Factors Influencing Internal Resistance

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A B S T R A C T

This project will examine the various factors that affect the internal resistance of cells or batteries. It will in particular study the effect the variations of electrode separation, area of electrodes and the concentration of electrolyte have on the internal resistance of a Leclanche cell.

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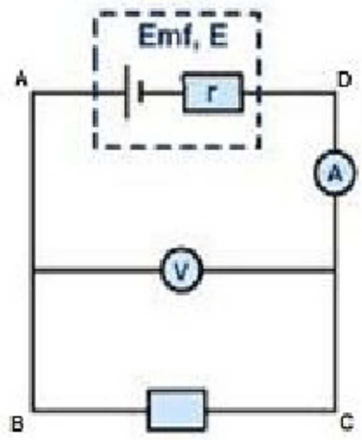
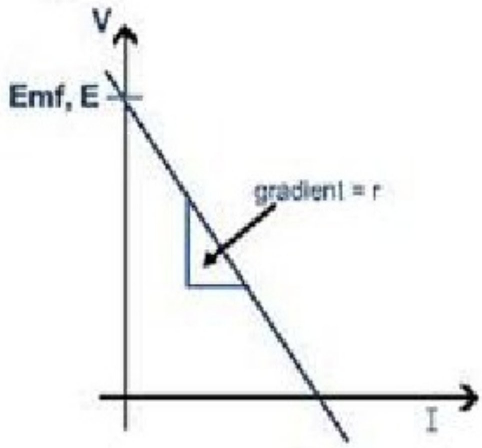
INTRODUCTION

Internal Resistance

Internal resistance is defined as the resistance offered by the electrolyte of the cell to the flow of ions. Its S.I. unit is Ohm (Ω).





For a cell of *emf* (E) and internal resistance (r), connected to an external resistance (R) such that (I) is the current flowing through the circuit,

Total resistance of the circuit = $(R + r)$

$$E = I\ (R + r) \qquad \text{-----------} \rightarrow 1$$

But the potential difference of the cell '*V*'

= P.D. between A and D = $E - Ir$

= P.D. between B and C = IR,

$$\text{i.e. } V = E - Ir = IR \qquad \text{----------} \rightarrow 2$$

From 1 and 2, the internal resistance

$$r = R\left(\frac{E}{V} - 1\right)$$

Potentiometer

A potentiometer is an instrument for measuring the potential or voltage across a portion of a circuit. Before the introduction of moving coil and digital voltmeters, voltage was measured using potentiometers. This method was described by Johann Christian Poggendorff around 1841 and has since then become a standard laboratory technique.

The potentiometer works on the principle that when a constant current flows through a wire of uniform cross section material, the potential difference between any two points on it is directly proportional to the length of the wire between the points.

$$\boldsymbol{V} \propto \boldsymbol{I}$$

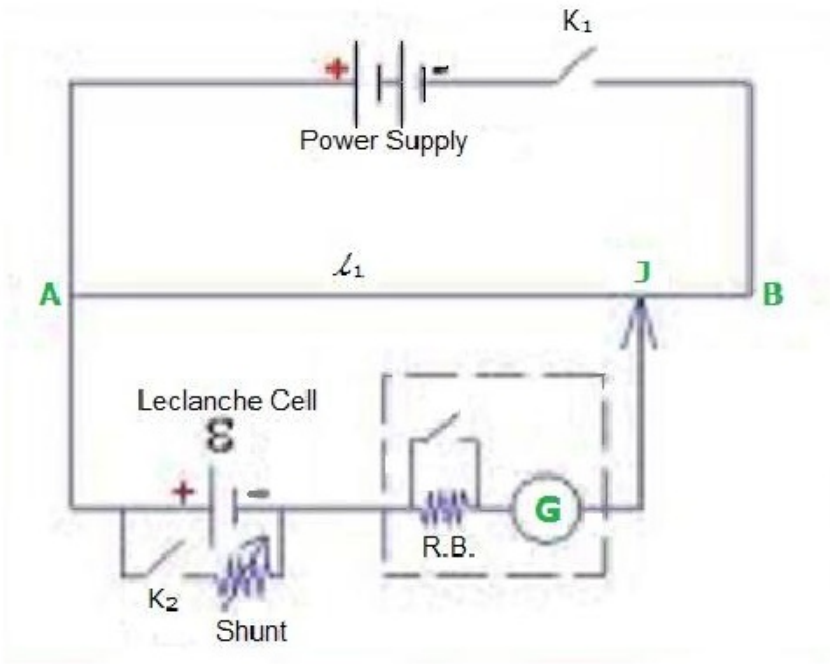
$$\boldsymbol{V} = \boldsymbol{k}\,\boldsymbol{I}$$

