IBDP
Physics HL Extended Essay

Investigating The Effect of Different Temperatures on The Power of a Zinc-Carbon Battery

What is the relationship between the temperature(326K, 250K, 258K, 266K, 275K, 283K, 292K, 300K, 309K, 317K) and the power output of a carbon zinc battery?

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Introduction

Batteries are daily used materials that convert chemical energy to electrical energy. We can see them everywhere, we use them everywhere, from the remote controller of our electronic devices such as televisions to electrical thermometers. Many devices depend on their performance. Furthermore, since these dives can make our daily life easier, we depend on batteries too. This dependence on something this small made me curious about what affects their performance and what should be done to maximize their maximum use. In my opinion, learning how temperature affects batteries is a good outcome for me since I can change the temperature quickly and use the experiment results on daily basis. For example, I first noticed the effect of temperature on batteries in different locations. The lamp in my travel backpack that I use daily throughout my vacations with my family lasted differently according to where we were camping. The battery lasted less in warmer places like Antalya than in colder places like Erzurum. This can be due to altitude differences and other uncontrolled variables. So first of all, I wanted to define what performance is. After looking up the internet I concluded that technological devices perform by how much output they can make with the smallest amount of income. In other words, I want to find out how a battery's efficiency can be increased just by changing something we all have control over temperature. Efficiency is derived from dividing the power out by the total power in. The power of a battery is calculated by multiplying the volts by the current. If we look at the efficiency formula, we can understand that the only thing we can change is the power out since the battery we are using is not changing so the total energy in hence the total power in does not change. So if we can change the useful power just by changing the temperature, we can increase the efficiency of our batteries with the right temperature. And with more efficiency, can get more work done with a single battery. And this is the main idea of this project.

Background Information

What are batteries and galvanic cells in general terms?

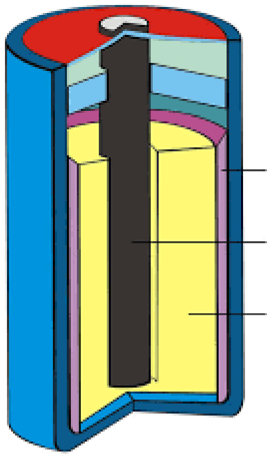
Batteries use electrochemical reactions to supply electricity as a result. Galvanic cells are also electrochemical cells. It gives electric current by transferring electrons via a redox reaction. In these reactions, there are two main parts, the anode, and the cathode. Anode is on the negative side and transfers its electrons to the cathode (the positive side) via electrolytes – electrolytes make an environment where ions can transfer freely and in this case, this transfer is a must to have a working battery- and if we put resistance to the path of electrons -which is the wire- we can turn electrical energy to heat energy and by changing the resistance to a lamp we can get both heat and light energy. The reaction in a battery is the same as that in a galvanic cell, but some properties separate batteries from galvanic cells. Batteries should be light in weight and compact in size and give a constant voltage.

What is power in electricity?

In physics, electric power measures the rate of electrical energy transfer by an electric circuit per unit of time. The symbol used to demonstrate it is P and the SI unit of power is one joule per second or watt. Electric power is usually supplied by electric batteries just like in this experiment.

How does a zinc-carbon battery work and why temperature can affect its voltage?

The carbon zinc battery uses a zinc anode, a manganese dioxide cathode, and an electrolyte of zinc chloride dissolved in water. Powdered carbon is used in the cathode mix, usually in the form of graphite to improve the mixture's conductivity. The chemical reaction that produces electricity occurs when a current between the anode and cathode exists. This means the battery works when it is in a circuit with resistance. This chemical reaction is an equilibrium reaction which means in different circumstances the reaction can slow down or speed up and the more the reaction moves toward the product side more work can be done per time. One of these variables that can affect the work done by the battery is temperature. This is because the zinc-carbon battery reaction is an exothermic reaction which implies that one of the products is heat energy. In an equilibrium reaction, the reaction moves towards the side less in the environment. For example, for an exothermic reaction if there is less heat energy in the environment the reaction goes towards products, if there is more heat energy in the environment the reaction's equilibrium point -the point where backward reaction and forward reaction is equal- gets closer to the reactants side which results in a slower reaction and energy release. In conclusion, if there is more heat energy in the environment, it



would decrease the potential difference in the battery. This would result in worse battery performance since the battery's power (work done per time) would decrease. Finally, heat energy is the total kinetic energy of the atoms of a substance. The average kinetic energy of atoms is temperature. So as the heat energy in a battery increases so does the temperature.

I will use three different potential differences (1563mV, 1498mV, 1635mV) to see if there is any relation between the battery's initial voltage and its relationship to temperature.

