# THERMAL, CHEMICAL AND THERMOELECTRIC EFFECT

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3. Electric Power and Electric Energy
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# THERMAL EFFECT OF CURRENT

## Joule's Law:

When an electric current is passed through a conducting wire, the electrical energy is converted into heat energy. This effect is called 'heating effect of electric current'.

It is also called 'Joule Heating'.

Joule's Law gives

$$Q = I^2 R t$$

Q is in Joule, I in Amp, R in ohm and t in sec.

$$Q = \frac{I^2 R t}{J}$$

Q is in Calorie, I in Amp, R in ohm and t in sec.

## Cause of Heating Effect of Current:

When a battery is connected to the ends of a conductor, electric field is set up. The free electrons move in the direction opposite to the field. They undergo collision with the positive ions and atoms of the conductor. The average kinetic energy of vibration of the ions and the atoms increases and hence the temperature increases.

**Note:** The course of electron through resistor is like that of the stone falling in water.

## Electric Power:

Electric power is the rate at which work is done by an electric current.

$P = V I$ $P = I^2 R$ $P = V^2 / R$

SI unit of power is 'watt'.

Other units are 'kW' and 'hp'.

1 kW = 1000 W 1 hp = 746 W

## Electric Energy:

Electric energy is the total work done by an electric current in a given time.

$E = V I t$ $E = I^2 R t$ $E = V^2 t / R$

Commercial Unit of Electric Energy is kWh or B.O.T.U.

1 kWh = $3.6 \times 10^6$ Joule

## Electric Fuse:

Electric fuse is a protective device used in series with an electric circuit or an electric appliance to save it from damage due to overheating produced by strong current in the circuit or appliance.

Fuse is generally made of alloy of 63% tin and 37% lead.

It has high resistance and low melting point.

Electric Heating Appliances use Nichrome wire (alloy of Ni and Cr).

It is used because:

i) It has high specific resistance   ii) It has high melting point

iii) It has high malleability   iv) It is not easily oxidised.

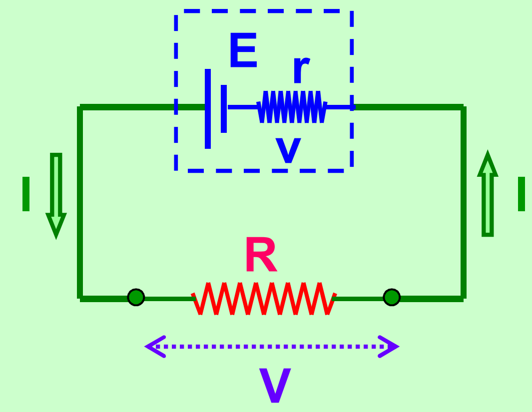
For given V, $P \propto I$   $P \propto 1 / R$

i.e. i) Higher the power of the appliance, more is the current drawn

ii) Higher the power of the appliance, less is the resistance.

## Maximum Power Theorem:

$$I = \frac{E}{R + r}$$




Output power of source of emf, $P = I^2 R$

$$P = \left[ \frac{E}{R + r} \right]^2 R$$

For output power to be maximum, $\frac{dP}{dR} = 0$

Manipulating, we get $R = r$

Maximum Power $= \frac{E^2}{4R}$

# CHEMICAL EFFECT OF CURRENT

**Electrolyte:** The substances which decompose and show chemical reactions when an electric current is passed through them are known as electrolyte.

