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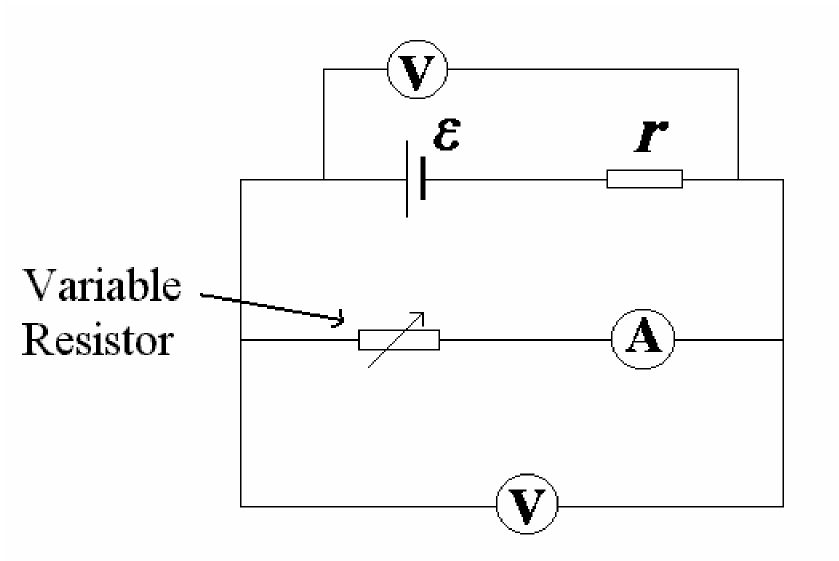
Measuring the e.m.f. And Internal Resistance of a Cell

Planning

I wish to find out the electromotive force (e.m.f.) and Internal Resistance of a direct current battery cell.

Circuit Diagram



1. Set up apparatus as shown.
2. Use ammeter to adjust variable resistor to vary of currents.
3. Read voltmeter value and record.
4. Disconnect circuit and take e.m.f reading from voltmeter across cell.
5. Repeat for another 9 resistor settings. Use variable resistor and ammeter to adjust the set up to get a range of 0.1 to 1.0A.
6. Repeat entire experiment to get more accurate average.

Safety Aspects

1. Do not have circuit connected up for too long, this will run the battery down and may cause it to heat up and maybe explode.
2. Wear safety goggles and lab-coats during experiment.
3. Follow standard laboratory safety procedures.

Apparatus

0 – 1.0A analogue ammeter
2 digital voltmeters
1 variable resistor
1 cell
8 connecting wires.
Safety goggles and lab-coat
Paper and pen

Arranging Evidence

Results

Current (Amps)	Potential Difference (V)			
	1	2	3	Average
0.1	1.46	1.47	1.46	1.46
0.2	1.42	1.42	1.41	1.42
0.3	1.36	1.39	1.36	1.37
0.4	1.33	1.33	1.33	1.33
0.5	1.27	1.29	1.28	1.28
0.6	1.24	1.23	1.23	1.23
0.7	1.18	1.19	1.20	1.19
0.8	1.13	1.15	1.14	1.14
0.9	1.10	1.09	1.11	1.10
1.0	1.04	1.03	1.06	1.04

Using these results I will be able to draw a graph to find the e.m.f. and the internal resistance of the cell.

Calculating Internal Resistance

The current is the same in any part of the circuit and the electromotive force = the sum of the potential differences.

$$\varepsilon = I R + I r$$

Since voltage = Current x Resistance and can be substituted into the above equation. ∴ $\varepsilon = V + I r$ Rearrange to get: $V = -r I + \varepsilon$

This equation is now in the form **y = m x + C**

This means that; **y** is the terminal voltage
m is the negative internal resistance
x is the current
C is the e.m.f.

Since the gradient is the change in y divided by the change in x, this is the terminal voltage divided by the current, therefore if the gradient of the best-fit line is found this is the value of internal resistance.

Gradient of best fit line = $\frac{\Delta y}{\Delta x} = -\frac{0.43}{0.92} = -0.47\ \Omega$(2dp)

However there is an error in the gradient, which can be calculated as shown:

Gradient of max^m line = $\frac{\Delta y}{\Delta x} = -\frac{0.38}{0.78} = -0.49$ (2dp)

Gradient of min^m line = $\frac{\Delta y}{\Delta x} = -\frac{0.425}{0.95} = -0.45$ (2dp)

$$\Delta m = \frac{m_{max} - m_{min}}{2} = \frac{0.487 - 0.447}{2} = \frac{0.040}{2} = 0.02 \text{ (2dp)}$$

∴ Gradient (m) = -0.47 ± 0.02

Since $V = -r I + \varepsilon$ and for a straight-line graph y = m x + C. The negative gradient must be the internal resistance.

