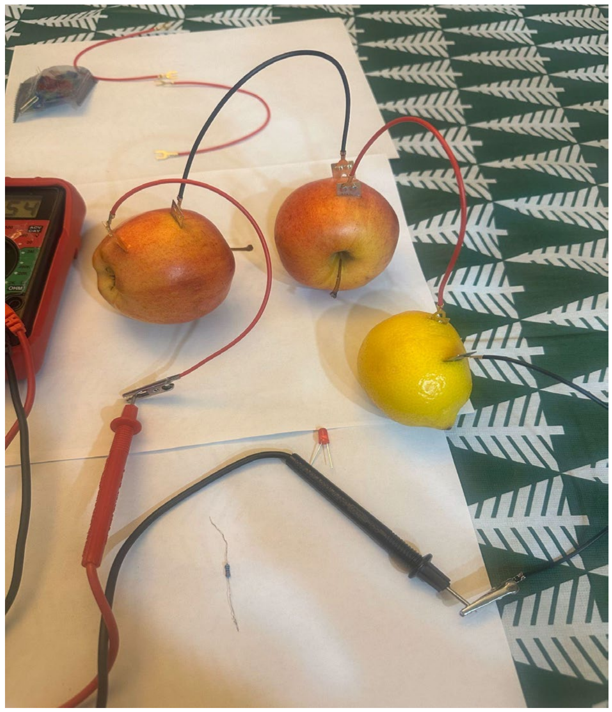
Deep Dive, Food Battery-Future Organic Power Bank



Siddhant Rao & Rishabh Rao

Calgary Youth Science Fair (CYSF)

Junior Division

School: Renert

Grade : 5

Date: Feb 6 2026

1.EXECUTIVE SUMMARY

This study investigated the electrical performance of food-based batteries constructed from lemons, apples, and potatoes using zinc and copper electrodes. Voltage, current, Voltage Decay, and power output were measured across four trials for each food type under both unheated and heated conditions. Results showed that heating significantly increased current output by reducing internal resistance, although voltage decreased slightly. Maximum power output remained below 1 milli W, which is insufficient for mechanical loads such as DC motors requiring milliwatt-level power. However, food batteries successfully powered ultra-low-power electronic loads including LED beepers and digital clocks when connected in series. The batteries have steep voltage decay rate compared to AAA batteries. These findings demonstrate that food batteries are limited primarily by internal resistance rather than voltage generation and suggest potential future applications in biodegradable micro-power sources for educational tools and ultra-low-power sensor systems, with diverse application for health, food and environmental monitoring.

Table of Content

2. Introduction

This project builds on food battery demonstrations by quantitatively measuring voltage, current, power, and internal resistance; investigating the effects of heating and electrode spacing; testing practical loads such as clocks and motors; and evaluating whether food batteries have potential applications in sustainable micro-power electronics rather than serving solely as educational battery demonstrations.

❖ Purpose

Modern batteries are widely used, but they create environmental waste and are difficult to recycle. Many contain chemicals that can harm soil and water if not disposed of properly.
At the same time, there are remote locations—such as farms, forests, disaster zones, or developing regions—where access to electricity and replacement batteries is limited.
This led us to ask an important question:
Could naturally occurring, biodegradable materials help generate small amounts of electrical energy?
Food is biodegradable, widely available, and contains chemical compounds. Therefore, the purpose of our experiment was to investigate whether **common food** items could act as **simple batteries**,

The purpose of this experiment was multifold as below. In summary the purpose is to study the food battery performance in detail and understand its real life applications.

- Find out if everyday food items can be used to make a simple battery.
- If so, which food items produce highest voltage and current.
- What different gadgets can the food battery power and how much power does it require
- How long can a food battery last?
- Are there any real life applications for food battery based on our findings?

❖ Hypothesis

Heating foods and reducing the distance between electrodes will decrease internal resistance, resulting in higher current and power output. However, total power will remain insufficient to operate mechanical devices such as DC motors.

HYPOTHESIS #1

If we measure the voltage of an apple, potato and a lemon, then lemon will produce the most voltage because it has higher concentration of acid (acidity).

HYPOTHESIS #2

If we measure the current across the lemon battery, then the current measured will be less then a normal battery because of the high internal resistance of the lemon battery (food battery) compared to standard AAA battery.

HYPOTHESIS #3

If we had enough food connected in series producing high voltage, then we should be able to light the LED, power the small clock, beeper and motor because higher voltage should be able to power the gadgets.

❖ Experimental Design

For designing our experiments, we had to come up with plan and answer a number of questions that had to align with our purpose and hypothesis. Questions below allowed us to come up with an experimental plan

1. *Best ways of measuring voltage and current?*

We found from literature and in discussion with our Dad who is our mentor that voltage can be reliably measured using a multimeter that has the capability to measure DC voltage from 0-9V and measuring currents on food batteries could be challenging with no load across it. That’s why we researched the right resistance to use to be used in series with the food battery set up to measure the current. We found that a 200-400 ohm resistor is suitable for the measurement, we were able to find a 220-ohm resistor in the shop that we decided to use.

2. *Selection of the food type?*

Based on our background research we selected Potato, Lemon and Apple as our candidate food items.

3. *Which food type produces the highest amount of voltage and current; potato vs Lemon vs Apple.?*

This is where we started our hypothesis from.

4. *Compare to the baseline Battery vs Highest Voltage producing food?*

For this step we choose a AAA Battery as our baseline or control.

5. *Can we measure voltage and current of the fruits and then light a small LED or power small clock, a motor and a beeper?*

6. *How much voltage, current was measured?*

7. *How does voltage decay over time for each food type over a certain period of time?*

8. *How many samples measurements, electrode numbers and methods of measurement are there?*

Based on the discussion with our mentors at school we selected 4 sample measurements for each trial, so we have better repeatability and improve accuracy of our measurements.

9. *Selection of the variables as shown in the Variables section below*

The variables in our experiments can be divided into 3 types dependent, independent and control variable

Independent variables are the ones that don't depend on anything in the experiments, and dependent variables are the variables that depend on independent variables. Control variables are the ones that are constants for all the experimental steps.

Independent Variables:
•Type of food (lemon, apple, potato)
• Thermal treatment (unheated vs heated)
• Electrode spacing

Dependent Variables:
• Voltage (V)
• Current (mA)
• Power (mW)
• Internal resistance (Ω)

Controlled Variables:
• Electrode materials (zinc and copper)
• Measurement equipment
• External load resistance
• Electrode insertion depth
• Ambient temperature (except heating trials)

❖ Background Research

As we started this project, we had to understand a number of basic concepts about electricity, battery, scientific principles, measurement techniques, sources of error, choice of electrodes, food battery candidates, and potential future applications of our experiments. This background research section addresses those topics that we researched and were helpful in our project.

1. What is Electricity?

Electricity is the flow of tiny particles called **electrons** through materials like wires. You can't see electrons because they're incredibly small, but you can see what they do when they flow, like lighting up a bulb or making a motor spin!

