1 **(a)** Define *resistance*.

.....

..... **[1]**

(b) The smallest conductor within a computer processing chip can be represented as a rectangular block that is one atom high, four atoms wide and twenty atoms long. One such block is shown in Fig. 3.1.

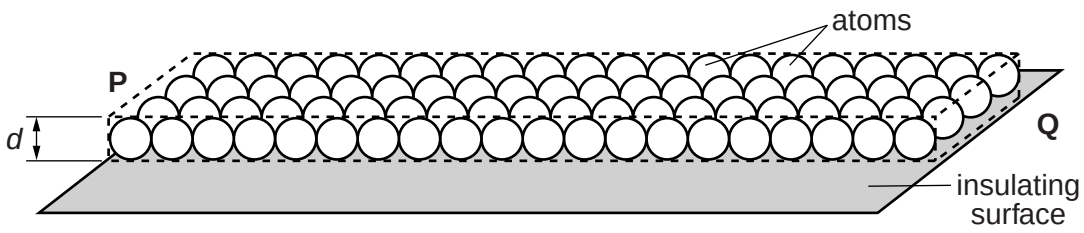

Fig. 3.1

The block is made from phosphorus atoms of diameter $d = 3.8 \times 10^{-10}$ m. The atoms are deposited on an insulating surface. This ensures that the atoms touch each other.

(i) Show that the resistance between the ends **P** and **Q** of this block is greater than 200 Ω. The resistivity of phosphorus is 1.7×10^{-8} Ω m.

[3]

(ii) Show that the number density of free electrons within the block is about 2×10^{28} m^{-3}. Assume that each phosphorus atom contributes one free electron.

[1]

(iii) Calculate the current between **P** and **Q** when the mean drift velocity of free electrons in the block is $1.9 \times 10^{-5}\,\text{m}\,\text{s}^{-1}$.

current = ... A **[2]**

(iv) There are about 10^9 of these tiny conductors in a single chip each carrying the current calculated in **(iii)**. Estimate the total power dissipated in these conductors in a single chip.

power = ... W **[3]**

(c) It takes about $4 \times 10^{-4}\,\text{s}$ for an electron to pass from **P** to **Q** but the electrical signal, an electromagnetic wave, is transmitted across the block in about $3 \times 10^{-17}\,\text{s}$. Explain why these times are so different.

.....

.....

.....

..... **[2]**

[Total: 12]

2 **(a)** State the difference between the directions of conventional current and electron flow.

.....

..... **[1]**

(b) Circle one or more of the combinations of units which could act as a unit for current.

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

[2]

(c) Fig. 1.1 shows a current I in a thick metal wire **X** connected to a longer thinner wire **Y** of the same metal as shown in Fig. 1.1.

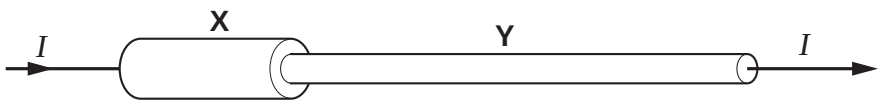

Fig. 1.1

(i) State why the current in **Y** must also be I.

.....

..... **[1]**

(ii) Wire **Y** has half the cross-sectional area of the thicker wire **X** and is three times as long.

The resistance R_X of **X** is $12.0\,\Omega$.

1 Show that the resistance R_Y of **Y** is $72\,\Omega$.

2 Calculate the total resistance R of both wires.

R = ... Ω **[4]**

(iii) The mean drift velocity v_X of electrons in **X** is $2.0 \times 10^{-5}\,m\,s^{-1}$.

Use the fact that **X** has twice the cross-sectional area of the thinner wire **Y** to calculate the mean drift velocity v_Y of electrons in **Y**. Show your working.

v_Y = ... $m\,s^{-1}$ **[2]**

[Total: 10]

3 **(a)** A battery of e.m.f. E and internal resistance r delivers a current I to a circuit of resistance R.

Write down an equation for E in terms of r, I and R.

..... **[1]**

(b) A 'flat' car battery of internal resistance 0.06 Ω is to be charged using a battery charger having an e.m.f. of 14 V and internal resistance of 0.74 Ω, as shown in Fig. 2.1.

