BATTERIES

Thus far we have assumed we can place voltages on conductors as we wish. But how do we get the voltage source? One way is through batteries, so let’s take a brief diversion to indicate how they work.

We consider a fictional battery which is not realistic for reasons which will become apparent. However it will serve to indicate how an actual battery works. Our battery consists of two solid electrodes – one of them Lithium, the other Oxygen (this is why it won’t do in practice – O₂ is not solid at room temperature), separated by a solid electrolyte.

![Electrolyte sketch]

The electrolyte has the property that it permits Li⁺ ions to move through it, but not electrons. Such materials actually exist, but they are the most difficult part of the battery to create.

At the Li-electrolyte interface some Li⁺ ions will enter the electrolyte by diffusion. At this point the concentration of Li⁺ in the electrolyte as a function of position looks as shown in sketch below.

![Li⁺ concentration sketch]

As time goes on the Li⁺ ions will diffuse across the electrolyte. If they could not leave it at the O₂ interface the concentration would be as shown in the sketch below.

![Li⁺ concentration sketch]
However Li and O combine to make Li₂O. Hence the concentration at the O₂ interface will be forced to zero and we get:

Since each Li⁺ that leaves the Li electrode leaves behind an electron, the Li electrode acquires a negative charge. The reverse is true for the O₂ electrode. Thus we end up with two charged conducting plates. That will result in a voltage.

Now consider a Li⁺ ion making the trip from left to right. To do so will cost an energy qV. where q is the charge on a proton. But once it reaches the O₂ it will get back an energy \( U = \frac{E_R}{4} \) where \( E_R \) is the energy released in the chemical reaction:

\[
4\text{Li} + \text{O}_2 = 2\text{Li}_2\text{O} + E_R
\]

Hence the ions will flow until:

\[
qV = \frac{1}{4} E_R \quad \Rightarrow \quad V = \frac{E_R}{4q}
\]

This is the open-circuit voltage of the battery.

Now suppose we connect a conductor from the Li electrode to the O₂ electrode. Now electrons (but not Li⁺) will flow through the conductor.
This results in no net charge transfer and hence can continue until the Li is exhausted. Thus the electron flow through the conductor is limited by the rate at which the ions move through the electrolyte. As we will see when we discuss circuits, these electrons can do work – which is ultimately paid for by the decrease in chemical energy stored in the battery:

External work = Chemical energy released

Obviously we would like to store the maximum possible energy/lb and have an electrolyte which allows large ion flow. These are the challenges for battery designers. Car batteries use Lead – hardly a light element, but have a high current electrolyte (sulfuric acid solution). Batteries for small electronic devices often use Li, but have small maximum ion flow.