Think of electricity like water flowing through a pipe. Just as water flows from high pressure to low pressure, electrons flow from one place to another, creating what we call **electric current**.

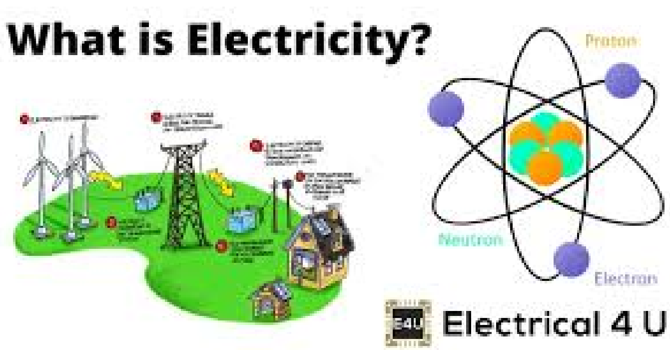


Figure 2.1 Basics Of Electricity

To understand how electricity works, you need to know about three important things:

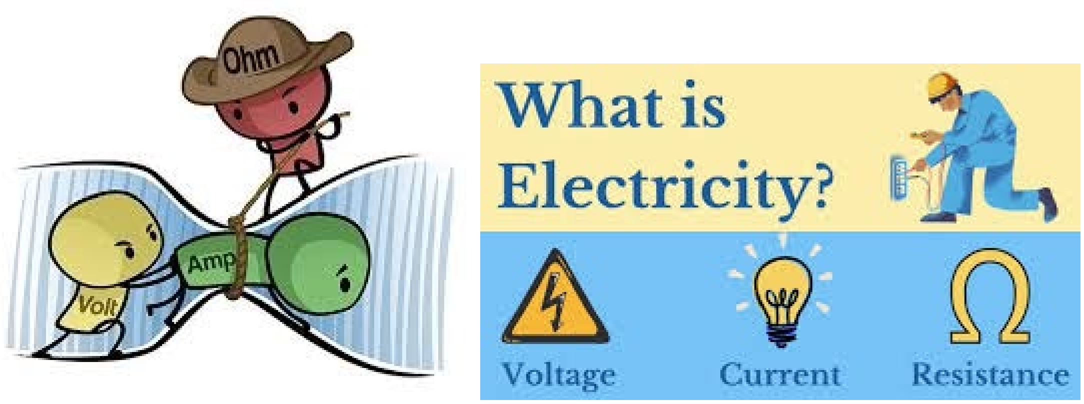


Figure 2.2 : Electricity Elements

- **Voltage (V)** - The pushing force (like water pressure)
- **Current (I)** - The amount of flow (like how much water flows)
- **Resistance (R)** - What slows down the flow (like a narrow pipe)

1. How do Batteries Work?

Batteries convert chemical energy into electrical energy through oxidation–reduction reactions occurring at two electrodes immersed in an electrolyte. At the anode, oxidation releases electrons, while at the cathode, reduction consumes electrons, creating an electric current in the external circuit. A battery is like a jar of chemicals that stores energy. When you connect a battery to something like a flashlight, the chemicals inside react with each other and create electricity!

According to Britannica Kids, batteries store energy as chemical energy, and when the battery is used, this chemical energy changes into electrical energy that can power devices.

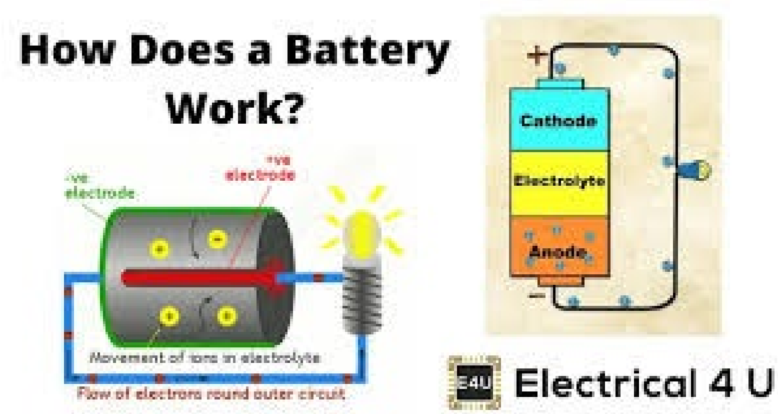


Figure 2.3 Battery working

Every battery has three main parts:

Anode (Negative Terminal - marked with a minus sign)

- This is where electrons build up and want to escape
- Usually made of zinc
- Marked with a "-" sign

Cathode (Positive Terminal - marked with a plus sign)

- This is where electrons want to go
- Usually made of materials like manganese dioxide or copper
- Marked with a "+" sign

Electrolyte (The Chemical Middle)

- A special liquid or paste between the two terminals
- Contains chemicals that help create the electron flow
- In alkaline batteries, this is often potassium hydroxide

2. How Does a Battery Make Electricity?

Here's the cool part! Inside the battery, a chemical reaction happens. This reaction takes electrons from some atoms and adds them to others. The electrons pile up at the negative terminal (anode), creating a crowd of electrons that want to move.

But here's the trick: electrons can't travel through the electrolyte to get to the positive terminal. They need an outside path, like a wire! When you connect a wire from the negative terminal to the positive terminal (with something like a light bulb in between), the electrons rush through the wire, creating an electric current that lights up the bulb.

According to The Conversation, the chemical reaction inside an alkaline battery moves negatively-charged particles called electrons around to create an electric current, and this reaction produces around 1.5 – 1.8 volts of electricity for a standard AAA battery

Fun Battery Facts

- ➢ The first battery was invented in 1800 by Alessandro Volta, an Italian scientist. That's why we call the unit of electrical pressure a "volt"!
- ➢ A dead battery isn't really "empty" - the chemicals inside have just changed so much that they can't make electricity anymore
- ➢ Rechargeable batteries can typically be recharged between 300 and 1,000 times before they wear out
- ➢ Car batteries are huge because cars need a lot of power to start the engine!

3. AC vs DC Electricity

There are two main types of electricity: Direct Current (DC) and Alternating Current (AC). Understanding the difference is important!

