Coursework To Find The Internal Resistance Of A Power Supply

The electrical supply on satellites needs to be kept at a constant voltage and the lost volts need to be taken into account when drawing different currents.

Aim

The aim of this investigation is to find the internal resistance of a power supply and to see if this value changes at five different voltage settings. Using a variable resistor to vary the load resistance at different voltage settings and obtaining both ampere and voltage readings and then plotting graphs of terminal potential difference against current to find the different values for the internal resistance of the power supply.

Theory

We can investigate the internal resistance of a power supply by setting up a circuit such as the one shown in figure 1. The voltmeter is connected in parallel to measure the potential difference across the power supply and the ammeter is connected in series to measure the flow of current.

We would connect the voltmeter across the terminals of the power supply. The variable resistor is used to vary the load resistance to gain a series of values for current and corresponding voltmeter readings. Given that the power supply supports ohms law, potential difference is proportional to current under constant physical conditions. Due to this relationship, a graph of current (amps) against terminal potential difference (volts) can be drawn which can be used to work out the internal resistance of the cell. This has been shown in figure 2.

In figure 2, he power supply in the circuit is supplying a current (amps) to the external circuit. The internal resistance (r) of the power supply is constant provided that temperature of the equipment is constant. The current in the circuit increases as the load resistance is reduced, resulting in the terminal potential difference across the power supply to fall. In order to understand why there is a drop in terminal potential difference, we need to consider the idea of internal resistance. Any power supply will have internal resistance because of the material it is made from. This material (conductor), under normal circumstances will have resistance, also called internal resistance (r). The internal resistance of the power supply obeys Ohm's law, which states that for an ohmic conductor the potential difference is proportional to current.

Therefore as a current flows through the circuit, there is a drop in potential difference across the internal resistance, which is called the lost volts. The potential difference across the power supply is known called the terminal potential difference (Ir). From Kirchhoff's second law we know that:

$$E = IR + Ir \qquad (1)$$

Where E is the Electromotive Force (EMF) of the power supply, maximum energy per unit charge that the power supply can deliver.
R is the external (load) resistance.
And I is the current flowing through the circuit.

We know that:

$$V = IR$$

This equation can be substituted into equation (1) to give us the equation:

$$\text{EMF} = \text{terminal potential difference} + \text{lost volts}$$

$$E = V - Ir \qquad (2)$$

Using this equation, we know that the internal resistance of the power supply is constant. As the current flowing through the power supply increases, the lost volts will increase. If the current decreases, then the lost volts also decreases until the current is zero. At this point, the potential difference across the terminals of the power supply will be equal to its EMF. This can also be seen in figure (2).

We can plot a graph of current (amps) against potential difference (volts) using the voltage and current figures as the load resistance is increased. We can use equation (2) and rearrange it in the form $y = mx + c$:

$$V = E - Ir$$

$$V = -Ir + E$$

$$y = mx + c$$

Therefore the gradient (m) is the internal resistance,-r, and the y-intercept is the Electromotive Force (E).

Safety Precautions:
As we are using mains electricity, we must make sure that no water should come in contact with the equipment which could damage the circuit and cause the fuse to blow. The work surface will be cleared of clutter before beginning experiment to make sure that the equipment is stable. When connecting and disconnecting equipment, I will turn of the power pack to avoid electrocution.

Variables that could affect my experiment:
The temperature of the power pack will affect the results obtained. If the power pack were at a low temperature, then its internal resistance would be less compared to a warmer power pack where its internal resistance will be higher. The greater internal resistance occurs since the temperature of the power pack (the components inside the power pack that transforms the mains voltage) increases because in the metal components there are positive ions which collide with electrons that are flowing around the circuit. As a result the electrons loose energy. As the metal components temperature increases, the positive ions vibrate more and as a result there are more collisions and more resistance to motion. In order to maintain the same, constant, temperature of the power pack, it will be switched on to take the results and then

switched off. I will use direct current in my experiment and as a result, the voltage being delivered by the power supply will fluctuate slightly and therefore a completely accurate reading from the voltmeter will not be able to be taken. In my calculations, I assumed that there is negligible resistance in the wires of the circuit, but this could increase if the power supply was switched on continuously for a long period of time.

Measurements and Readings That Will Be Taken:
I will measure the length of the metal rail and split the length into eight different sections. Readings of voltage and current will be taken from the voltmeter and ammeter.

