B1 BATTERIES

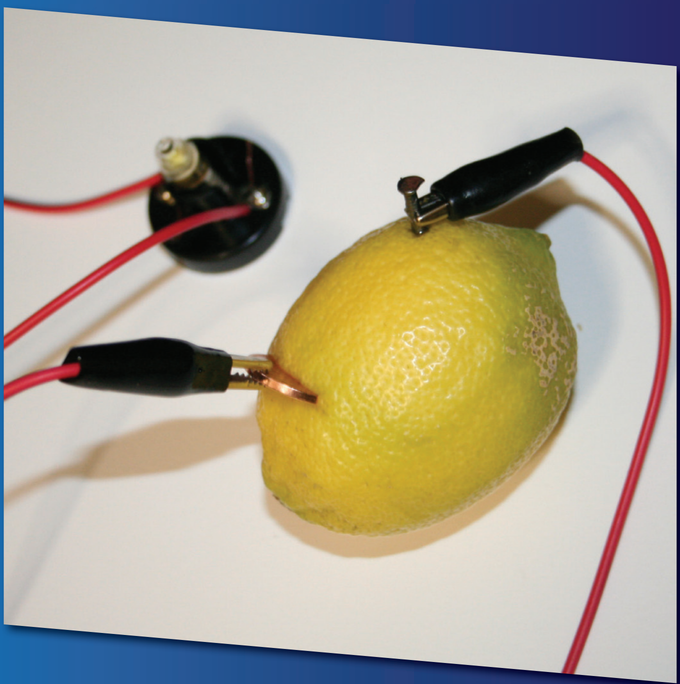
THE ELECTROCHEMICAL CELL

CHEMICAL INDUSTRIES
RESOURCE PACK

Making your own battery

You can use lemon juice as an electrolyte! Use a lemon (whole) and copper coin and galvanised nail, making sure they do not touch inside the lemon, and set up a circuit as in the picture. When a low-voltage light bulb, or LED, is connected to this circuit, it will light up. A voltmeter can be connected to measure the potential difference between the electrodes. The potential difference is determined by the choice of electrodes and not the type of fruit. The fruit juice, lemon juice in this case, merely acts as the electrolyte.

The lemon battery



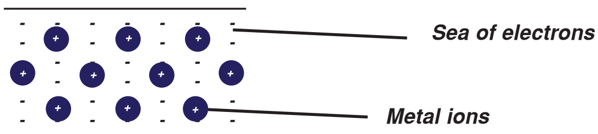
This battery can be made with almost any fruit. The metal electrodes can be varied but must be different metals.

Let's start at the very beginning...

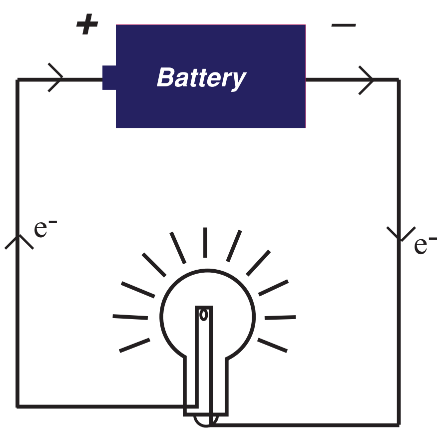
Reduction is when an atom, ion or molecule gains electrons. For example chlorine is reduced to chloride ions in the following reaction: $Cl_2 + 2e^- \rightarrow 2Cl^-$ or magnesium ions are reduced to magnesium metal as follows: $Mg^{2+} + 2e^- \rightarrow Mg(s)$.

Oxidation is when an atom, ion or molecule loses electrons. For example sodium loses an electron to form a sodium ion: $Na(s) \rightarrow Na^+ + e^-$, or sulfide ions lose electrons to form sulfur: $S^{2-} \rightarrow S(s) + 2e^-$.