Research Question

What is the relationship between the temperature(326K, 250K, 258K, 266K, 275K, 283K, 292K, 300K, 309K, 317K) and the power output of a carbon zinc battery?

Hypothesis

As the temperature of the battery increases (326K, 250K, 258K, 266K, 275K, 283K, 292K, 300K, 309K, 317K) the potential difference would decrease so the work done in unit time would decrease (the power of the battery). And since the input energy doesn't change the efficiency of the battery would decrease as well.

Design

Variables

Independent variables:

Temperature (326K, 250K, 258K, 266K, 275K, 283K, 292K, 300K, 309K, 317K)

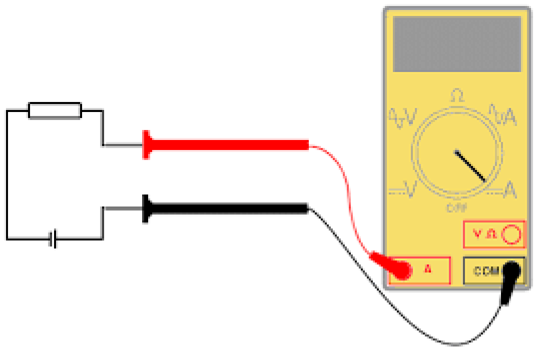
To change the heat energy battery has.

Dependent Variable

Power of the battery

Controlled Variables

The lengths of the wires used:



Reason: Using different lengths of circuits would result in different resistance.

Method: After constructing the circuit nothing should be touched, the only thing that will be changed is the batteries.

Battery’s internal resistance:

Reason: Every battery is slightly different from another even if they are the same brand these little differences can cause a variety in chemical reactions or internal resistance.

Method: Using the same battery and charging it before changing its temperature.

Ambient temperature:

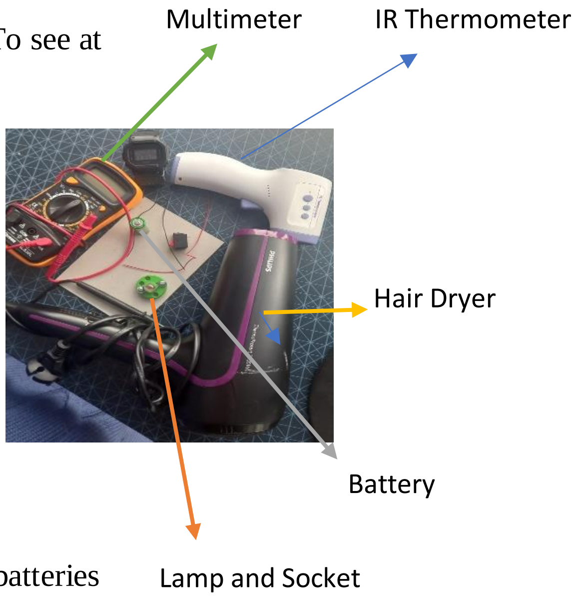
Reason: By controlling the ambient temperature, any changes in voltage are due to temperature changes and not due to changes in the environment.

Method: Experimenting with room temperature on the same day.

Apparatus

- A 1.5V zinc-carbon battery

- IR Thermometer: To see at what temperature we are reading voltage. It can read with 0.1 Kelvin sensitivity.



Fridge: To get the batteries as cold as desired.

- Lamp: To have a resistance big enough to have current.

- Wires: To make a circuit that can stay still while changing the batteries of this circuit

Hair dryer: To get the batteries as hot as desired.

Battery charging station: To make sure the battery is full at every use and make sure the initial voltage is a controlled variable.

Multimeter: To read values of voltage and current. It can read with 0.1. Current/mA and Volt/mV.

Method

1) With three short wires -since there would be more resistance in the wires as they get longer, this is because the resistance of the wires is directly proportional to the length of the wires-, one lamp and one multimeter; construct an unfinished circuit by connecting two ends -the positive and the negative- of the lamp with two wires. Get the wire which is connected to the positive side of the lamp and connect its end to the positive side of the multimeter. To understand which is the positive side of the multimeter, you should check its connection points. Plug this positive end of the wire into the ammeter section. Plug another wire into the "COM" section of the multimeter. This is the "Common" port which is used for both measuring volt and current. The wire plugged into the "COM" will be plugged into the battery's positive end throughout the experiment. The wire plugged into the negative side of the lamp will be attached to the negative side of the battery. At this stage, the lamp won't be able to give any light since there isn't any power supply. Constructing the circuit this early will give us a circuit that won't change as the experiment goes on since the only thing we will be changing is the battery of the circuit. Other variables such as the resistance will be the same throughout the experiment.