where (k) is a constant of proportionality called the potential gradient of the potentiometer wire.

In this arrangement, a fraction of a known voltage from a resistive slide wire is compared with an unknown voltage by means of a galvanometer. The sliding contact or wiper of the potentiometer is adjusted and the galvanometer briefly connected between the sliding contact and the unknown voltage. The deflection of the galvanometer is observed and the sliding top adjusted until the galvanometer no longer deflects from zero. At that point, the galvanometer draws no current from the unknown source, and the magnitude of voltage can be calculated from the position of the sliding contact.

Determination of Internal Resistance Using the Potentiometer

For the determination of internal resistance, set up the circuit as shown,



It can be seen that when only key K_1 is closed, (l_1) is the balancing length.

$$E = k\,l_1 \qquad \text{------------------(3)}$$

When key K_2 is also closed, (l_2) is the balancing length.

$$V = k\,l_2 \qquad \text{------------------(4)}$$

From (3) and (4),

$$\frac{E}{V} = \frac{l_1}{l_2}$$

Therefore

$$r = R\left(\frac{l_1}{l_2} - 1\right)$$

Factors Affecting Internal Resistance

The resistance of a metallic conductor is given by

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

where (l) is the length of the conductor, (A) its area of cross-section and (ρ) the resistivity of the metal.

By analogy, the internal resistance of the cell can be given in terms of the distance between the electrodes of the cell (d), common area of the cross-section of the electrodes of the cell (A) and the ionic concentration of the electrolyte (C),

$$R = \frac{d}{CA}$$

From the above equation it can be seen that:

1. Larger the separation between the electrodes of the cell, more the length of the electrolyte through which current has to flow and consequently a higher value of internal resistance.
2. Greater the conductivity of the electrolyte, lesser is the internal resistance of the cell.ie internal resistance depends on the nature of the electrolyte.
3. The internal resistance of a cell is inversely proportional to the common area of the electrodes dipping in the electrolyte.
4. The internal resistance of a cell depends on the nature of the electrodes.

Primary Batteries

Primary batteries are non-rechargeable, used once and then discarded. They have the advantage of convenience and cost less per battery, with the disadvantage of costing more over the long term. Generally, primary batteries have a higher capacity and initial voltage than rechargeable batteries and a sloping discharge curve. Most primary batteries do not presently require special disposal.

Advantages:

- High energy density since no design compromises necessary to accommodate recharging.
- Best alternative for low cost, low drain applications such as watches or hearing aids.
- The obvious choice for single use applications such as guided missiles and military ordnance.
- Low initial cost
- Convenient
- Wide availability of standard products

Shortcomings:

1. Not suitable for high drain applications due to short life time and the cost of continuous replacement.
2. In terms of overall energy efficiency, single use, disposable, primary batteries are an extremely uneconomical energy source since they produce only about 2% of the power used in the manufacture.
3. They also produce much more waste than rechargeable batteries.

Applications:

Consumer batteries are used in

- Toys
- Flashlights
- Watches
- Clocks
- Hearing aids
- Radios

Specialist batteries are used for

- Implanted medical devices
- Missiles
- Weapons systems

Battery Chemistries:

Bases on their chemical reactions, primary batteries can typically be classified as

- Alkaline
- Leclanche
- Lithium
- Silver Oxide
- Zinc Air

Secondary Batteries

Secondary batteries are rechargeable batteries. They have the advantage of being more cost efficient over the long term, although individual batteries are more expensive. Generally, secondary batteries have a lower capacity and initial voltage, a flat discharge curve, higher self-discharge rates and varying recharge life ratings. Secondary batteries usually have more active (less stable) chemistries which need special handling, containment and disposal. Ni-Cd and small-size lead acid batteries require special disposal and should not be simply thrown away.

