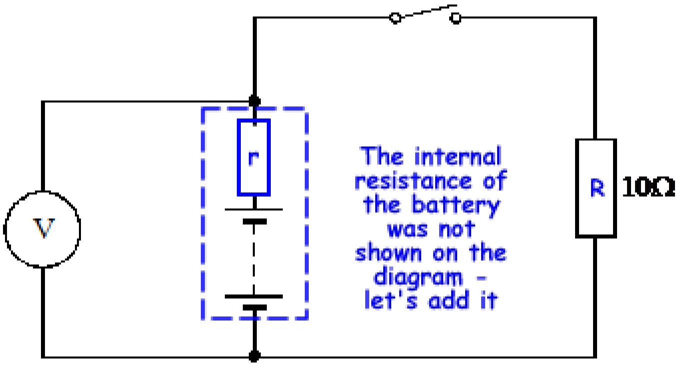
Q1. A battery is connected to a 10Ω resistor as shown. The e.m.f. (electromotive force) of the battery is 12V.



(a) (i) Explain what is meant by the e.m.f. of a battery.

Use your data sheet! Put the equation into words…

$$\varepsilon = \frac{E}{Q} \quad \varepsilon = I(R + r)$$

The electromotive force is the energy provided by the battery per unit charge. **(1 mark)**

Wnen the switch is open the voltmeter and the battery are in series. The voltage from the battery is spread across the voltmeter (which is the external resistance) and the internal resistance of the battery. Voltmeters have a very high resistance so the voltmeter has virtually the full voltage an very little current flows - it reads the EMF of the battery

When the switch is closed the 10Ω resistor comes into play.It is in series with the internal resistance. A current flows through the external circuit and a tiny current through the volmeter. The voltage of the battery is shared out across 'r' and 'R'. The voltmeter reads the terminal voltage of the battery

(ii) When the switch is open the voltmeter reads 12.0V and when it is closed it reads 11.5 V. Explain why the readings are different.

When the switch is open the full voltage of the battery is across the battery internal resistance. The voltmeter therefore reads the EMF of the battery. **(1 mark)** When the switch is closed the voltage from the battery shares out across the external resistance and the internal resistance. Therefore the voltage reading on the voltmeter reads a smaller amount – the terminal voltage. **(1 mark)**

(3)

(b) Calculate the internal resistance of the battery.

ε = I(R + r) but V = IR so ε = V + Ir

We have ε (12 volts), V (11.5 volts), R (10Ω) and we therefore need I to find r.

V = IR so I = V/R = 11.5/10 = 1.15A **(1 mark)**

ε = V + Ir

12 = 11.5 + 1.15 x r **(1 mark)**

R = 0.5/1.15 = 0.43Ω **(1 mark)**

(3)
(Total 6 marks)

Q2. A very high resistance voltmeter reads 20V when connected across the terminals of a d.c. power supply. The high resistance meter is disconnected and a second voltmeter of resistance 1.0 kΩ is then connected across the supply. The second meter gives a reading of 16V.

In open circuit a power supply is basically in series with the voltmeter. The voltage is spread across the internal resistance and the resistance of the voltmeter. The voltmeter has a high resistance so it gets most of the voltage and shows that voltage on its dial. You should always use a voltmeter that has such a high resistance compared to the internal resistance that the voltage drop across the power supply is negligible compared to the one across the voltmeter.

In this question the very high resistance voltmeter allows virtually no current to flow through the power supply. The resistance of the voltmeter is so much higher than the resistance of the power supply that virtually all of the voltage is across it. (20V). This is the EMF of the supply.

When the second voltmeter is connected, it is of a lower resistance that the first one. It therefore gets a smaller share of the voltage than the first one did and the voltage reading on the voltmeter is lower (16V). The voltmeter is an external resistance of 1000Ω. The terminal voltage is 16V

(i) State the e.m.f. of the power supply. 20V **(1 mark)**

(ii) Calculate the current which flows through the second meter.