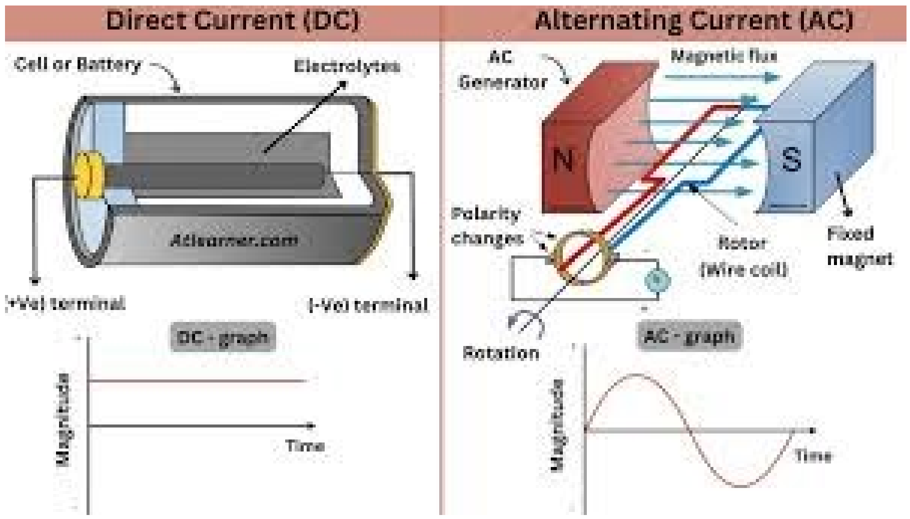


Figure 2.4 AC/DC illustration (www. centralwires.com)

What is DC? Direct current is electricity that always flows in the same direction, like a river flowing downstream. The electrons move from the negative terminal to the positive terminal in one steady stream.

According to Kiddle Encyclopedia, direct current is when electricity always flows in a certain direction, like the flow of a river, and it refers to the flow of electricity obtained from batteries and solar cells.

Where do we use DC?

- All batteries (AA, AAA, phone batteries, car batteries)
- Solar panels
- Flashlights
- Toys
- Cell phones and tablets (even though they plug into the wall, they convert AC to DC inside)

- Computers and TVs (they have special parts that change AC from the wall into DC)

What is AC? Alternating current is electricity that constantly switches direction back and forth, like ocean waves moving in and out. The electrons don't flow steadily in one direction; instead, they vibrate back and forth very quickly!

According to SparkFun Learn, alternating current describes the flow of charge that changes direction periodically, and as a result, the voltage level also reverses along with the current.

Where do we use AC?

- Wall outlets in your home
- Power lines that bring electricity to your house
- Large appliances like refrigerators, washing machines, and air conditioners
- Ceiling lights

Ohm's Law: The Golden Rule of Electricity and Power

Ohm's Law is one of the most important rules in all of electronics! It was discovered in 1827 by a German scientist named Georg Simon Ohm, and it tells us how voltage, current, and resistance work together.

Before we learn Ohm's Law, let's understand what each part means:

1. Voltage (V) - The Push

- Measured in **Volts (V)**
- This is the force that pushes electrons through a wire
- Think of it like water pressure in a hose
- A battery's voltage tells you how hard it pushes electrons
- Common voltages: AA battery = 1.5V, Car battery = 12V, Wall outlet = 120V (USA)

2. Current (I) - The Flow

- Measured in **Amperes or Amps (A)**
- Current is labelled **I** as it was initially called “Intensite de courant” meaning current intensity.
- This is how many electrons flow past a point each second
- Think of it like how much water flows through a hose
- One amp is about 6,241,500,000,000,000,000 electrons per second!
- Sometimes we use smaller units: milliamps (mA), where 1,000 mA = 1 A

3. Resistance (R) - The Obstacle

- Measured in **Ohms (Ω)** - that's the Greek letter Omega
- This is anything that slows down or opposes the flow of electrons
- Think of it like a narrow part in a hose that slows the water down
- Every material has resistance - even wires!
- Light bulbs, heaters, and motors all have resistance

Here's the magic formula that connects all three:

V = I × R

Or in words: **Voltage = Current × Resistance**

This formula tells us that voltage equals current multiplied by resistance. According to Ducksters, Ohm's law states that the current passing through a conductor is proportional to the voltage over the resistance.

4. What is Power?

Power is how fast energy is being used or produced. In electricity, we measure power in **Watts (W)**, named after James Watt, a famous Scottish inventor.

According to Wikipedia, Watt is the unit of power in the International System of Units, equal to 1 joule per second, and it is used to quantify the rate of energy transfer.

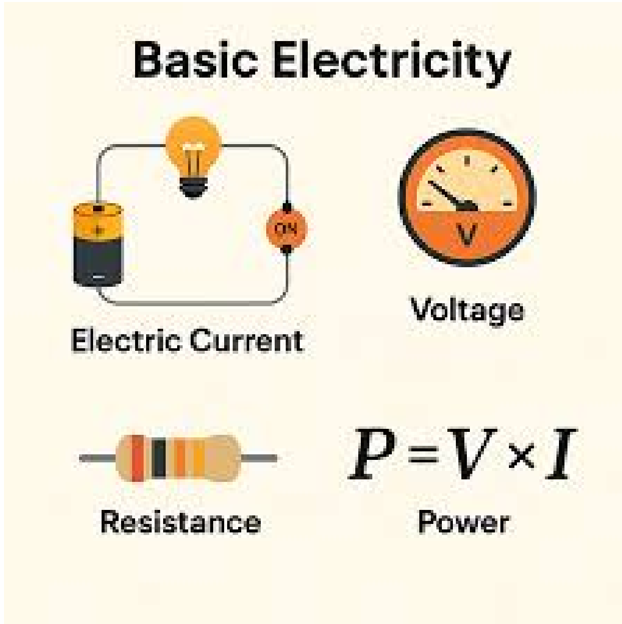


Figure 2.5 : Electric Power

Think of power this way:

- Energy is like the total amount of work you can do
- Power is how fast you're doing that work

One watt means using one joule of energy every second. In electrical terms, one watt is the power used when one amp of current flows through a circuit with one volt of electrical pressure.

The basic formula for electrical power is:

P = V × I

Or in words: **Power = Voltage × Current**

This tells us that power (in watts) equals voltage (in volts) multiplied by current (in amps).

5. Food battery

Based on our research we figured out that food battery produces DC current and Voltage. Like a regular battery, food batteries have electrodes and electrolytes. A battery works by producing voltage and current because of the chemical reaction between electrodes and electrolyte which is the food juice or the food itself. V food batteries rely on naturally occurring acids and ions within fruits and vegetables, resulting in much higher internal resistance and lower current delivery.

➢ ***What best electrodes to choose?***

From our book "How to be good at Science", it states that electrodes are chosen based on the electrochemical potential difference between the anode and cathode electrodes, higher the potential difference easier the electrons will flow from anode to cathode. Based on our research zinc as anode and copper as cathode came out as the best choice. It is also available easily in stores and they remain stable under food electrolyte chemical reactions.

We found that there are other choices we could have used, like Magnesium as Anode, copper as cathode – but magnesium corrodes faster and is also harder to buy.

Aluminum and Copper, but they produce less voltage. Aluminum also has high potential to have oxide layer formation.

Iron-Copper, again this produces less voltage.

➢ ***What food items are best candidates for food battery, that is easily available? Why?***

The food with a electrolyte must contain ions (charged particles) for electricity to flow. Higher acidic food produces more voltage.

More acidity → more H^+ → stronger zinc–copper chemical reaction → larger electron flow

→ higher voltage.

