# Electricity and Circuits



## Electric Circuits

**An *electric circuit* is a *closed loop* around which charges flow.**

**A circuit consists of an energy source connected to a device that uses energy.**

**In a circuit, the charges that are moving are *electrons*.**



## Charges in Motion

*Electric Current* (*I*)

**The net amount of charge that passes through a device per unit time at any point.**

**Current is defined as:**

$$I = \frac{\Delta q}{\Delta t}$$

**Electric current is measured in *coulombs per second* or *amperes*. (1 A = 1 C/s)**

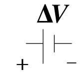


## Batteries (*emf*)

**In order to produce an electric current in a circuit, a potential difference is needed. Batteries are one way of providing a difference in potential (called *electromotive force* or *emf*). Potential difference is called voltage $\Delta V$ and is measured in units of volts (V).**

$$\text{V} \; [=] \; \frac{\text{J}}{\text{C}}$$

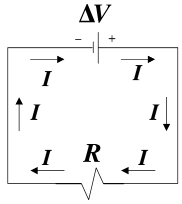
$\Delta V$






## Schematic Diagrams

$\Delta V$




**The *direction of current* is by convention the *direction a positive charge moves* through the circuit, which is towards the negative terminal of the battery.**



## Ohm's Law

**Georg Ohm (1787-1854)**

- **Current depends upon the conductivity of the material.**
- **It is more common to talk about *resistance R* (inverse of conductivity) and express this relationship as:**

$$I = \frac{\Delta V}{R} \quad \text{or} \quad \Delta V = I \cdot R$$

- **The unit for resistance is called the *ohm* and is abbreviated Ω (omega)**

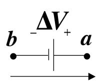
## Voltage

**Ohm's Law is often written as:**

$$V_{ab} = I \cdot R$$

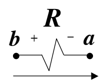
**where:** $V_{ab} = V_a - V_b = \Delta V$

**For power sources:**




$$\Delta V = V_a - V_b = V_{ab} > 0$$

**For resistive loads:**




$$\Delta V_R = V_a - V_b = V_{ab} < 0$$



## Resistance ($R$) and Resistivity ($\rho$)

**It can be experimentally determined that the resistance of a wire is directly proportional to its length $\ell$ and inversely proportional to its cross-sectional area $A$.**

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

**The proportionality constant $\rho$ is called the *resistivity* and depends upon the material used for the wire.**

$$\rho \; [=] \; \Omega \cdot \mathrm{m}$$



## Electric Power

***Power (P)*** **is the rate energy is transformed in a device.**

$$P = I \Delta V$$

**The unit for power is a J/s or watt (1 W = 1 J/s).**

**For *resistors*, combining the above with Ohm's Law results in:**

$$P = I^2 R = \frac{\Delta V^2}{R}$$



## Electric Energy

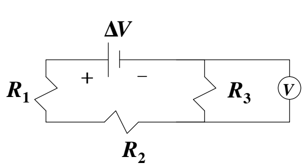
**The total energy $E$ (in joules) is the power in watts times the time in seconds.**

$$E = Pt$$



## Measuring Voltage

- ***Voltmeters are placed in parallel*** **with the points between which the voltage measurement is made**
- ***Voltmeters have a very high resistance*** **and do not affect the circuit (they draw a very small current)**

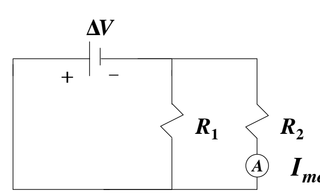



$$V_{meter} = V_{R_3}$$



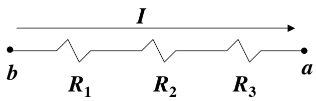
## Measuring Current

- ***Ammeters are placed in series*** **with the device through which the current measurement is made**
- ***Ammeters have a very low resistance*** **and do not affect the circuit (the voltage drop is very low)**




$$I_{meter} = I_{R_2}$$

## Resistors in Series



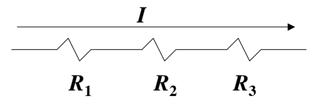

$$V_{ab} = \Delta V_1 + \Delta V_2 + \Delta V_3 = IR_1 + IR_2 + IR_3$$

$$V_{ab} = I(R_1 + R_2 + R_3)$$

$$I = \frac{V_{ab}}{R_1 + R_2 + R_3} = \frac{V_{ab}}{R_s}$$



## Resistors in Series

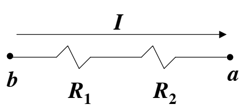



- ***Current is the same*** **through each resistor and is the same as the current in the equivalent resistance**
- **Voltage drop across each resistor is different unless the resistance is the same.**

