# THE CONCEPT OF ELECTRICITY

## 1. Charge, Current and Kirchhoff's Current Law

**Charge:**

About 2500 years ago, it was discovered that the static charge on amber was capable of attracting very light objects. The word electricity comes from the word "elektron", which was "amber" in ancient Greek.

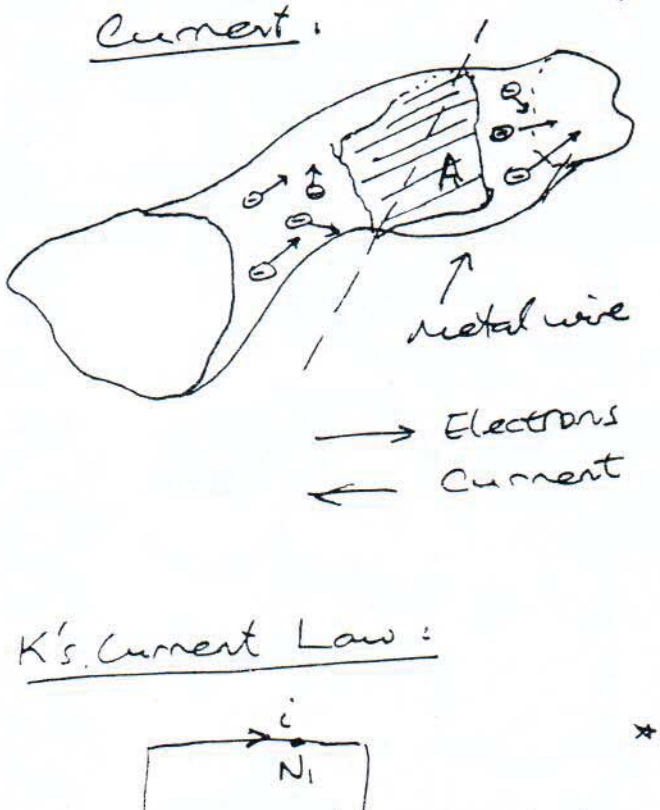
The fundamental electric quantity is "charge"

Charge on an electron : $q_e = -1.602 \times 10^{-19}$ Coulomb

Charge on a proton : $q_p = +1.602 \times 10^{-19}$ Coulomb (1 electron missing)

(Modern Atom Theory, See (B2))

**Current:**

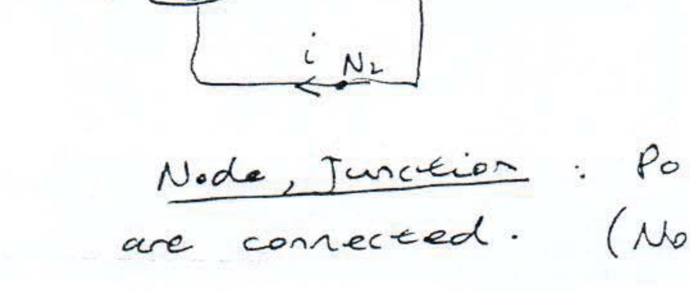



Electric current is defined as the charge passing thru a cross-section per unit time.

$$\boxed{I = \frac{Q}{t}}, \quad i = \frac{\Delta q}{\Delta t}, \; i = \frac{dq}{dt}$$

$$\left(A = \frac{C}{s}\right)$$

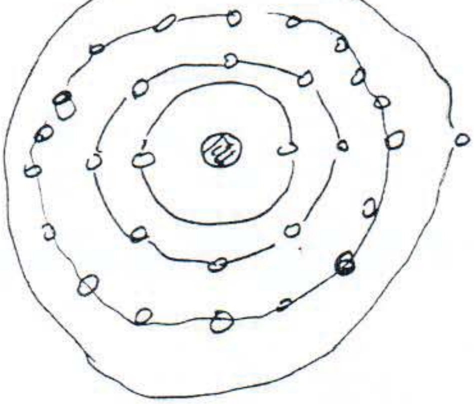
**K's Current Law:**




* Same current everywhere, no charge is lost or created

Node, Junction : Point where 2 or more elements are connected. (Nodes 1 and 2 above)

