# (**VOLTAGE LAW**)  KIRCHHOFF'S SECOND LAW  (**LOOP LAW**)

**Loop Law :** The algebraic sum of the potential differences in circuit loop must be zero. The potential rises are positive while the potential drops are negative.

This law is called as Kirchhoff's second law or Kirchhoff's voltage law or Kirchhoff's loop law.

This law is based on the conservation of energy.

Let us imagine in a circuit loop the potential difference between the two points at the beginning of the loop has a certain value. As we move around the circuit loop and measure the potential difference across each component in the loop, the potential difference may decrease or increase depending upon the nature of the element like a resistor or a battery. But when we have completely traversed the circuit loop and arrive back at our starting point, the net change in the potential difference must be zero.

Thus, the algebraic sum of changes in potential differences is equal to zero in a circuit loop.

**How could the sign convention be taken?**

1. EMF of the battery is taken as negative when we move from positive terminal to negative terminal across the battery.
2. It is taken as positive when we move across the battery from negative terminal to positive terminal.
3. The direction of electric current is observe to give a sign to potential difference on a resistor.
4. The potential difference across the resistor is taken as negative when we move along the direction of electric current through the resistor.
5. It is taken as positive when we move against the direction of electric current through the resistor.

**Why we can take the sign convention like this ?**

First we have to understand that how to calculate potential difference between two points.
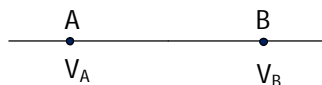


Let 'A' and 'B' are any two points in a current carrying conductor.
Let $V_A$ is the Potential at point 'A'. and $V_B$ is the potential at point 'B'.
Potential difference (P.D) between 'A' and 'B' is said to be as the work done to move unit positive charge from point 'A' to point 'B'. It is equal to the difference between potentials at point 'A' to point 'B'.
So P.D. = $V_D = V_B - V_A$
Case (i) If  $V_A = V_B$  then $V_D = V_B - V_B = $  0  (Zero)
Case (i) If  $V_A < V_B$  then $V_D = V_B - V_A = + V$  (Positive value)
      Here A is low potential point. We are moving from low potential point to high potential point.
Case (i) If  $V_A > V_B$  then $V_D = V_B - V_A = - V$  (Negative value)
      Here A is high potential point. We are moving from high potential point to low potential point.

In a battery ' + ' is always high potential point and ' – ' is always low potential point. So there is no need to consider the flow of current in the circuit, while we are crossing the battery. If we move from positive terminal to negative terminal, we take negative sign for potential difference. If we move from negative terminal to positive terminal, we take positive sign for potential difference.
In a resistor, the direction of flow of current indicates the different potential points. The current flows from high potential point to low potential point. So if we move towards low potential point the Potential difference must be negative and if we move towards a high potential point the potential difference must be positive.
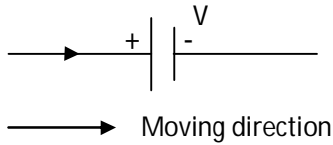
# DIAGRAMS FOR SIGN CONVENTION OF KIRCHHOFF'S LOOP LAW

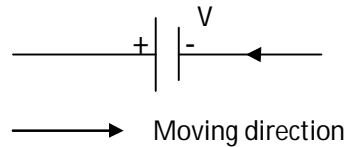**Point:1 :** While moving across a battery ;
 there is no need to consider the direction of flow of current in the circuit.

**Case (i)** Let the emf of a battery is "V".
 While moving across the battery; from high potential point to low potential point
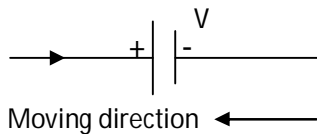 i.e. from positive terminal to negative terminal, we take potential as "-V".
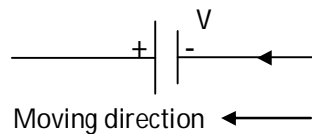


Potential = - V                                Potential = - V

**Case (ii)** Let the emf of a battery is "V".
 While moving across the battery; from low potential point to high potential point
 i.e. from negative terminal to positive terminal, we take potential as "+V".
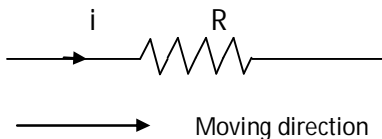


Potential = + V                                Potential = - V

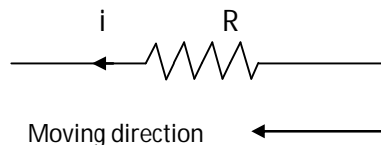**Point:2 :** While moving across a resistor ;
 It is necessary to consider the direction of flow of current in the circuit.

