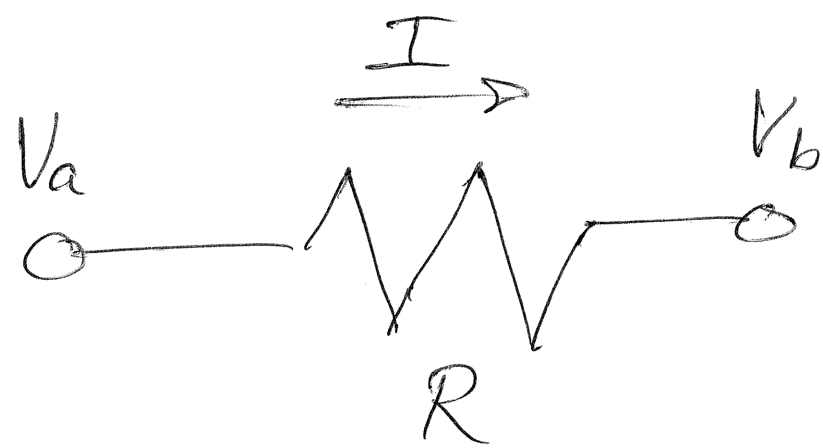
Lecture 15

A "resistor" is one of the basic components of electrical circuits. It has the property that current $I = (V_a - V_b)/R$ flows between its two "terminals" when these have potential difference $V_a - V_b$:



The direction of positive current flow indicated above in the circuit diagram implies $V_a > V_b$. This is consistent with $\vec{E} = -\vec{\nabla}\varphi$, as $\vec{E}$ is always in the same direction as I by

$$\vec{J} = \frac{1}{\rho}\vec{E}.$$

Most circuits are designed with resistors in mind that have a constant value of R. However, as we have seen, physical parameters such as temperature can change R.

A charge (e.g. conduction electron) moving through a resistor loses energy to frictional forces. The <u>rate</u> of energy loss, or power, for all the free charge that moves between the terminals during time Δt is

$$P = \frac{\Delta Q \cdot V_a - \Delta Q \, V_b}{\Delta t}$$

$$= \frac{\Delta Q}{\Delta t} V = IV$$

Using Ohm's law this can be also written using just I or just V:

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

Even though both I and V involve electrical units, the combination IV is just the mechanical unit of power: Watt

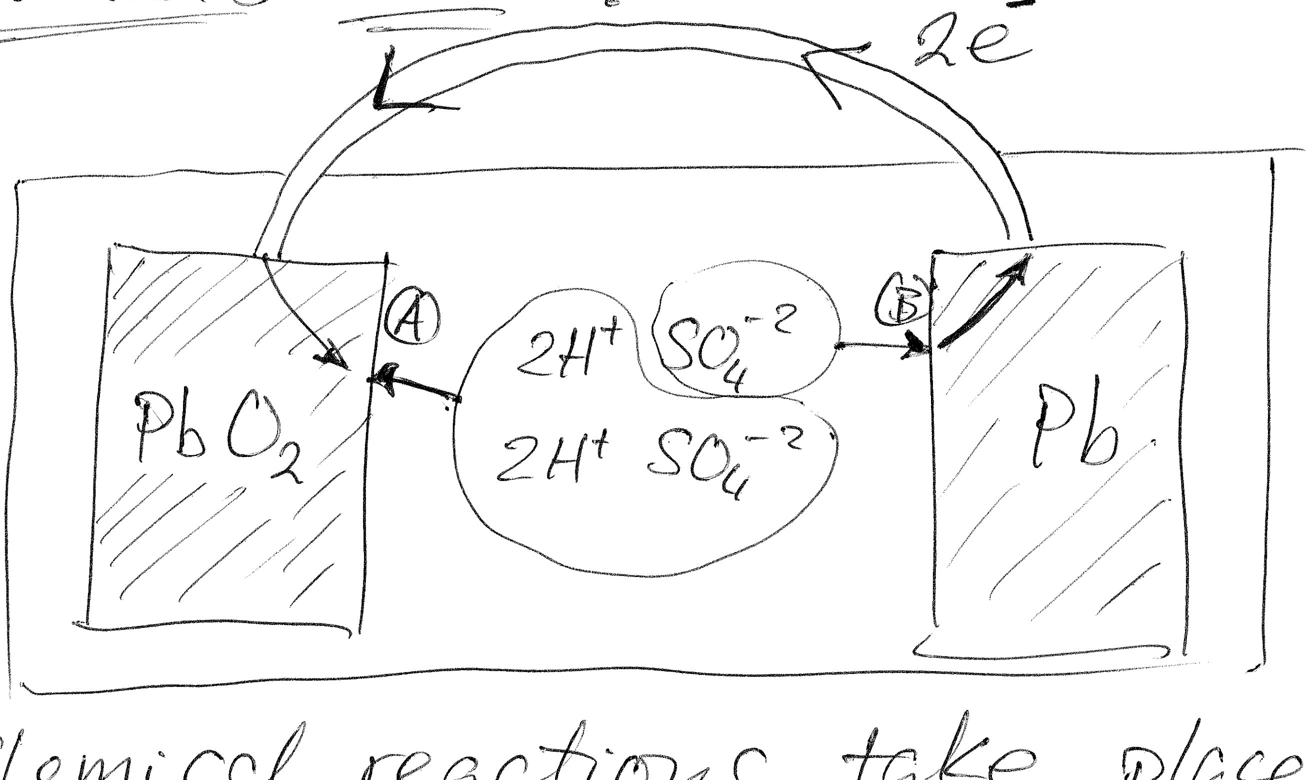
$$\text{Amp} \times \text{Volt} = \frac{C}{S} \times \frac{J}{C} = \frac{J}{S} = W$$