2) Get the battery to the desired temperature. This can be done with several methods but the one I prefer is using a type of heat gun like a hair drier from a safe distance. Since we can adjust the distance, the temperature increase can be much slower and thus can be monetarized easier than using the same approach with a smaller distance from the battery. This will be useful especially when the experiment is done at 326 Kelvin because the risk of damaging a battery increases as the temperature gets closer to 333 Kelvin. To get the battery cooler than room temperature I used the freezer of my fridge. Cooling a battery is safer than heating it at the temperature interval this experiment is done so no safety concerns or precautions are necessary. To know if the batteries reached the desired temperature an IR thermometer will be used. An infrared thermometer makes this experiment more dependable since it can measure faster than a stick thermometer and it can measure temperature at a distance so I can keep my distance while heating the batteries.

3) Charge the battery's volt to a desired potential difference (in this experiment there will be three potential differences for every same temperature to get more data, however since I can't measure how much they have charged, I will first look to their initial volt after leaving them charging for some time, if the volt values are too similar or too different, I will recharge or use it to achieve a different volt value.)

4) Put the battery into the circuit by plugging its negative end into the wire connected to the negative side of the lamp and by plugging its positive end into the wire plugged into the "COM" on the multimeter.

5) Measure the current with a multimeter by setting the multimeter to "DCA" 2000, this will measure the Direct Current in the milliampere unit.

6) After measuring the current, measure the volt of the circuit with the multimeter but this time plug the wire at the ammeter terminal to the voltmeter terminal and make a parallel circuit. To do this construct the circuit with only a lamp and the battery by uniting their positive and negative ends together. Then plug the multimeter into the lamp socket's proper ends. Make sure to use the same amount of wire used in the circuit for measuring current.

7) Measure the volt with the multimeter by setting the multimeter to "DCV" 2000, this will measure the Direct Current Volt in the Volt/mV unit.

8) Do these 29 more times with 10 different temperatures for 3 initial voltages.

Results

Raw Data

Temperature(K)	Volt/mV (1)±1	Current/mA (1) ±1	Volt/mV (2) ±1	Current/mA (2) ±1	Volt/mV (3) ±1	Current/mA (3) ±1
250	1573	983	1509	943	1641	1025
258	1570	981	1506	941	1643	1026
266	1568	980	1504	940	1639	1024
275	1566	978	1502	938	1638	1023

283	1565	978	1500	937	1637	1023
292	1564	977	1499	936	1636	1022
300	1563	976	1498	936	1635	1021
309	1563	976	1497	935	1635	1021
317	1562	976	1496	935	1634	1021
326	1562	976	1496	935	1624	1015

Table 1: The volt and current data measured at different temperatures and volt values at room temperature. Each number between brackets represents a different initial volt: (1) is 1563mV, (2) is 1498mV, and (3) is 1635mV.

Calculation/Analysis

Multiplying the voltage with the current gives the power of the battery.

For example, to find the battery's power output at 250K with an initial voltage of 1563mV, we need to multiply 1563mV by 976mA. This would give us 9161138 10^-6 joules per second.

Temperature(K) ±1	Power (1) (joules per second*10^-6)	Power (2) (joules per second *10^-6)	Power (3) (joules per second *10^-6)
250	1546259	1422987	1682025
258	1540170	1417146	1685718
266	1536640	1413760	1678336
275	1531548	1408876	1675674
283	1530570	1405500	1674651
292	1528028	1403064	1671992
300	1525488	1402128	1669335
309	1525488	1399695	1669335
317	1524512	1398760	1668314
326	1524512	1398760	1648360

Table 2: Power of the battery at different temperatures and different initial voltages.

Error Bars

Since the measuring devices are electronic the calculation needed for error bars is easier. Since for both voltage and current, the multimeter goes to Volt/mV and Current/mA, there is a ±0.001 error for both. To get to the power of the battery and thus the graphs we multiply current and volt so to get the error bars we need to sum the error percentage.

Temperature(K)	Volt/V (1)	Current/A (1)	Volt/V (2)	Current/A (2)	Volt/V (3)	Current/A (3)
250	6.3573E-05	0.0001	6.6E-05	0.00011	6.1E-05	9.7561E-05
258	6.3694E-05	0.0001	6.6E-05	0.00011	6.1E-05	9.7466E-05
266	6.3776E-05	0.0001	6.6E-05	0.00011	6.1E-05	9.7656E-05
275	6.3857E-05	0.0001	6.7E-05	0.00011	6.1E-05	9.7752E-05
283	6.3898E-05	0.0001	6.7E-05	0.00011	6.1E-05	9.7752E-05
292	6.3939E-05	0.0001	6.7E-05	0.00011	6.1E-05	9.7847E-05
300	6.398E-05	0.0001	6.7E-05	0.00011	6.1E-05	9.7943E-05
309	6.398E-05	0.0001	6.7E-05	0.00011	6.1E-05	9.7943E-05

