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International Baccalaureate

Physics Extended Essay

Investigating the Effect of Temperature on Power of Battery

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Name of Candidate: Umutcan ŞAHAN

Number of Candidate: 001129-0099

Name of Supervisor: Mehmet BOZKURT

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Abstract

The aim of this experiment is to investigate the question of "How temperature effects on power of battery in a circuit?" Lithium batteries which we use commonly on daily life, are used in this investigation to explore temperature effects on power of lithium batteries. Batteries have 1.5V electric potential. Their size is rated as D and IEC(International Electrotechnical Commission) code is R20. The temperature of a battery increased slowly by using water bath and measured its value by using digital surface thermometer. The data collected in certain points of temperature. Battery was put in a circuit and made the circuit running with closing the circuit. The ammeter attached to the circuit in series and voltmeter attached to parallel to the battery. The cables and battery which was used in the experiment covered with water-proof material to prevent the possible negative effect because batteries and certain parts of cables need to be in the water to prevent any measurement error. The usage of water-proof material ensured healthy experimentation. In this experiment, data retrieved when the temperature of battery reached to 15, 20, 25, 30, 35, 40, 45, 50 and 55^0C. Data that recorded in this experiment are *ampere*, *voltage*, *resistance* of the circuit and *temperature* of battery. These data are measured by a multi-meter which can measure DC current, potential difference (voltage), temperature and resistance. The calculation according to the value of current and voltage was made for obtaining the power of battery. Differences of power of battery were observed according to result and in the graph due to temperature changes. Results show that the power of battery increases proportionally with the temperature of the battery between 10.0^0C and 57.0^0C.

Word Count: 279

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1.Introduction

The scope of this investigation is to find out the effect of temperature on power of batteries. In daily life, a lot of device we use needs a battery to obtain electrical energy. And these energy suppliers efficiency of power they able to give is very important for running the devices safely and outlasting the batteries life in phones, laptops. There are some external factors affect on the power of battery and one of probable factor effect on this is the temperature of surrounding where the battery works in. So in this experiment as a power supplier common *D size* and*1.5V* battery is used for observing the effect of temperature on power of battery easily and clearly. Other reason for using 1.5V of battery is because in daily life these have the one of the most areas of usage in numbers from other batteries. Increase in temperature may affect the power of battery they able to give by interfere with *internal resistance* of the battery by causing expansion of the conductor parts in the circuit so due to *Ohm's Law* which indicates the relationship of certain terms like *ampere, voltage* and *resistance*, clearly states that resistance of circuit difference changes the ampere and voltage which are the key factors to deduce the power of energy supplier. So the aim of this experiment is to answer the question of *"How the surrounding temperature of battery does affect on the power of battery by using 1.5V D size batteries to observe the possible effect of temperature change on power of battery can able to give?"*. The objective of this investigation is to find a temperature that battery can work efficiently by observing the output power of battery variation in a certain temperature range.

Background Information

1.1 What is battery?

Batteries are used for converting chemical energy to electrical energy for using as an energy supplier. They produce direct current which can pass through the conductive wires in one direction. They also have cathode which is the positive part of the battery and anode which is the negative part of the battery. Their working principle is to create a way in a circuit that ions can pass through and obtaining flow in the battery so the battery starts to work.

Figure 1(left): Shows a D size battery with brand "Eveready"

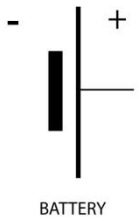


Figure 2(right): Shows the symbol of battery in circuit diagram

1.2 Voltage

Voltage is a measuring unit of a force called "electromotive force". Voltage is the potential difference between two points in a circuit or electrical field. There are two types of voltage; one of them is direct voltage and the other one is alternating voltage. In battery there is direct voltage, so direct voltage will be measured in this experiment since we use used portable common batteries for investigation.

1.3 Ampere

Ampere is the measurement of the number of electric charges passes from a certain point in unit time. Ampere is a unit measure of electrical current in the circuits. There are two types of current. One of this is alternating current (AC) and the other one is direct current

(DC). AC current is a wave like current that can flow periodically. It can also has different direction. DC current is different from AC current because it has one motion direction. This type of current can pass through in conductive wires and flows in constant path. So in this experiment we take measurements according to direct current (DC) due to power supply are battery.

