AS Physics – Internal resistance investigation

I will conduct the following investigation with the aim to find the internal resistance of a lemon battery, which I will construct myself.

The variables that could affect my experiment are as follows:

- Size of lemon – I will conduct my experiment in no longer than an hour, allowing me to use the same lemon for all results
- Size of metal electrodes – I will use the exact same electrodes throughout the whole experiment
- Length of any connecting wires – I will use the exact same wires throughout my experiment and will not break the circuit once I have started collecting data
- Resistance in the circuit – I will vary this using a highly sensitive variable resistor as shown in my method.

To make my experiment fair I will only vary the most relevant variable to what I am investigating, which is the resistance in the circuit. All the other variables will be kept the same throughout the experiment as stated above.

In my experiment I will need to measure the terminal pd, V, and the Current, I (in amps), for many values of resistance, R (in Ω), I will measure these as I know that V=E-Ir so these are the values that I need to know if I am to eventually calculate the batteries internal resistance. I think that to make my graphs and conclusions accurate I will need to take at least 10 measurements, covering the full range of the variable resistor I have available to me.

To improve the accuracy of my experiment I will take my readings to the most decimal places as my voltmeter and ammeter will allow me. To do this I will need to make sure that I am using the milliamp/volt or 2 amp/volt setting on my meters. As I said before I will also do all I can to ensure that no other variables other that the one I am investigating are varied at any time during the experiment. It is hard to determine the exact resistance that a variable resistor is set at but I will try to ensure that the resistances I use are equally spread across the working range of the available variable resistor.

The apparatus that I will need available to me when conducting this investigation is:

- A Lemon
- A Zinc electrode
- A Copper electrode
- Voltmeter
- Ammeter
- Variable resistor
- Crocodile clips
- Several insulated wires
- A sharp knife

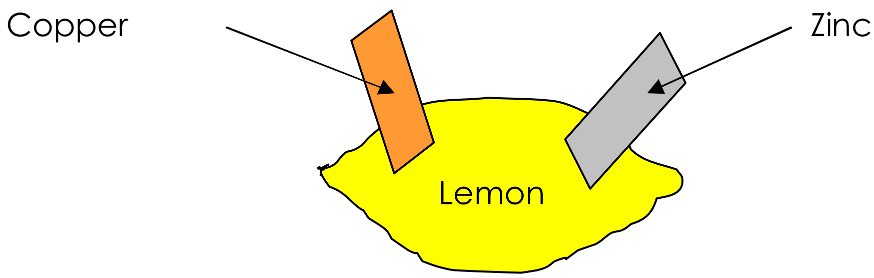
Before I begin my investigation I will need to consider the following safety aspects:

- Take care with knives when cutting the lemon
- Avoid contact of lemon juice with eyes (citric acid can irritate)
- Always handle electrical equipment with care

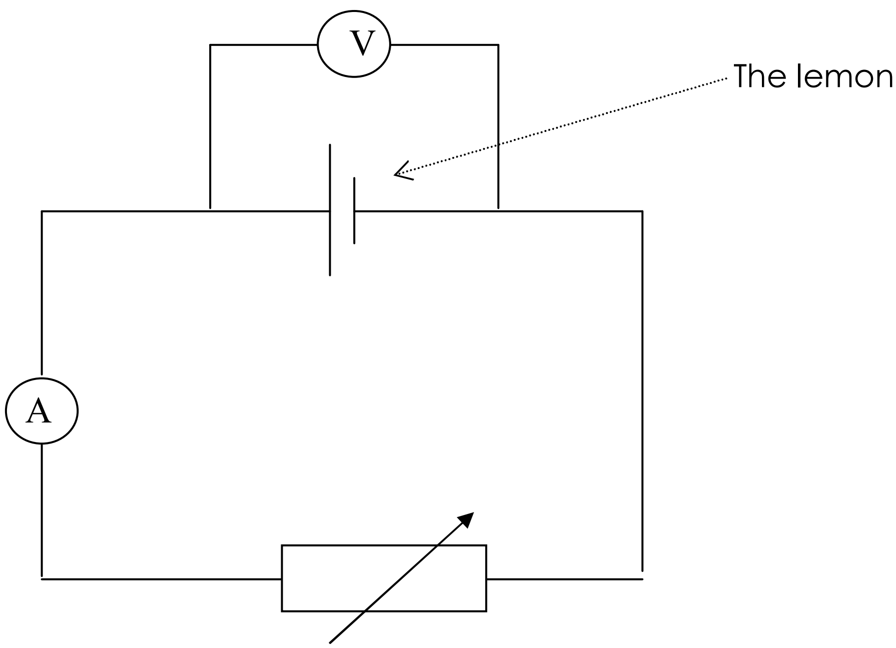
Method:

To complete my investigation I will use the following method:

1. Roll the lemon firmly on a tabletop to break up the small sacks of juice inside the lemon
2. Make 2 slits, in either side of the lemon using a knife.
3. In one slit, insert the copper electrode, and insert the Zinc electrode into the other.