$V = IR$ so $I = V/R = 16/1000 = 0.016A$ **(1 mark)**

(iii) Calculate the internal resistance of the power supply.

$\varepsilon = I(R + r)$ but $V = IR$ so $\varepsilon = V + Ir$

$20 = 16 + 0.016r$ **(1 mark)**

$r = 4/0.016 = 250\Omega$ **(1 mark)**

(iv) Show that the current is equal to 0.080 A when the supply is short circuited. When the supply is 'short circuited', it means that the external circuit has been short circuited. R = 0Ω. We know r = and ε = 20V.

$\varepsilon = I(R + r)$

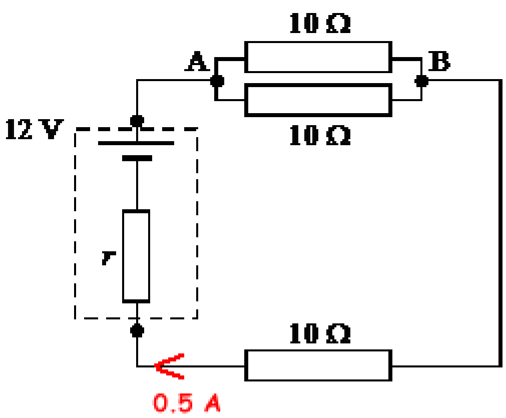
$20 = I\,(0 + 250)$

$I = 20/250 = 0.080A$ Q.E.D. **(1 mark)**

(Total 5 marks)

Q3. A battery of e.m.f. 12 V and internal resistance *r* is connected in a circuit with three resistors each having a resistance of 10 Ω as shown. A current of 0.50A flows through the battery.

The parallel arrangement - two equal resistances in parallel - equivalent resistance is 5Ω



total external resistance R is 15Ω

Calculate

(i) the potential difference between the points A and B in the circuit,

You can get away with stating that the resistance between A and B is 5Ω but it is probably best to show the working.

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$$

= 1/10 + 1/10 = 2/10

So, $R_T = 10/2 = 5\Omega$ **(1 mark)**

$V = IR = 0.5 \times 5 = 2.5V$ **(1 mark)**

(ii) the internal resistance of the battery,

$$R_T = R_1 + R_2 + R_3 + \ldots$$

= 5 + 10 = 15Ω **(1 mark)**

ε = 12 volts, R = 15Ω, I = 0.5A

$$\varepsilon = \frac{E}{Q} \quad \varepsilon = I(R + r)$$

12 = 0.5(15 + r)

24 = 15 + r

r = 9.0 Ω **(1 mark)**

(iii) the total energy supplied by the battery in 2.0 s,

$$E = IVt, \; P = IV, \; P = I^2R$$

E = IVt = 0.5 x 12 x 2.0 = 12 J **(1 mark)**

(iv) the fraction of the energy supplied by the battery that is dissipated within the battery.

We have to compare the energy dissipated by the whole circuit

P = IV for whole circuit = Iε = 0.5 x 12 = 6.0 J each second **(1 mark)**

To the energy dissipated by the internal resistance of the battery

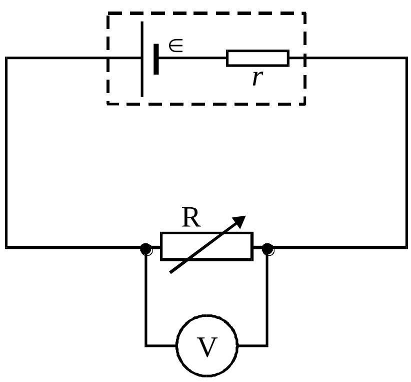
P = I^2R for the internal resistance of the battery = 0.5^2 x 9.0 = 2.25 J each second **(1 mark)**

Fraction = 2.25/6.0 = 0.375 **(1 mark)** (3 MAX)

(7)

(Total 7 marks)

Q4. A battery of e.m.f. ε and internal resistance *r* is connected in series with a variable resistor R as shown below. A voltmeter is connected as shown.