- Apple: pH 3.0 – 4.0 Give less voltage (Mildly acidic; varies by variety and ripeness)
- Lemon: pH 2.0 – 2.6 gives the most voltage (Highly acidic because of citric acid)

- Potato: pH 5.4 – 6.0 gives even less voltage (Slightly acidic to near-neutral; varies by type and soil conditions)

Our research showed that malic acid and citric acid are the two major organic acid components in Malus species. In cultivated apples, malic acid is the predominantly detectable organic acid, while malic acid and citric acid are the predominant organic acids in wild apple species.

From our research we also found out that other foods like cucumber can produce a lot higher voltage in the 5V range with different electrodes like magnesium, however their application might be limited due to electrode corrosion.

Acidity has two main meanings: chemically, it's the quality or degree of being acid, measured on a pH scale

A pH of 7 is neutral, while a pH below 7 is acidic and a pH above 7 is basic.

The term Ph stands for "potential of hydrogen," and it represents the concentration of hydrogen ions (H^+) in a liquid.

For example, a solution with a pH of 3 is 10 times more acidic than a solution with a pH with a pH of 4.

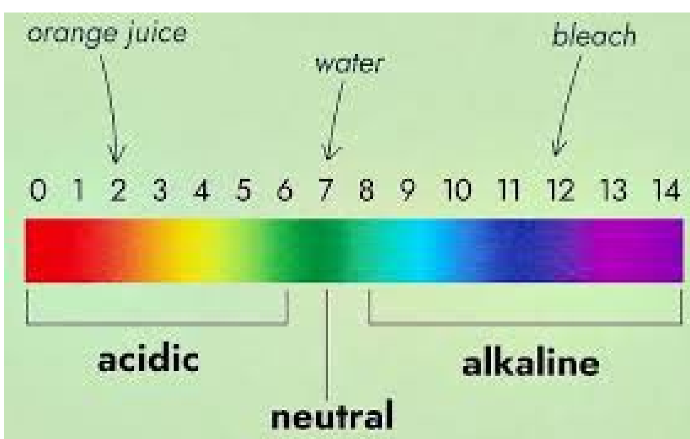


Figure 2.6 Ph Scale (source water basics 101)

6. Potential real-life applications for food batteries?

As per eepower.com article, the solid phase bacteria powered biobattery has been in testing and could prove to be a low power source for the internet of disposable things. The internet of disposable things (LOT) is a phenomenon in which wireless sensors are attached to nearly any type of device in order to provide up to date information via internet, for example a sensor could be attached to a food packaging to monitor the freshness of the food inside, sensors could be used in low power environmental applications for wild fire, crop management and soil condition detection. These could then be designed to have finite life and designed as one time use when they are designed using sustainable and biodegradable batteries to power them. Some of the early studies have indicated very strong potential for such applications with 100-1000s of hours of sustained power being provided by food based and biodegradable batteries.

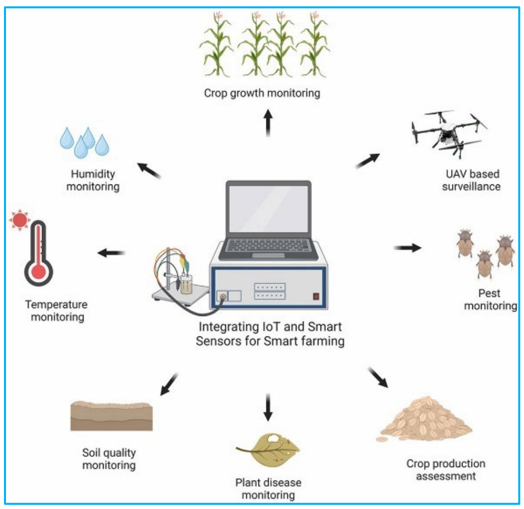


Figure 2.7 Low power smart sensor in agriculture (source IOT Science Direct)

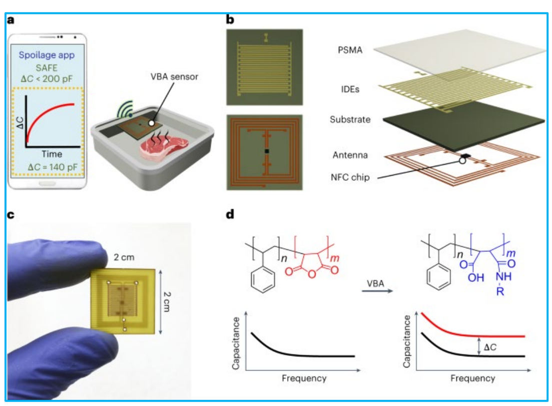


Figure 2.8 Smart food quality sensors (source Nature.com)

3. Materials and Methods

❖ Materials

Following material was used for our experiments.

- Fresh lemons, apples, and potatoes
- Zinc electrodes (galvanized nails or zinc strips)
- Copper electrodes (copper wire or copper strips)
- Digital multimeter capable of measuring voltage and current
- 220 Ω resistor
- Connecting wires and alligator clips
- Microwave oven – at home standard
- LED beeper module
- Low-power digital clock
- Small DC motor
- Ruler for electrode spacing
- Temperature measurement gun – at home from our Dad’s tool chest.
- Safety goggles and gloves

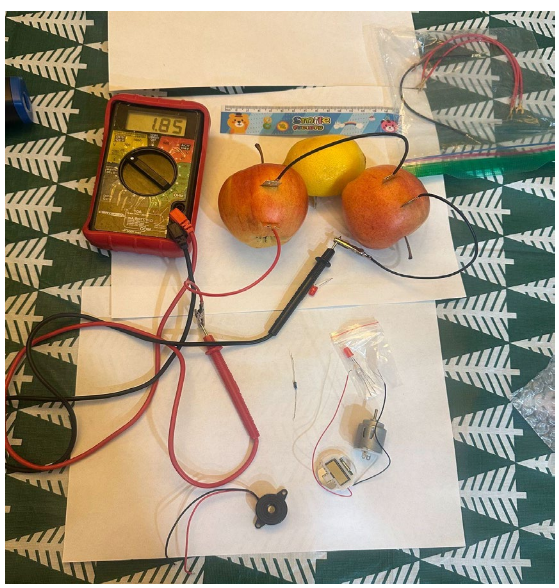


Figure 3.1 : Materials used for the experiment

❖ Methods

In this section an outline our experimental methods are provided.