4. Using crocodile clips to connect the electrodes to wires, set up the following circuit:



5. Put the variable resistor on its highest resistance setting
6. Take a reading from the voltmeter and ammeter and record these results.
7. Now change the setting on the variable resistor just slightly, to give it a slightly lower resistance, and record the new readings shown on the ammeter and voltmeter.
8. Repeat this 10 times (the variation of the resistance each time will depend on the min. and max. resistance of the variable resistor I have available)

When I have collected all my results I will need to analyse them. To find the internal resistance I will draw a graph of Volts against Amps and plot the points that I have found. I will then join these up with a line of best fit and find the gradient. If, as hoped, my method has been successful and my results are fair and accurate then the gradient should be the internal resistance of my lemon battery. If there are any apparent anomalies in my data I will do my best to detect and explain them with regard to the relevant theory.

Background theory:

Lemon batteries: A small charge can be produced by putting two dissimilar metal electrodes in either side of a lemon, and joining it into a circuit, the charge produced is small but to give the largest voltage possible the electrodes need to be largely different in electrode potential. This is why I have chosen Zinc (E°= -0.76v) and Copper (E°= +0.34) this gives a standard cell potential of: +0.34 – (-0.76)

= 1.1v

A lemon battery because the copper atoms electrons more than do the Zinc atoms, so if you bathe the two electrodes in a conductive solution (Citric acid in a lemon) and connect them externally with a wire, many electrons pass from the zinc to the copper, producing an electrical current. The reactions between the electrodes and the solution furnish the circuit with charges continually, this means that the process that produces the electrical energy continues and becomes useful. However, like any battery, this has a limited life. The electrodes undergo chemical reactions that block the flow of electricity. The electromotive force diminishes and the battery will eventually stop working.

Internal resistance: Batteries are not perfect. Use them for a while and you notice they get hot. Where is the heat from? It's from the stored energy in every battery. So batteries turn some of their available energy into heat inside themselves. Therefore, inside the cell you get some energy put IN to the circuit by the cell (an e.m.f.) some energy taken OUT of the circuit by the internal resistor (a pd)

So the pd, V, available to the rest of the circuit is:

$$V = E - Ir$$

Where: E = the e.m.f. of the cell
I = the current through the cell
And r = the value of the internal resistance

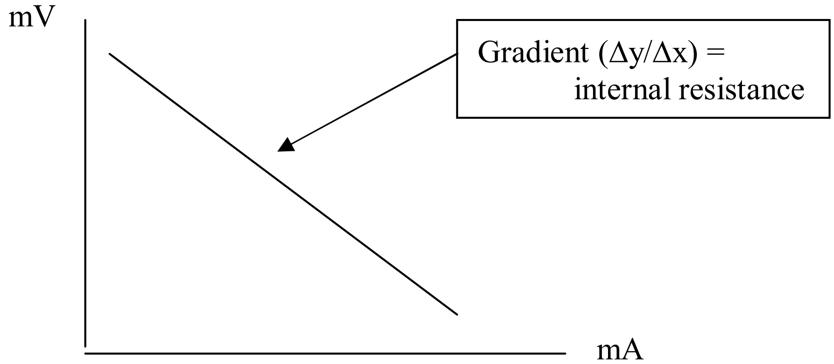
So Ir = the pd across the internal resistor

To find the internal resistance experimentally:

As V = E – Ir, if you plot a graph of terminal pd, V, against current, I, the gradient of the graph will be equal to the internal resistance of the cell.