1.4 Resistance

Resistance is the opposing effect that interfere the flow of electric current. Unit of resistance is "ohm" which is shown with using "Ω" symbol. Every substance has different resistance and also two same elements can also has different resistance from each other.

There are some factors affect on the resistivity of a substance.

Length of substance directly proportional with the resistance because electrical charges needs to travel over more distance and this causes electrical charges be exposed to more resistance on their way. Unit of length of the conductor needs to be meter (m) for calculations.

Cross-sectional area is also a very important factor for determining the resistance value of a substance. Cross sectional area has different affect on resistance from the length of substance. Cross sectional area is inversely proportional to resistance. If the cross sectional area increases the resistance of the substance decreases because electrical charges can move easily in large cross sectional area so they will be exposed less resistance along the way. Cross sectional area needs to be square meter (m^2) for determining the resistance of the substance. Cross-sectional area and length changes with temperature due to expanding property of metals.

There is another factor that is very important for determining the resistance of a substance is what material substance is made of. Electrical resistivity is differs in every material due to its made of material. Electrical resistivity of metals is the lower than non-metals and semimetals so metals are used for making conductor wires. The unit of electrical resistivity is ohm.meter which is symbolized by "Ω.m" according to SI unit system.

The relationship between cross sectional area, length and material for determining resistance of a conductor can be seen in the following equation. Also resistances can be calculated by this formula

$$R = \rho \frac{\ell}{A}$$

R: Resistance of conductor (ohm) (Ω)

p: Electrical Resistivity(rho)(ohm.meter) (Ω.m)

l: Length of the conductor (meters)(m)

A: Cross sectional area of conductor (square meter) (m^2)

1.5 Internal Resistance

Internal resistance is the resistance in a circuit because of the inner system of the battery. Voltage value without any resistance differs from voltage value in a current due to the internal resistance of batteries. Internal resistance value of a battery depends on some factors like the size, chemical properties and temperature. So if temperature affect on power of battery is investigated, chemical properties and size of the battery need to be stabilized to obtain reliable results.

1.6 Voltmeter

Voltmeter is a device that measures the potential difference between two points in an electric circuit. Internal resistance of voltmeter is very high. I used this device to observe the differences in electric potential in the experiment due to temperature difference of battery. It needs to be connected in parallel to circuit to the investigated part of the circuit with two wires.

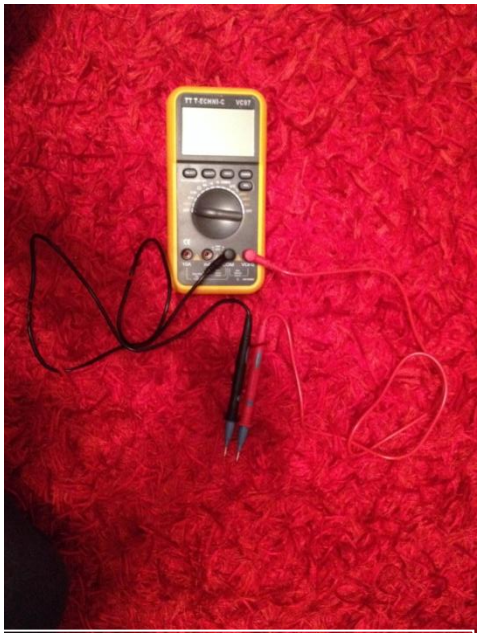


Figure 3: Shows a multi-meter with ability to measure ampere and voltage

1.7 Ammeter

Ammeter is a device that measures the flow rate of charged particles in a circuit. Internal resistance value of ammeter needs to be low because it needs to be connected the circuit in series so resistance of this device can prevent the flow in the circuit easily. I used this device to observe the change in current in the circuit.