**Case (i)** Let the resistance of a resistor is "R" and the flow of current through that resistor is " i ".
 While moving across a resistor; in the direction of flow of current,
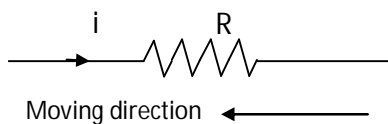 we take potential difference (V) as negative. i.e. $V = -iR$.
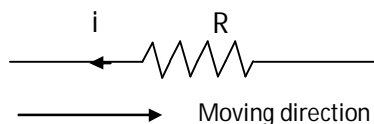


Potential difference = - iR                    Potential difference = - iR

**Case (ii)** Let the resistance of a resistor is "R" and the flow of current through that resistor is " i ".
 While moving across a resistor; in the opposite direction of flow of current,
 we take potential difference (V) as positive. i.e. $V = +iR$.
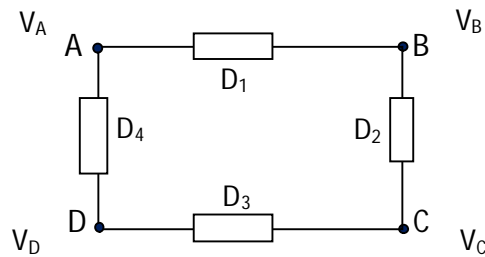


Potential difference = + iR                    Potential difference = + iR

# UNDERSTANDING THE STATEMENT

## "THE ALGEBRAIC SUM OF POTENTIAL DIFFERENCES IN A CIRCUIT LOOP IS ZERO"



Observe the diagram. In that diagram, four devices $D_1$, $D_2$, $D_3$, $D_4$ are connected in a loop.

The two ends of $D_1$ are A and B. The potential difference between the ends of $D_1$ is $V_{AB} = V_B - V_A$.

The two ends of $D_2$ are B and C. The potential difference between the ends of $D_2$ is $V_{BC} = V_C - V_B$.

The two ends of $D_3$ are C and D. The potential difference between the ends of $D_3$ is $V_{CD} = V_D - V_C$.

The two ends of $D_4$ are D and A. The potential difference between the ends of $D_4$ is $V_{DA} = V_A - V_D$.

Let us consider a circuit loop ABCDA which starts at point 'A' and ends at point 'A'.

The algebraic sum of potential differences in loop $= V_{AB} + V_{BC} + V_{CD} + V_{DA}$

$$= (V_B - V_A) + (V_C - V_B) + (V_D - V_C) + (V_A - V_D)$$

$$= V_B - \cancel{V_A} + V_C - V_B + V_D - V_C + \cancel{V_A} - V_D$$

$$= 0$$

The potential difference between point 'A' and point 'A' $= V_{AA} = V_A - V_A = 0$

Kirchhoff's loop law :  $V_{AB} + V_{BC} + V_{CD} + V_{DA} = V_{AA} = 0$

## How can we calculate ?

First we have to select a loop in the given circuit.

The loop may be in clock wise direction or in anti clock wise direction.

Next identify the number of electrical devices in that loop.

Next mark the both ends of each device.

Estimate the potential differences between the ends of each device.

If the device is a battery, take emf as potential difference.(Apply sign convention)
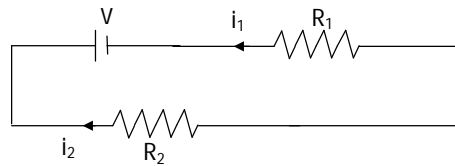
If the device is a resistor, take 'iR' as potential difference.(Apply sign convention)

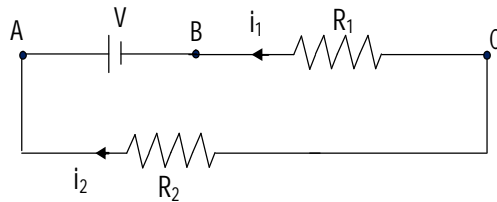Write algebraic sum of potential difference in that loop.

Kirchhoff's loop law is valid.

**Example :** Apply Kirchhoff's loop law for the following circuit diagram.



**Answer:** The diagram contains 3 electrical devices. They are 1 battery and 2 resistors.

Consider a loop 'ABCA' in clock wise direction.

The two ends of Battery are A and B. The potential difference between the ends $V_{AB}$ = - V
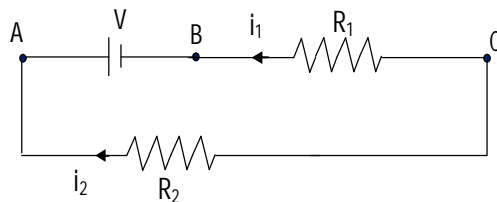
(We are moving from Plus to minus)

The two ends of $R_1$ are B and C. The potential difference between the ends of $R_1$ is $V_{BC}$ = + $i_1 R_1$

(We are moving in the opposite direction of flow of current)

The two ends of $R_2$ are C and A. The potential difference between the ends of $R_2$ is $V_{CA}$ = - $i_2 R_2$

(We are moving in the direction of flow of current)

If we apply Kirchhoff's loop law for the loop 'ABCA',

$$V_{AA} = V_{AB} + V_{BC} + V_{CA}$$
$$V_{AB} + V_{BC} + V_{CA} = V_{AA}$$
$$V_{AB} + V_{BC} + V_{CA} = 0$$
$$-V + i_1 R_1 + (- i_2 R_2) = 0$$
$$-V + i_1 R_1 - i_2 R_2 = 0$$

**Answer:** The diagram contains 3 electrical devices. They are 1 battery and 2 resistors.

Consider a loop 'ACBA' in anti clock wise direction.