Which Variables Will Be Changed and Which Kept Constant:
The variable resistor will be used to change load resistance in the circuit by moving the sliding contact along in order to record several values of current and potential difference to enable me to find the internal resistance of the power supply. The internal resistance of the power supply will be kept constant by keeping its temperature constant through all tests; this will be achieved by turning on the power supply for a small period of time to take the voltage and ammeter reading and then switching it off again to let it cool. The load resistance will be increased uniformly by moving the contact in the potentiometer across 2cm seven times and therefore current readings will decrease. Therefore load resistance and as a result current in the circuit was varied. I did this by marking seven points along the bar of the variable resistor and I moved the variable resistor to each of these points, with my first reading starting from the end of the variable resistor. Figure 3 below illustrates how I did this:

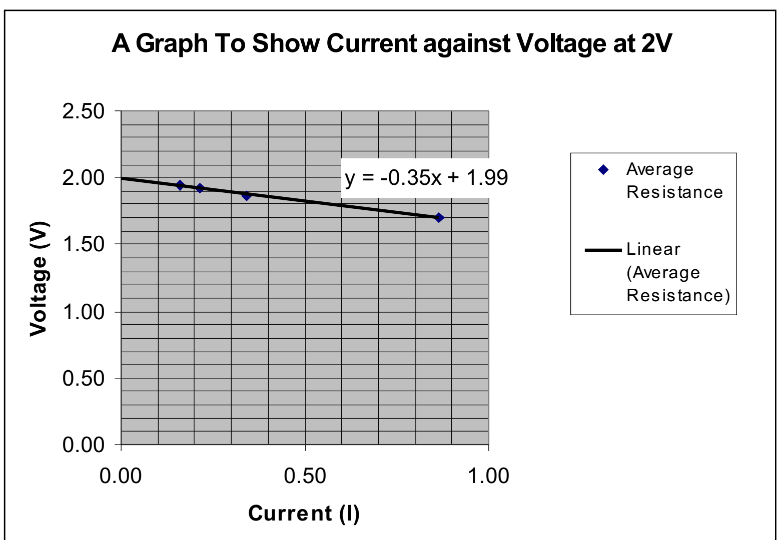
Prediction:
I predict that as the internal resistance of the power supply will increase as the voltage setting is increased and there will be a greater voltage drop across the power supply as the voltage setting in increased.

Plan of Action:

Day	Plan Of Action
Friday periods 2&3	Collect and process preliminary data
Friday periods 1&3	Modify equipment and collect data
Friday periods 2&3	Collect and process data

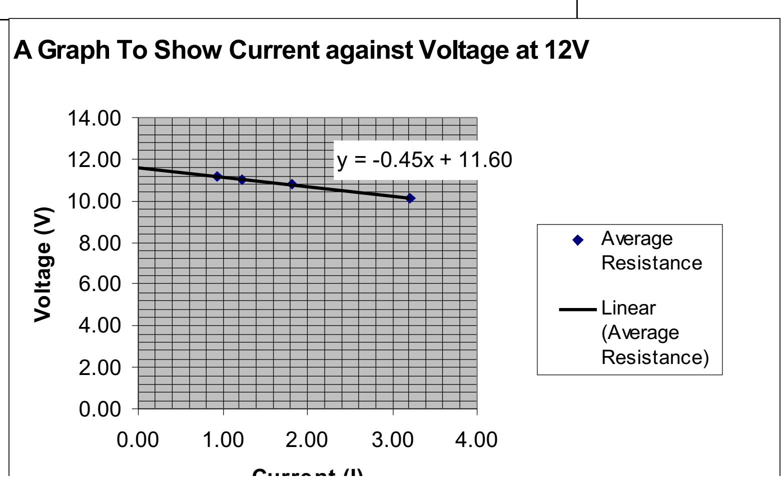
Preliminary Experiment:
In my preliminary experiment I used the apparatus as shown on the next page in figure 4. I turned the power supply on, set at two volts and increased the load resistance by moving the bow contact further along the metal rail slightly. After each slight increase in resistance, the reading on the voltmeter and ammeter were recorded. I recorded these readings at four different load resistances. I repeated the experiment at each voltage setting three times. The voltage settings used were: 2V, 4V, 6V, 9V and 12V. For this experiment I used a long rheostat which I expected to give me smaller increases in current.

