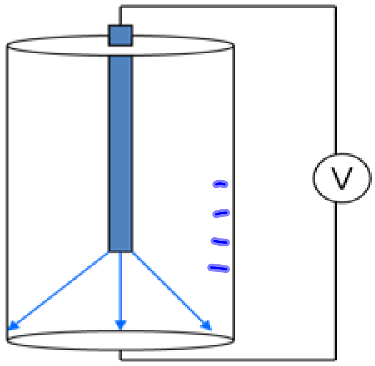
Section 4: Voltage

As **electrons are moved within the cell** by the electrolyte, work is done on the electrons. This work is stored as potential energy in the electrons. In other words, they have the ability to do work. The amount of work done per charge to move the electrons is defined as the **potential difference** or **voltage** of the cell.



Potential Difference or **Voltage** is the force behind the current - - it is the force that makes the electrons move. This is the **EMF** (electromotive force) or **ideal voltage** of the cell.

The **EMF, ideal voltage** or **open circuit voltage** is defined as the energy per unit charge developed **within** a source.

The ideal voltage (the values stamped on the cell) is a little more than the **effective voltage (i.e., usable voltage)** because the internal resistance in the cell itself consumes some of the voltage.

$$EMF = V = \frac{E}{Q} = \frac{W}{Q}$$

V - volts = $\frac{J}{C}$

work - J

Q - C

One volt is **the amount work required to move one coulomb of charge between the two points.**

1 Volt = 1 J/C

This quantity can be measured by a device known as a Voltmeter. It measures the potential difference between the terminals of the cell. A voltmeter is a large resistance instrument and it is connected in parallel with the component across which the voltage is bein measured. (more on this shortly)

Question: AA, AAA, C, and D cells all have a voltage of 1.5 V. How can this be when the D cell is much larger than the rest? What is the advantage of using a D cell over a AA?

Voltage depends only on the materials that make up the cell. For example, if the rod is carbon and the casing is zinc, and the paste is the same in the cell, then you could make the cell as big as a barn and the voltage would still be 1.5 V.

A ‘D’ cell is bigger--the rod is bigger, the casing is bigger, there is a lot more paste. Therefore, it will keep pumping electrons to a higher potential on the casing for a much longer time than will a AAA cell. The ‘D’ cell will operate the light bulb for a much longer time before its chemical action becomes all used up. The larger the cell, the longer it can supply a certain amount of current.

A cautionary note

It is the chemical action in the 1.5 V cell provides the electrical energy increase or **rise** for the electrons. However, the potential **drop** that electrons experience in the external circuit, e.g., in passing the wires, the lamp, and the ammeter is not quite 1.5 V. It will more likely be 1.3 V or 1.4 V, or 1.45 V--i.e., less than the rated 1.5 V. This is because the dry cell itself is part of the circuit. The electrons must pass through the cell as they go around the circuit. So, the cell itself provides a resistance to the current. As a result you can feel the cell become warm when it is being used. So, some electrical energy is changed to heat within the cell.