1.8 Ohm's Law

Ohm's Law states the relationship between resistance voltage and ampere in a circuit. According to Ohm's Law, potential difference is directly proportional to current of the circuit. Resistance is inversely proportional to the current.

$$I = \frac{V}{R}$$

I: Current of the circuit (ampere) (A)

V: Potential Difference (voltage) (volt) (V)

R: Resistance of the circuit(ohm) (Ω)

2.Design of the Experiment

2.1 Research Question

How the temperature of battery does affect on the power of 1.5V and D size batteries, to observe the possible effect of temperature change on power of battery identical circuits with same resistance value are used?

2.2 Hypothesis

Increasing of temperature from the common room temperature increases the power of battery that can able to give by causing expansion of internal conductive parts of the battery. This situation may causes decrease in internal resistance of batteries and due to this situation total resistance of circuit decreases and this decrease in resistance interfere the ampere and voltage so there will be an efficiency gain due to temperature change of surrounding.

2.3 Variables

Dependent Variable

- Power of battery

Independent Variable

- Temperature of surrounding of battery

Controlled Variables

1. Voltage of Battery
2. Brand of Battery
3. Chemistry of Battery
4. Length of the cables in circuit
5. Material of the cables made in the circuit
6. Thickness of the cables in circuit
7. Sensitivity of the voltmeter
8. Sensitivity of the ammeter
9. Pressure of surrounding

2.4 How to Control Controlled Variables?

1) Initial Voltage of Battery

Batteries need to have same voltage before the experiment for observing the possible difference of the voltage value due to temperature change. To get more reliable result and compare the difference between possible differences of voltage, making the initial voltage similar to each other is very important.

For stabilizing the initial voltage value of batteries 1.5V batteries prepared for the experiment.

2) Brand of the battery

Although all batteries with different brands in the market looks similar and same values written on them, all batteries with different brands in the market have different electrical quality, this situation changes the affect of external factors on battery. Because of this situation, we need to stabilize these affect rate of batteries to get more reliable result from the experiment.

For minimizing the difference between affection rate in batteries, batteries with "Eveready" brand are used in this experiment.

3) Chemistry of battery

Due to difference between working principle of battery is a chemical reactions, we need to stabilize the chemical materials used in the batteries to investigate the physical result of the experiment without being interfered by chemical differences. Also conductive parts of batteries may differ due to battery is rechargeable or not.

For minimizing the chemistry of battery, alkaline based batteries used in every trial in this experiment.

4) Resistance of resistor

The resistance of the circuit needs to be constant to observe the difference between the power changes due to internal resistance.

So resistor with 1 ohm resistance used in all trials for make the resistance constant in the circuit.

5) Length of the cables in the circuit

The resistance of circuit needs to be constant every trial to observe the voltage and ampere differences only affected by the situation of battery, otherwise the measured values will become unreliable due to resistance difference in the circuit apart from batteries. Resistance affected by the length of the cable in the circuit.

For stabilizing the resistance, identical cables with 2 cables with 3cm are used every trial in the experiment.

6) Material of the cables made in the circuit

Conductivity of conductor material may differ from each other due to made of material. Because every metal has different resistance constant so difference between materials of the cables affects the resistance and the calculated voltage and ampere values of the battery.

For stabilizing the resistance of circuit, cables which are made of copper is used in every trial in the experiment.

7) Thickness of the cables in the circuit

Thickness of the cables in the circuit is also the key factor for determining the resistance of cables. So thickness of cables needs to be constant for calculating and comparing the result of the investigation.

For stabilizing the resistance of circuit, cables which has 0.1cm diameter are used in every trial of the experiment.

8) Sensitivity of the voltmeter used

During the data calculation digits and sensitivity of raw data values are very important to get more reliable answers from the experiment. So the multi-meters used in this experiment needs to measure the voltage with same digits and precise among them.

For obtain reliable result from the experiment, multi-meters which can measure the volt with 3 digits after integer part of the value used in all trials of this experiment. Also these two multi-meter are chosen due o their precision between them.

9) Sensitivity of the ammeter used

During the data calculation ampere values are another key factor that determine the result and its reliability so measuring devices for measuring ampere needs to be same sensitivity and precise with each other. 2 multi-meter used in this experiment for see the precision of the result.

For obtaining more reliable result, raw data needs to have same number of digits because during data comparing, results need to have same number of digit to obtain precise results. So in this experiment, multi-meters which can measure 3 digits after integer value of DC current, are used in every trial.