Advantages:

- Best solution for high drain applications
- For high utilization applications the cost of the charger is soon paid back.

Shortcomings:

- Cost of charger. For low cost applications such as toys the charger could cost much more than the product it supports.
- Safety issues with mains power
- Lower energy density than primary cells unless exotic chemistries used.
- Lack of standards
- Many custom pack designs and limited interchangeability. (Disadvantage for the user but creates a captive aftermarket for the manufacturer).

Applications:

- Traction
- Power Tools
- Motor Drives
- Laptop computers
- Mobile phones
- PDAs
- Camcorders
- Toys

Battery Chemistries:

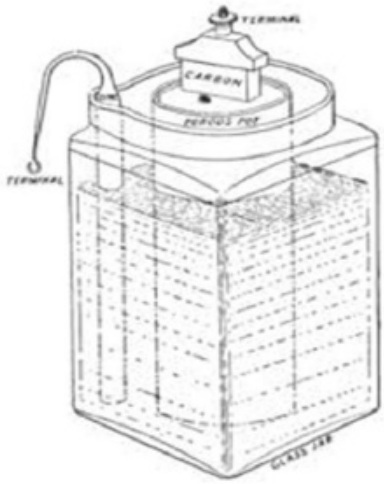
- Alternatives
- Lead Acid
- Lithium
- Nickel Cadmium (Ni-Cd)
- Nickel Hydrogen
- Nickel Iron (Ni-Fe)
- Nickel Metal Hydride (NiMH)
- Nickel Zinc
- Zebra (NaNiCl)

Leclanche's Cell

The Leclanche cell is a battery invented and patented by Georges Leclanche in 1866. The battery contained an electrolyte (conducting solution) of ammonium chloride, a cathode (positive terminal) of carbon, a depolarizer of manganese dioxide and an anode (negative terminal) of zinc. The Leclanche battery (or wet cell as it was referred to) was the forerunner of the modern zinc-carbon battery (a dry cell). The addition of zinc chloride to the electrolyte paste raised the emf 1.5 volts. Later developments dispensed with the ammonium chloride completely, giving a cell that could endure more sustained discharge without its internal resistance rising as quickly (the zinc chloride cell).

History

In 1866, Georges Leclanche invented a battery that consisted of a zinc anode and a manganese dioxide cathode wrapped in a porous material, dipped in a jar of ammonium chloride solution. The manganese dioxide cathode had a little carbon mixed into it as well, which improved conductivity and absorption. It provided a voltage of 1.4 V. This cell achieved very quick success in telegraphy, signaling and electric bells.



The dry cell form was used to power early telephones. The Leclanche cell could not provide a sustained current for very long. This was because certain chemical reactions in the cell increased internal resistance and thus, lowered the voltage. These reactions reversed themselves when the battery was left idle, so it was only good for intermittent use.

Construction

The original form of the cell used a porous pot. This gave it a relatively high internal resistance and various modifications were made to reduce it. In Leclanche's original cell, the depolarizer (which consisted of crushed MnO_2) was packed into a pot and a carbon rod was inserted to act as cathode. The anode, which was a zinc rod, was then immersed along with the pot in a solution of ammonium chloride. The liquid solution acted as the electrolyte, permeating through the porous pot to make contact with the cathode. However, this results in an internal resistance of several ohms when a porous pot is used.

Chemistry

The chemical process which produces electricity in a Leclanche cell begins when zinc atoms on the surface of the anode oxidize, i.e. they give up both electrons to become positively charged ions. As the zinc ions move away from the anode, leaving their electrons on its surface, the anode becomes more negatively charged than the cathode. When the cell is connected in an external electrical circuit, the excess electrons on the zinc anode flow through the circuit to the carbon rod; the movement of electrons forms an electrical current.

