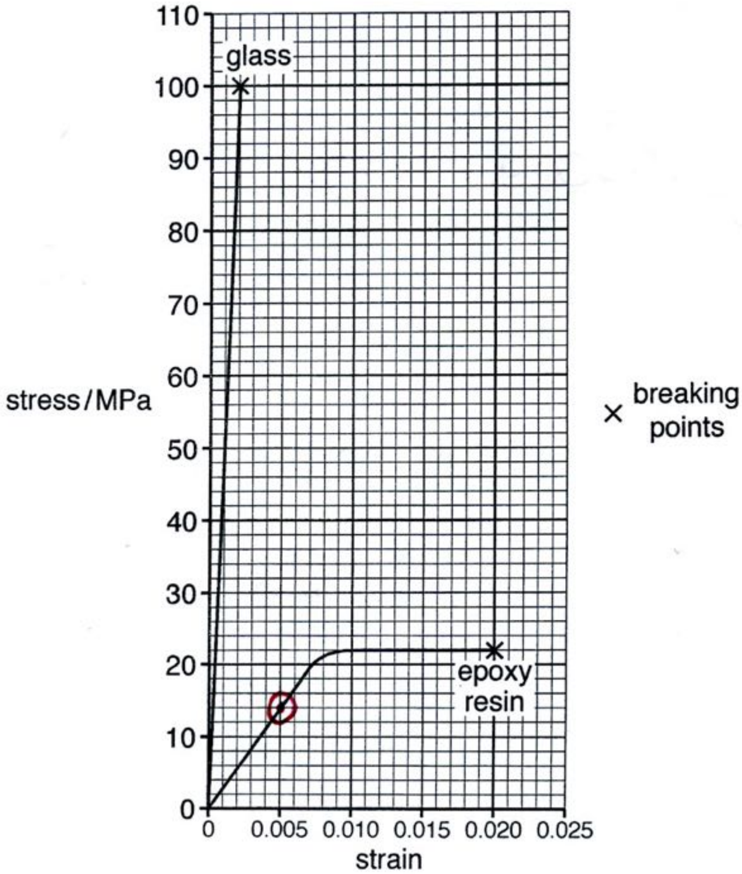


Fig. 9.1

(a) Describe the features of the graph that indicate:

(i) epoxy resin is a plastic material

Large increase in strain at 22 MPa as the material yields **[1]**

(ii) glass is an **elastic** material and is **stiffer** than epoxy resin.

Graph is straight line through the origin so stress is proportional to strain. The gradient at the start is higher for glass than epoxy resin. **[2]**

(b) Use data from Fig. 9.1 to calculate by what factor glass is stronger than epoxy resin.

$= \frac{\text{Breaking stress glass}}{\text{Breaking stress epoxy}} = \frac{100\text{ MPa}}{22\text{ MPa}}$

factor = 4.55 **[1]**

(c) (i) Calculate the Young modulus for the epoxy resin within its elastic region.

$E = \frac{\text{stress}}{\text{strain}} = \frac{14 \times 10^6}{0.005} = 2.8 \times 10^9$ Pa

Young modulus of epoxy resin = 2.8×10^9 Pa **[2]**

(ii) The molecules of epoxy resin are long chain molecules, with cross-links between the chains, as illustrated in Fig. 9.2.

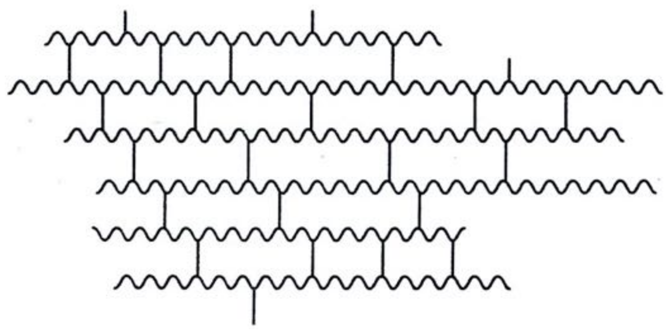


Fig. 9.2

Suggest how material consisting of long chain molecules can show plastic behaviour and how cross-linking between the chains can restrict this behaviour.

Your answer should be well structured and use appropriate technical terms.

Long chain molecules can uncoil & extend due to bond rotation. Cross links bond the chains together preventing them from fully uncoiling so limiting how far they can extend.

[3]

(d) One type of GRP (glass reinforced plastic) composite contains epoxy resin which sticks strongly to a mat of randomly-oriented glass fibres embedded in it.
A canoe can be made from this GRP composite.

(i) Name a material property and a problem that might arise from that material property, for a canoe made:

1 only of glass

Glass is not tough - it is brittle so would shatter if it hit a rock.

2 only of epoxy resin.

Epoxy is flexible so would bend too much

[2]

(ii) Composite materials combine useful properties of their component materials.