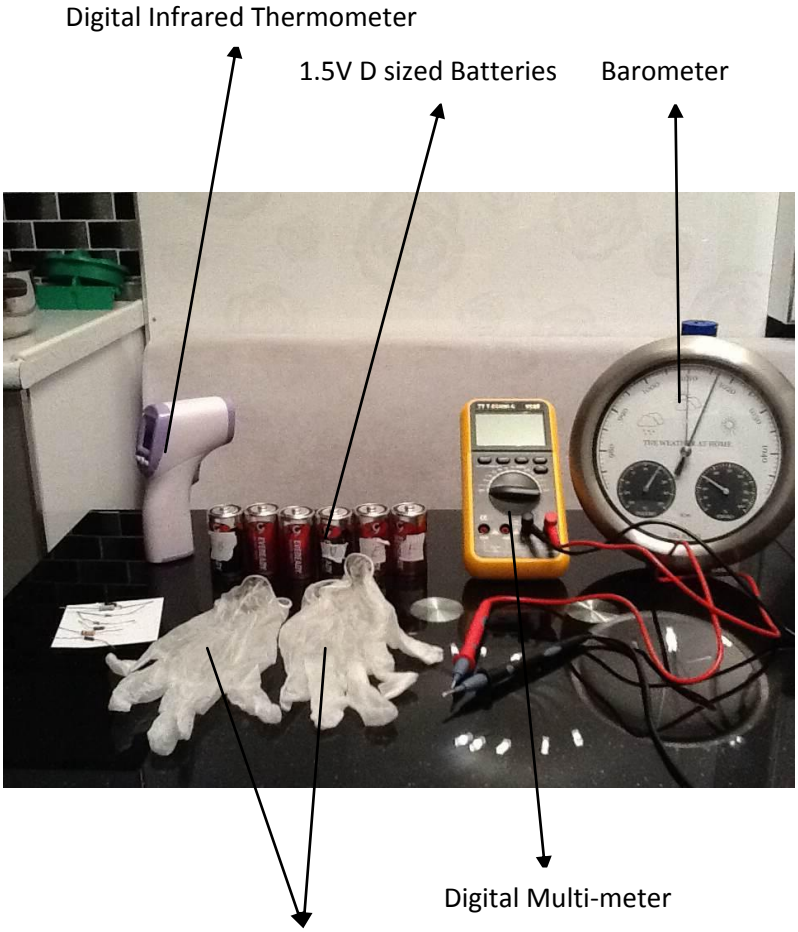
10) Pressure of the surrounding

Temperature of batteries will change by changing temperature of water which battery operated in it. So Temperature change of water depends on pressure of surrounding.

To get rid of any errors due to air pressure, air pressure of the room needs to be measured before every trail by barometer in the experiment.

2.5 Materials Used

- Battery x 27 (1.5V/D size)
- Resistor x 2 (1ohm)
- Copper cable x 2
  - 6cm length
  - 0.1cm diameter
- Digital Multi-meter x 2
  - Ampere ±0.001A
  - Voltage ±0.001V
- Ruler(30.0cm±0.1)
- Pliers
- Utility Knife
- Scissors
- Barometer
- Water Heater
- Glass x 5 (1L)
- Digital Infrared Thermometer(±0.1^{0}C)
- Refrigerator with thermometer(±1^{0}C)
- Surgical Gloves
- Barometer



2.6 Method

1. Cut 2 pieces of cables which have 3cm length each.
2. Attach 1ohm resistor between the cables with bending the metal parts of the wires.
3. Set multi-meter to resistivity meter and attach the resistance and take measurement of the resistance of the circuit without the internal resistance.
4. Prepare boiling water from the water heater.
5. Take a glass and put some boiling water into it.
6. Take a surgical glove and put the battery inside of the glove.
7. Tie a knot to the opening of the glove to prevent the water flow into the glove because water can damage the battery.
8. Put the surgical glove with battery to the boiling water in the glass carefully to prevent damage to the experimenter. (You can wear oven glove to prevent burned skin due to hot water.)
9. Take measurement with digital infrared thermometer every 15 seconds to obtain certain temperature of battery.
10. Put out the glove carefully from the glass when the temperature of the battery becomes 57.0^0C.
11. Carefully cut the glove and put out the battery.
12. Set one multi-meter as ammeter and the other one as voltmeter.
13. Attach battery to voltmeter and record the data as electromotive force of the battery.
14. Attach the battery to circuit in series
15. Attach the voltmeter parallel to battery and the ammeter in series to the circuit.
16. Record the data read from the ammeter as current and voltmeter as voltage.
17. Do steps 4^{th} to 16^{th} for 3 times with different batteries to get accurate results.