After passing through the whole circuit, when the electrons enter the other electrode (carbon rod), they combine with manganese dioxide (MnO_2) and water (H_2O), which react with each other to produce manganese oxide (Mn_2O_3) and negatively charged hydroxide (OH^-) ions. This is accompanied by a secondary reaction in which the negative hydroxide (OH^-) ions react with positive ammonium (NH_4^+) ions in the ammonium chloride (NH_4Cl) electrolyte to produce molecules of ammonia (NH_3) and water (H_2O).

$$Zn(s) + 2\ MnO_2(s) + 2\ NH_4Cl(aq) \rightarrow ZnCl_2(aq) + Mn_2O_3(s) + 2NH_3(aq) + H_2O(l)$$

Alternatively, the reaction proceeds further, the hydroxide ions reacting also with the manganese oxide to form manganese hydroxide.

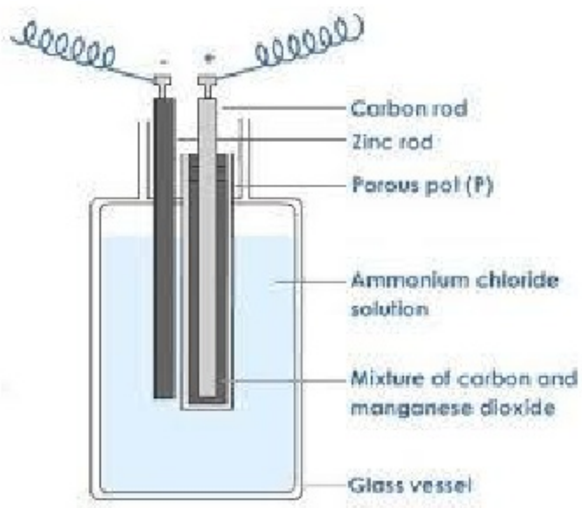
$$Zn(s) + 2\ MnO_2(s) + 2\ NH_4Cl(aq) + 2H_2O(l) \rightarrow ZnCl_2(aq) + 2Mn(OH)_3(s) + 2NH_3(aq)$$

Advantages:

- Leclanche cells use inexpensive materials and have low costs.
- They are available in a wide range of sizes including AAA, AA, C, D and 9V.
- They are suitable for a wide range of consumer applications.
- They are interchangeable with alkaline batteries.

Shortcomings:

- It has a lower energy density than alkaline batteries.
- They show poor performance at low temperatures.
- The use of naturally occurring MnO_2 from different sources can lead to wide performance variations due to the presence of small quantities of impurities like Ni, Cu, As and Co.
- The Leclanche cell, also known as wet cell, has a tendency to leak.



Experiment

Objective

To study the factors affecting internal resistance of cell:

a) Separation between electrodes
b) Size (area of cross-section) of electrodes
c) Concentration/nature of electrolyte

Apparatus

A potentiometer, a battery (or battery eliminator), two one way keys, a rheostat, a galvanometer, a resistance box, an ammeter, a cell (Leclanche cell), a jockey, a set square, connecting wires and sand paper.

Circuit Diagram

Theory

The internal resistance of a cell is the resistance offered by its electrolyte to the flow of ions. The internal resistance of a cell is

(i) Directly proportional to distance between the electrodes.
(ii) Inversely proportional to concentration of electrolyte
(iii) Inversely proportional to the exposed surface area of electrodes in electrolyte

The internal resistance of a cell is given by

$$r = R\left(\frac{l_1}{l_2} - 1\right)$$

Where (l_1) and (l_2) are the positions of the null points without and with a shunt resistance respectively and (R) is the shunt resistance in parallel with the given cell.

Procedure

1. Clean the ends of the connecting wires with sand paper and make tight connection according to the circuit diagram.
2. Tighten the plugs of the resistance box.
3. Check the emf of the battery and of the cell and make sure that emf of the battery is more than that of the cell, otherwise null or balance point will not be obtained.

To study variation of internal resistance with distance of separation

4. Keep both the electrodes at a distance of 16 cm.
5. Take maximum current from the battery, making rheostat resistance small.
6. Without inserting a plug in key K_2, adjust the rheostat so that a null point is obtained on the last wire of the potentiometer.
7. Determine the position of the null point accurately using a set square and measure the balancing length (l_1) between the null point and the end P.