Explain how embedding the glass fibres in epoxy resin combines useful properties of the two materials.

The stiff glass fibres stop the epoxy flexing and the tough epoxy stops the glass from cracking. This works because they are bonded together.

[2]

(iii) Explain the advantage of having the glass fibres randomly oriented in the composite material.

The composite has high strength and stiffness in all directions.

[1]

10 (a) Fig. 10.1 shows how the total number of people in the world with internet access has increased.

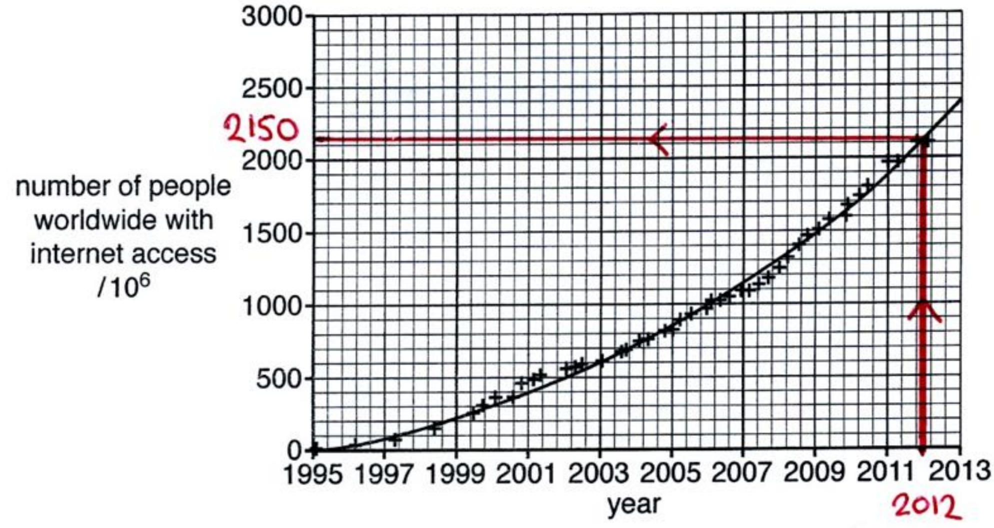


Fig. 10.1

(i) The world population was about 7×10^9 in 2012.

Estimate the percentage of this population that could access the internet in 2012.

Make your method clear. From graph Number with internet access = 2150×10^6

$\therefore \% = \frac{2150 \times 10^6}{7 \times 10^9} \times 100 =$

percentage = ...31...... % **[2]**

(ii) The average power used by a typical tablet computer is about 5W.
Assume that 1% of people with access to the internet were online at any one time in 2012 using typical tablet computers.

Estimate the combined power consumption of all these computers.

$\frac{1}{100} \times 2150 \times 10^6 \times 5 =$

power = ...1.075×10^8...... W **[2]**

(b) In a computer, energy is required to perform a computation. Fig. 10.2 shows how the average number of computations per joule of energy has improved with computer design.

$< 2 \times 10^8$

$\approx 1.8 \times 10^8$

allow $(1.6 \rightarrow 2.0 \times 10^8)$

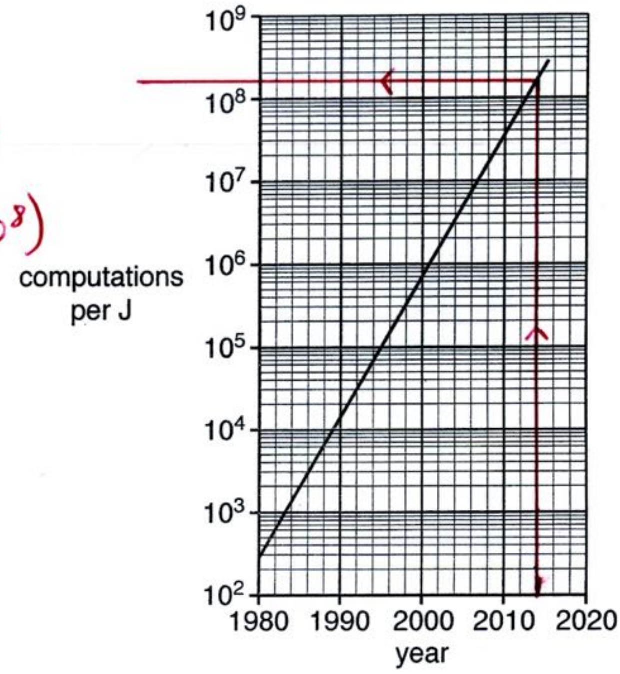


Fig. 10.2

(i) Describe how the number of computations per joule has varied from 1980 onwards.

It increases by a factor of 10 in equal time intervals = exponential growth. **[1]**

(ii) Use data from Fig. 10.2 to calculate the number of computations per second for a typical tablet computer in **2014**. Assume its power consumption is 5W.