$Cu$ : 29 (Atomic number) $\underbrace{1s^2}_{2} \cdot \underbrace{2s^2 \cdot 2p^6}_{8} \cdot \underbrace{3s^2 \cdot 3p^6 \cdot 3d^{10}}_{18} \cdot \underbrace{4s}_{1}$



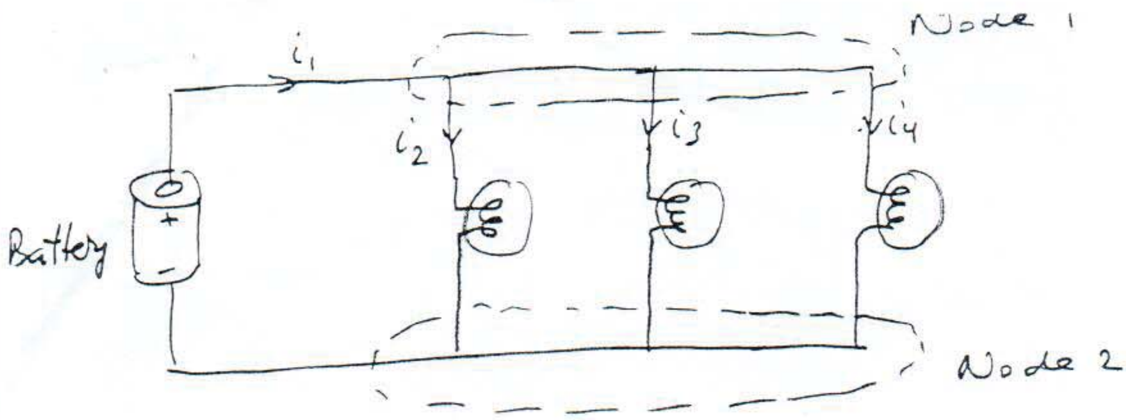
$Ag : 47 = \underbrace{1s^2}_{2} \cdot \underbrace{2s^2 \cdot 2p^6}_{8} \cdot \underbrace{3s^2 \cdot 3p^6 \cdot 3d^{10}}_{18} \cdot \underbrace{4s^2 \cdot 4p^6 \cdot 4d^{10}}_{18} \cdot \underbrace{5s^1}_{1}$

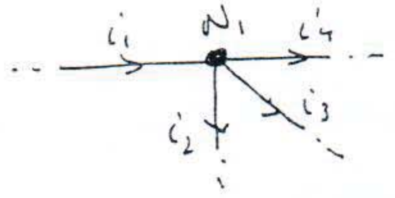
$Au : 79 = \underbrace{1s^2}_{2} \cdot \underbrace{2s^2 \cdot 2p^6}_{8} \cdot \underbrace{3s^2 \cdot 3p^6 \cdot 3d^{10}}_{18} \cdot \underbrace{4s^2 \cdot 4p^6 \cdot 4d^{10} \cdot 4f^{14}}_{32} \cdot \underbrace{5s^2 \cdot 5p^6 \cdot 5d}_{18}$

$\underbrace{6s^1}_{1}$

$N : 7 = \underbrace{1s^2}_{2} \cdot \underbrace{2s^2 \cdot 2p^3}_{5}$

$Si : 14 = \underbrace{1s^2}_{2} \cdot \underbrace{2s^2 \, 2p^6}_{8} \cdot \underbrace{3s^2 \cdot 3p^2}_{4}$