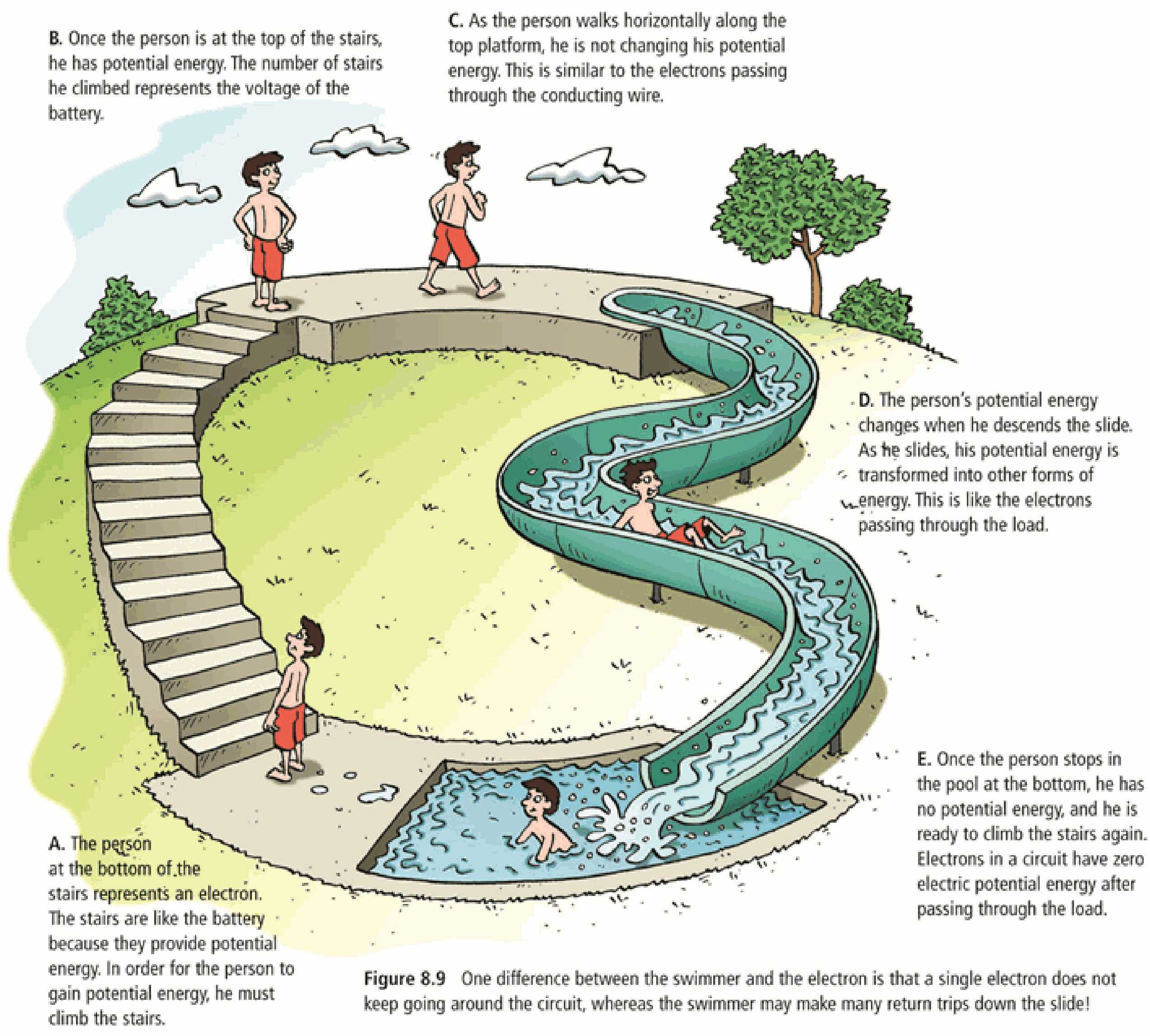
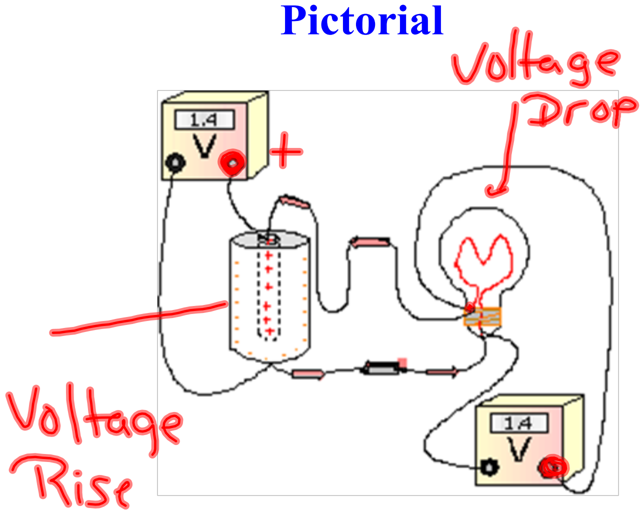


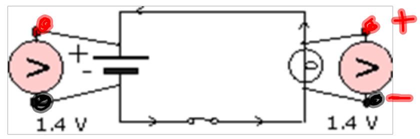
Figure 8.9 One difference between the swimmer and the electron is that a single electron does not keep going around the circuit, whereas the swimmer may make many return trips down the slide!

Measuring Voltage

As mentioned earlier, a **voltmeter** is used to measure potential difference or voltage. A voltmeter can measure the **increase in potential** at the terminals of the dry cell, and the **decrease in potential** as the electrons give up their energy in the lamp. This can be accomplished by connecting two voltmeters as shown below.