I was expecting that the internal resistance of the power supply, i.e. the gradient of the plotted results would all be constant. But as you can see from graph 1 and graph 2 below, the internal resistance of the power supply ranges from 0.35Ω at minimum voltage setting of 2V to 0.45 Ω at maximum voltage setting of 12V. These results especially show that there must be something wrong with my procedure which gives me a range of 10Ω which goes against my theory. These problems have been outlined below.



Graph 1

Graph 2



Problems experienced with preliminary experiment:
The results I obtained were not very reliable because the current increases and voltage decreases were fairly large that an accurate graph of current against voltage could not be plotted. Only four current and voltage reading were taken at each voltage setting on the power supply which meant that a small range of results could be plotted on a graph. Therefore the gradient can not be seen as being very reliable. I used a long rheostat which meant that I had to move the bow contact along the metal rail by a large amount; this resulted in a fairly large change in the current and potential difference readings. All readings were taken in succession, starting with two volts and finishing on twelve volts. During this time the power supply was continuously running which meant that the mechanism inside could have heated up as the experiment proceeded. This could have resulted in the internal resistance of the power supply to rise slightly.

Changes Made To Preliminary Experiment:
My preliminary results showed me that there was a problem with the quality of connection throughout the circuit which gave me inaccurate readings. As a result, I changed and replaced the equipment used and then retested the circuit until the potential difference value was as close to the EMF set on the power supply and the current reading was low at the lowest load resistance setting. These circuit components were used in my final experiment to give me the most reliable and more accurate results due to the connections being better. I decided not to change the resistance setting on the rheostat while the power pack is continuously running but in order to maintain the same, constant, temperature of the power pack, it will be switched on to take the results and then switched off. I will now use a shorter rheostat so to give me a greater change in current as the bow connector is moved along the metal rail slightly. I am also going to increase the range of the results gathered and I will record the voltage and current readings at eight different resistance settings which will enable me to plot more points on the graph and therefore will give a more accurate line of best fit (or value for the internal resistance of the power supply).

Improved Method:
I am going to take eight readings of potential difference of the power supply and the current flowing through the circuit at each voltage setting. Each of the eight readings will be taken after increasing the load resistance slightly. A voltmeter will be connected in parallel with the power supply and the ammeter and variable resistor will be in series. The power supply will be set at the lowest voltage, 2V to begin with and the variable resistor set at one end, then the power supply will be switched on and the voltage and current readings will be recorded. The power supply will then be switched off. The resistor will then be moved up slightly and the same procedure will begin until results of V and I have been taken for eight increasing resistance settings. This procedure will then be followed for power supply voltage set at 4V, 6V, 9V and 12V. The apparatus will be set up as shown in the diagram below:

How Accuracy Will Be Increased:
I am going to repeat the experiment at each of the eight different resistance setting three times at each voltage. This will give me more reliable results because the more times the experiment is repeated, the more reliable it will get. I feel that three repeats will be adequate to give me reliable results. I am going to use eight resistance settings to give me a fairly large range for current. This will give me more point to plot on my graph of current against voltage and therefore a more accurate line of best fit can be produced to give me a more reliable value for the internal resistance (gradient) on the power supply. The voltmeter and ammeter used were accurate to two decimal places, so giving me more accurate results which when used in my graph, will give me a further more accurate line of best fit.

Sensitivity considered:
Sensitivity is the reaction to change, therefore maximum sensitivity is the biggest reaction possible to a very small change. In the circuit in figure 1, there would be a large change in potential difference across the power supply to a small change in internal resistance and load resistance of the circuit which would be brought on by a slight change in temperature. A small change in temperature of the power supply as well as the connecting wires may result in the current being reduced dramatically and as a result unreliable and inaccurate results would be recorded. To reduce this effect of voltage and ammeter readings being affected by a significant amount to a small change in temperature, I will conduct the experiment at room temperature and I will aim to keep the equipment at this temperature throughout. I know that the longer the power supply is running for, the hotter the equipment will become because more collisions have occurred between electrons and the lattice structure of the wires. The power supply will be switched on to note down the readings and then switched off to cool for thirty seconds and the process will then go on. This will ensure that the temperature of all the components will be kept constant and that no temperature change can occur.
The connection between components can affect both ammeter and voltmeter reading significantly as I learnt from my preliminary experiment; a small gap between contacts can result in a large reduction in the flow of current and results would be inaccurate. To avoid this problem, connecting wires will be pressed well into connections and once the circuit has been set up, the wires will not be disturbed in order to avoid connections becoming loose.