$i_1 = i_2 + i_3 + i_4$

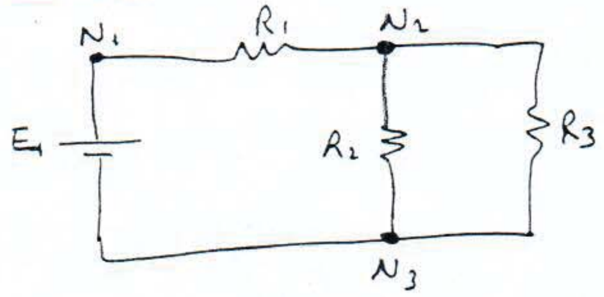
OR

$$-i_1 + i_2 + i_3 + i_4 = 0$$

$$i_1 - i_2 - i_3 - i_4 = 0$$

$$\sum_{n=1}^{N} i_n = 0 \quad \text{(Algebraic sum)}$$

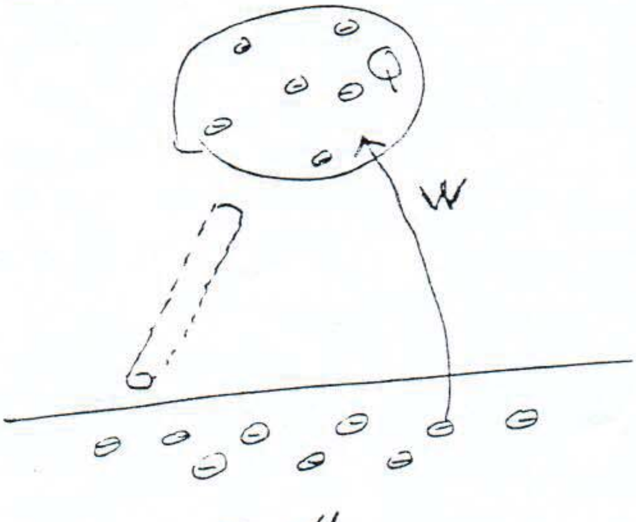
__Branch__: An electrical element or a group of elements connected together with two external terminals is called a branch.




Branches: the four elements, $E$ & $R_1$, $E$ & $R$ & $R_2$, $R_2$ & $R_3$, $R_1$ & $R_2$ & $R_3$

Nodes: $N_1, N_2, N_3$

2. Voltage and Kirchhoff's Voltage Law

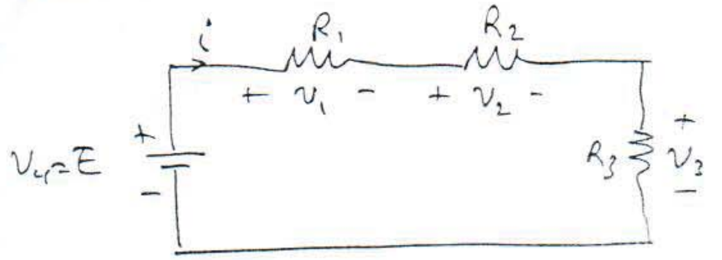



__Potential__ $= \frac{W}{Q} \quad \left(\frac{J}{C} = V\right)$

__Voltage__: The potential difference between two points (nodes) is called voltage.

__Loop and mesh__: A closed path of elements is called a loop. If this loop does not contain any elements inside it, then it may also be called a mesh.

## K's Voltage Law:




$$v_4 = v_1 + v_2 + v_3$$

$$v_1 + v_2 + v_3 - v_4 = 0$$

$$-v_1 - v_2 - v_3 + v_4 = 0$$

$$\sum_{n=1}^{m} v_n = 0 \quad \text{(Algebraic sum)}$$

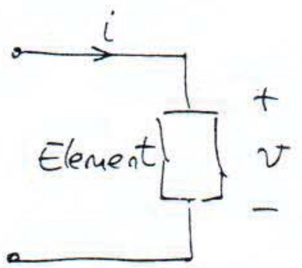
* No energy is lost or created in an electrical circuit.