18. Do steps 4^{th} to 17^{th} with the changing the temperature of battery to “10, 20, 25, 30, 35, 40, 45, and 50^{0}C.
19. Do calculation for obtaining power of the battery with using experimental data
20. Sketch the graph of temperature of battery vs. power of battery to get a better visual to see the relationship between these two factors.

Figure 4: Shows the data collection of temperature values with using digital infrared thermometer. Batteries are in a surgical glove bag and they are In hot water.

Figure 5: Shows the data collection method for electromotive force of batteries with multi-meter.

2.7 Diagrams of the Experiment

Figure 6: Shows the heating process of the battery to change the temperature. The battery is in a surgical glove to prevent the contacnt with water in case of possible damages to battery. The water is boiling water to increase the temperature of battery.

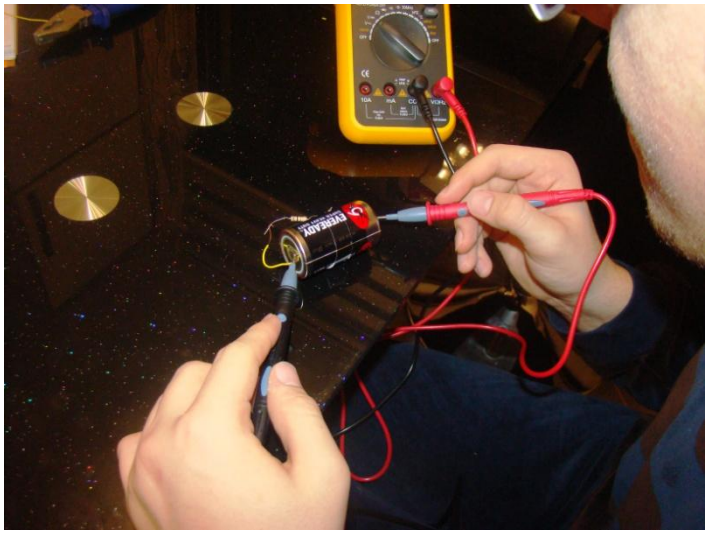


Figure 7,8: Shows the experiments setup. Voltmeter connected the battery parallel and ammeter connected to circuit in series. As a resistance cables and resistor with 1ohm are used for creating a resistance in the circuit. The resistance of the circuit is shown with R and the internal resistances of the battery is shown with r. Temperature of battery increased by the usage of boiling heater and make the temperature steady with the help of digital thermometer. Battery put into this circuit to find its potential difference with voltmeter and the ampere value of the circuit with ammeter.

