Physics Factsheet

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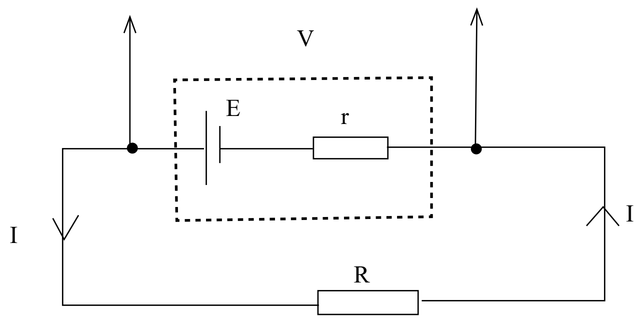
E.M.F. and Internal Resistance of a Dry Cell

We purchase dry cells labelled as 1.5 volts, 9 volts, etc., but when we use these cells, we generally find that the output voltage is considerable less than this stated value. This is because the cells are rated according to the *electromotive force, or e.m.f. (E)*, of the cell, while what we measure at the terminals is the *output voltage, or p.d. (V)*, of the cell.

The cell produces a voltage based upon the chemicals which compose the cell. This is called the e.m.f. of the cell, and we generally think of this as fixed. However, these chemicals also resist the flow of current through the cell. This is called the *internal resistance, r*, of the cell, and it causes a reduction in the voltage measured at the terminals.



From this circuit, we can see that the p.d. measured at the terminals is:

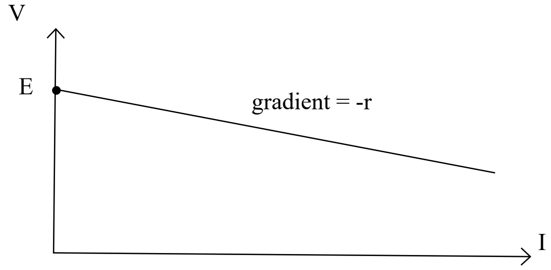
V = E – Ir

or alternatively we can write:

E = IR + Ir (where R is the external load).

We want to measure the e.m.f. and internal resistance of the cell by taking readings of output voltage, V, and current, I, for various values of current. We can see that changing the current will change the output voltage.

In theory, we should get a straight line graph with a negative gradient for V graphed against I. The y-intercept (for zero current) will give us a value for the e.m.f., E. The gradient of the graph should give us the value for the internal resistance, r.



However, as you might expect, things are not that simple.

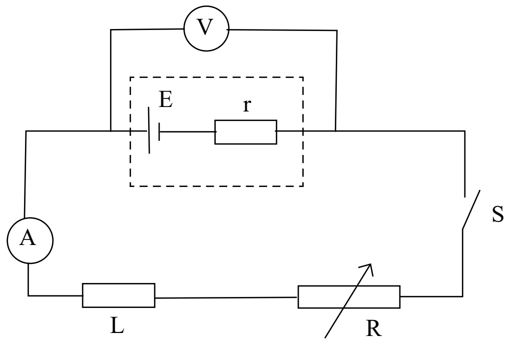
Are e.m.f. and internal resistance really constant for a dry cell?
The simple answer is no. This means that our straight line graph is not really a straight line, unless we can keep E and r constant throughout the investigation. This is not that difficult:

1. Prolonged use of the cell, especially at high current values, leads to production of gas bubbles which temporarily reduce the e.m.f. of the cell. By limiting the current and the time that the current is flowing, we can ensure that the e.m.f. of the cell is effectively a constant.

2. High current flow leads to a rise in temperature. We know that higher temperatures tend to increase resistance. So we must limit the current in order to keep the internal resistance a constant. And prolonged current flow will "run down" the cell, also increasing the internal resistance. Once again, limiting time and current is important.

3. This heating will also cause the cell to become hot (not surprisingly). This is perhaps the only real safety issue involved in this investigation. Once again, we should limit the current flow and the time for the measurements.