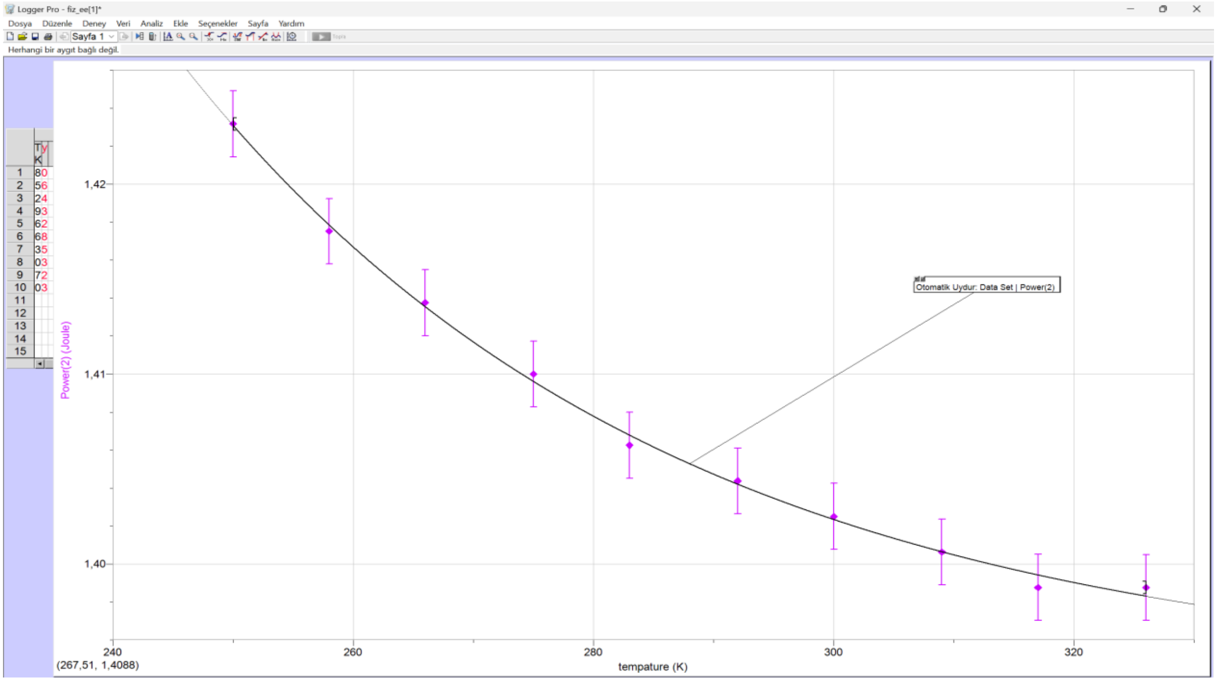
317	6.402E-05	0.0001	6.7E-05	0.00011	6.1E-05	9.7943E-05
326	6.402E-05	0.0001	6.7E-05	0.00011	6.2E-05	9.8522E-05

Table 3: The values of error percentages of every data.

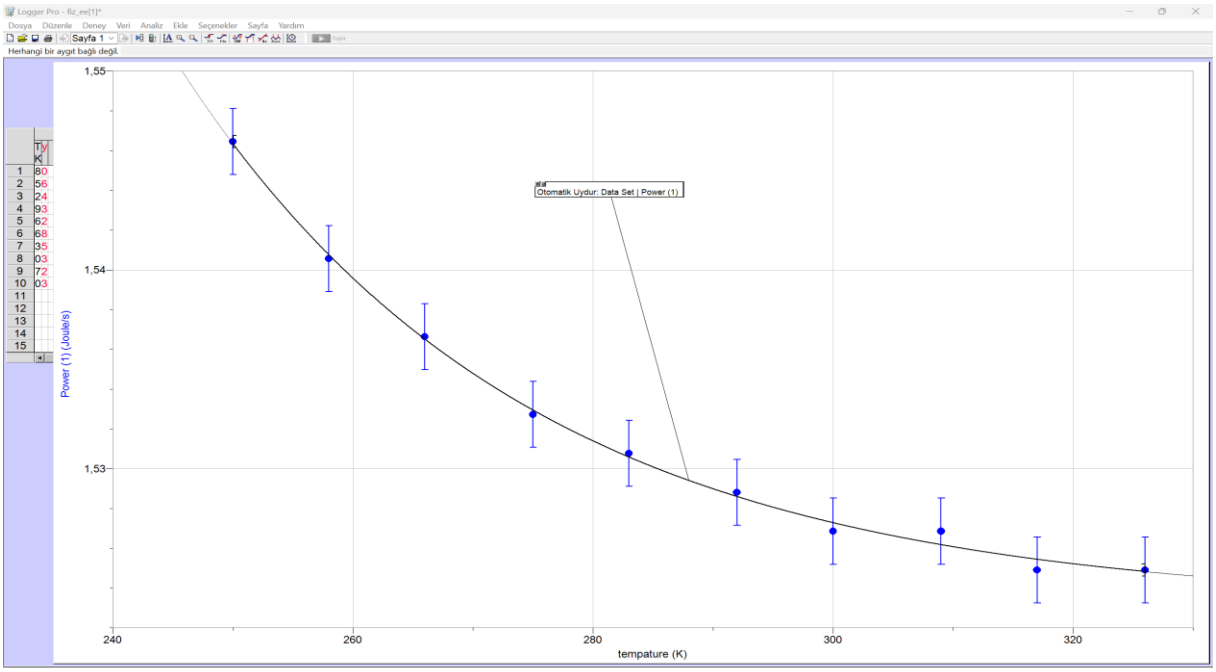
After this, to find the error percentage values of power we need to add the respective current percentage error value to the respective volt error value. For example, to find the percentage error of power(1) at 250K, we need to add 6.3573E-05 to 0.0001 which is equal to 0.000165302.