(From www.s-cool.co.uk/asphysics)

From this information I have predicted that a graph of my results should look like this:



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Results:

Experiment 1 (mV)	Experiment 2 (mV)	Average (mV)	Experiment 1 (mA)	Experiment 2 (mA)	Average (mA)
387	388	**387.5**	0.0350	0.0345	**0.0348**
374	376	**375.0**	0.0380	0.0370	**0.0375**
368	369	**368.5**	0.0395	0.0390	**0.0393**
357	357	**357.0**	0.0410	0.0415	**0.0413**
344	345	**344.5**	0.0435	0.0430	**0.0433**
317	319	**318.0**	0.0465	0.0465	**0.0465**
285	285	**285.0**	0.0505	0.0500	**0.0503**
251	255	**253.0**	0.0550	0.0550	**0.0550**
211	212	**211.5**	0.0620	0.0625	**0.0623**
165	168	**166.5**	0.0720	0.0720	**0.0720**
106	104	**105.0**	0.0880	0.0865	**0.0873**

As you can see, I repeated my experiment 2 times and took an average of the results. This should make my graph more accurate. At this stage, I cannot see any obvious anomalous results. I noticed straight away as I was doing my experiment that as the volts increased, the amps decreased and this remained consistent throughout. I did not need to make any changes or modifications to my method during the experiment as following my pre-recorded method seemed to work just as I had planned.

Interpretation:

From my results I have used the average of each measurement to construct a graph of voltage against current (see graph) I have drawn a line of best fit and believe from the look of the graph and from the background information I collected earlier that it is a straight line. At first it appears to be a perfect straight line, it then starts to curve slightly. This is because, after a while, all batteries start to deteriorate. The electrodes undergo chemical reactions that begin to block the flow of electricity. The electromotive force diminishes and the battery stops working. Usually what happens is the production of hydrogen at the copper electrode and the zinc electrode acquires deposits of oxides that act as a barrier between the metal and the electrolyte (lemon juice). This is referred to as the electrodes being polarized.

From my straight line of best fit, I can see that as expected, as the voltage increased, the current decreased. As expected from my electrode potential calculations in my plan, the cell did not exceed its potential off 1.1v, in fact, my results were all considerably lower than this because that calculation was for a perfect experiment which is almost impossible to achieve, as impurities in the electrolyte or the electrodes and the fast rate of cell deterioration mean that a lot less current is actually produced.

As I explained in my plan (background theory section) because V = E – Ir, if you plot a graph of terminal pd, V, against current, I, as I have done, then the gradient of the graph, $\Delta y/\Delta x$, will be equal to the internal resistance of the cell. Using my line of best fit, I will now calculate the internal resistance of my lemon battery:

$$\frac{400 - 75}{0.088 - 0.033}$$

$$= \frac{325}{0.055}$$

$$= 5909.1\ \Omega$$

From this calculation I can conclude that the internal resistance of this lemon battery was 5909.1 Ω This is a very large internal resistance as the voltage produced was very high compared to the current, and means that, of the energy produced by the battery, only a small amount is put into the circuit, and a lot of energy is taken out and converted to waste heat energy. A lemon has a high internal resistance because the electrolyte (citric acid) is not a very strong acid so there will not be many free ions to carry the electrical charge through the whole lemon. Because of this, I think an electrolyte of a higher PH would have a lower internal resistance.

Evaluation:

As my graph was a straight line, with no un-explainable anomalous results, I think that my experiment went very well. The method that I devised gave accurate enough results for me to do an accurate approximation of the internal resistance and draw a conclusion. There will have been some error in my results but because I measured each result to 3 significant figures and repeated my experiment to get an average to 4 significant figures this error will have been limited to the best of my ability and the results should be exact to 4 significant figures. Next time I did this experiment I would try to use more sensitive electronic measuring devices so that I could measure the voltage and current to more decimal places and further reduce the margin of error and improve the detail of my conclusion.

The only other problem I had with my experiment was the slight curve in my graph due to the deterioration of the battery as I was collecting my results. I could have avoided this by taking my results more quickly so the battery had less time to deteriorate and repeating the experiment more times to get a better average. This deterioration must have also greatly affected the margin of error in my experiment so I should have really thought about this more before I started taking my results.

Because the battery deteriorates so quickly, this limits the amount of time that you can collect data without the results becoming more inaccurate, so repeating my experiment twice with the same lemon and electrodes probably also limited the accuracy of my experiment.

Next time I would take more results more quickly and be more organised to make my results and conclusions more accurate. I could also investigate this topic further by using different substances for my electrolyte like different fruit juices or acids. I could also try using different materials for the electrodes and see how that affected the internal resistance

I have completed my aim to find the internal resistance of my self-constructed lemon battery and found the internal resistance to be 5909.1 Ω.