home

Physics 2415 Lecture 10: Electric Charge and Current

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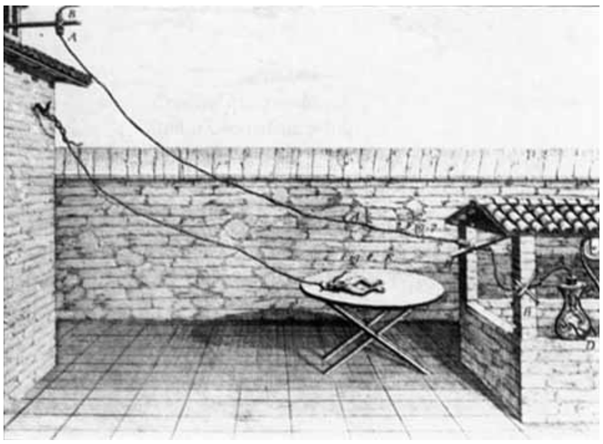
Electricity and Frog's Legs

- In 1771, Luigi Galvani, at the University of Bologna, was dissecting frog's legs at a table that also had an electrostatic generator. He found by accident that the legs twitched in response to a charge, and were far more sensitive than the best electroscopes. He tried to detect atmospheric electricity.



- He found instead that electricity was generated by touching the legs with *dissimilar metals*.

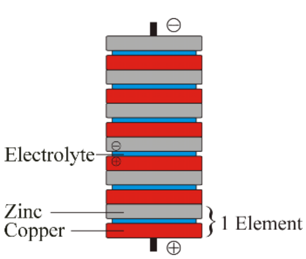
Reviving Dead Criminals?

Galvani's nephew, Giovanni Aldini, a showman, electrified corpses just after decapitation at a prison in London, with various muscular reactions.

This was the inspiration behind Frankenstein.

It also led to the belief that electricity was the "life force", the essential non-material component of living matter, absent in ordinary inanimate matter. This idea was demolished by Volta.

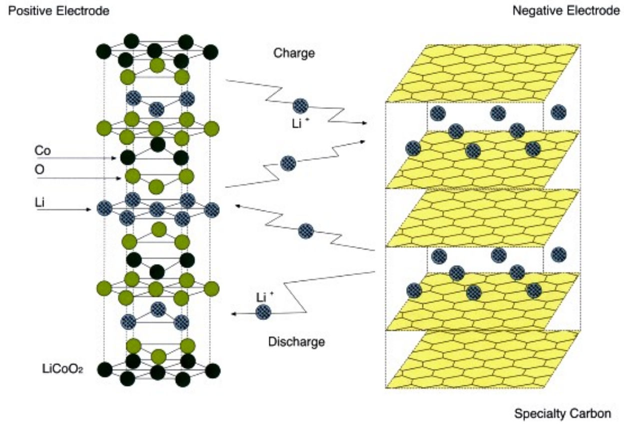
Volta's Pile



Galvani's colleague Volta was the first to realize that using different metals to touch the frog's leg was crucial to producing electricity, and in fact the leg could be replaced with *cardboard soaked in brine*: no sign of life!

He built a pile of such metal pairs—the first such battery—with dubious medical applications, as diagrammed here.

A Modern Battery: Lithium Ion



Lithium ions Li^+ are *very tiny*: remember H, He, Li, …they are He atoms with an extra nuclear charge. They can fit between atomic layers in graphite, to which they bond, but bond more strongly in $LiCoO_2$. Charging is by attracting them from the $LiCoO_2$ into the graphite by pumping in electrons.

Batteries, Circuits, Currents

The two terminals of a battery, called *electrodes*, are immersed in an *electrolyte*. Positive ions are formed at one electrode by atoms depositing electrons.

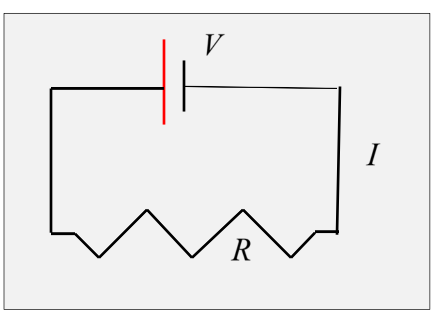
For suitably chosen materials, energy is generated by these electrons *flowing round an outside wire* to take part in a chemical reaction (or just rejoin the ions) at the other electrode.

The "outside wire" is the circuit. Flow is measured in coulombs per sec, called Amperes.

Ohm's Law

Ohm found experimentally in 1825 that for a given piece of wire, the current, labeled I, was directly proportional to the applied voltage (from number of battery cells) V, and wrote it as $I = V/R$, where V is in volts, I in amps.

R is called the *resistance* of the wire, and is *measured in ohms*: one volt sends one amp through one ohm.



These are the standard symbols for a battery and a resistance: remember the standard "current" is really electrons flowing the other way!

Electric and Water Currents Compared

It's sometimes useful to think of electric current down a wire as resembling water flowing down a pipe.

Pressure difference between two ends of a water pipe corresponds to *voltage* difference between the ends of a wire.

Flow rate is determined by pressure gradient: a water pipe twice as long drops twice the pressure during flow, in electrical terms, *a wire twice as long has twice the resistance*.

Resistance and Cross-Section Area

Suppose we take two identical wires, having the same area of cross section A, and twist them together to make one wire.

When this is done, it's found (not surprising) that the combination delivers twice the current of a single wire for the same voltage.

But effectively we've doubled the cross-section area: so R is proportional to $1/A$.

(In fact, this turns out not to be true for real fluid, like water, in a pipe, where doubling the cross-section area for the same shape more than doubles the flow rate—but it's accurate for electric current flow.)

Resistance and Resistivity

To summarize: for a given material (say, copper) the resistance of a piece of uniform wire is proportional to its length ℓ and inversely proportional to its cross-sectional area A.

This is written:

$$R = \frac{\rho \ell}{A},$$

where ρ is the *resistivity*. For copper, $\rho = 1.68 \times 10^{-8}\ \Omega \cdot \mathrm{m}$.

Electric Power

Remember voltage is a measure of potential energy of electric charge, and if one coulomb drops through a potential difference of one volt it loses one joule of potential energy.

So a current of I amps flowing through a wire with V volts potential difference between the ends is losing IV joules per sec.

This energy appears as heat in the wire: the electric field accelerates the electrons, which then bump into impurities, vibrations, and defects in the wire, and are slowed down to begin accelerating again, like a sloping pinball machine.

Power and Energy Usage

Using Ohm's law, we can write the power use of a resistive heater (or equivalent device, such as a bulb) in different ways:

$$P = IV = I^2 R = V^2 / R.$$

The unit is *watts*, meaning *joules per second*.

Electric meters measure *total energy* usage: adding up how much power is drawn for how long, the standard unit is the kilowatt hour:

1 kWh = 1,000x3,600J = 3.6MJ.

Energy Storage

A more recent energy unit is the watt.hour, used in energy storage capability: a tesla battery is currently (2024) capable of storing around 270 w.h/kg, so a four-kilogram battery is needed to store 1 kWh. Tesla is now building batteries to store wind power, single units store 3.9 MWh. Presumably these units weigh several thousand tons.