$$R_s = \sum_i R_i$$



## Resistors in Series (Voltage Divider)




$$I = \frac{V_{ab}}{R_1 + R_2}$$

$$\Delta V_1 = IR_1 = \frac{V_{ab} R_1}{R_1 + R_2} \qquad \Delta V_2 = IR_2 = \frac{V_{ab} R_2}{R_1 + R_2}$$



Example 3:
A 120 Ω, a 60 Ω, and a 40 Ω resistor are connected in series with a 110 V power source.

a.) Draw a schematic diagram.

b.) What is the equivalent resistance of the circuit?

c.) What is the current from the power source?

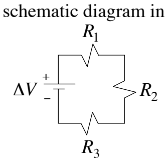
d.) What is the current through each resistor?

e.) What is the voltage drop across each resistor?



Example 3: $R_1 = 120\ \Omega$, $R_2 = 60\ \Omega$, $R_3 = 40\ \Omega$, and $\Delta V = 110$ V

a.) schematic diagram in series



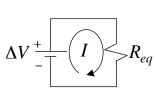

b.) $R_{eq} = ?$

$R_{eq} = R_1 + R_2 + R_3$

$R_{eq} = 120\ \Omega + 60\ \Omega + 40\ \Omega$

$\boxed{R_{eq} = 220\ \Omega}$

c.) $I = ?$




$\Delta V = IR_{eq}$

$I = \frac{\Delta V}{R_{eq}} = \frac{110\text{ V}}{220\ \Omega}$

$\boxed{I = 0.50\text{ A}}$

d.) $I$'s = ? for each resistor

Resistors in series have the same current and the same current as their equivalent so:

$\boxed{I_1 = I_2 = I_3 = I = 0.50\text{ A}}$

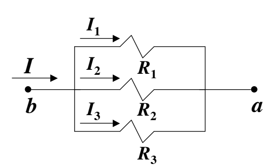
e.) $\Delta V$'s = ? for each resistor

$\Delta V_1 = I_1 R_1$ $\quad \Delta V_2 = I_2 R_2$ $\quad \Delta V_3 = I_3 R_3$

$\Delta V_1 = (0.5\text{ A})(120\ \Omega)$ $\quad \Delta V_2 = (0.5\text{ A})(60\ \Omega)$ $\quad \Delta V_3 = (0.5\text{ A})(40\ \Omega)$

$\boxed{\Delta V_1 = 60\text{ V}}$ $\quad \boxed{\Delta V_2 = 30\text{ V}}$ $\quad \boxed{\Delta V_3 = 20\text{ V}}$

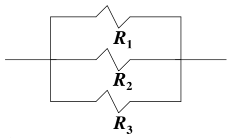
## Resistors in Parallel




$$I = I_1 + I_2 + I_3 = \frac{V_{ab}}{R_1} + \frac{V_{ab}}{R_2} + \frac{V_{ab}}{R_3} = \frac{V_{ab}}{R_p}$$

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

## Resistors in Parallel




- *Voltage drop is the same* across each resistor and the same as the voltage drop across the equivalent resistance
- Current is different through each resistor, the higher the resistance the lower the current

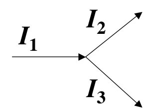
$$\frac{1}{R_p} = \sum_i \frac{1}{R_i}$$



## Kirchhoff's Rules

1.) *Junction Rule* (Conservation of charge)

At any junction point, the sum of all currents entering the junction must equal the sum of all currents leaving the junction.



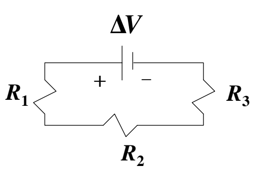

$$I_1 = I_2 + I_3$$



## Kirchhoff's Rules

2.) *Loop Rule* (Conservation of energy)

The sum of the changes in potential around any closed path of a circuit is zero.




$$\Delta V + \Delta V_{R_1} + \Delta V_{R_2} + \Delta V_{R_3} = 0$$