Pictorial **Schematic**





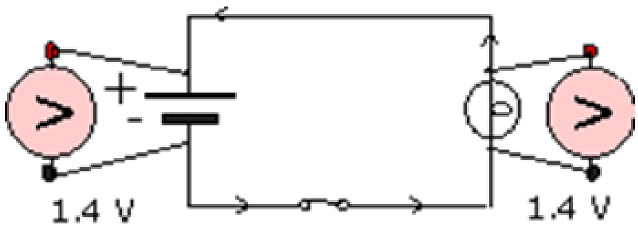
Recall that the circuit had to be broken to connect the ammeter. **No such requirement is necessary to connect the voltmeter.**

Note: The red terminal of the voltmeter is connected to the positive terminal of the cell. Of course, the terminals of the bulb are neither positive nor negative because it is not a source of electricity. However, **the red terminal of the voltmeter must be connected to the terminal of the bulb that is towards the positive terminal of the dry cell.**

Recall:

The ammeter was low resistance device so as not to contaminate the circuit. (We wanted all the current to pass through the ammeter.)

A Voltmeter, however, cannot have a tiny, tiny, tiny resistance to the flow of electrons. If it did most of the current would flow through the voltmeter and not through the lamp. The lamp would become very, very dim. So, **voltmeters must have an extremely large resistance to discourage electrons from passing through them.** Then only a tiny, tiny, tiny current will by-pass the bulb. This tiny current is enough for the voltmeter to determine the potential drop across the bulb.



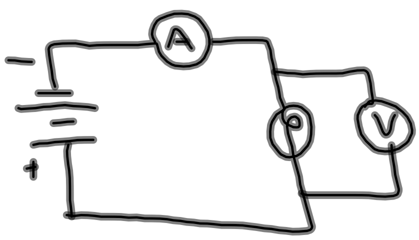
REMEMBER:

MC

An **ammeter** is a **small resistance** instrument. It is connected in **series** with the other components of the circuit.

A **voltmeter** is a **large resistance** instrument. It is connected in **parallel** with the component across which the voltage is being measured.

DOE



Relating current (I) and voltage (V) to electrical energy (E)

Consider the mathematical expressions for the definitions of current and voltage:

1) **I = q/t** which can be written as **q = It**......eq. 1

2) **V = E/q** which can be written as **E = Vq**......eq. 2

Substituting for ***q*** from eq. 1 into eq. 2 gives

$$E = VIt$$

V·A·s

$\frac{C}{s} \cdot \frac{J}{C} \cdot s$

J

Electrical energy produced in a circuit is dependent on:

(i) the **voltage or potential difference across** the circuit,
(ii) the **current flowing through** the circuit and
(iii) the **time** that the circuit is being used.

This is the energy that makes the little wheels go round inside the electric meter on your house.

Examples:

1. A curious physics student wonders how long a single 1.5 V AA dry cell will last if connected to a small flashlight bulb until no more light can be seen from the bulb. She sets up a circuit that includes an ammeter so that the current can be read. The current diminishes over time but the student estimates the average current to be 5.0 mA, and determines the time to be five and half hours. How much energy did the cell supply to the bulb in that time?

$V = 1.5\,V$

$I = 5 \times 10^{-3}\,A$

$t = 5.5\,h \times 3600\,\frac{s}{h}$

$= 19800\,s$

$E =$

$E = VIt$

$E = (1.5\,V)(5 \times 10^{-3}\,A)(19800\,s)$

$E = 150\,J$

or ① $q = It$

② $V = \frac{E}{q}$

$E = Vq$

2. The sticker on a new hot water tank states that for an average 24 hour day with the thermostatically controlled heating elements being on for about half the time, the energy consumption is 113 MJ. If the heating elements draw 12.0 A, what is the voltage across them?

$t = 12h = 43200s$

$I = 12A$

$E = 113MJ$

$= 113 \times 10^6 J$

$V =$

$E = VIt$

$V = \frac{E}{It}$

$V = \frac{113 \times 10^6 J}{(12A)(43200s)}$

$V = 220V$

3. It takes about 336 kJ of energy to bring ~~4 cups~~ (1.0 kg) of water to the boiling point (assuming the water was at room temperature at the start.) If the electric kettle is plugged into a 115 V line and draws 13.0 A, how long will you have to wait for your cup of tea?

$E = 336 \times 10^3 J$

$V = 115V$

$I = 13.0A$

$t = ?$

$E = VIt$

$\frac{E}{VI} = t$

$\frac{336 \times 10^3 J}{(115V)(13A)} = t$

$225s = t$

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