Our New Circuit



1. The variable resistor, R, allows us to vary the current through the circuit.

2. The fixed resistor, L, prevents high currents flowing for small values of R.

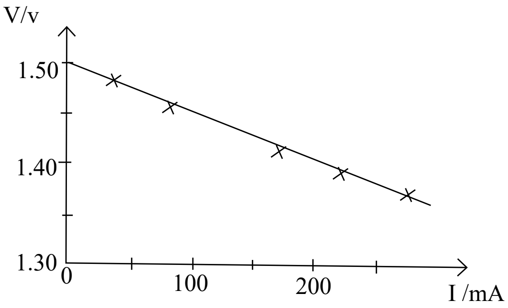
3. Switch, S, allows us to take each measurement quickly, to prevent running down the cell.

> In any investigation, we must assess what safety aspects exist (to us or to the equipment). We have identified the problems and taken steps to avoid them.

A Set of Data
A student took a set of readings for V against I (by varying the resistance, R). The voltmeter reads to 0.01 volts. The ammeter reads to 5 mA.

Terminal potential, V / V	Current, I / mA
1.37	270
1.39	220
1.42	165
1.46	75
1.49	30

The student then plotted these values on a graph, and drew the best-fit straight line:



From the graph, the y-intercept is 1.51 volts.

The gradient is – (1.48 – 1.38) / (0.250 – 0.050) = - 0.50 V/A.

From theory, we can say that the e.m.f. of the cell is 1.51 volts, and the internal resistance is 0.50 ohms.

How can we check and improve the accuracy of these results?

Without using software to work out the best fit line, we can try to draw extreme best fit lines, and see what effect this has on our values. However we could probably improve the accuracy more by taking more data points. It should then be clear whether or not the data really does follow a straight line. More data points should also make it easier to draw a more accurate best fit line.

Exam Hint: Always be ready to discuss weaknesses in the investigation in terms of accuracy and precision. In our investigation, our ammeter only reads to the nearest 5mA. But as our calculations are based on our best straight line for several readings, this lack of resolution in the ammeter becomes less important. We could take more readings to improve accuracy, and do more repeat sets of readings.

We also had concerns about the internal resistance (and possibly the e.m.f.) changing during the course of the investigation. By repeating the investigation, it should be clear whether or not this is a problem. As long as we have a value for L large enough to avoid high current flow, and we only turn on the current briefly to take each set of measurements, there should be no problem.

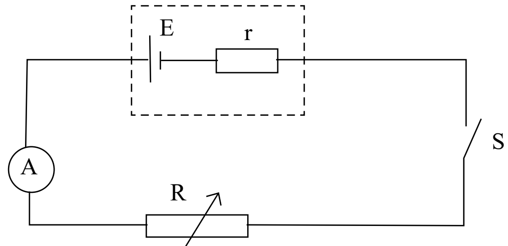
Some students are concerned that we cannot measure the different values of R that we use when we change the variable resistance. This is of no concern. We only use the variable resistor as a means of altering the current. The current and p.d. values are what we require.

In addition, when repeating the investigation, it is not necessary to repeat the exact values of current. It is the best fit line that will tell us whether our results are trustworthy.

An Alternative Method

If we look at our table of results, we notice that the output voltage readings are quite close to each other. This is a result of the internal resistance being small, and the fact we have to avoid high current flow during the investigation. Consequently the "lost voltage" across the internal resistance will be small. This leads to limits in our accuracy.

But there is a way of performing this investigation without measuring e.m.f. However, we will need to measure the values of R – this implies that we need to use a resistance box (or alternative). Often these are not available. But let us see how we could do this investigation.