Procedure for Data Collection:
Before beginning the experiment, tables were drawn up so to aid and quicken the process of taking down readings. During data collection I paid due notice to the readings being taken and recognised a clear trend in the voltmeter and ammeter readings. The trend was that as the load resistance was increased slightly, the voltmeter readings went down and the ammeter readings went gradually higher. I was methodical in data collection as I recorded the readings for the lowest voltage setting first, repeating the experiment at each voltage three times before increasing the voltage setting.
I will study the data as it is collected and I will look for any results that appear to be anomalous. The anomalous results will not be used when calculating averaged and further repeats will be done if necessary.

Results

Setting 2V	Voltage$_1$ (volts)	Voltage$_2$ (volts)	Voltage$_3$ (volts)	Average Voltage (volts)	Current$_1$ (amps)	Current$_2$ (amps)	Current$_3$ (amps)	Average Current (amps)
1	1.96	1.95	1.97	1.96	0.11	0.11	0.11	0.11
2	1.94	1.94	1.93	1.94	0.18	0.19	0.18	0.18
3	1.93	1.91	1.92	1.92	0.30	0.32	0.29	0.30
4	1.87	1.89	1.86	1.87	0.44	0.40	0.43	0.42
5	1.83	1.84	1.83	1.83	0.55	0.54	0.55	0.55
6	1.81	1.78	1.80	1.80	0.73	0.69	0.68	0.70
7	1.73	1.70	1.76	1.73	0.88	0.84	0.82	0.85
8	1.67	1.63	1.69	1.66	1.20	1.60	0.96	1.08

Setting 4V	Voltage$_1$ (volts)	Voltage$_2$ (volts)	Voltage$_3$ (volts)	Average Voltage (volts)	Current$_1$ (amps)	Current$_2$ (amps)	Current$_3$ (amps)	Average Current (amps)
1	3.95	3.96	3.95	3.95	0.22	0.22	0.22	0.22
2	3.91	3.92	3.92	3.92	0.39	0.38	0.39	0.39
3	3.89	3.90	3.89	3.89	0.53	0.53	0.52	0.53
4	3.86	3.86	3.85	3.86	0.69	0.69	0.67	0.68
5	3.78	3.78	3.77	3.78	0.89	0.89	0.89	0.89
6	3.70	3.69	3.69	3.69	1.13	1.14	1.14	1.14
7	3.58	3.62	3.57	3.59	1.46	1.47	1.46	1.46
8	3.43	3.47	3.41	3.44	1.90	1.71	1.83	1.81

Setting 6V	Voltage$_1$ (volts)	Voltage$_2$ (volts)	Voltage$_3$ (volts)	Average Voltage (volts)	Current$_1$ (amps)	Current$_2$ (amps)	Current$_3$ (amps)	Average Current (amps)
1	5.73	5.75	5.73	5.74	0.28	0.27	0.28	0.28
2	5.72	5.70	5.66	5.69	0.48	0.48	0.47	0.48
3	5.67	5.67	5.60	5.65	0.69	0.69	0.69	0.69
4	5.63	5.62	5.56	5.60	0.88	0.88	0.88	0.88
5	5.53	5.53	5.48	5.51	1.12	1.13	1.11	1.12
6	5.44	5.40	5.38	5.41	1.54	1.51	1.53	1.53
7	5.17	5.17	5.23	5.19	1.98	2.01	2.03	2.01
8	4.97	4.92	4.94	4.94	2.73	2.81	2.76	2.77

Setting 9V	Voltage$_1$ (volts)	Voltage$_2$ (volts)	Voltage$_3$ (volts)	Average Voltage (volts)	Current$_1$ (amps)	Current$_2$ (amps)	Current$_3$ (amps)	Average Current (amps)
1	8.60	8.67	8.64	8.64	0.36	0.36	0.36	0.36
2	8.45	8.50	8.48	8.48	0.61	0.61	0.62	0.61
3	8.40	8.43	8.40	8.41	0.89	0.89	0.89	0.89
4	8.30	8.33	8.28	8.30	1.23	1.23	1.21	1.22
5	8.16	8.19	8.18	8.18	1.75	1.75	1.74	1.75
6	7.97	8.01	8.03	8.00	2.41	2.38	2.34	2.38
7	7.72	7.72	7.84	7.76	3.15	3.03	3.01	3.06
8	7.38	7.33	7.38	7.36	4.15	3.93	3.97	4.02