1. Zinc and copper electrodes were cleaned and inserted approximately 3 cm apart and depth of 1 cm into each food sample.
2. Open-circuit voltage was measured using a digital multimeter.
3. A 220 Ω resistor was connected in series with the food battery, and current was measured to determine loaded performance of the food battery.
4. Voltage across the resistor was recorded, and power was calculated using $P = V \times I$
5. Each measurement was repeated four times for each food type, and averages were calculated. All reported numbers in the presentation are average numbers.
6. Electrode spacing was reduced from 3 cm to 1 cm and steps 2–6 were repeated. This was done to see if changing electrode distance changed the current and voltage generated by the food battery.
7. Food samples were microwaved for 15 seconds, allowed to cool slightly, and steps 2–6 were repeated. The food temperature was measured and was allowed to around 30-35C for safe handling. Just for one food item (heated potato), we also reduced the electrode distance to 1 cm to study the effect of electrode distance variation.
8. Two food cells were connected in series and tested with an LED beeper, digital clock, and DC motor
9. Voltage and current were recorded for each load condition, when the food battery was powering LED, beeper, digital clock and DC motor. Power was calculated for each load.
10. During all the steps voltage, current and power measurements were noted down.
11. For voltage decay measurements, each battery open circuit voltage was measured over a period of 2 hours every 15 minutes and recorded.
12. For comparison AAA Battery open circuit was measured, their decay rates were determined from our background research.

Safety and good house keeping rules were followed in all steps. We kept an inventory of all our science experiment materials and put them away in an orderly fashion in a bin after our experimentation. Following safety steps were followed

- Safety goggles were worn when handling metal electrodes and electrical equipment.
- Foods were not consumed after experimental use.
- Microwave heating was conducted under adult supervision. Food surface temperature was measured to make sure it is safe to handle.
- Electrical measurements were limited to low voltages and currents, presenting minimal electrical hazard and was also done under adult supervision.
- Strict rules were followed by washing hands after handling the electrodes and electrical components.

4. Results

In this section we present all our tabulated results and plots.

Finding 1: We found that the highest voltage producing food was apple (1.05V), followed by lemon (0.91V) and then potato (0.81 V), this proved that our initial Hypothesis#1 is NOT true. This is most likely because of the variation of electrolyte quality and chemical reactions driving the reactions.

Figure 4.1 shows various open circuit voltages measured for the food items, with food items on the Y axis and Voltage (V) on the X axis.

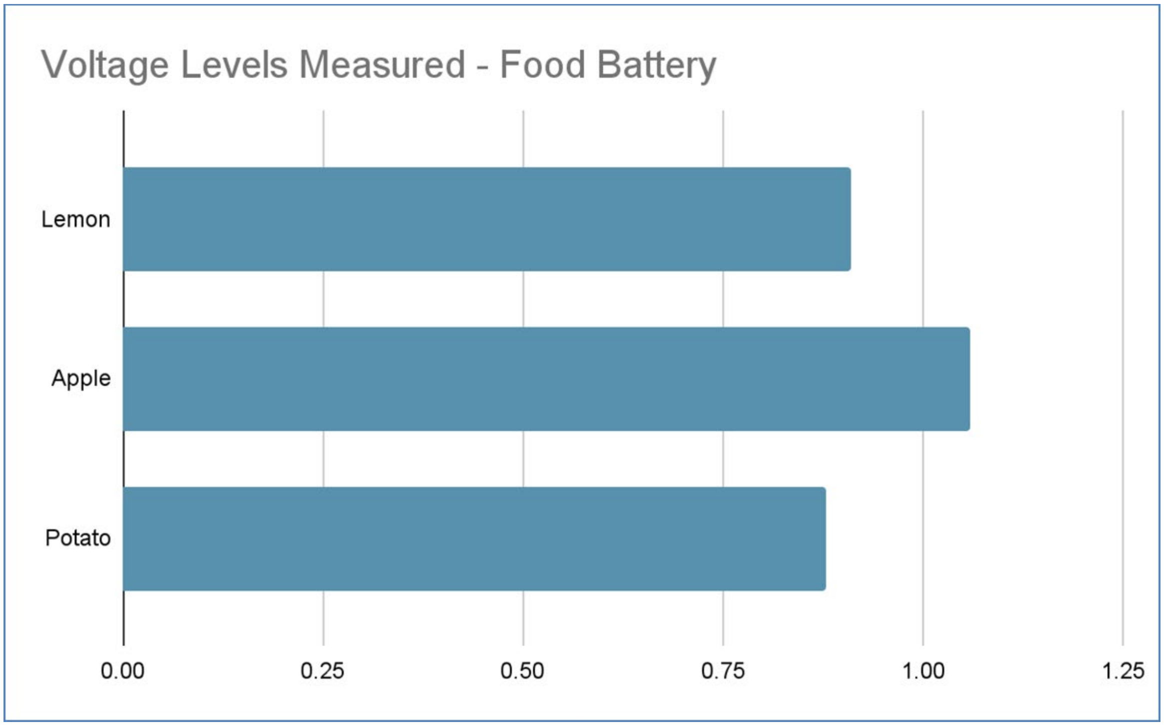


Figure 4-1 Open Circuit Voltage for food items

Finding 2: We produced enough voltage with 2 apples about 2.1 V to light a small LED, digital clock, and a beeper, but we could NOT power the DC motor. As it can be seen from table 4.1.

Finding 3: The amount of current produced in a food battery is very low orders of 0.088 mA to 1.1 mA compared to AAA batteries which produce 6.6 mA when powering the DC Motor. This supports finding 2 and shows that food batteries are limited by their high internal resistance. We found in our research that real batteries are engineered to have low internal resistance by controlling the electrolyte composition and hence the chemical reaction. We calculated that highest power delivered by series connected apple was 0.18 Milli Watts and that required by the DC motor is actually 9.9 milli Watts. Our food battery is about 55x weaker in power to run the DC Motor. This is shown in figure 4.2 with food items on the Y axis and Power in milli-Watts (mW) on the Y axis. Table 4.2 shows the measured power values.