Umutcan ŞAHAN
001129-0099

3.Data Collection and Processing

3.1 Raw Data Table

Temperature of Battery(±0.1^{0}C)	Trials	EMF Voltage Value(±0.001V)	Voltage Value in Circuit(±0.001V)	Ampere Value (±0.001A)	Resistance of Cables(±0.1Ω)	Resistance of Resistor(±0.05Ω)	Material of CableMade	Air Pressure in the Room(±1hPa)
10.0	1	1.526	1.343	0.959	0.4	1.00	Copper	1015
	2	1.537	1.352	0.965	0.4	1.00		1015
	3	1.536	1.351	0.965	0.4	1.00		1015
20.0	1	1.537	1.359	0.971	0.4	1.00	Copper	1015
	2	1.543	1.365	0.975	0.4	1.00		1015
	3	1.538	1.360	0.972	0.4	1.00		1015
25.0	1	1.545	1.372	0.980	0.4	1.00	Copper	1015
	2	1.542	1.370	0.978	0.4	1.00		1015
	3	1.539	1.367	0.977	0.4	1.00		1015
30.0	1	1.555	1.386	0.990	0.4	1.00	Copper	1015
	2	1.548	1.380	0.985	0.4	1.00		1015
	3	1.547	1.380	0.985	0.4	1.00		1015
35.0	1	1.567	1.399	0.999	0.4	1.00	Copper	1015
	2	1.557	1.390	0.993	0.4	1.00		1015
	3	1.554	1.388	0.991	0.4	1.00		1015
40.0	1	1.576	1.411	1.007	0.4	1.00	Copper	1015
	2	1.565	1.401	1.001	0.4	1.00		1015
	3	1.562	1.398	0.999	0.4	1.00		1015
45.0	1	1.563	1.402	1.001	0.4	1.00	Copper	1015
	2	1.579	1.416	1.012	0.4	1.00		1015
	3	1.578	1.415	1.011	0.4	1.00		1015
50.0	1	1.580	1.421	1.015	0.4	1.00	Copper	1015
	2	1.583	1.423	1.017	0.4	1.00		1015
	3	1.581	1.422	1.015	0.4	1.00		1015
57.0	1	1.585	1.429	1.020	0.4	1.00	Copper	1015
	2	1.582	1.426	1.019	0.4	1.00		1015
	3	1.587	1.431	1.022	0.4	1.00		1015

Table 1: Shows the electromotive force of battery, the ampere of circuit and potential difference of battery as voltage in respect to change in temperature and change of battery per trial with uncertainties due to sensitivity of the multi-meter. Table also shows the controlled variables like resistance of resistor, resistance of cables, material of cable made of and air pressure of the room. The uncertainties due to resistance are because of the sensitivity of the resistivity meter function of multi-meter.

3.2 Calculations

Ɛ = I x (R+r)

Ɛ= Electromotive Forces (Voltage recorded when only battery attached to the voltmeter) (V)

I= Current of circuit (Ampere recorded when ammeter attached to the circuit in series) (A)

R= Resistance value of circuit (Ω)

r= Internal resistance of battery(Ω)