(a) (i) State what is meant by the e.m.f of a battery.

EMF is the energy provided by the battery **(1 mark)** per unit charge **(1 mark)**

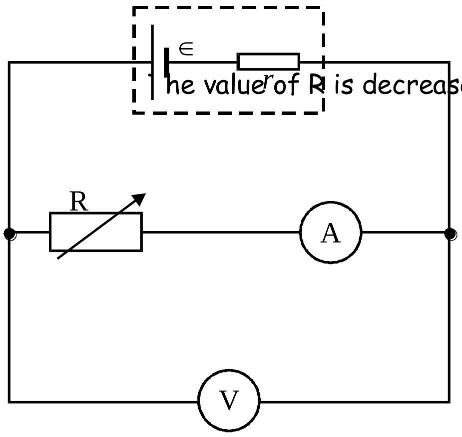
[or potential difference across battery **(1 mark)** when no current flows **(1 mark)** in an external circuit]

(ii) The reading V on the voltmeter is the voltage across R.
Why is V less than ε ?

When a current flows, work is done inside the battery to overcome the internal resistance **OR** the total voltage of the battery is shared out across the internal resistance of the battery and the external circuit (hence $V < \varepsilon$) **(1 mark)**

(3)

(b) In order to measure ε and r, an ammeter is used in the circuit, as shown below.

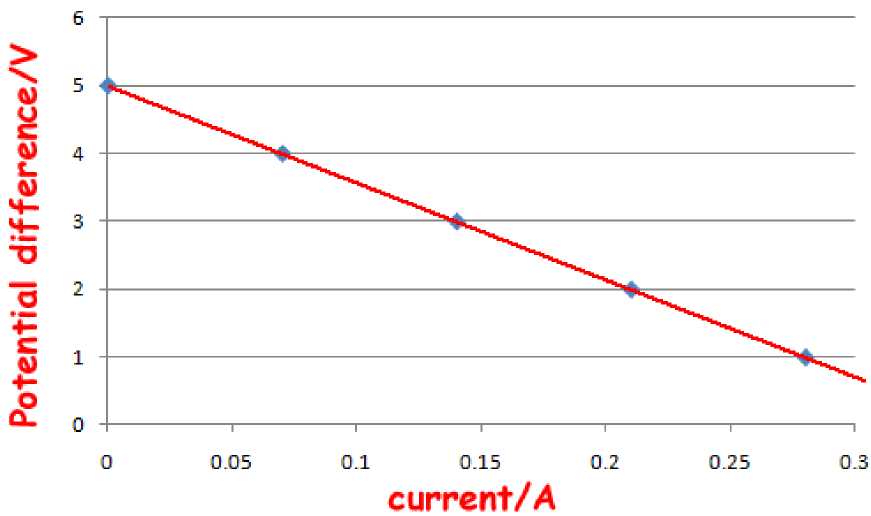


he value of R is decreased in steps and at each step the readings V and

reading on voltmeter/V	reading on ammeter/A
4.0	0.07
3.0	0.14
2.0	0.21
1.0	0.28

The table headings of this question are poor – if you did it on an examination paper you would lose marks – you should head the columns with 'potential difference' or 'terminal voltage' and 'current'.

(i) Plot a graph of V (on y axis) against I (on x axis) and draw the best straight line through the points.



suitable scale - fill the graph paper**(1 mark)**
four correct points **(2 marks)**
best straight line **(1 mark)**

(ii) Determine the values of ε and *r* from the graph, explaining your method.

$\varepsilon = Ir + V$ can be rearranged to give $V = -rI + \varepsilon$

This is in the form Y = mx + c **(1 mark)**

intercept = ε = 5 V **(1 mark)**
gradient = (–)*r* **(1 mark)** = 5/0.35 = 14.(2) Ω **(1 mark)**

(8)
(Total 11 marks)