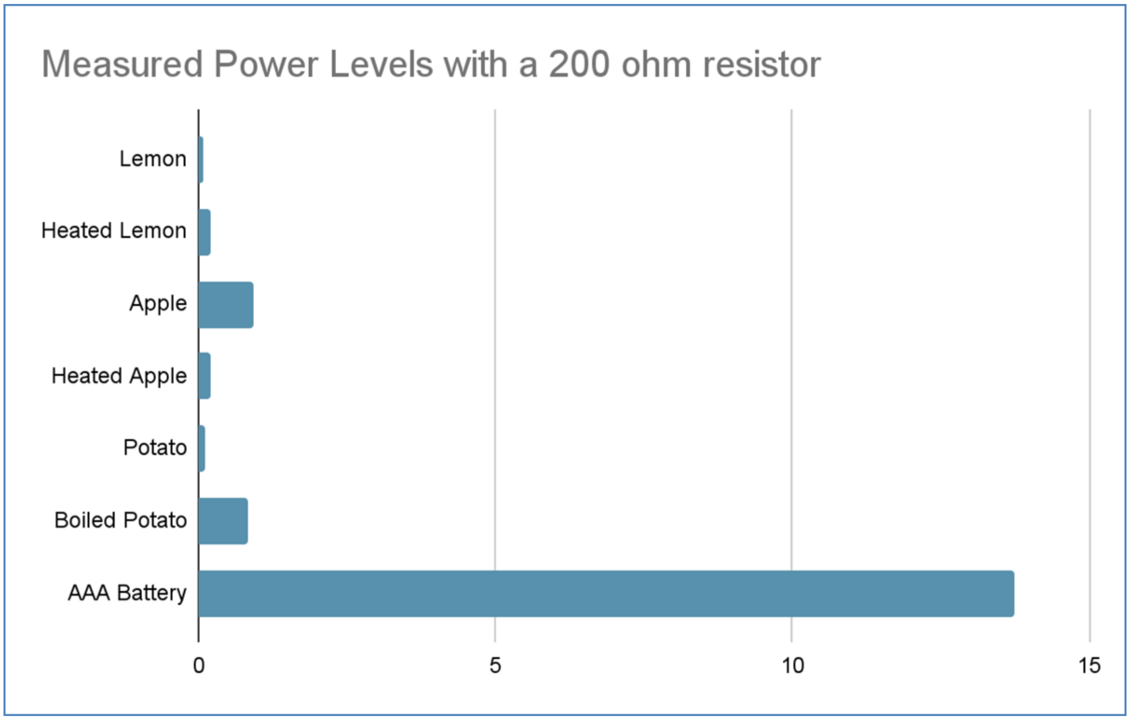


Figure 4-2 Measured Power Produced by food vs AAA Battery

Table 4-1 Measured Average Voltage and Average Current for Different Food Items

Battery Type	Measured Power (milli Watt)	Measured Average Voltage (V)	Measured Average Current (I)
Lemon	0.082	0.92	0.09
Heated Lemon	0.204	0.85	0.245
Apple	0.932	1.06	0.088
Heated Apple	0.193	0.92	0.21
Potato	0.0957	0.87	0.11
Boiled Potato	0.828	0.82	1.01
AAA Battery	13.746	1.74	7.9

Table 4-2 Measured Power

Food type	Measured Power (milli Watt) with a 200 ohm resistor
Lemon	0.082
Heated Lemon	0.204
Apple	0.932
Heated Apple	0.193
Potato	0.0957
Boiled Potato	0.828
AAA Battery	13.746

Finding 4: Current Produced by the food items increased when they were heated or microwaved. Voltage dropped compared to when they were cold. This Occurred because heat broke down the cell walls released more ions which lowered the internal resistance of the electrolyte in the food. However, heating caused voltage decay because of the possible secondary reaction and gas formation on electrode surface. It was also noted that current measurement was challenging and current dropped drastically after initial increase. The measured current when heated is shown in table 4.1. We also varied the electrode distance from 3 cm to 1 cm for heated potato and did not find huge change in either the voltage or the current measured, this experiment was only done once as there was very minimal changes.

Finding 5: The voltage dropped drastically in food items in the first one hour to a value that is pretty low compared to a standard AAA Battery. After the initial drop the voltage stabilized to a lower value. This is partially because of the variability in the food electrolyte, ability to sustain chemical reactions, polarization and internal chemical losses. The values measured are shown in table 4.3 and plot is shown in figure 4.3 with voltage on the Y axis and time increments on X axis .

Table 4-3 Voltage Decay Data Measured

Time	2 Applies in series Voltage (V)	AAA Battery	Lemon	Potato
6	2.06	1.74	0.92	0.881
6.15	1.98	1.74	0.71	0.781
6.3	1.91	1.73	0.666	0.665
6.45	1.84	1.7	0.537	0.52
7	1.8	1.7	0.485	0.482
7.15	1.77	1.7	0.484	0.481
7.3	1.75	1.7	0.483	0.47
7.45	1.73	1.7	0.481	0.45
8	1.72	1.7	0.48	0.45
8.15	1.7	1.7	0.48	0.45
8.3	1.67	1.7	0.48	0.45

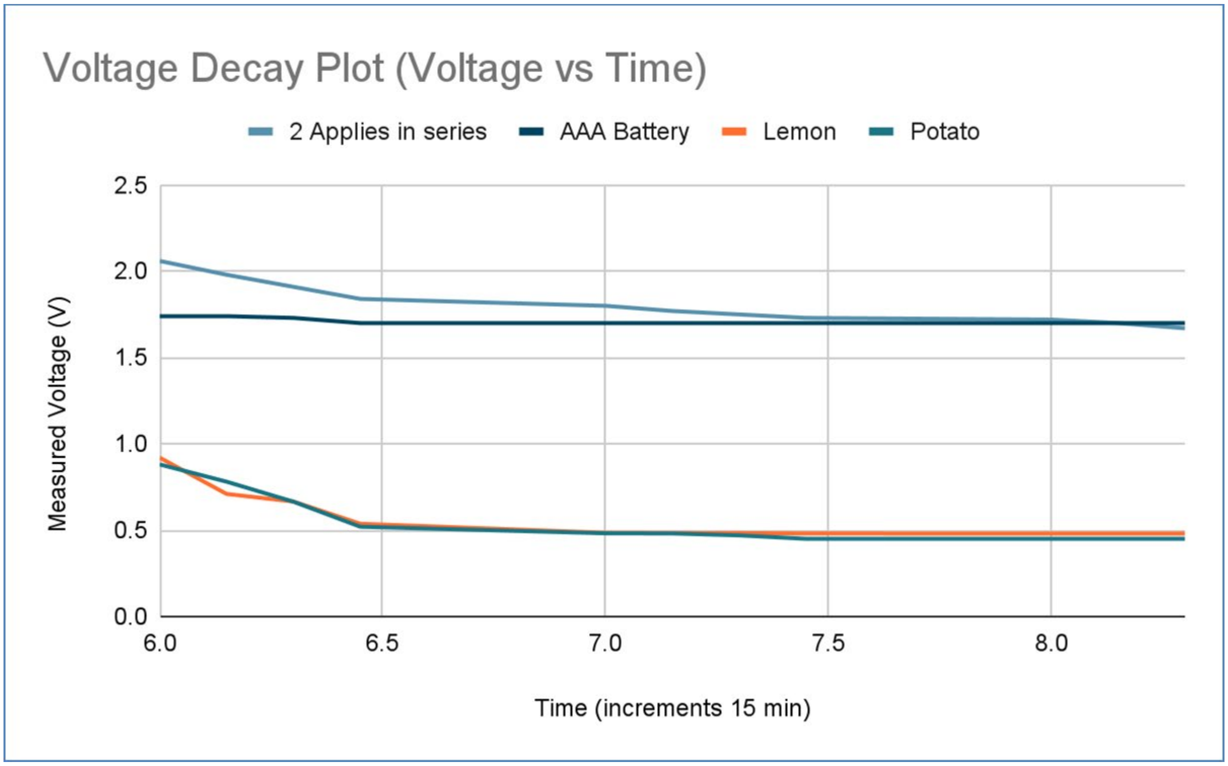


Figure 4-3 Voltage Decay Plot

5. Discussion

❖ Applications

The results from our testing proved that our initial hypothesis #1 is NOT true, where in we ended up measuring higher open circuit voltage across the apple, followed by lemon and then potato. This is most likely because of the variation of the electrolyte quality and chemical reactions driving the reactions. **(HYPOTHESIS 1 Proved In-Correct)**

