Episode 105: Sources of electrical energy

It is worth discussing energy transfer in electric circuits and linking this by analogy to other more familiar examples.

Summary

Demonstrations: Human and lemon batteries. (10 minutes)

Discussion: Energy and work in an electric circuit. (10 minutes)

Discussion: Quantitative energy transfers. (10 minutes)

Student questions: Practice with the ideas. (30 minutes)

Demonstrations:

Human and lemon batteries

Two fun demonstrations showing that there is nothing special about the chemical substances that are needed to make a battery. The limitation is, of course, the high internal resistance of the cells.

TAP 105-1: The Human Battery

TAP 105-2: Making Electricity

Discussion:

Energy and work in an electric circuit

Show a cell connected to a lamp. The idea to get across is that charge carriers are pushed around a circuit by the emf of the cell. The charge carriers are rather like water in a hydroelectric power station - they do work (e.g. in the lamp) just as the flowing water does work in the turbo-generators. Neither the charge nor the water is 'used up' but it does lose potential energy. In the power station, water loses gravitational potential energy by moving from higher GPE to lower GPE. In an electric circuit the charge 'falls' from high electrical potential energy to lower electrical potential energy.

This can lead to the idea that a cell provides a potential difference and that charges move around the circuit from higher to lower potential (beware of signs here - negative charges 'fall' from - to + whilst positive charges would 'fall' the other way!). The greater the vertical drop in the hydroelectric station the greater the change in potential energy per kilogram of water. In a similar way, the higher the emf across a source of electrical energy the greater the change in potential energy per coulomb of charge moving between its terminals.

Discussion:

Quantitative energy transfers

The volt is defined as the energy transfer per coulomb of charge as charges move between two points in a circuit.

$V = \Delta W / \Delta Q$

i.e. energy change per unit charge (so that $1\ V = 1\ J\ C^{-1}$)

Introduce the terminology of electromotive force (voltage across a source of electrical energy) and potential difference (voltage across a component that uses electrical energy). Stress that, despite its name, emf is not a force but a voltage, measured in volts.

Kirchhoff's second law comes later, but there is no harm in preparing the way here. They will be familiar with the concept of energy conservation and this can be applied to a single charge carrier (or more simply 1 C) as it is followed around any closed loop in a circuit. The essential idea is that the total energy supplied equals the total energy used around any loop (leading to sum of emfs = sum of pds).

This leads on to the basic principle behind the chemical cells shown in the demonstrations. Different metals have different affinities for electrons. This pushes electrons from one to the other through the intervening electrolyte. The accumulation of charge on the cell terminals provides the push that drives charge carriers around the external circuit. Large emf. can be obtained by connecting cells in series. Larger currents can be drawn if they are connected in parallel.

Discuss the energy per coulomb from the human and lemon batteries and compare it with familiar AA cells.

The idea that emf is energy supplied per coulomb leads to the idea that more charge must pass through the cell to increase the energy delivered to the circuit.

$\mathbf{\Delta W = V \, \Delta Q}$

Student questions:

Practice with the ideas

TAP 105-3: Measuring potential difference

TAP 105- 1: The human battery

Apparatus

high resistance digital voltmeter

zinc sheet

copper sheet.

Instructions

Place one hand on a copper sheet and the other on a zinc sheet and measure the potential difference between them. Voltages of about 0.7 V can be produced due to the electrochemical reaction between the two dissimilar metals and the moisture of the hand.

Wash hands after touching the plates.

External references

This activity is taken from Resourceful Physics http://resourcefulphysics.org/

The Human Battery

TAP 105- 2: Making electricity

Lemon battery

Apparatus

Lemons

copper and zinc plates to act as electrodes

LED

connecting leads (crocodile clips can be used to connect to the electrodes)

high resistance voltmeter or multimeters.

Instructions:

Wear safety spectacles

Ensure you wear safety spectacles throughout this experiment. Eye protection is necessary is the electrodes are pushed into a whole lemon – a jet of juice may enter an eye. If the electrodes are dipped into lemon juice in a test tube, the internal resistance is lower and the risk is so low that eye protection becomes unnecessary.

A simple cell can be formed using two different metals (copper and zinc) embedded in an acidic electrolyte (the lemon juice). Copper coins and galvanised nails can be used. This demonstrates the simplicity of the apparatus required.

However there are some pitfalls that need to be avoided. The internal resistance of the cell is high, so minimise it by having a large area of electrodes and a small separation. Since the emf is about a 1 V, you will need several cells in series to light the LED. Do not attempt to light even a small incandescent bulb, as its resistance will be far too low compared to the internal resistance of the lemon cell, and will short it out.

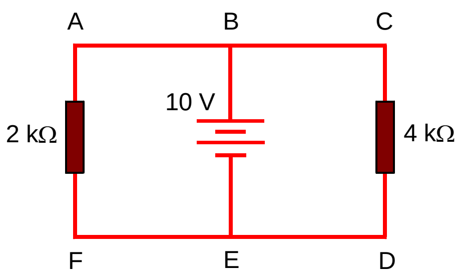
Electronic watches and other very low power consumption devices can be powered by kits based on simple cells.

External references

This activity is taken from http://www.hilaroad.com/camp/projects/lemon/lemon_battery.html

TAP 105- 3: Measuring potential difference

A pupil wants to measure the potential difference across a battery connected to a circuit:



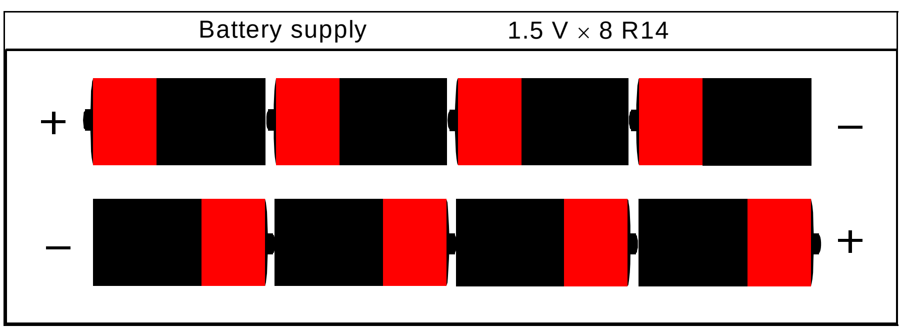
1. What instrument should he/she use?

2. The pupil notices that when the meter is put across the terminals AF, BE, CD in turn, the reading is always the same. Why is that so?

3. State and account for the voltmeter readings when placed across FE or AC.

A portable radio

You buy a new portable radio. It is powered by eight cells and there is a diagram printed on the battery chamber to show you how to fit the cells:



4. What is the total potential difference of this arrangement of cells?

5. This radio can also be connected to the 240 V ac mains supply which is far too large for this radio to be used directly. What component must be included inside the radio to change the incoming supply to 12 V?

6. Battery and mains supplies vary in potential difference. State one other significant difference.

Answers and worked solutions to measuring potential difference

1. Voltmeter
2. The answer could be ‘the pd across all parallel branches is the same’ or ‘the potential at the points A, B and C is the same (assuming the connecting leads have negligible resistance). The potentials at the three points F, E and D are equal but differ from A, B and C. Therefore the potential difference between the stated pairs must be the same.’
3. Following the argument above there is no potential difference between the specified pairs and the reading will be 0 V.
4. 12 V
5. Step-down transformer
6. Mains supply is an alternating supply; battery supplies direct current; mains supply is at 230 V, batteries usually produce much lower emf.

External references

This activity is taken from Advancing Physics Chapter 2, 30S