$5W = 5J/s$ so $5 \times 1.8 \times 10^8 =$

number of computations per second = 9×10^8 **[3]**

$8 \times 10^8 \rightarrow 1 \times 10^9$ allowed

(c) The internet depends on connections via many giant data centres ('server farms') run by internet service providers. In 2012 there were more than 1000 such centres worldwide. Some statistics for one such data centre are shown in Fig. 10.3.

total power consumed (including 30% for cooling)	180 MW
average cost of electrical energy	12 pence kWh^{-1}
cost to build and maintain per year	£75 000 000
average number of users with access to the centre	2×10^6

Fig. 10.3

It has been stated that: "*Access to the vast resources of the internet is essentially free.*"

Perform calculations or estimates based on the data in Fig. 10.3 and use other facts you may know to argue for or against the statement. You should estimate any costs on a yearly basis.

In your answer you should present and organise your ideas and calculations clearly and coherently.

$1\,kWh = 1000 \times 3600 = 3.6 \times 10^6\,J$

1 year is 8800 hours

Cost for one data centre for 1 year = Build + Energy

Build $= £7.5 \times 10^7$

Energy $= 180 \times 10^6 \times 8800 \times 3600 = 5.7 \times 10^{15}\,J$

$= 5.7 \times 10^{15} / 3.6 \times 10^6 = 1.58 \times 10^9\,kWh$

Energy Cost $= 1.58 \times 10^9 \times 0.12 = £1.9 \times 10^8$

Total Cost per user $= \dfrac{7.5 \times 10^7 + 1.9 \times 10^8}{2 \times 10^6}$

[4]

$= £133$ per user per year.

So it is not essentially free.

11 Fig. 11.1 shows a resistor **R** of resistance 4.7 Ω connected in series with a battery having internal resistance **r** of 0.90 Ω. The current drawn from the battery is 0.55 A and the p.d. across the 4.7 Ω resistor is 2.6 V.

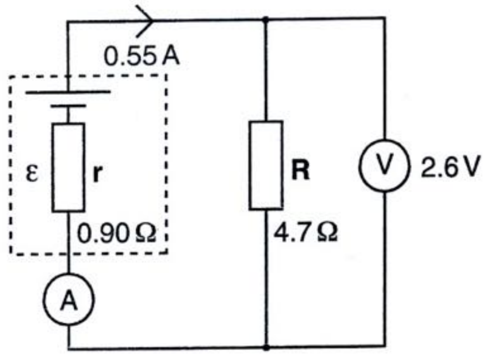


Fig. 11.1

(a) Show that the emf ε of the battery is about 3 V.
Assume the meters are ideal.
Make your method clear.

$V = \varepsilon - Ir \quad \therefore \quad \varepsilon = V + Ir$

$\varepsilon = 2.6 + (0.55 \times 0.9) =$

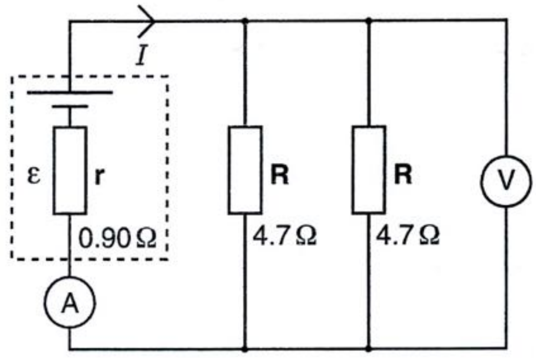
ε = ...3.1........ V **[2]**

(b) The current drawn from the battery is now increased by adding an identical 4.7 Ω resistor **R** in parallel with the original resistor **R**. See Fig. 11.2.

$R_{EXT} = 4.7/2$

OR

$\frac{1}{R_{EXT}} = \frac{1}{4.7} + \frac{1}{4.7}$



$R_{EXT} = 2.35\ \Omega$

& $R_{TOTAL} = 2.35 + 0.9$
$= 3.25\ \Omega$

Fig. 11.2

(i) Show that the current *I* now drawn from the battery is about 1 A.

$I = V/R = \varepsilon / R_{TOTAL} = 3.1/3.25 = 0.95\ A$

[3]

(ii) Calculate the p.d. V across the resistors.

$V = \mathcal{E} - Ir = 3.1 - (0.95 \times 0.9) =$

or $V = IR_{TOTAL} = 0.95 \times 2.35 =$

$V =$ ....2.2.......... V **[2]**

(iii) Show that the power dissipated in the two resistors of Fig. 11.2 is about 1.5 times the power dissipated in the single resistor of Fig. 11.1.

In single resistor $P = IV = 0.55 \times 2.6$
$= 1.4\ W$

In double $P = IV = 0.95 \times 2.2 = 2.1\ W$

$2.1/1.4 = 1.5$

[2]

END OF QUESTION PAPER

OR use $P = I^2R = V^2/R$