Temperature(K)	Power (1)	Power(2)	Power(3)
250	0.000165302	0.000172	0.000158
258	0.000165631	0.000173	0.000158
266	0.000165816	0.000173	0.000159
275	0.000166106	0.000173	0.000159
283	0.000166147	0.000173	0.000159
292	0.000166293	0.000174	0.000159
300	0.000166439	0.000174	0.000159
309	0.000166439	0.000174	0.000159
317	0.000166480	0.000174	0.000159
326	0.000166480	0.000174	0.000160

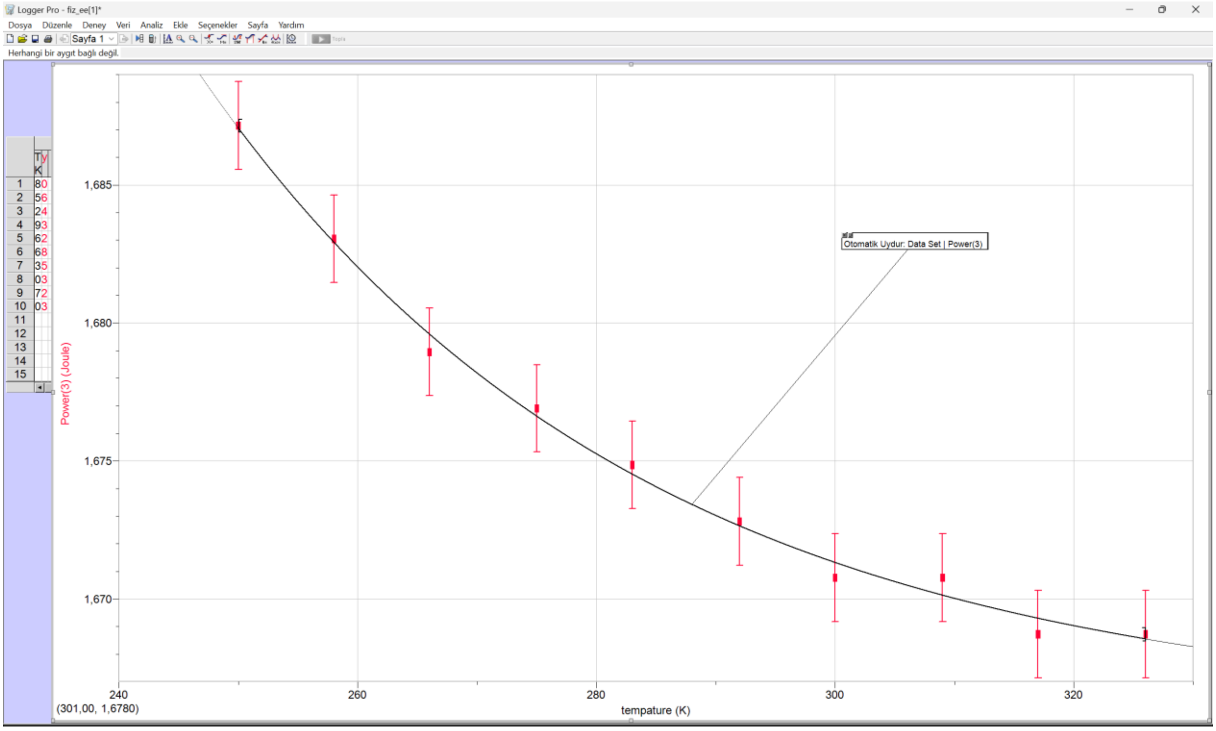
Table 4: The values of error percentages for every power value.



