Internal resistance and cells

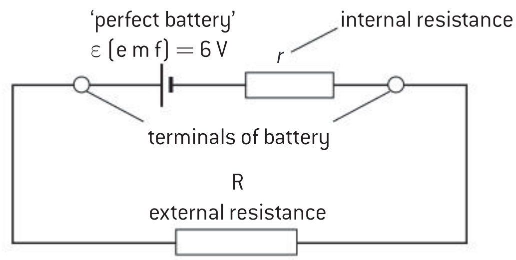
ELECTROMOTIVE FORCE AND INTERNAL RESISTANCE

When a 6V battery is connected in a circuit some energy will be used up inside the battery itself. In other words, the battery has some **internal resistance**. The TOTAL energy difference per unit charge around the circuit is still 6 volts, but some of this energy is used up inside the battery. The energy difference per unit charge from one terminal of the battery to the other is less than the total made available by the chemical reaction in the battery.

For historical reasons, the TOTAL energy difference per unit charge around a circuit is called the **electromotive force** (**emf**). However, remember that it is not a force (measured in newtons) but an energy difference per charge (measured in volts).

In practical terms, emf is exactly the same as potential difference if no current flows.

$\varepsilon = I(R + r)$



$$\text{e m f} = I \times R_{total}$$
$$= I(r + R)$$
$$= Ir + IR$$
$$IR = \text{emf} - Ir$$

IR: terminal p d, V; Ir: 'lost' volts

$$V = \varepsilon - Ir$$

CELLS AND BATTERIES

An electric **battery** is a device consisting of one or more cells joined together. In a cell, a chemical reaction takes place, which converts stored chemical energy into electrical energy. There are two different types of cell: primary and secondary.

A **primary** cell cannot be recharged. During the lifetime of the cell, the chemicals in the cell get used in a non-reversible reaction. Once a primary cell is no longer able to provide electrical energy, it is thrown away. Common examples include zinc–carbon batteries and alkaline batteries.

A **secondary** cell is designed to be recharged. The chemical reaction that produces the electrical energy is reversible. A reverse electrical current charges the cell allowing it to be reused many times. Common examples include a lead–acid car battery, nickel–cadmium and lithium-ion batteries.

The **charge capacity** of a cell is how much charge can flow before the cells stops working. Typical batteries have charge capacities that are measured in Amp-hours (A h). 1 A h is the charge that flows when a current of 1 A flows for one hour i.e. 1 A h = 3600 C.

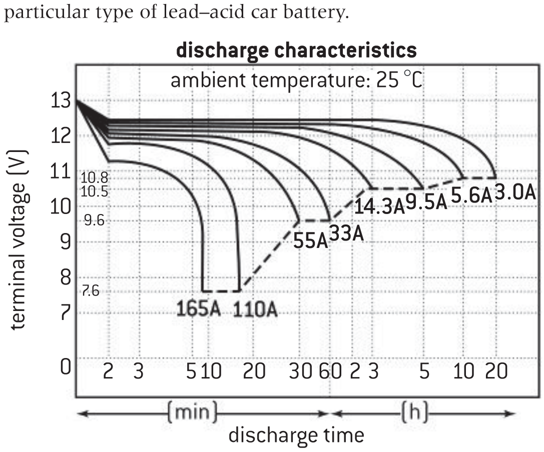
DISCHARGE CHARACTERISTICS

When current (and thus electrical energy) is drawn from a cell, the terminal potential difference varies with time. A perfect cell would maintain its terminal pd throughout its lifetime; real cells, however, do not. The terminal potential difference of a typical cell:

- loses its initial value quickly,
- has a stable and reasonably constant value for most of its lifetime.

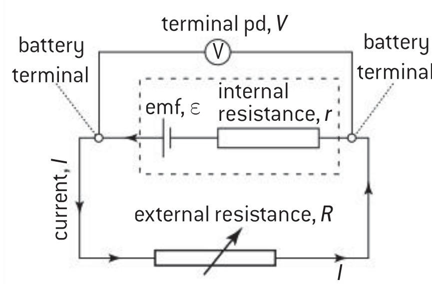
This is followed by a rapid decrease to zero (cell discharges).

The graph below shows the discharge characteristics for one particular type of lead–acid car battery.



DETERMINING INTERNAL RESISTANCE EXPERIMENTALLY

To experimentally determine the internal resistance r of a cell (and its emf ε), the circuit below can be used:



Procedure:

- Vary external resistance R to get a number (ideally 10 or more) of matching readings of V and I over as wide a range as possible.
- Repeat readings.
- Do not leave current running for too long (especially at high values of I).
- Take care that nothing overheats.

Data analysis:

- The relevant equation, $V = \varepsilon - Ir$ was introduced above.
- A plot of V on the y-axis and I on the x-axis gives a straight line graph with
  - gradient $= -r$
  - y-intercept $= \varepsilon$

RECHARGING SECONDARY CELLS

In order to recharge a secondary cell, it is connected to an external DC power source. The negative terminal of the secondary cell is connected to the negative terminal of the power source and the positive terminal of the power source with the positive terminal of the secondary cell. In order for a charging current, I, to flow, the voltage output of the power source must be slightly higher than that of the battery. A large difference between the power source and the cell's terminal potential difference means that the charging process will take less time but risks damaging the cell.