## Power and Energy:

$$\text{Power} = \frac{\text{Work}}{\text{Time}} = \frac{\text{Work}}{\text{Charge}} \cdot \frac{\text{Charge}}{\text{Time}} = \text{Voltage} \cdot \text{Current}$$

$$P = V \cdot I \qquad \left( \text{watt} = \frac{\text{Joule}}{\text{second}} = \frac{J}{C} \cdot \frac{C}{s} = V \cdot A \right)$$

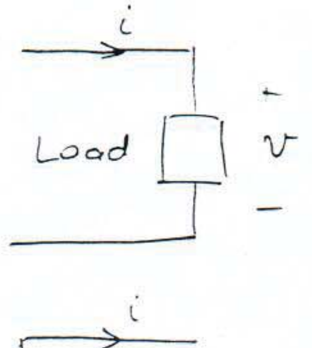
## Passive Sign Convention:




Power dissipated $= v \cdot i$

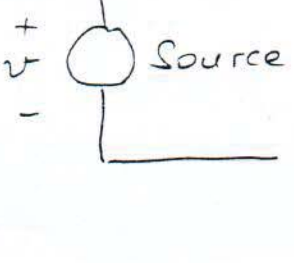
Power generated $= -vi = (-v) \cdot i = v(-i)$

Thus



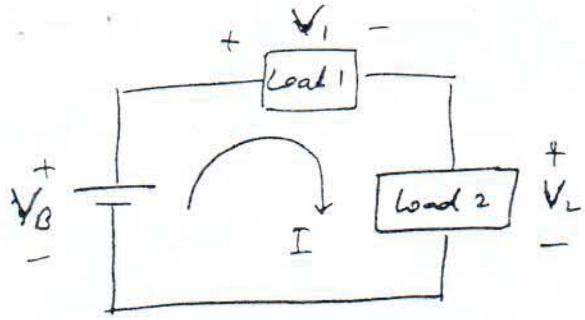

Power dissipated $= v \cdot i$

Power generated $= v(-i) = (-v)i = -vi$




Power dissipated $= v(-i) = (-v) \cdot i = -vi$

Power generated $= v \cdot i$




$V_B = +12\,V$, $V_1 = +8\,V$, $V_2 = +4\,V$, $I = +0.1$

$P_B = (-V_B)I = +(-12)(+0.1)$
$= -1.2\,W$ dissipated $= 1.2\,W$ generated

$P_1 = V_1 I = (+8)(+0.1) = 0.8\,W$ dissipated

$P_2 = V_2 I = (+4)(+0.1) = 0.4\,W$ dissipated

(Total Power Dissipated $= -1.2 + 0.8 + 0.4 = 0$)

<u>Average Power</u>: If power is a periodic function of time with period T, then the average power is