Graph 1: Relation of temperature with the power of a battery with the first initial volt.



Graph 2: Relation of temperature with the power of a battery with the second initial volt.



Graph 3: Relation of temperature with the power of a battery with the third initial volt.

If we try fitting a slope for these graphs, we can see the relation between them. After a few trials and errors, the relation between them seems to be a natural exponential function, however, to be sure about this we need to linearize graphs.

Linearizing Graphs

To linearize graphs we need to find what temperature is directly proportional for this we need to leave temperature alone the type of the relation between them is exponential in which means their relation can be expressed like this:

$$P = A\exp(-C * T) + B$$

Where T is temperature, P is the power of the battery, and A, B, and C coefficients are real numbers.

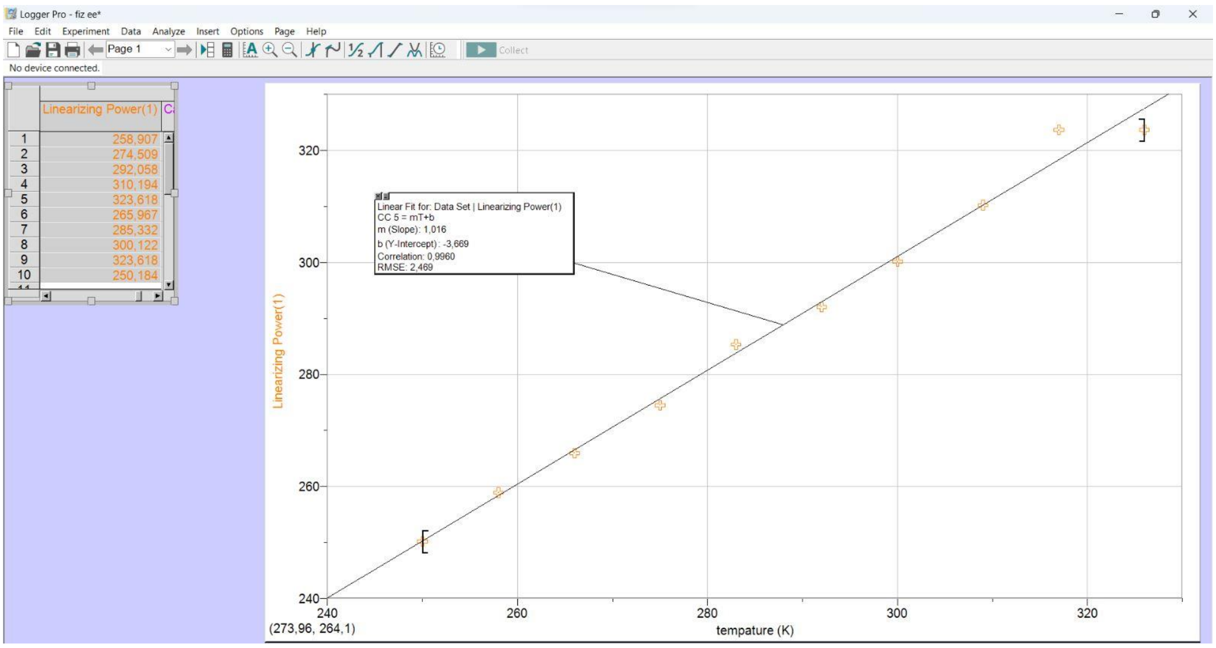
The values of A, B, and C for each graph are as follows:

	Coefficient A	Coefficient C	Coefficient B
Power (1)	18.56	0.02709	1.666
Power (2)	127.7	0.03445	1.523
Power (3)	14.05	0.02469	1.394

