Kirchoff’s laws

Objective: *Understand Kirchoff’s laws as well as use it calculate unknown parameters in circuits.*

Background

- The essence of **kirchoff’s laws** is due to the fact that calculation across *multi loop* and *multi source* circuits are limited by **Ohm’s law.**

Kirchoff Current Law

Terms

- **Junction** is a point in electric circuit where at least **three** electrical nodes are *connected.*

Sign Convention

- **Outgoing** current are taken as **negative.**
- **Incoming** current are taken as **positive.**

Statement

- **Kirchoff’s Current law** states that *algebraic* sum of **incoming** and **outgoing** current in a junction is **0**.

$$\sum I = 0$$

- **Kirchoff’s Current Law** is based on *principle* of **conservation of charge.**

Kirchoff’s Voltage Law

Sign Convention

Resistor:

- The **algebraic** sign of voltage in a circuit resistor is **positive** if the direction of **observer** and current is opposite.

- The **algebraic** sign of voltage in a circuit resistor is **negative** if the direction of **observer** and current is same.
- This convention is chosen as **current** *flows* from **positive** to *negative* direction.

Source:

- The **algebraic** sign of voltage in a circuit source is **positive** if the direction of **observer** and current is same.
- The **algebraic** sign of current in a circuit source is **negative** if the direction of **observer** and current is opposite.
- This convention is chosen as **current** *flows* from **high potential** to *low potential* direction.

Kirchoff's Voltage Law

- **Kirchoff's** Voltage Law states that the **algebraic** sum of change in *potential* around a circuit is **0.**

$$\sum \triangle V = 0$$

- **Potential** includes the **terminal p.d.** and **emf** of source.
- **Kirchoff's Voltage Law** is base on the **principle of conservation of energy.**

Wheatstone Bridge

Objective: *Describe the circuit diagram and working of wheatstone bridge circuit and undersatnd it's importance in real situation.*

Principle

- The principle of **wheatstone bridge circuit** states that , the product of resistances in opposite arms is equal in a circuit arranged in the form of a **quadilateral** when *current* flowing in between **the diagonal** of circuit is **0.**

Application

- Wheatsone bridge circuit can be used to find the **unknown** electrical resistance in a circuit if other 3 resistances arranged in the quadilateral are known.

- If R , P , Q , X are the resistances arranged serially in a circuit then,

$$PX = RQ$$

$$X = \frac{Q}{P}R$$

Construction

- A circuit is arranged in the form of a **quadilateral** $ABCD$.
- A **source** is present between A and C .
- A **galvanometer** is present between B and D .
- Two resistances of **known** parameter are placed between A and B and between B and C .
- A resistance box or a **variable** resistor is placed between A and D .
- The **unknown** resistance to be calculated is placed between D and C .

Description

- The *wheatstone bridge* is said to be **balanced** when *current* through B and D is **0** .
- This is **shown** by **null** *deflection* of the galvanometer.
- The **null deflection** is achieved by *adjusting* the value of **resistance** of the **variable** resistor.

Meter Bridge

Objective: *Describe meter bridge and understand it.*

Definition

- **Meter bridge** is a *simple* circuit used to **measure** and **compare** resistances and hence **resistivity.**
- It is *described* as an **application** of **wheatstone bridge.**

Principle

- **Meter bridge** is based on the **principle of wheatstone bridge.**

Construction

- *Circuit elements* of **meter bridge** are:

  1. A **wire** having *length* of $100cm$ as AC .
  2. Two *L shaped* **brass** plates between A and B and between B and C.
  3. After each **brass** plate there is a **gap** to a reach at point B .
  4. A **resistance box** R is placed between gap B and C .
  5. A **unknown resistor** X is placed between gap A and B .
  6. A **galvanometer** is connected at point B with it's one **terminal** connected to a **jockey.**

Working

Operation

- A **resistance** R is setup across B and C by the *resistance box.*
- The jockey is slide over the **wire** AC to **null point** by **null deflection** of *galvanometer.* at point D.