Setting 12V	Voltage$_1$ (volts)	Voltage$_2$ (volts)	Voltage$_3$ (volts)	Average Voltage (volts)	Current$_1$ (amps)	Current$_2$ (amps)	Current$_3$ (amps)	Average Current (amps)
1	11.26	11.28	11.32	11.29	0.63	0.64	0.64	0.64
2	11.19	11.22	11.20	11.20	1.01	1.02	1.02	1.02
3	11.00	11.05	11.08	11.04	1.36	1.37	1.38	1.37
4	10.94	10.92	10.98	10.95	1.82	1.82	1.82	1.82
5	10.78	10.78	10.80	10.79	2.36	2.39	2.39	2.38
6	10.54	10.55	10.58	10.56	3.02	3.01	3.01	3.01
7	10.31	10.29	10.21	10.27	3.96	4.02	4.13	4.04
8	9.56	9.54	9.00	9.56	5.45	5.30	5.97	5.57

In table 1, I have processed my data and shown the internal resistance of the power supply at the different Electromotive Force (EMF) settings. The EMF values have been gathered from where the average gradient line crosses the y-axis in graphs 3 to 7. The point at which the average gradient line crosses the y-axis shows the maximum energy per unit charge that the power supply can deliver which has been extrapolated from the results by extending the average gradient line. The internal resistance values have been got from the average gradient values in graphs 3 to 7 and then a mean average value has been calculated. The lost volts show the voltage drop across the power supply at the minimum load resistance setting and have been calculated by taking away the minimum potential difference from the EMF value at the five different voltage settings.

EMF (volts)	Internal Resistance (ohms)	Average Internal Resistance (ohms)	Lost Volts (volts)
2.00	0.31		2.00-1.66=0.34
4.05	0.33		4.05-3.44=0.61
5.86	0.33	0.33	5.86-4.94=0.92
8.72	0.33		8.72-7.36=1.36
11.55	0.34		11.55-9.56=1.99

Table 1

Accuracy of Readings:

I have used values in my table and also in my graph which are to an accuracy of two decimal places. This is because the readings obtained from the voltmeter and ammeter was also to an accuracy of two decimal places. As a result, when calculating the average voltage and average current readings from the three different repeats for the eight resistance settings, the values cannot be any more accurate than two decimal places. Using figures accurate to more decimal places then the original figures would mean that the value is more inaccurate and therefore the results would be less reliable. The voltmeter and ammeter both read to an accuracy of ±0.005V or ±0.005A as stated in their manuals. The digital ammeter and voltmeter were very sensitive and the fluctuating power supply (direct current) and they were very sensitive to these very small fluctuations in current, and as a result, the values being displayed were fluctuating.

The procedure I used enabled me to repeat the experiment, which I did three times for the five different voltage settings and this enabled me to record then calculate more accurate average potential difference and current values. From graphs 3 to 7, we can see that the points lie close to the line of best fit showing that my results follow a definite trend in that as the current increased due to a decrease in load resistance and the potential difference reduced as a result.

Error Analysis

During the collection and processing of my data, I have encountered various parts to have a certain degree of accuracy. One area where errors were encountered was when reading the voltmeter and ammeter. This was because when reading the values shown as load resistance was increased slightly, the values fluctuated by about ±0.02 volts or amps from the value that was noted down. Therefore the error in reading the digital ammeter and voltmeter needs to be taken into account as forming part of the errors.

Also the ammeter and voltmeter used gave me readings to two decimal places and therefore the errors associated with the accuracy of the reading would be ±0.005 volts or amps because the digital ammeter and voltmeter rounded the values to two decimal places.

There would also be errors in the voltage and ammeter readings as a result of the wires used in the experiment heating up as the experiment went on. But I can say that this error was reduced significantly by switching the power supply off after each reading was taken, resulting in the wires and also the power supply staying cooler. The size of this error can be seen when looking at my results graphs, which show that there has only been an increase in internal resistance from 0.31Ω at the lowest setting of 2V to 0.34Ω at the highest setting of 12V. As a result of such a slight increase of 0.03Ω (0.34Ω – 0.31Ω) in internal resistance, I can say that the error due to the temperature of the equipment was largely negligible.

