Measuring Electrically

Lots of physics majors don't know how to use an electrical multimeter appropriately. A common error is to mis-wire when attempting to determine voltage or current. Another error is to wire properly but mis-setting the multimeter. Yet another common problem is using a multimeter to determine the "strength" of a battery. When a multimeter is used to test the voltage of an unloaded battery, the voltage of the battery is a poor indicator of its useful lifetime or "strength". So doing is not the way to determine the voltage that a battery will apply when in place within a circuit.

Measuring Voltage – In order to measure voltage difference between two points in a live circuit, wire the leads of the multimeter in *parallel* with the circuit element over which you are attempting to determine the voltage drop. When used to measure voltage, the resistance of a multimeter circuit is very high so as not to affect the current flow through the circuit and hence change the voltage drop. The current is measured through a "shunt" of high resistance that in turn can be used to determine the voltage difference using Ohm's law.

Measuring Current – In order to measure the current through an element within a circuit, wire the leads of the multimeter in *series* with the circuit element through which you are attempting to determine the current flow. (You will have to "break" the circuit in order to introduce the leads of the multimeter.) When used to measure current, the resistance of a multimeter is very low so as not to affect the voltage drop in the circuit and affect the current flow. The current passing through the multimeter goes through a "shunt" of low resistance that can be used to determine the current flow using Ohm's law.

Mis-wiring and mis-setting a multimeter can have disastrous consequences for both a circuit and a multimeter due to the differences in the resistances of "shunt" settings. Fortunately, most multimeters are protected with a fuse to limit current flow; this is not often the case in electrical circuits to which mis-wired multimeters are introduced.

Determining the "Strength" of an Electrical Cell or Battery – So, do you know the difference between a cell and a battery? Lots of students do not, and the terms are often used interchangeably. A battery is two or more identical cells wired in one of two ways – either in parallel or series. When added in parallel, the battery has the voltage of a single cell, but can deliver much more current at the same voltage than a single cell. When cells are wired in series, a battery has the sum total of all voltages of all cells. A 12-volt lead-acid car battery has six cells each producing 2 volts. Is a car battery wired in series or in parallel?

Students in introductory physics courses sometime see this formula in relation to cells or batteries but fail to grasp its significance:

$$V = \mathcal{E} - IR$$

where $\mathcal{E}$ constitutes the electromotive force, V the voltage of the cell or battery, I the current provided by the cell or battery, and R the internal resistance of the cell or battery. By merely attaching a multimeter to a cell or battery to determine its strength, what one is actually measuring is $\mathcal{E}$ because there is essentially no current flow. (Recall that multimeters when used to measure voltage have very high internal resistances.) When a load is applied to a poor cell or battery, current flows and the voltage drops. This is why a car mechanic will "load test" a car battery to determine if it needs to be replaced. If, under a substantial load (high current, low resistance) the voltage does not drop substantially, then the difference between V and $\mathcal{E}$ is small suggesting low internal resistance. A battery is "good" if it has low internal resistance. As batteries age, their internal resistances go up and the difference between V and $\mathcal{E}$ grows proportionately.

So, if you want to determine how much voltage a cell or battery is applying to a circuit, you cannot do so by measuring the battery out of the circuit. You must measure the voltage across the leads of the cell or battery when it is in the operating circuit to determine the actual voltage applied to the circuit.