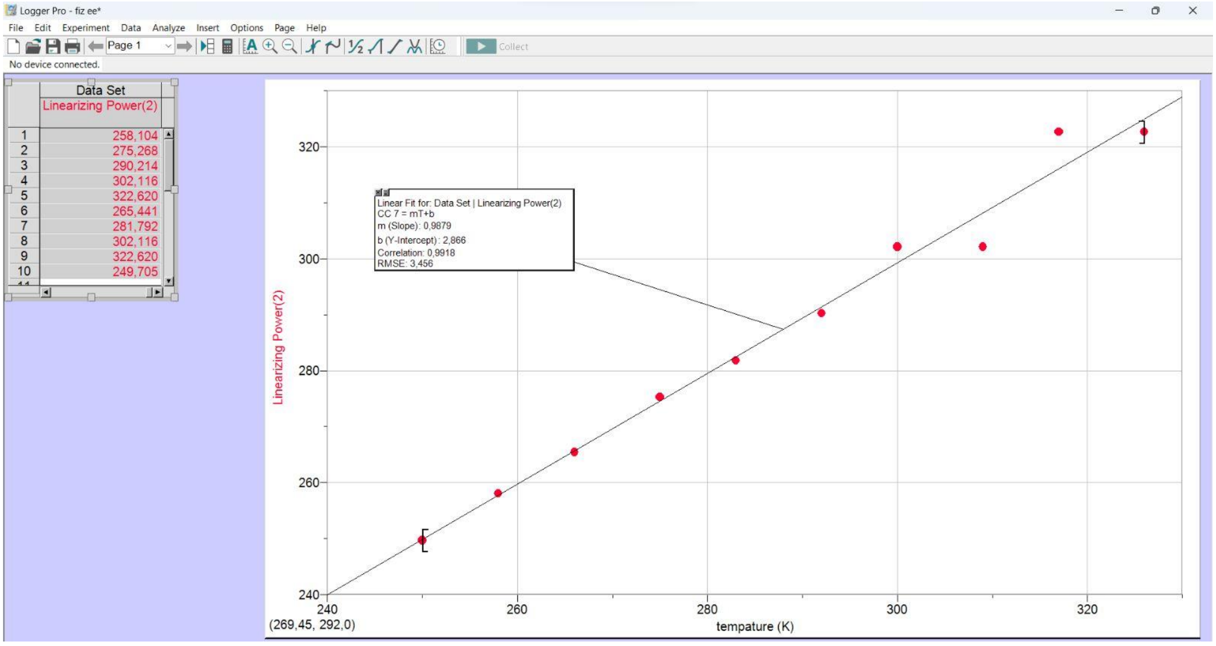
To leave T alone first subtract B form both sides than divide both sides to A before taking the natural logarithm and finally divide both sides to -C. the last result is:

$$\frac{\ln\left(\frac{P-B}{A}\right)}{-C} = \mathrm{T}$$

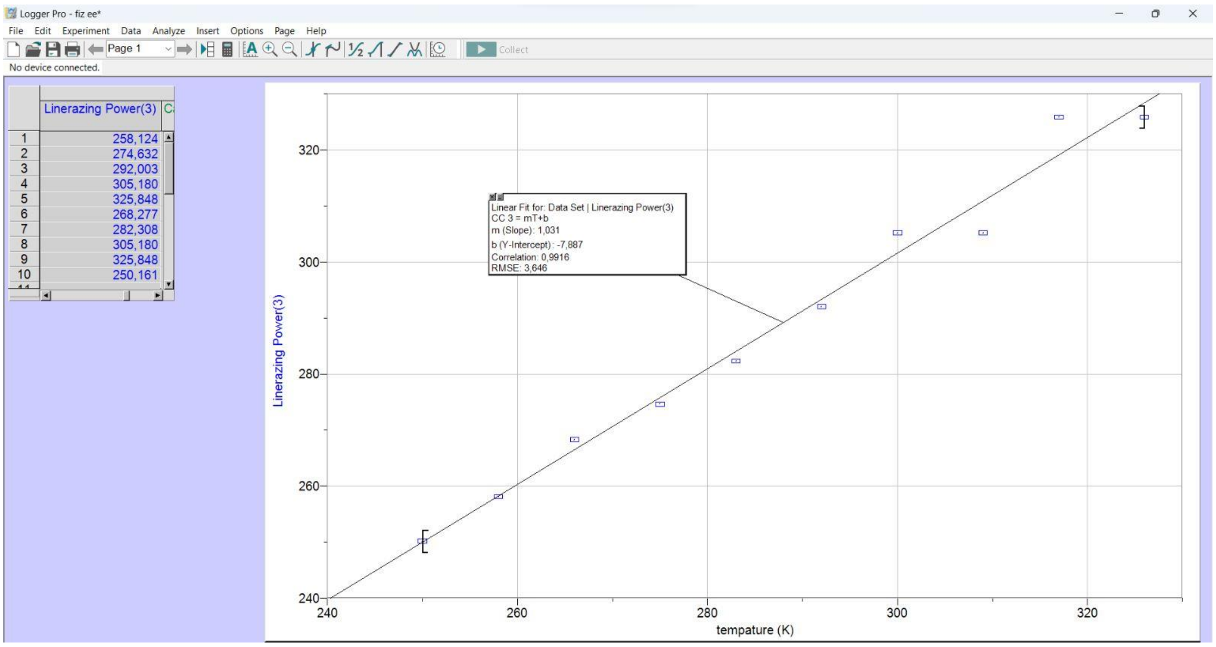
So, the graphs that are made this way should be linear.



Graph 4: Linearizing Power (1)'s graph.



Graph 5: Linearizing Power (2) ’s graph.



Graph5: Linearizing Power(3) ’s graph.