Calculation

Variables:

- Length of segment AD = l
- Resistance of segment AD = $\rho\frac{l}{A}$
- Length of segment DC = $100 - l$
- Resistance of segment DC = $\rho\frac{100-l}{A}$

According to the principle of **Wheatstone bridge**,

$$X\rho\frac{100-l}{A} = R\rho\frac{l}{A}$$

$$X = \frac{l}{100-l}R$$

- If L is the length of resistor X and A is the cross section area, **resistivity** can be *calculated* by:

$$\rho = X\frac{A}{L}$$

- Comparison of **resistances** of *resistors* can be done by replacing R with an unknown resistance X_2 and considering another *unknown* resistance between A and B as X_2 .

$$\frac{l}{100-l} = \frac{X_1}{X_2}$$

Potentiometer

Objective: *Know construction,working and importance of potentiometer*

Definition

- **Potentiometer** is a *circuit* that is used to determine **emf** or **terminal p.d.**.

Principle

- **Potentiometer** is based on the principle of *uniform* decrease in **p.d.** across a length.
- In a **steady** current the **potential difference** across a *portion* of wire is directly proportional to it's **length**.

$$V \alpha l$$

$$V = IR$$
$$R = \rho\frac{l}{A}$$
$$V = \frac{I\rho}{A}l$$

- If steady current I flows in a wire of uniform **length** l ,

$$V = kl$$

- k is termed as **potential gradient** or **constant of potentiometer.**

Construction

- The **circuit elements** of a *potentiometer* circuit are:
  1. A **driver's source** E_{DV} to provide *steady current* known as an *accumulator.*
  2. A **rheostat** to maintain *current* across the *circuit.*

Calculation of internal resistance of cell.

Setup

- The **circuit elements** of the setup *apparatus* are:
  1. A **driver's source** whose *positive terminal* is attached at a point A.
  2. A cell of emf E whose *positive* terminal is attached to a point A with **internal resistance** r .
  3. A resistance box of **resistance** R connected in parallel with the cell of *emf* E
  4. A switch k_1 in series with *resistance box.*
  5. A **galvanometer** connected to the *negative* terminal of the *cell* whose one end is equipped with a **jockey.**

Operation

Keeping k_1 open:

- The **jockey** is slided over the wire AB to obtain null point C .
- The length AC is l_1 .

Keeping k_1 closed:

- The **jockey** is slide over the wire AB to obtain null point at D .
- The length AD is l_2 .

Calculation

$$V_{AC} = E$$
$$E = kl_1$$
$$V_{AD} = V$$
$$V = kl_2$$

Further,

$$I = \frac{E}{r}$$
$$V = I\frac{Rr}{R+r}$$
$$V = \frac{ERr}{r(R+r)}$$
$$R + r = \frac{ER}{V}$$
$$r = (\frac{E}{V} - 1)R$$

- The **internal resistance** of the cell is give by:

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

Comparison of $e.m.f.$ of two cells.

Setup

- The **circuit elements** of the setup *apparatus* are:

  1. A **driver's source** whose *positive terminal* is attached at a point A.
  2. A cell of emf E_1 whose *positive* terminal is attached to a point A.
  3. A cell of emf E_2 connected in parallel with the cell of *emf* E_1
  4. A switch k_1 in series with the cell e.m.f E_1.
  5. A switch k_2 in series with the cell of e.m.f. E_2.
  6. A **galvanometer** connected to the *negative* terminal of the *cell* whose one end is equipped with a **jockey.**

Operation

Keeping k_1 open and k_2 closed:

- The **jockey** is slided over the wire AB to obtain null point C .
- The length AC is l_1 .

Keeping k_1 closed and k_2 open:

- The **jockey** is slide over the wire AB to obtain null point at D .
- The length AD is l_2 .

Cases:

- $E_1 > E_2 \implies l_1 > l_2$
- $E_1 < E_2 \implies l_1 < l_2$

Calculation

$$E_{AC} = kl_1$$
$$E_{AD} = kl_2$$

- Dividing the **equations** , the relation of comparison is:

$$\frac{E_{AC}}{E_{AD}} = \frac{l_1}{l_2}$$

Conductors

Objective:

1. *Understand the concept of super conductors.*
2. *Know the meaning of perfect conductors and distinguish it from super conductors.*

Super Conductors

- **Superconductors** are elements, alloys or materials that conduct electricity with zero resistance in below a certain *temperature* .
- **Superconductors** can sustain *electrons* across the circuit without needing any **emf** after setting up the electrons initially .