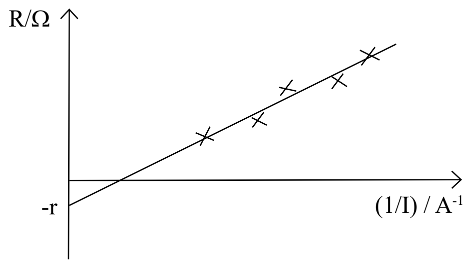
Our set-up is even simpler. We don't need the limiting resistor, L, as we will be choosing the resistance we use each time. And we don't need the voltmeter, as we won't be measuring output voltage.

This time we take a set of readings of I against R.

The theory is the same. But we rearrange our equation in a different way:

E = IR +Ir = I(R+r)
E/I = R+r
R = E(1/I) – r

Now if we plot a graph of R against 1/I, we can see that the y-intercept will give us the internal resistance, r, and the gradient will give us the e.m.f., E.



But where would the data values fall on this graph?

It must have a positive gradient (as E is a positive value), and the measured values for resistance R must also be positive. However, the y-intercept is –r (and r must also be positive). So we can predict the graph as drawn.

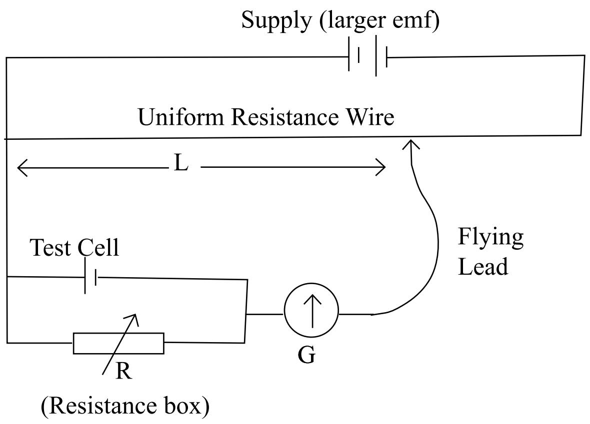
A possible set of results:

R/ohms	I/mA
5	275
10	145
20	75
30	50
50	30

At the end of this factsheet, you will be asked to determine E and r from these results.

Another Alternative Method

We shall briefly look at another alternative. It seems more complex, and just provides the same set of results, but it involves a technique which gives excellent accuracy in experimental work.



Only the bare essentials of the circuit are shown. Switches, protective resistors, etc., are omitted for simplicity. For each value of the resistance box, R, the length, L, along the resistance wire is found so that no current flows through the sensitive, centre-zero galvanometer.

The length, L, is now proportional to the terminal p.d. of the test cell. By taking pairs of readings of R and L, we can use graphical techniques again to find the e.m.f., E, and the internal resistance, r, of the test cell.

This technique means that we don't need to use either a voltmeter or an ammeter. Historically, these devices were far from perfect, and even now only expensive meters can be relied on to be accurate. This zero balance technique is thought by purists to be superior. It can be used in a variety of investigations.

Question 1

(a) For our first alternative method, redraw the table, including a third column for 1/I. When redrawing the table, change the current from milliamps to amps and include the unit for 1/I.
(b) Set up a graph for R against 1/I. Put R on the vertical axis, and ensure that values for R of less than zero ohms can be graphed.
(c) Plot the points, and draw the best straight line so that the y-intercept can be read from the graph.
(d) Find values for the e.m.f. of the cell, E, and the internal resistance of the cell, r (your values should be close to the values we found for the first method.)

Question 2

It is now possible to buy traditional cells and rechargeable cells. Find out what you can about the e.m.f. and internal resistance of various types of cell.

Answer

There are many differences between cells. Just as examples, traditional zinc-carbon cells have an e.m.f. of 1.5V, while rechargeable nickel-cadmium cells only have an e.m.f. of 1.25V. And as far as internal resistance goes, it increases slowly as a zinc-carbon cell approaches the end of its life. However with a nickel-cadmium cell, the internal resistance tends to stay the same until it gets very near the end of its life (before recharging), then suddenly increases. This means you get very little warning that the cell is about to give up the ghost.

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