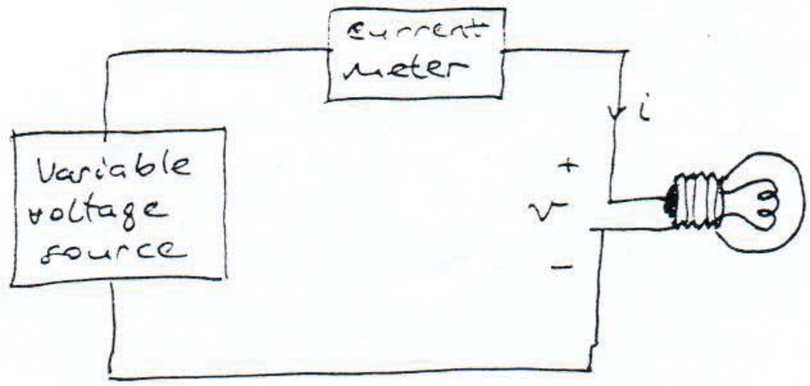
$$P_0 = \frac{1}{T}\int_0^T p(t).dt$$

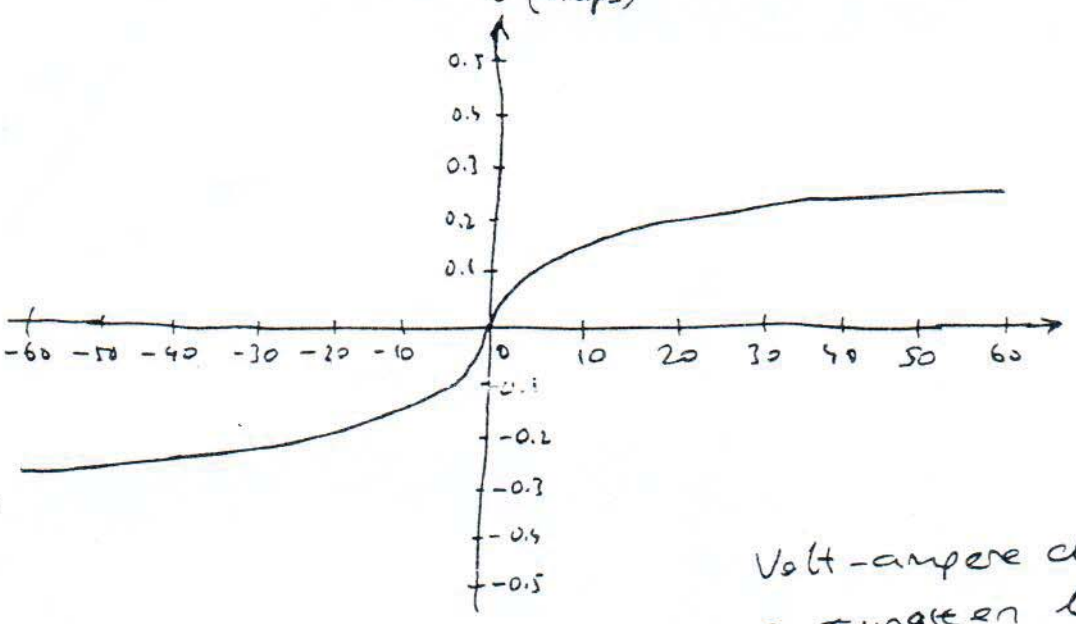
* From now on, we will use small case letters to represent variables which are functions of time and capital letters to represent constants. (Except for the dependent variables).

<u>Energy</u>: Since power is work done per unit time, work being energy, we can write

$$p = \frac{dw}{dt} \quad \text{or} \quad w = \int_{t_1}^{t_2} p.dt$$

Circuit Elements and Their i-v Characteristics





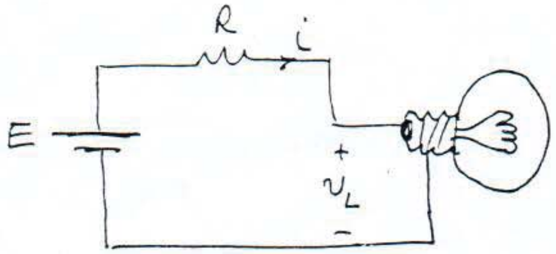

$i = f(v)$
or
$v = g(i)$

Volt-ampere characteristics of a tungsten light bulb.

If the i-v characteristic for an element is a straight line, then

$v = ki$ , where k is a constant.