Mechanism of superconductivity

- **Superconductivity** occurs by the principle of **phonon** mediated **cooper pairs.**
- **Two** electrons pair to *mutually* traverse the lattice, against the *electrostatic* repulsion.
- **Electrons** are bounded together by binding energy from *net attractive* force which is in the *order* of **millivolts** .

Critical Temperature in Super Conductors T_C

- **Critical temperature** is a particular value of *temperature* below which the *material* exhibits **superconducting** property.

Types of super conductors

- **Type I** superconductors are those that exhibit superconducting property by:
  - Formation of **Cooper Pairs** .
  - Shifting to **normal** conducting phase by **destruction** of superconducting phase after application of **magnetic field** larger than *critical magnetic field* .
  - Consist of single **elements** only.
  - Mercury, Lead are *examples* of these conductors.
- **Type II** superconductors are those that exhibit superconducting property by:
  - Consists of materials commonly **alloys** .
  - Common **materials** include 3 *oxygen* atoms for each two *metal* atoms.
  - Can carry **small** amounts of current and behave as super conductors even when there is application of **magnetic field** exceeding critical magnetic field.

Perfect conductors

- **Perfect conductors** are those that have **infinite** conductivity or **zero** resistivity.
- **Perfect conductors** can maintain current in a circuit without requiring sustaining **source** in the circuit.
- The **magnetic field** applied in such conductor has no effect in changing the ability of the **conductor** to conduct *electricity* .

Distinction between perfect conductors and superconductors

- **Superconductors** are a victim to *quantization of magnetic flux* and *Meissner effect* .
- There is no **magnetic field** inside superconductors while perfect do.
- **Superconductors** are practical whilst **perfect conductors** are hypothetical and ideal description.

Galvanometer

Objective: *Learn the technique to convert galvanometer into voltmeter and ammeter.*

Galvanometer

- **Galvanometer** is sensitive instrument that *detects* feeble currents in a circuit.
- **Galvanometer** has low resistance.
- It is equipped with a **pointer** to show deflection on flow of **current** .

Voltmeter

- **Voltmeter** is an electrical instrument that measures **potential** difference in a circuit.
- **Voltmeter** has very high resistance.

Multiplier

- **Multiplier** is a component of electrical circuit that has **large** resistance.
- **Multiplier** is used to decrease current in a circuit by **decreasing** resistance.

Ammeter

- **Ammeter** is an electrical instrument that measures **current** in an electrical circuit.
- **Ammeter** has very *low* resistance.

Shunt

- **Shunt** is a component of electrical circuit that has very low *resistance* .
- **Shunt** is used to increase current in **electric** circuits by increasing **resistance.**

Conversion of galvanometer to voltmeter

- A **galvanometer** is converted into a voltmeter by adding *multiplier* in **series** in the circuit.

Structure of Circuit

- The *electrical* components in the circuit are:
  1. A galvanometer having **resistance** G .
  2. A **multiplier** having **resistance** R .

Calculation

- The same **current** I_g flows through galvanometer and **multiplier**

$$\begin{aligned} V &= V_R + V_g \\ V &= I_g R + I_g G \\ I_g R &= V - I_g G \end{aligned}$$

$$R = \frac{V}{I_g} - G$$

- Evaluation of the **total** resistance in the circuit to give **resistance** of new voltmeter yields:

$$R_{total} = R + G$$

Conversion of galvanometer to ammeter

- A **Galvanometer** is converted into a ammeter by adding shunt in parallel with the **galvanometer** in the circuit.

Structure of circuit

- The **electrical** components in the circuit are:
  1. A galvanometer of resistance G .
  2. A **shunt** connected parallel with the galvanometer of resistance S.

Calculation

- The $p.d.$ across both the galvanometer and shunt is same.

$$V_g = V_s$$
$$I_g G = (I - I_g)S$$
$$S = \frac{I_g G}{I - I_g}$$

- Effective resistance of the shunt and galvanometer to give **resistance** of *new* ammeter is:
$$R_{total} = \frac{SG}{S + G}$$