Conclusion

Conclusion

From the data above we can understand that temperature is important for a galvanic battery since as the temperature increases the output power decreases and we can only use a smaller amount of the power than how much we could use if the temperature of the battery were lower. Even with the same initial voltage, we can only use a smaller amount of power as the temperature gets higher so the efficiency of the battery decreases. These results support our hypothesis, to get the best use out of them we need to make our batteries as cold as we can since with the same amount of substance the energy they can give per time increases as they get colder. A cooler environment should be considered if more power is needed since this would result in a cooler battery.

One of the reasons there are fans in our computer is to decrease internal components' temperature and make sure the energy supports the machine depended on stays cooler. There are even coolers in energy supplies just for them. In laptops, there are batteries too. The battery they use is not zinc carbon but the lithium-ion battery – one of the main battery types used as technological devices' battery such as smartphones and laptops- is also a galvanic cell which means they are exothermic too. There are some laptop fan structures designed not just for cooling the CPU or GPU, but the airflow also cools the battery to get the best performance out of it.

Evaluation

The method and results seem to be correct since as the temperature increases the work done decreases but there are some data where even though the temperature is changed neither the voltage nor the current changes. I believe the reason for this is the fact that my multimeter can only read Volt/mV and Current/mA, so any changes smaller than 10^-3 cannot be deduced. Even though there is a problem like this, with error bars, it could be fixed, and a graph can still be constructed. Also, I used two multimeters to make sure my data is trustable, and two multimeters didn't show the same results on the same batteries at the same temperature, but they always had a 0.03 difference which shows that at least one of them has a systematic error. Since there was no way for me to check which one is true or even if one of them is true, I had to take every data's average to maintain a reasonable graph. However, since these incorrect values are caused by systematic error, they can only change the value B which changes as the battery's initial volt changes. As the battery reached the desired temperature, I stopped giving heat so any changes in temperature after that point can intervene with the results. To prevent this change, this experiment can be conducted in an environment where we can control the room's temperature. Using an IR thermometer made it possible to read the temperature values accurately and faster and this was important because every second the battery stayed at room temperature it would get closer to the room temperature. Throughout the experiment, things such as internal resistance are neglected but still, the correlation of the main graphs for power and temperature difference is around 0.98, we can say they do not change too much as the temperature changes. However, this experiment can be done regarding these neglected variables. The value of correlation also indicates that the experimental errors are low. The other way we can analyze experimental values is by looking at the "RMSE" values of the initial graphs. RMSE "measures the average magnitude of the errors and is concerned with the deviations from the actual value. RMSE value with zero indicates that the model has a perfect fit."[1] The initial graph's RMSE scores' average is 0.004 (in 3 s.f.) this means also means the experimental error is low. The linearized graphs go near the origin point. This makes sense since there cannot be any current at 0 Kelvin, so the power should be equal to zero. The main reason behind this can be the systematic errors my multimeter has caused.

Arrhenius Equation

Arrhenius Equation is an equation proposed in 1889, in physical chemistry this formula tells the relation between temperature and reaction rates. Currently, it is best seen as an empirical relationship. It can be used to model the temperature variation of diffusion coefficients, the population of crystal vacancies, creep rates, and many other thermally induced processes/reactions.

The equation may be expressed as:

$$k = Ae^{\frac{-E_a}{k_B T}},$$

Were,

k is the rate constant (frequency of collisions resulting in a reaction),

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[1] https://www.analyticsvidhya.com/blog/2021/10/evaluation-metric-for-regression-models/#:~:text=RMSE%20is%20computed%20by%20taking,model%20has%20a%20perfect%20fit.

T is the absolute temperature (in Kelvin or degree Rankine),

A is the pre-exponential factor.

E_a is the activation energy for the reaction (in the same units as kBT),

k_B is the Boltzmann constant.

This equation is likewise to the equation we derived from our data, they both are exponential functions, this similarity is because the Arrhenius equation gives us the rate constant, and our equation gives us the power of the battery. The rate constant is the frequency of collisions resulting in a reaction and since what makes the potential difference is the reaction occurring in the battery, As the frequency of these reactions increases, so does the potential difference, and since power and potential differences square are directly proportional, power is also directly proportional to the rate constant's square of the reaction in the battery.

Improvements

With a more precise multimeter, we can see how there is a change in the data more clearly, and doing this experiment with other types of batteries can lead us to the most dependable one to use in a situation where there are sudden changes in the temperature. To find the battery type to use in this extreme situation, functions should be derived via using this experiment method and the battery with the minimum power difference should be used in such situation. With more initial voltages an equation can be built about the correlation between initial voltage and the effect of temperature. Additionally, this experiment can be done with different resistance values to get a more universal equation that explains the relationship between power and temperature that includes the relationship between all three of them.

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