Unit 1
Particles, Quantum Phenomena and Electricity

5.3
Emf and internal resistance

AS26

5.3 Emf (ε) and internal resistance (r)

- The electromotive force (emf) of a cell or power supply is defined as the electrical energy given to each unit of charge flowing through it. The units are joules per coulomb ($J\,C^{-1}$) or volts (V).
- It is easiest to think of the emf of a cell as ***the p.d. across its terminals when it is not driving a current***.

When the cell does drive a current, the p.d. across it falls. The greater the current, the greater the drop in p.d. This drop in p.d. occurs because the cell has a resistance of its own – known as **internal resistance**.

An easy way to think about it is to imagine a coulomb of charge arriving at one terminal of a 6V cell. It is given 6J of energy, as you would expect but, in flowing through the cell, it loses 0.5J because it has to do work against the resistance of the cell. When it emerges from the other terminal it has only 5.5J. A voltmeter connected across the cell only reads the difference in potential between each terminal, so it reads 5.5 V.

$$lost\ volts = \varepsilon - V = Ir$$

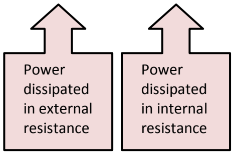
Where V is the terminal p.d. when a current I flows.

For a circuit with a total internal resistance r, and a total external resistance R, we can write

$$\varepsilon = I(R + r)$$

The total power supplied by a cell is then

$$P = \varepsilon I = I^2R + I^2r$$



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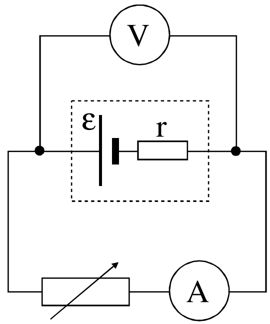
Measuring internal resistance and emf

- The experimental arrangement shown opposite could be used.
- Reduce the resistance of the variable resistor so that the current drawn from the cell increases.
- Take pairs of readings of the p.d. across the cell (V) and the current (I).



Rearranging the equation $\varepsilon - V = Ir$

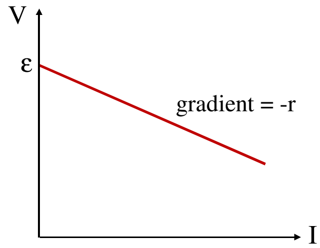
gives $V = -rI + \varepsilon$

$y = mx + c$

Plotting a graph of V against I will give a straight line of negative gradient.

Gradient = -r

Intercept on V axis = ε



Cells in series and parallel

When cells are connected in parallel, the total internal resistance falls but the p.d. stays the same. They can therefore drive a larger current.

$$\frac{1}{r_T} = \frac{1}{r_1} + \frac{1}{r_2}$$

When cells are connected in series, the p.d.s add up but so do the internal resistances.

$$r_T = r_1 + r_2$$