Ex




$E = Ri + v_L$

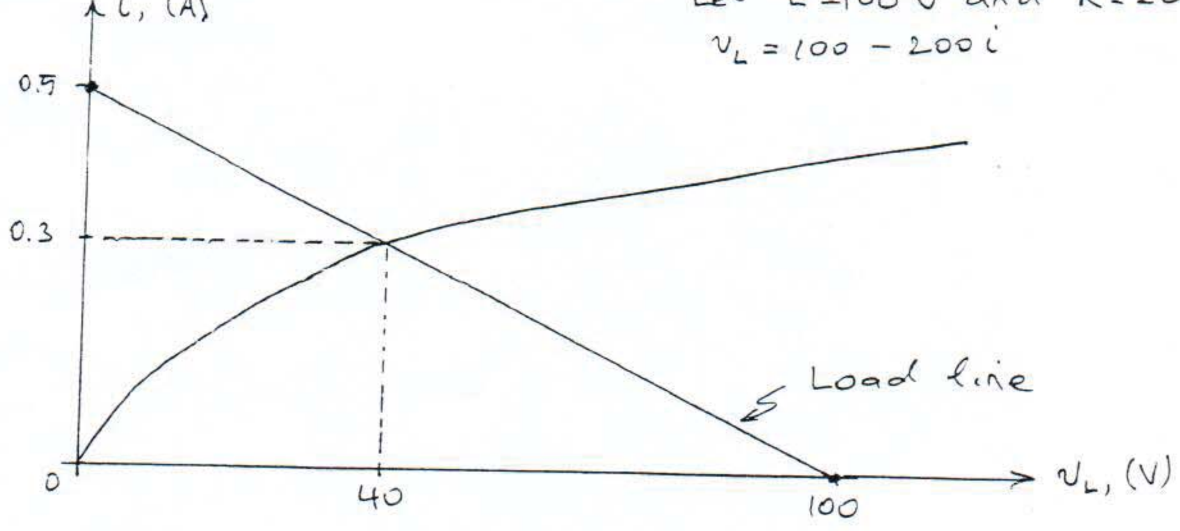
$v_L = E - Ri$ (Load line)

$v_L = 0 \rightarrow i = \frac{E}{R}$

$i = 0 \rightarrow v_L = E$

Let $E = 100$ V and $R = 200\ \Omega$.

$v_L = 100 - 200i$




From the graph, $i = 0.3$ A and $v_L = 40$ V. In fact

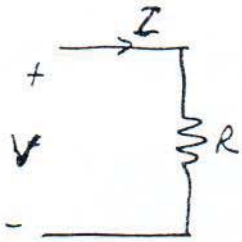
$v_L = 100 - 200(0.3) = 40$ V.

Resistance : When electric [illegible] flows [illegible] an element, it encounters a certain amount of resistance. A resistor is such an element with i-v characteristics such as above.

Ohm's Law: An ideal resistor exhibits linear resistance and this is expressed by Ohm's Law.

$$V = RI \quad \text{where } R \text{ is the resistance.}$$

$$(V = \Omega . A \quad \text{where } \Omega = \text{ohms})$$




The resistance of a material depends on a property called resistivity (öz direnç), denoted by $\rho$, which is the inverse of conductivity (öz iletkenlik), denoted by $\sigma$.

For a cylindrical resistive element

$$R = \rho \frac{l}{A}, \quad \text{where } l = \text{The length of the cylinder}, \; A = \text{Cross-sectional area}$$

For copper $\rho_{Cu} = 1.72 \times 10^{-8}\ \Omega\text{-m}$

For carbon $\rho_{C} = 3.5 \times 10^{-5}\ \Omega\text{-m}$

For silver $\rho_{Ag} = 1.59 \times 10^{-8}\ \Omega\text{-m}$

For gold $\rho_{Au} = 2.21 \times 10^{-8}\ \Omega\text{-m}$

Ex: Copper wire : $l = 100\text{ m}$, $A = 2\text{ mm}^2$

$$R = 1.72 \times 10^{-8} \frac{100}{2 \times 10^{-6}} = 0.86\ \Omega$$

Carbon : $l = 4\text{ cm}$, $A = 2\text{ mm}^2 \Rightarrow R = 3.5 \times 10^{-5} \frac{0.04}{2 \times 10^{-6}} = 0.7$

Conductance: The inverse of resistance is called conductance (iletkenlik).

$$G = \frac{1}{R} \quad (S = \text{Siemens})$$

* (Concepts of OPEN CIRCUIT and SHORT CIRCUIT, if not explained so far