From our finding 2 we found out that even though we produced higher voltage, we still couldn't power the DC motor. This proves that producing higher voltage alone is not enough but we also need current to be higher to do useful work. Power = V x I, in our case we only increased the voltage but current measurements were always low as shown in the plots and tables in results section. **(HYPOTHESIS 2 is True)**

Our findings in 3 supports finding 2 and shows that food batteries are limited by their high internal resistance but could successfully power smaller electronics that needed very low power. We found in our research that real batteries are engineered to have low internal resistance by controlling the electrolyte composition and hence the chemical reaction. Our food battery is about 55x weaker in power to run the DC Motor.
(HYPOTHESIS 3 is not always Correct)

The finding# 4 supports that heating increase current output by reducing internal resistance. Reduced electrode spacing doesn't have a huge effect on voltage and current. This occurred because heat broke down the cell walls released more ions which lowered the internal resistance of the electrolyte in the food. However, heating caused voltage decay because of the possible secondary reaction and gas formation on the electrode surface. It was also noted that current measurement was challenging and current dropped drastically after initial increase.

Our finding5 showed the high voltage decay rate in food batteries, which is partially because of the variability in the food electrolyte, ability to sustain chemical reactions, polarization and internal chemical losses..

Food batteries are biodegradable, non-toxic, and constructed from waste materials, making them environmentally sustainable compared to conventional chemical batteries that contain hazardous substances. Although they cannot replace commercial batteries, food batteries an be used for educational purposes.
Recent research has demonstrated ultra-low-power sensors capable of operating in the microwatt and nanowatt range and battery-free electronics powered by energy harvesting While food batteries alone cannot continuously power such devices, they could potentially serve as supplementary or temporary power sources when combined with other sources as hybrid sources. This suggests future applications in biodegradable environmental sensing, educational field experiments, and short-term monitoring systems.

A few early research applications of biodegradable bacteria and food powered battery were used for power disposable sensors that could be used to monitor food freshness, temperature and moisture for various monitoring activities.

❖ Sources of Error and Limitations

- The measurement uncertainty of the multimeter.
- Electrodes are not production grade could have variation.
- Food quality is variable. Variations in fruit ripeness, acidity, and moisture content likely affected electrolyte conductivity.
- Room temperature and measurement conditions could be different.
- The experiment did not include long-term stability testing beyond short discharge periods.
- Electrode surface oxidation may have altered electrode reaction rates.

6. Conclusion

This study demonstrated that lemons, apples, and potatoes can reliably generate electrical voltage using zinc and copper electrodes, but their power output is severely limited by high internal resistance. However, food batteries successfully powered ultra-low-power electronics such as clocks and LED beepers. These results confirm that food batteries are best suited for educational demonstrations and exploratory sustainable low-power sensing and remote power applications with lot of promise.

➢ ***Voltage vs Power***

Food Batteries can produce measurable voltage (0.8-1.1V) but voltage alone does not mean useful Power. Power depends on Voltage and Current, and its ability to last longer.

➢ ***Extremely Low Current:***

Apple, Lemon and Potato batteries produced very small currents (<0.3 mA), this limited their power due to high internal resistance.

- ***Why Motor would not run:***

Based on our measurements the motor required about 10 milli watt of power, and much higher current to start it. The apple food battery could only supply 0.18 milliwatt when we powered the DC motor *and also that would rapidly decay in the first hours.*

“There is huge potential based on the findings could these biodegradable energy sources be used for powering smart low power sensors that could provide real insights and future work lies in proving them out !”

Could this be used as high breed method reducing the carbon footprint, could they be used as environmental monitoring devices?

APPENDIX 1 Experimental Measurements All samples

LEMON

Table A1 – Voltage and Current 4 samples for lemon at room temperature

Sample #	Open Circuit Voltage (V)	Loaded Current (milli Amp)
1	0.90	0.088
2	0.92	0.091
3	0.92	0.090
4	0.93	0.91
	Average V = 0.92	Average I = 0.09

HEATED LEMON

Table A2 – Voltage and Current 4 samples for heated lemon

Sample #	Open Circuit Voltage (V)	Loaded Current (milli Amp)
1	0.83	0.27
2	0.84	0.23
3	0.86	0.24
4	0.87	0.24
	Average V =0.85	Average I = 0.245

APPLE

Table A3 – Voltage and Current 4 samples for apple at room temperature

Sample #	Open Circuit Voltage (V)	Loaded Current (milli Amp)
1	1.05	0.088
2	1.06	0.088
3	1.06	0.088
4	1.07	0.088
	Average V = 1.06	Average I = 0.088

HEATED APPLE

Table A4 – Voltage and Current 4 samples for heated apple

Sample #	Open Circuit Voltage (V)	Loaded Current (milli Amp)
1	0.92	0.23
2	0.92	0.19
3	0.92	0.21
4	0.92	0.21
	Average V =	Average I = 0.21

POTATO

Table A5 – Voltage and Current 4 samples for potato at room temperature

Sample #	Open Circuit Voltage (V)	Loaded Current (milli Amp)
1	0.86	0.11
2	0.87	0.11
3	0.87	0.11
4	0.88	0.11
	Average V = 0.87	Average I = 0.11

HEATED POTATO

Table A6 – Voltage and Current 4 samples for heated potato

Sample #	Open Circuit Voltage (V)	Loaded Current (milli Amp)
1	0.80	0.98
2	0.83	1.00
3	0.84	1.03
4	0.81	1.03
	Average V =	Average I = 1.01

Table A7 – Voltage and Current for electrode distance of 1cm – Heated Potato

Note that this step was only done for one food item as changes were minimum.

Sample #	Open Circuit Voltage (V)	Loaded Current (milli Amp)
1	0.81	1.02
2	0.82	1.01
3	0.81	1.01
4	0.81	1.01
	Average V = 0.812	Average I = 1.01

7. Acknowledgements

★ Our Mentors at School - Mr H and Ms Fauzia
★ Our Science Teachers - Dr. Soares, Ms. Sarah
★ To Renert School for giving us an opportunity to participate in CYSF.
★ To our Dad - Hemanth for Helping us with the experiments and acting as our mentor outside school.
★ To my mom Pooja and grandparents for supporting us throughout the experimentation and presentation.