∴ If m = -0.47 ± 0.03

Therefore Internal Resistance of the cell = 0.47±0.02Ω

Calculating e.m.f. Using the Graph

According to Kirchhoff's second law:
"*The algebraic sum of potential differences around a closed circuit is zero*"

This means the current is the same in any part of the circuit and the electromotive force = the sum of the potential differences.

$$\boldsymbol{\varepsilon = I\,R + I\,r}$$

Since voltage = Current x Resistance and can be substituted into the above equation.

$\therefore$ $\qquad$ $\boldsymbol{\varepsilon = V + I\,r}$

Rearrange to get: $\qquad$ $\boldsymbol{V = -r\,I + \varepsilon}$

This equation is now in the form $\qquad$ $\boldsymbol{y = m\,x + C}$

This means that; **y** is the potential difference
m is the negative internal resistance
x is the current
C is the e.m.f.

Therefore, if the equation of the line can be found then the e.m.f. can also be found. By using the results from the gradient calculations I know that the gradient is –0.47 ± 0.03. If I use a pair of co-ordinates that lie on the line I can find the constant value, C, using the equation $\boldsymbol{y - y_1 = m\,(x - x_1)}$.

Using co-ordinates (0.2,1.415)

$$y - 1.415 = -0.47\,(x - 0.2)$$
$$y - 1.415 = -0.47x + 0.094$$
$$y = -0.47x + 1.509$$

This means that C must equal 1.51 (3sf).

To find the error in this value I substituted the gradients and a set of points for the minimum line and maximum line in to the equation **E = Ir + V.**

For the maxm line: $\quad E = 0.86 \times 0.49 + 1.1$
$E = 1.52$ (3sf)

For the minm line: $\quad E = 1.0 \times 0.45 + 10.5$
$E = 1.50$ (3sf)

The difference between these two values and the values calculated is 0.01.

Therefore the electromotive force of the cell = 1.51±0.01V(3sf)

Evaluating Evidence

These were the possible sources of error:

- As I was using an analogue ammeter the needle that is used to read the values off is slightly higher than the actual scale so to enable a completely accurate reading you have to look directly down at it. This is called a parallax.
- The ammeter also only read to the nearest 0.02 of an Amp, which is an error of $\pm$ 0.01A.
- The digital voltmeter only read to the nearest 0.01 of a Volt and so had an error of $\pm$ 0.005V.
- The voltmeter also jumped from value to value so the second decimal place was not always reliable.
- There could also have been a systematic error on either of the meters in that there was a zero error, which would lead to all the readings taken to be out by that error amount. I checked this and there was no error as far as I could see.
- I may have taken too long to take the reading and allowed the cell to run down slightly each time. This would mean that the e.m.f. value would not be constant throughout the experiment.
- The greatest error occurred in the ammeter since it only read to the nearest 0.02 of an Amp. This is an error of $0.02 \div 1 \times 100 = 2\%$ which is very significant.

There appeared to be no great variance in the potential difference values obtained and they were all along the best-fit line. The repeat readings only had variations of around 0.01 of a Volt. The only reading that is slightly anomalous is the reading taken from the second set of results at the 0.3A current. This was 0.03 Volts out from the other, but this difference is negligible.

I am happy with the values that I have obtained from this experiment; I found no major discrepancies between the expected results and the experimental evidence. I feel that the results and conclusions are accurate to the standard I was trying to achieve and so can be taken as reliable since the techniques were accurate though not always suitable.

The technique used to perform this experiment was sufficiently accurate for this investigation. However the suitability of the techniques was doubtful. It was very difficult to get an accurate reading at a precise point because the meters kept flickering between readings. Although the ammeter could have been more accurate by having a smaller error and it may even be more precise if two or even three people were to perform the experiment together. One to turn the circuit on and off, one to take the voltmeter reading and one to take the ammeter reading. This way there is no loss of accuracy due to the time delay between taking readings that is caused by the operator.

As the technique used was very accurate and precise, this made the conclusions drawn also very accurate. Although there may have been a human error made when drawing the best-fit, maximum and minimum lines on the graph and reading the results off accurately.

To confirm my final value of e.m.f. I found the e.m.f. of the cell in the circuit each time I took a reading. These were the results.

Current (Amps)	E.M.F. taken from Voltmeter			
	1	2	3	Average
0.1	1.50	1.51	1.51	1.51
0.2	1.51	1.51	1.50	1.51
0.3	1.51	1.52	1.50	1.51
0.4	1.50	1.51	1.50	1.50
0.5	1.52	1.50	1.50	1.51
0.6	1.51	1.50	1.50	1.50
0.7	1.50	1.50	1.50	1.50
0.8	1.49	1.50	1.49	1.49
0.9	1.50	1.49	1.48	1.49
1.0	1.48	1.49	1.48	1.48

These show that the e.m.f value is actually around 1.50V, compared with my final result of 1.51V. This shows that the techniques appear to be very accurate and precise. This table also shows that at times the value overlaps the result I found which adds weight to the conclusion that my answer is accurate.