For Trial 1 of 10.0^{0}C

Ɛ=1.526V

I=0.959A

So,

$$\frac{1.526}{0.959} = 1.591\Omega = (R + r)$$

The resistance of cables= 0.4Ω

The resistance of resistor=1.0Ω

Total resistance of circuit without internal resistance of battery is 1.4Ω

$1.591 - 1.4 = 0.191\Omega$ = **Internal resistance of the battery**

$$\mathcal{E} \times I = P(Output\ Power\ of\ battery)$$

$$1.526 \times 0.959 = 1.463\text{W}$$

Average Internal Resistance of 3 trials of 10.0^{0}C

$$\frac{0.191+0.193+0.192}{3}=0.192\Omega$$

Power Percentage of 3 trials of 10.0^{0}C

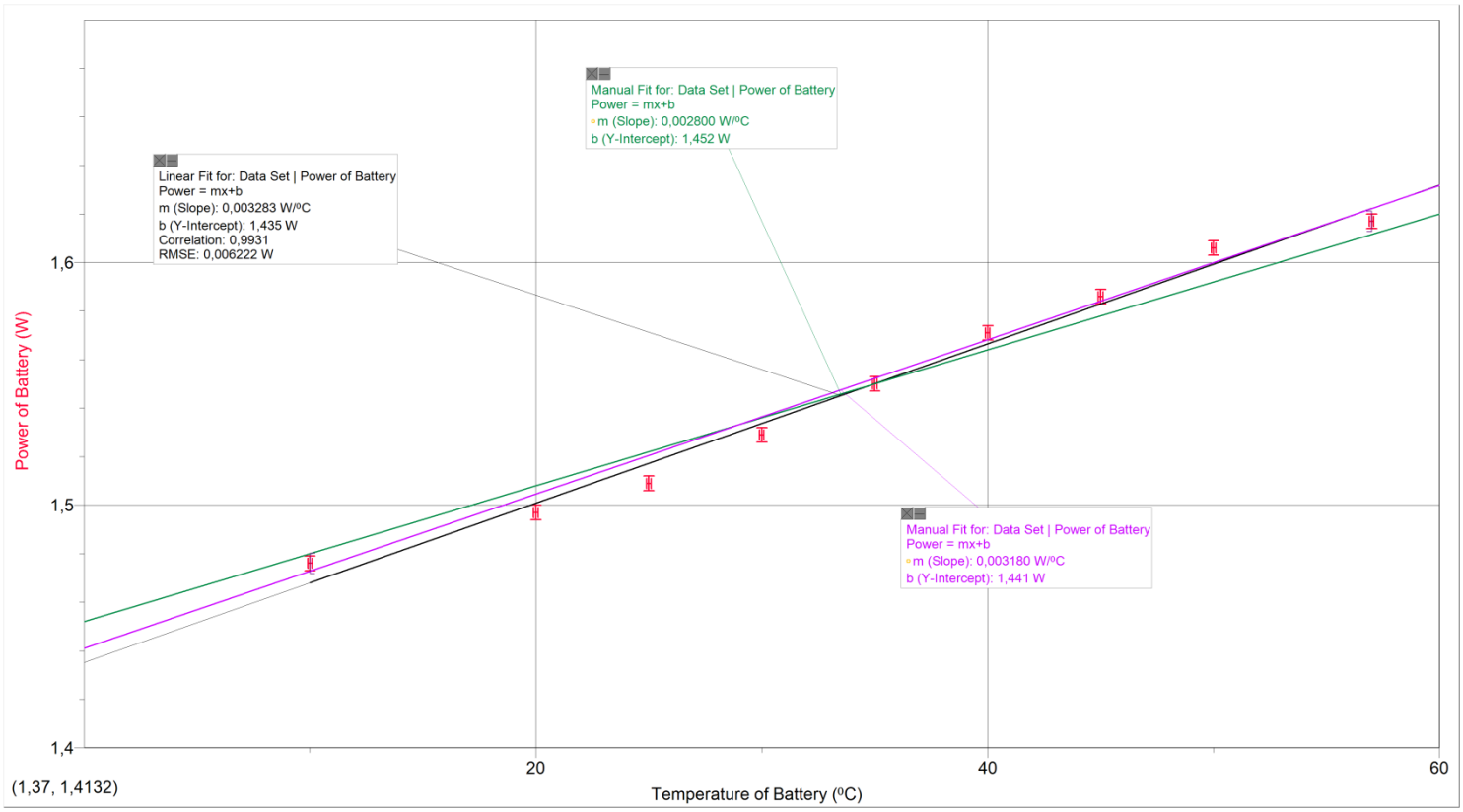
$$\frac{1.463+1.483+1.482}{3}= 1.476W$$

3.3 Processed Data Table

Temperature of Battery(±0.1^{0}C)	Average Internal Resistance of Batteries(±0.001Ω)	Average Power of Batteries(±0.001W)
10.0	0.192	1.476
20.0	0.183	1.497
25.0	0.176	1.509
30.0	0.171	1.529
35.0	0.168	1.550
40.0	0.164	1.571
45.0	0.161	1.586
50.0	0.157	1.606
57.0	0.153	1.617

Table 2: Shows processed data (power of battery, internal resistance of battery) which are obtained after some certain calculations

3.4 Graph of the Experiment



Graph 1: Shows the relationship between power of battery and the temperature of the battery. Y- axis starts from 1.4W value and ends at 1.7W and X-axis starts from 0^0C and ends at 60^0C. Graph also has error bars which indicate the uncertainty of power of battery and temperature of battery. For make it easier to see the relationship there is also best line of the experimental values with slope of data. There are also maximum and minimum bars for calculating experimental error.