8. Citations

General

1. All About Circuits. (2023). Internal resistance of a battery. https://www.allaboutcircuits.com/textbook/direct-current/chpt-11/internal-resistance/
2. Bockris, J. O'M., & Reddy, A. K. N. (2000). Modern Electrochemistry: Fundamentals of Electrodics. Springer.
3. Hester, J., & Jacobson, B. (2019). The battery-free internet of things. Proceedings of the IEEE, 106(1), 91–103. https://ieeexplore.ieee.org
4. Khan, W. T., et al. (2017). Ultra-low power temperature sensor for wireless sensor networks. IEEE Sensors Journal, 17(6), 1689–1696. https://ieeexplore.ieee.org
5. Scientific American. (2022). Bring science home: Fruit batteries. https://www.scientificamerican.com/article/bring-science-home-fruit-batteries/
6. U.S. Department of Energy. (2023). Battery basics: Electrochemical energy storage. https://www.energy.gov/eere/vehicles/articles/battery-basics
7. How to be Good At Science Engineering and Technology - DK Publishing.
8. DOE How to Batteries work
9. Electronics Tutorials for DC Circuit.
10. Internet of Things and smart sensors in agriculture: Scopes and challenges – ScienceDirect
11. Miniaturized wireless sensor enables real-time monitoring of food spoilage | Nature Food
12. pH of Water Definitions - Basic Water Science 101
13. What You Need to Know About Current, Voltage and Resistance

Batteries

14. The Conversation - "Curious Kids: how do batteries work?" (August 4, 2025) - Explains how alkaline batteries work through chemical reactions (https://theconversation.com/curious-kids-how-do-batteries-work-123023)
15. Britannica Kids - "Battery" - Overview of how batteries store and convert energy (https://kids.britannica.com/kids/article/battery/390651)
16. Britannica Kids Students - "Battery" - Detailed explanation of primary and secondary batteries (https://kids.britannica.com/students/article/battery/273129)
17. Science Sparks - "How do batteries work?" (July 18, 2022) - Kid-friendly explanation of battery chemistry (https://www.science-sparks.com/how-do-batteries-work/)
18. Explain that Stuff - "How do batteries work? A simple introduction" (February 13, 2024) - Comprehensive battery science explanation (https://www.explainthatstuff.com/batteries.html)
19. Kiddle - "Battery facts for kids" - Overview of battery types and history (https://kids.kiddle.co/Battery)
20. Dummies.com - "How Batteries Work" - Simple explanation of battery components and operation (https://www.dummies.com/article/technology/electronics/general-electronics/how-batteries-work-138048/)
21. Mocomi - "How Do Batteries Work? - Chemistry for Kids" (February 27, 2020) - Educational video and article on batteries (https://mocomi.com/how-do-batteries-work/)

AC and DC Electricity

22. Matsusada Precision - "Difference DC and AC power" - Technical comparison of direct and alternating current (https://www.matsusada.com/column/dc_and_ac.html)
23. Kiddle - "Alternating current facts for kids" - Explains AC electricity, history, and applications (https://kids.kiddle.co/Alternating_current)
24. SparkFun Learn - "Alternating Current (AC) vs. Direct Current (DC)" - Comprehensive guide to understanding both types of current (https://learn.sparkfun.com/tutorials/alternating-current-ac-vs-direct-current-dc/all)
25. PBS - "AC/DC: What's the Difference?" (September 12, 2019) - Historical context and simple explanation of AC vs DC (https://www.pbs.org/wgbh/americanexperience/features/light-acdc/)
26. Power and Beyond - "What's the difference between AC and DC power?" (April 5, 2024) - Practical applications and differences (https://www.power-and-beyond.com/whats-the-difference-between-ac-and-dc-power-a-0c5c48e598b5e1266e6cebc5731227c2/)
27. Florida Academy - "AC vs. DC Power: A Beginner's Guide" (January 3, 2024) - Educational overview for students (https://florida-academy.edu/ac-vs-dc-power-a-beginners-guide/)

28. EcoFlow - "AC vs. DC Current: What's the Difference?" - Modern applications and explanations (https://www.ecoflow.com/us/blog/ac-vs-dc-current)

Ohm's Law

29. All About Circuits - "Ohm's Law - How Voltage, Current, and Resistance Relate" (August 26, 2022) - Detailed tutorial on Ohm's Law fundamentals (https://www.allaboutcircuits.com/textbook/direct-current/chpt-2/voltage-current-resistance-relate/)
30. Britannica - "Ohm's law" - Encyclopedia entry on the physics and history of Ohm's Law (https://www.britannica.com/science/Ohms-law)
31. Study.com - "Ohm's Law | Relationship Between Voltage, Current & Resistance" (May 7, 2013) - Educational lesson with examples (https://study.com/academy/lesson/ohms-law-definition-relationship-between-voltage-current-resistance.html)
32. Wikipedia - "Ohm's law" - Comprehensive coverage of the law and its applications (https://en.wikipedia.org/wiki/Ohm's_law)
33. SparkFun Learn - "Voltage, Current, Resistance, and Ohm's Law" - Practical tutorial with experiments (https://learn.sparkfun.com/tutorials/voltage-current-resistance-and-ohms-law/all)
34. NCBI - "Ohms Law - StatPearls" (May 22, 2023) - Scientific and medical applications (https://www.ncbi.nlm.nih.gov/books/NBK441875/)
35. ROHM TechWeb - "Ohm's Law: Voltage, Current, and Resistance" - Technical guide with calculator (https://techweb.rohm.com/product/circuit-design/electric-circuit-design/21859/)
36. Electronics Tutorials - "Ohms Law Tutorial and Power in Electrical Circuits" (September 1, 2024) - Comprehensive tutorial with diagrams (https://www.electronics-tutorials.ws/dccircuits/dcp_2.html)
37. Fluke - "What Is Ohm's Law?" (November 25, 2025) - Practical application in electrical work (https://www.fluke.com/en-us/learn/blog/electrical/what-is-ohms-law)
38. Ducksters - "Physics for Kids: Ohm's Law" - Simple explanation designed for children (https://www.ducksters.com/science/physics/ohms_law.php)

Electrical Power

39. Electrical4U - "Watts Law: What is it? Formula, Examples & Ohm's Law" - Comprehensive guide to electrical power (https://www.electrical4u.com/watts-law/)
40. All About Circuits - "Calculating Electric Power" (January 11, 2021) - Practical power calculations with examples (https://www.allaboutcircuits.com/textbook/direct-current/chpt-2/calculating-electric-power/)

41. Omni Calculator - "Watt Calculator" (June 7, 2024) - Interactive tool and explanations for power calculations (https://www.omnicalculator.com/physics/watt)
42. Study.com - "Electric Power Definition, Formula & Examples" (May 10, 2013) - Educational lesson on electrical power (https://study.com/academy/lesson/what-is-electric-power.html)
43. Wikipedia - "Electric power" - Comprehensive encyclopedia entry on electrical power (https://en.wikipedia.org/wiki/Electric_power)
44. Wikipedia - "Power (physics)" - General physics concept of power (https://en.wikipedia.org/wiki/Power_(physics))
45. Cables and Kits - "Amps Watts and Volts Calculation Guide for Electrical Safety" (September 10, 2025) - Practical safety guide (https://www.cablesandkits.com/learning-center/amps-watts-and-volts-calculation/)
46. Wikipedia - "Watt" - History and definition of the unit (https://en.wikipedia.org/wiki/Watt)
47. IB Lenhardt - "Watt (W) – Power Formula, Definition, and Use Cases" - Technical reference (https://ib-lenhardt.com/kb/glossary/watt)