The two ends of $R_2$ are A and C. The potential difference between the ends of $R_2$ is $V_{AC}$ = + $i_2 R_2$

(We are moving in the opposite direction of flow of current)

The two ends of $R_1$ are C and B. The potential difference between the ends of $R_1$ is $V_{CB}$ = - $i_1 R_1$

(We are moving in the direction of flow of current)

The two ends of Battery are B and A. The potential difference between the ends $V_{BA}$ = + V
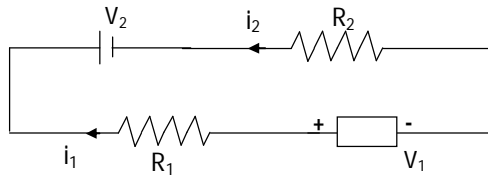
(We are moving from minus to plus)

If we apply Kirchhoff's loop law for the loop 'ACBA',

$$V_{AA} = V_{AC} + V_{CB} + V_{BA}$$
$$V_{AC} + V_{CB} + V_{BA} = V_{AA}$$
$$V_{AC} + V_{CB} + V_{BA} = 0$$
$$+ i_2 R_2 + (- i_1 R_1) + V = 0$$
$$i_2 R_2 - i_1 R_1 + V = 0$$
$$-V + i_1 R_1 - i_2 R_2 = 0$$

We get same answer in both methods.
So we have to take the loop as per our wish.

**Example :** Apply Kirchhoff's loop law for the following circuit diagram.



**Answer:** The diagram contains 4 electrical devices. They are 2 batteries and 2 resistors.
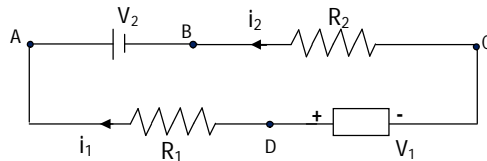


Consider a loop 'ABCDA' in clock wise direction.

If we apply Kirchhoff's loop law for the loop 'ABCDA',

$$V_{AA} = V_{AB} + V_{BC} + V_{CD} + V_{DA}$$
$$V_{AB} + V_{BC} + V_{CD} + V_{DA} = V_{AA}$$
$$V_{AB} + V_{BC} + V_{CD} + V_{DA} = 0$$
$$-V_2 + i_2 R_2 + V_1 + (-i_1 R_1) = 0$$
$$-V_2 + i_2 R_2 + V_1 - i_1 R_1 = 0$$
$$V_1 - V_2 + i_2 R_2 - i_1 R_1 = 0$$

## ONE MORE EXAMPLE

**Example :** Find the electric current drawn from the battery of emf 12 V.
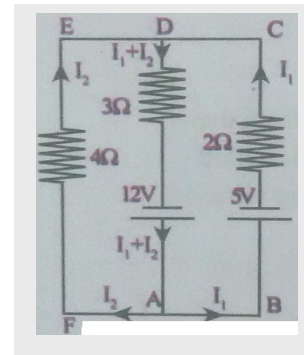


**Answer:** The given circuit contains three loops.

Apply Kirchhoff's loop law for ABCDA loop :  $-5 - 2 I_1 - (I_1+I_2) 3 + 12 = 0$

$$-5 - 2 I_1 - 3 I_1 - 3 I_2 + 12 = 0$$
$$5 I_1 + 3 I_2 = 7 \text{--------(i)}$$

Apply Kirchhoff's loop law for AFEDA loop :  $-4 I_2 - (I_1+I_2) 3 + 12 = 0$

$$-4 I_2 - 3 I_1 - 3 I_2 + 12 = 0$$
$$3 I_1 + 7 I_2 = 12 \text{--------(ii)}$$

Do (ii) x 5 then        $15 I_1 + 35 I_2 = 60$ ------(iii)

Do (i)  x 3 then        $15 I_1 + 9 I_2 = 21$ ------(iv)

Do (iii) − (iv)        $26 I_2 = 39$ ➔ $I_2 = \frac{39}{26} = \frac{3}{2} = 1.5$ A

From (i)        $5 I_1 + 3 I_2 = 7$ ➔ $5 I_1 + 3 (1.5) = 7$ ➔ $5 I_1 + 4.5 = 7$ ➔ $5 I_1 = 2.5$ ➔ $I_1 = 0.5$ A

The current drawn from the battery having 12 V e.m.f. is $I_1 + I_2 = 1.5 + 0.5 = 2$ A