8. Next introduce plugs in both keys K_1 and K_2. At the same time, take out a small resistance (1 – 5 Ω) from the shunt resistance box connected in parallel with the cell.
9. Slide the jockey along a potentiometer wire and obtain the null point.
10. Measure the balancing length (l_2) from end P. Record these observations.
11. Now keep the electrodes 12 cm apart.
12. Then remove the plugs of keys K_1 and K_2. Wait for some time and repeat steps 7 to 10.
13. Next keep the electrodes 9 cm apart to obtain another set of observations.

To study variation of internal resistance with area of electrodes

14. Keeping all other factors constant, increase the area of electrodes in the electrolyte by dipping them into the electrolyte at different depths for each observation.
15. Obtain three such observations by repeating steps 7 to 10. Record your readings.

To study variation of internal resistance with concentration of electrolyte

16. Keeping all other factors constant, decrease the concentration of electrolyte by adding distilled water for different observations.
17. Obtain three such observations by repeating step 7 to 10. Record your readings.

Observations

Variation Of Internal Resistance With Distance Of Separation

Distance of Separation	Position of Null point (cm)		Shunt Resistance R(Ω)	Internal resistance r (Ω) $r = R\left(\frac{l_1}{l_2} - 1\right)$
	Without shunt R (l_1)	With Shunt R (l_2)		

Variation Of Internal Resistance With Area Of Electrodes

Area of Electrodes	Position of Null point (cm)		Shunt Resistance R(Ω)	Internal resistance r (Ω) $r = R\left(\frac{l_1}{l_2} - 1\right)$
	Without shunt R (l_1)	With Shunt R (l_2)		

Variation Of Internal Resistance With Concentration Of Electrolyte

Concentration of Electrolyte	Position of Null point (cm)		Shunt Resistance R(Ω)	Internal resistance r (Ω) $r = R\left(\frac{l_1}{l_2} - 1\right)$
	Without shunt R (l_1)	With Shunt R (l_2)		

Result

From the above observation, it is verified that:

(i) The internal resistance of a cell is directly proportional to the separation between the electrodes.

(ii) The internal resistance of a cell is inversely proportional to the area of the electrodes dipped in electrolyte.

(iii) The internal resistance of a cell is inversely proportional to the concentration of the electrolyte.

Precautions

1. The connections should be neat, clean and tight.
2. The plugs should be introduced in the keys only when observations are to be taken.
3. The positive poles of the battery E and the Leclanche cell (carbon rod) should both be connected to the terminal at the zero of the potentiometer.
4. The jockey should not be rubbed along the wire. It should touch the wire gently.
5. The ammeter reading should remain constant for a particular set of observations. If necessary, adjust the rheostat for this purpose.
6. The emf of the battery should be greater than that of the cell.
7. Some high resistance plug should always be taken out from the resistance box before the jockey is moved along the wire.
8. Current should be passed for a short time only, while finding the null point.
9. Rheostat should be adjusted so that the first null point lies on the last wire of the potentiometer.
10. The cell should not be disturbed during the experiment.

Sources of Error

1. The instrument screws may be loose.
2. Thick connecting wires may not be available.
3. Rheostat may have high resistance.
4. The auxiliary battery may not be fully charged.
5. The potentiometer wire may not be of uniform cross-section section and material density throughout its length.
6. End resistances may not be zero.

CONCLUSION

This project has examined the various factors that affect the internal resistance of a cell; the separation between its electrodes, their surface area and the concentration of its electrolyte.

Internal resistance is the property responsible for decreasing the terminal voltage of a cell below its emf. As such, it is generally advantageous to reduce the internal resistance of cell. Hence, the study of factors affecting internal resistance is of economic relevance.

Bibliography

- ✓ www.wikipedia.org
- ✓ www.wikibooks.org
- ✓ www.hyperphysics.com
- ✓ www.batteryuniversity.com
- ✓ www.physics.stackexchange.com