Slope of best line (black): 0.003283

Slope of minimum worst line (green): 0.002800

Slope of maximum worst line (pink): 0.003180

Equation of a line: y=mx+i where,

y= P(W)(Power of battery) **x=**T (^{0}C) (Temperature of Battery)

i=Y-intersect value (W) **m**=slope of best line

Equation of the Experiment: $P = \left(0.003283 \frac{W}{^\circ C}\right) T + 1.435W$

Error Calculation

$$\frac{0.003180-0.002800}{2} = \pm 1.9 \times 10^{-4} \frac{W}{^{\circ}C}$$

Slope of the graph= $0.003283 \pm 0.000190 \frac{W}{^{\circ}C}$

4.Discussion, Conclusion and Evaluation

This experiment clearly answers the research question and the hypothesis is confirmed which is power of battery increases proportional with temperature of battery. Experiment not only answers the research question but also shows the reasons of this result. From the graph it can be understood that the power of battery increases proportionally with the temperature of the battery. Also, internal resistance of the battery is inversely proportional to power of battery and temperature. With some certain calculations, the internal resistance of each battery calculated and these data shows that internal resistance changed while we were changing the temperature of battery. So the power differences due to temperature are caused by the change in internal resistance of the battery. Internal resistance of battery decreases when its temperature increases due to expansion of metal conductive parts in it. It also indicates that cross-sectional area of metal parts expansion is bigger than the expansion of its length. To conclude experiment shows that the efficiency of battery increases proportionally with temperature because efficiency of a battery can be determined with the formula of "Potential Difference of Battery/Electromotive force of Battery" and experiment shows that this rate increases proportional with temperature of the battery.

There are some error bars in the graph of the experiment which indicate some errors in the experiment. For example, in the first trial of 45^0C battery, the electro motive force of battery is 1.563V where the battery works in circuit with 1.001A so the power of battery used is 1.565W. on the other hand, in the 1st trial of 40^0C, the electro motive force of battery is

1.576V and ampere value of circuit is 1.007 so the power of this battery calculated as 1.587W. According to the result of the experiment, power increases proportional with temperature but in this example an opposite situation observed on these two batteries. Temperature of the battery increased but power of battery is lower than the other battery which is colder than it. This situation is caused by the random errors due to sensitivity of measuring devices, observer factor, and difficulties of controlling controlled variables. These factors can be seen as not make such a big difference in results but they combined in the process of experiment that causes some errors that slightly affects the results of trials which causes some inconsistent values like in the example.

First of all, the sensitivity of the measuring devices used in the experiment caused some minor errors in the process of experiment. The multi-meter used in the experiment can measure ampere till 0.001A and it also can measure the voltage till 0.001V so it has uncertainty of "±0.001" for both ampere and voltage values in all trials in the experiment. These uncertainties is low but the function of resistivity meter of multi-meter can only measure 0.1Ω so it has high uncertainty for measuring the resistance of cables and resistors used in for making a circuit. Also the resistor with 1Ω value has %5 tolerances so the resistance value of resistor can be in the range between 0.95 to 1.05Ω.

We can minimize the error due to these factors by making more trials for same independent variable to minimize the errors from the sensitivity of measuring devices. Making more trials can lead some another random errors but it certainly decreases the uncertainty of measuring device effecting on the result of experiment. By calculating the average value of the trials we can obtain more precise and accurate data for getting reliable results.

Other factor that affects the results of the experiment is the observer factor in the experiment. For example when I attach the battery to the circuit, some parts of surface of cable not covered by non-conductor material and I touched it with bare hands. The current in the circuit is very high due to the low resistance value of the circuit so it causes some minor burns in my hand and my hand may cause increase in resistance in the circuit which may affect the results of the trial. Also, there is an another situation that affects cause some random errors by experimenter factor can be seen in the process of putting out the glove bag from the hot water and taking out the battery from the glove bag. During this process, when the bag cut of the small amount of water droplets drop on to the battery which may cause damage to the battery but I instantly dried batteries with towel so it may not cause any major error.

We can minimize the problems due to the experimenter factor in the experiment by using non-conductive gloves while touching the circuit and drying the glove bag before opening it to prevent contact with battery and water.

Finally, there are some errors due to controlling difficulties of some controlled variables. In the experiment temperature of battery cannot be stabilize when we attached to the circuit. However, the process of taking measurements takes only 10 to 15 seconds the temperature change during this short period may caused some errors.

We can minimize this error by making the experiment in different circuit which we can attach the battery in the water and the bag to the circuit so we can prevent both temperature loss and contact of circuit and battery with water.

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