A **reduction-oxidation reaction (redox reaction)** is a reaction that involves electron transfer. One species is oxidised while another is reduced. In a redox reaction electrons therefore move from one species to the other. Metals are good conductors of electricity and are therefore used in electrochemical cells to connect the anode to the cathode. Charges are able to move in the metal wires because delocalised electrons are present:

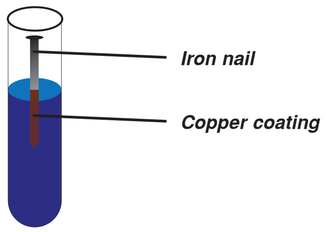


Part of a layer of metal



When the battery is connected in an electric circuit the potential difference in the battery will result in a flow of electrons

An **electrolyte** is a liquid that can conduct electricity. Electrons do not move freely through these liquids, rather it is charged ions present within the liquid that move. The effect is still the movement of charge. Many liquids with ions present are used as electrolytes. Some are pure liquid compounds and some are in solution. Some substances are more readily reduced or oxidised than others. For example, if you place a galvanised (zinc coated) nail into a solution of copper sulfate you can see a red-brown layer forming on the nail. Eventually the blue colour of the solution starts to fade.



Zinc atoms are oxidised to form zinc ions. Copper ions are reduced to form copper atoms.

In this reaction, zinc metal is oxidised to zinc ions by the copper ions in the solution. Two electrons are given off for each zinc atom that is oxidised. $Zn(s) \rightarrow Zn^{2+} + 2e^-$ The copper ions in the solution accept these electrons and become copper atoms. $Cu^{2+} + 2e^- \rightarrow Cu(s)$

These copper atoms then coat the zinc layer. This is the red-brown layer that is observed. The copper ions that are dissolved in water give the solution a blue colour. Since there are less and less of these present in the solution, the blue colour fades during the reaction. The concentration of zinc ions in the solution increases. The overall ionic reaction is:

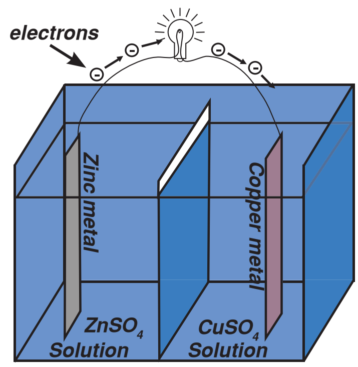
$Cu^{2+}(aq) + Zn(s) \rightarrow Cu(s) + Zn^{2+}(aq)$

The sulfate ions (SO_4^{2-}) remain unchanged in the solution and are called 'spectator' ions. The full balanced reaction, including these, can be written as:

$CuSO_4(aq) + Zn(s) \rightarrow ZnSO_4(aq) + Cu(s)$

The reduction and oxidation process can be physically separated by letting them take place in different compartments. An electrochemical cell, also known as a galvanic or voltaic cell, takes advantage of this situation. With a bit of engineering we have found a way to place a circuit in the middle of this reaction so that instead of electrons moving directly from the zinc to the copper, they move through an external circuit. In doing this we also separate the reduction and oxidation reactions. Both still occur simultaneously, but in different places.

The terminal at which oxidation occurs is called the "anode". For a voltaic cell or battery, this is the negative terminal.



In this picture the two half cells are separated by a membrane that allows SO_4^{2-} ions through, but not Zn^{2+} or Cu^{2+} ions.

The terminal at which reduction occurs is called the "cathode". For a voltaic cell or battery, this is the positive terminal. Since copper ions are constantly being removed from the solution containing the cathode the concentration of Cu^{2+} ions decreases, which causes the blue colour to fade. The mass of the copper electrode increases as copper atoms are formed on its surface. Zinc ions are constantly being added to the solution containing the anode, increasing the Zn^{2+} concentration. The zinc electrode loses mass as zinc atoms are removed from its surface. Once an electrode is completely eroded, or the electrolyte can no longer supply the necessary ions, the battery is said to be 'flat'.

This principle works for many combinations of metals and electrolytes, and is what batteries are based upon. Different anode-cathode combinations give different voltages to the external circuit. If you place in the external circuit a power supply that forces the electrons in the opposite direction, you can force the reactions to reverse, restoring the original state of the electrodes and electrolyte. This is what happens when you recharge a battery.

Concentrations of the electrolytes and surface area of the electrodes influence what kind of battery is produced, but all are based on the same principle: oxidation at the anode, electrons move through the external circuit, reduction at the cathode. The salt bridge/ion-selective membrane/common electrolyte all allow charges to move in the internal circuit, completing the internal (inside the cell) circuit.