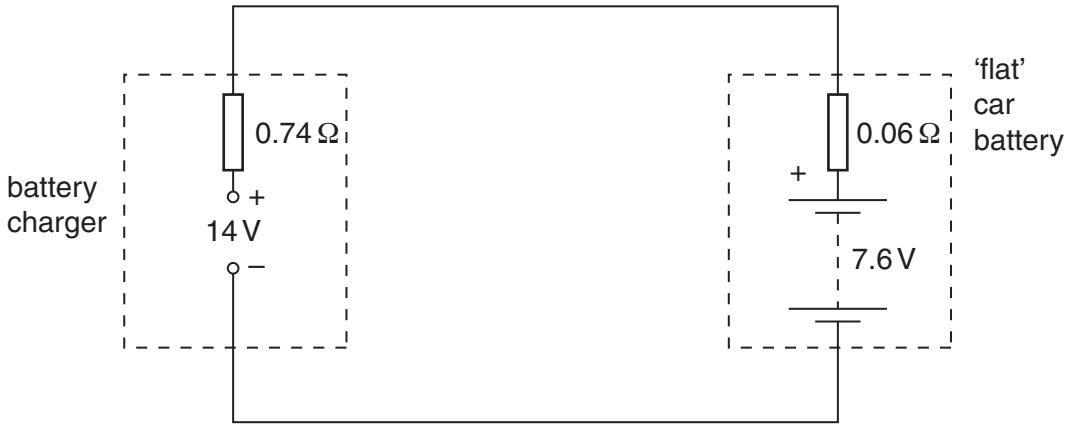

Fig. 2.1

You can see that the battery to be charged has its positive terminal connected to the positive terminal of the battery charger.

At the beginning of the charging process, the e.m.f. of the 'flat' car battery is 7.6 V.

(i) For the circuit of Fig. 2.1, determine

1 the total resistance

resistance = ... Ω **[1]**

2 the sum of the e.m.f.s in the circuit.

e.m.f. = ... V **[1]**

(ii) State Kirchhoff's second law.

.....

..... **[1]**

(iii) Apply the law to this circuit to calculate the initial charging current.

current = ... A **[2]**

(c) For the majority of the charging time of the car battery in the circuit of Fig. 2.1, the e.m.f. of the car battery is 12 V and the charging current is 2.5 A. The battery is charged at this current for 6.0 hours. Calculate, for this charging time,

(i) the charge that passes through the battery

charge = ... C **[2]**

(ii) the energy supplied by the battery charger of e.m.f. 14 V

energy = ... J **[2]**

(iii) the percentage of the energy supplied by the charger which is dissipated in the internal resistances of the battery charger and the car battery.

percentage of energy = ... % **[2]**

[Total: 12]

4 **(a)** A 12V car battery contains an electrolyte. The battery is connected to an electric motor **M**. There is a current in the motor and the battery. See Fig. 2.1.

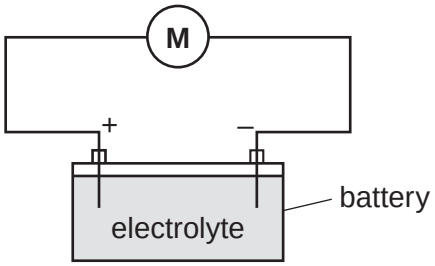

Fig. 2.1

State

(i) the charge carriers in the electrolyte

..... **[1]**

(ii) the charge carriers moving through the electrolyte to the positive terminal of the battery

..... **[1]**

(iii) the charge carriers moving through the wires to the positive terminal of the battery.

..... **[1]**

(b) When used to start the engine of the car, the electric motor draws 40A from the battery of e.m.f. 12V. The potential difference across the motor at this time is only 8.0V.

(i) Explain why the potential difference across the motor at this time is not the same as the e.m.f. of the car battery.

.....

.....

.....

..... **[2]**

(ii) Show that the internal resistance of the battery is 0.10Ω.

[3]

(iii) It takes 1.2 s for the electric motor to start the engine. Calculate the charge Q which passes through the electric motor in this time.

Q = ... C **[2]**

(c) The car has two 12 V headlamps each rated at 54 W, connected in parallel to the battery. In normal working conditions the current in each lamp is 4.5 A.

(i) Explain how and why the resistance of the headlamp filament varies with the current passing through it.

.....

.....

.....

.....

..... **[2]**

(ii) Suggest a value for the current rating of a fuse for the headlamp circuit. Justify your choice.

.....

.....

..... **[2]**

(iii) A car contains a number of different fuses for its various electrical circuits. Suggest why this is necessary.

.....

.....

..... **[1]**

[Total: 15]