Energy/power is introduced in a circuit by <u>batteries</u>. The origin of the energy is chemical: the formation of lower energy molecules in processes that involve the transfer of charge. We will explain the battery mechanism using the example of the lead-acid storage battery:

sulfuric acid:

$$H_2SO_4 \longrightarrow \underbrace{2H^+ + SO_4^{-2}}_{\text{ions in solution}}$$

chemist's view:



Chemical reactions take place at the surface of the leadoxide electrode (A) and the surface of the lead electrode (B) :

(A) : $2e^- + PbO_2 + 4H^+ + SO_4^{-2}$

$$\downarrow$$

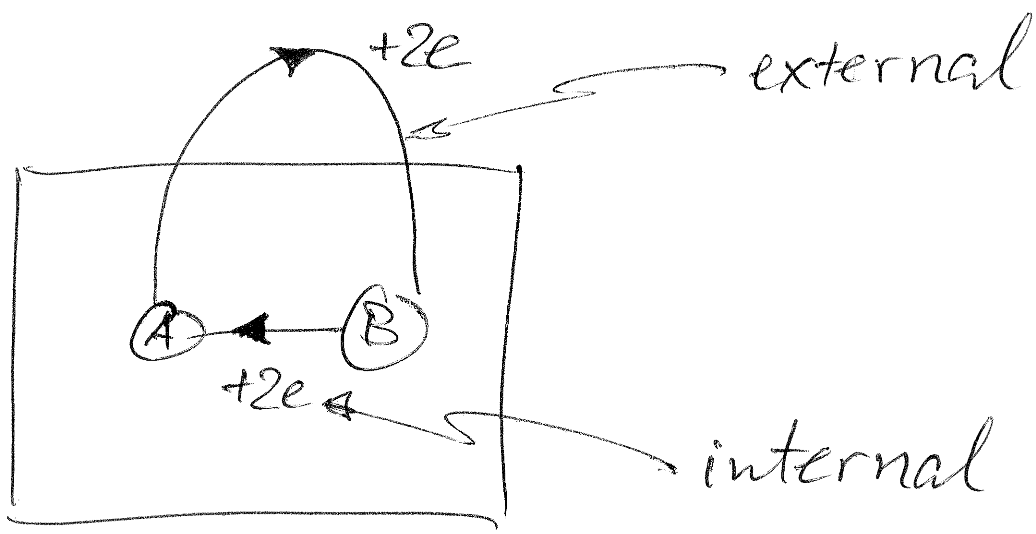
$$\underbrace{PbSO_4 + 2H_2O}_{\text{low energy molecules}} + 3.37\ eV$$

(B) : $SO_4^{-2} + Pb \longrightarrow \underbrace{PbSO_4}_{\text{low energy}} + 2e^-$ $+ .71eV$

Notice that whenever a pair of these reactions takes place, charge $-2e$ flows <u>directly</u>

from the Pb electrode to the PbO_2 electrode (via the circuit that the battery is connected to) while charge +2e flows <u>internally</u> (through the solution) between the same pair of electrodes.

<u>physicist's</u> <u>view</u>



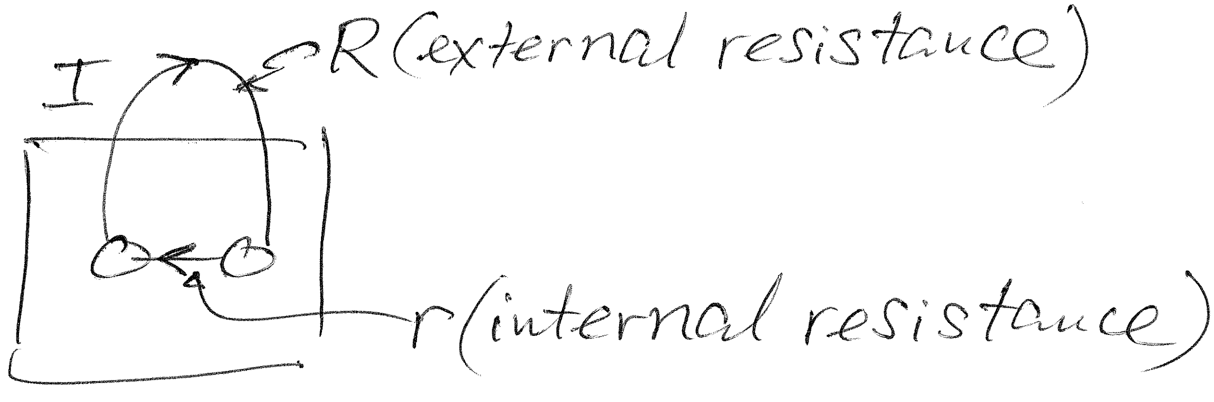
net chemical energy gain when charge +2e moves around loop:

$$3.37\,eV + .71\,eV = 4.08\,eV$$

The "electromotive force" (emf) of the battery is defined as the energy gain per unit ~~unit~~ charge that moves through the battery:

$$\text{emf} = \mathcal{E} = \frac{4.08\ eV}{2e} = \underline{2.04\ \text{Volt}}$$

This energy output of the battery is dissipated by both the external and internal parts of the circuit:



$$\mathcal{E} = IR + Ir$$

We should contrast $\mathcal{E}$ with the potential "seen" by the external circuit, the "terminal voltage" V:

$$V = IR = \left(\frac{\mathcal{E}}{R+r}\right)R$$

$$= \left(\frac{R}{R+r}\right)\mathcal{E} < V$$

Normally $r \ll R$ and $V \simeq \mathcal{E}$, but when a battery "runs low" it's usually because r is large.