Error in:-	Error	Total Error
Fluctuating ammeter readings	±0.02A	±0.03A
Accuracy of ammeter readings	±0.005A	
Fluctuating voltmeter readings	±0.02V	±0.03V
Accuracy of voltmeter readings	±0.005V	

I can use these errors and calculate the maximum and minimum values for voltage and current and then plot them on a graph to give two lines, one showing the maximum gradient (i.e. the maximum internal resistance) and the other showing minimum gradient (i.e. the minimum internal resistance). I can use another method for finding the error in the internal resistance of the power supply, which is by doing it graphically. I can plot two more lines on my results graphs. By plotting a line from the y-axis at the EMF of the power supply to the point along the line of best which gives the maximum gradient, it also shows the maximum internal resistance of the power supply. To find the minimum internal resistance, I plot a line from the y-axis at the EMF of the power supply to the point along the line of best fit which gives me the minimum gradient.

To see whether the errors in the internal resistance of the power supply were significant, I have plotted the maximum and minimum gradients on all my results graphs. I can then use the gradients to work out the error in the gradient. The steps below show how I did this:

From Graph 4 we can see that the maximum gradient is -0.32 (0.32Ω) and the minimum gradient is -0.27 (0.27 Ω). We can use these values to calculate the error in the internal resistance of the power supply at setting 2V. If we take away the minimum internal resistance from the maximum internal resistance and then divide the value by two, then this will give me a value half way between the maximum and minimum internal resistance, i.e. the error in the internal resistance of the power supply. To do this we can use the equation (3):

Error in internal resistance = (MAX internal resistance – MIN internal resistance) ÷ 2
= $(MAX_{Ir}-MIN_{Ir}) \div 2$

The table below shows the errors in the internal resistance of the power supply at the five different voltage settings:

Voltage Setting (V)	Gradient	$MAX_{Ir}-MIN_{Ir}$	Error in internal resistance (Ω)
2	0.31	(0.32-0.27)/2	±0.03
4	0.33	(0.45-0.28)/2	±0.09
6	0.33	(0.43-0.29)/2	±0.07
9	0.33	(0.39-0.22)/2	±0.09
12	0.34	(0.37-0.32)/2	±0.03

The errors in the internal resistance of the power supply are fairly large when compared to the small value of internal resistance. The error in the internal resistance is almost as much as one tenth of a volt which is a significant value when comparing it to the small values of the gradient (average internal resistance). The errors in my readings must be the cause of the final error in the internal resistance of the power supply being fairy large. Therefore I can say that my method was to blame for my results having such a large error and therefore my experiment needs to be improved further by using improved techniques or equipment to reduce the errors in my readings. I conclude by saying that such large errors in the internal resistance of the power supply has resulted in value being inaccurate rather than being unreliable.

<u>Analysis</u>

From the graphs we can see that my predictions matched my results. As the current increased, so did the lost volts as shown in the graphs. The internal resistance of the power supply increased slightly as the voltage setting on the power supply was increased. This would have been due to the increasing voltage settings, which means that more current is drawn from the power supply resulting in an increasing amount of electrical energy being lost as heat. As more electrical energy passes through the power pack, more is wasted as heat. Therefore as the lab pack heats up, its resistance increases. This is because more electrons move within the power supply, they collide with the positive ions of the lattice. Kinetic energy from the electrons is now lost to the positive ion, which then increases its vibration energy and therefore the temperature of the power supply increases. From my graphs we can see that there is a fairly clear trend that as the load resistance is increased, the potential difference drops while current passing through the circuit also drops. Therefore the current drawn from the power supply can be varied by changing the external or load resistance.

If we look at table 1, we can see that the lost volts increase from 0.34V to 1.99V as the voltage setting is increased. A reason for this is because more electrical energy is changing to heat (wasted) energy at higher voltages and as a results there is an increase in voltage loss.

Looking at the graphs we can see that the internal resistance at 2V was 0.31Ω which then increased to 0.33 Ω and stayed the same at 6V, 9V but it then increased to

0.34 Ω at 12V. We can clearly see that the range for the internal resistance of the power supply for the five different voltage settings was 0.03 Ω (0.34 Ω – 0.31 Ω). The internal resistance of the power supply at the five different voltage settings was very similar, as shown from the graphs. This value had risen as the voltage settings increased because gradually more electrical energy was flowing through the power pack which would have lead to it heating up as the experiment went on and therefore there would have been more collisions between electrons and ion lattices so increasing the internal resistance.

In more depth, as the voltage setting was increased, the electrons flowing through the power supply in the circuit were given more kinetic energy. The electrons move within the metal and collide with the positive ions of the lattice. These electrons then transfer the higher kinetic energy (compared with lower voltage settings) to the positive ion and increase its vibrational energy. Now that the power pack is heated, the positive ions now vibrate over a greater sphere of influence and thus electrons have a greater chance of hitting the ions. As the voltage was increased, more electrons hit these ions slowing their progress and increasing the resistance to motion through the power supply and so we saw an increase in internal resistance. Another reason for an increase in internal resistance as the voltage setting was increased could have been due to the material that the mechanism (used to deliver the current to the circuit) was made from.

The graphs plotted all show that the power supply follows Ohm's law as they show that potential difference is proportionate to current because the gradient of the line of best fit does not change and the internal resistance is constant. In this case the internal resistance of an "ohmic" conductor (the power pack) was constant and did not change when the current was changed.

The ammeter readings were not as accurate as I had expected because the value on the voltmeter was fluctuating and as a result, the voltmeter reading was also fluctuating. Therefore the results gathered show a greater degree of inaccuracy. The inaccurate results therefore would have had a direct effect on the value found for the internal resistance of the power supply. The fluctuations in the current being delivered to the circuit would be due to the use of direct current, where the current peaks and then drops back down many times every second.

Conclusion

My results were very close to my line of best fit and also there was a very small change in the internal resistance of the power supply at the five different voltage setting as shown in graphs 3 to 7. Therefore I can say that my overall method was improved sufficiently enough to give me more accurate (internal resistance) results which were closer to each other. My calculations were as a result fairly accurate which resulted in my calculations and final outcomes to be more accurate. I used eight repeats for all voltage settings which gave me more reliable results which I can say are truer as more repeats would give you more reliability. Limiting factors of the experiment were that only a few voltage settings were available to me, these were 2V, 4V, 6V, 9V and 12V. There were no intermediate voltage settings available on the power pack which meant that my results were limited to an accuracy of five results and if you were to do further experiments at these intermediate voltage settings, then it would help me more reliable results. Another limiting factor for my experiment was that a smoothing unit was not available at the time of the experiment which resulted in readings on both voltmeter and ammeter fluctuating by about ±0.02V or ±0.02A which also added to the error of reading these values off the ammeter and voltmeter.

Evaluation

The fluctuation in current could have been removed by using a smoothing unit. I used direct current which has certain peaks and troughs as the current is supplied to the circuit, and the result is a fluctuating current value. To reduce the fluctuations, a smoothing unit can be used in the circuit to supply an almost constant direct current that does not fluctuate as much and therefore more accurate readings can be obtained. The circuit below illustrates what the circuit would look like when a smoothing unit it used:

Figure 5 shows how the output from a rectifier circuit (which was inside the power pack) can be smoothed by connecting a large capacitor across it. As shown in figure 6, the capacitor charges up during the forward peaks, then releases its charge in between.

The temperature of the power supply was increasing as I changed from a lower voltage setting to a higher one. To avoid this scenario, I could do this experiment in colder temperatures such as in a freezer. This will help ensure that the power pack stays cool and does not heat up, so helping to keep the internal resistance constant. The freezing environment will also lower the temperature in the wires and therefore the resistance in the wires will be more negligible. Collisions between electrons flowing through the circuit and positive ions in the metal are reduced because fewer vibrations occur due to the less heat energy provided by the surroundings.

Anomalous results:
In the tables on pages 5 and 6, I have highlighted two cells which I have counted as anomalous results. I have omitted these results when calculating the average voltage and current because they skew the average higher. Such a high current reading of 1.60A compared with the other two results at the same resistance setting could have occurred because the power supply was delivering peak current at that point in time. The other highlighted cell showing a low voltage reading of 9.00V could have been because of a poor connection in the circuit and therefore a lower reading was obtained. I have not decided to repeat these results because only one result from three repeats was anomalous and therefore it is reasonable to say that the other two results are reliable as they are very close to each other.

Bibliography

Books:

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