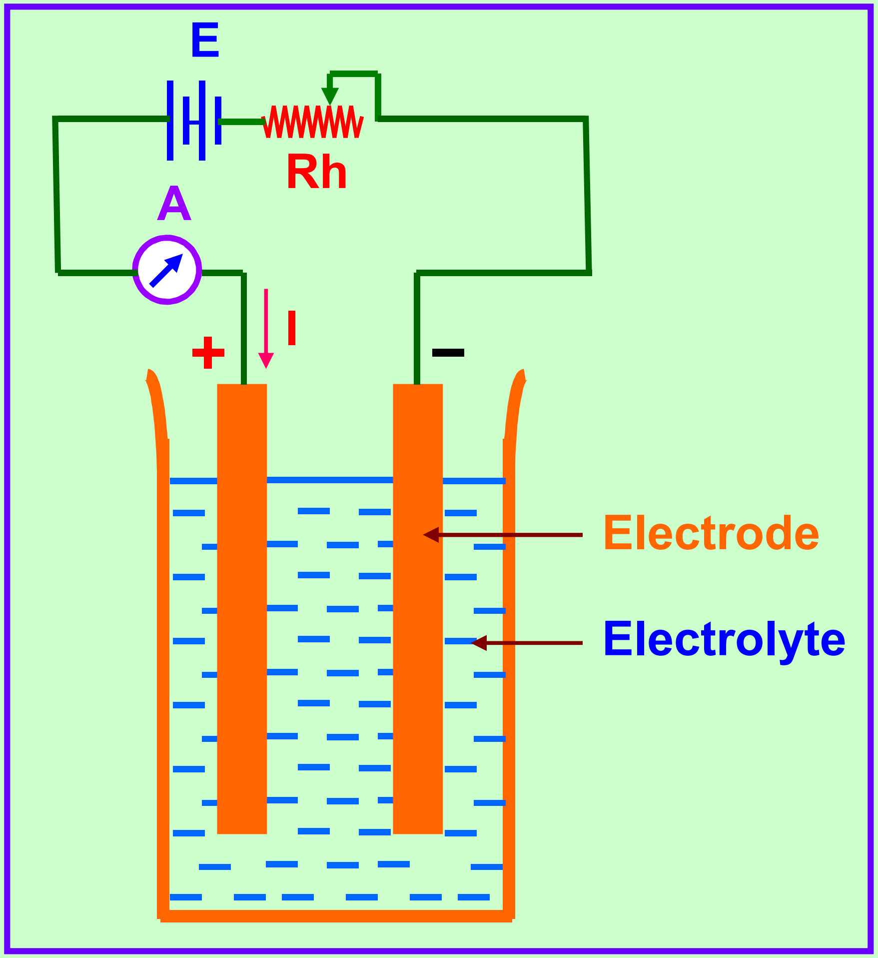
An electrolyte should be capable of i) conducting current and ii) dissociating into ions.

Eg. Copper sulphate, acidulated water, etc.

Mercury is a good conductor but can not dissociate into ions.

Vegetable oil can dissociate into ions but can not conduct current.

**Electrode:** It is a plate or rod through which electric current is passed. The electrode though which current enters is called anode (+ ve) and the other is called cathode (- ve).



**Electrolysis:** **The process by which free elements are liberated from an electrolytic solution by the passage of an electric current though it is called electrolysis.**

**Chemical Equivalent:** **It is numerically equal to atomic weight of an element divided by its valency.**

## Faraday's Laws of Electrolysis:

### I Law:

**The mass of the ions liberated at the anode or deposited at the cathode in electrolysis is directly proportional to the quantity of electricity, i.e. charge passed through the electrolyte.**

**If m be the mass of the ions and q the total charge passed, then**

$$m \propto q \qquad \text{or} \qquad m = z\,q \qquad \text{or} \qquad m = z\,I\,t$$

**where z is called electrochemical equivalent (e.c.e) of the substance.**

### II Law:

**When the same electric current is passed through several electrolytes for the same time, the masses of the various ions deposited at the respective cathodes or liberated at the respective anodes are proportional to their chemical equivalents.**

$$\frac{m_A}{m_B} = \frac{E_A}{E_B}$$

**Electrochemical equivalent of a substance is defined as the mass of the ions liberated or deposited during electrolysis when one coulomb of electricity is passed through the electrolyte or when one ampere of current is passed through the electrolyte for one second.**

## Relation between z, E, M, p, F, etc.:

$$\frac{z_A}{z_B} = \frac{E_A}{E_B}$$

$$z \propto \frac{M}{p}$$

$$\frac{E}{z} = F \quad \text{or} \quad \boxed{F = \frac{E\,q}{m}}$$

**Faraday (F) is the quantity of charge required to liberate one gram equivalent of a substance during electrolysis.**

**It may also be defined as the charge required to liberate one mole of a monovalent element during electrolysis.**

$$F = 96500 \text{ C / mol}$$

## Applications of Electrolysis:

1. Electroplating
2. Extraction of metals from the ores
3. Purification of metals
4. Medical applications
5. Printing Industry
6. Noden valve
7. Preparation of chemicals
8. Production of hydrogen and oxygen
9. Chemical analysis

# Source of EMF (Cells):

An electrochemical cell or simply a cell is an arrangement which converts chemical energy into electrical energy at a steady state.

The cells are of 4 types:

i) Primary cells

ii) Secondary cells

iii) Fuel cells

iv) Solid State cells

# Daniel cell:

## Action at Zn Anode:

Zn dissociates and Zn ions pass into the solution.

$$Zn \rightarrow Zn^{++} + 2e^-$$

$$H_2SO_4 \rightarrow 2H^+ + SO_4^{--}$$

$$Zn^{++} + SO_4^{--} \rightarrow ZnSO_4$$

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$$Zn + H_2SO_4 \rightarrow ZnSO_4 + 2H^+ + 2e^-$$

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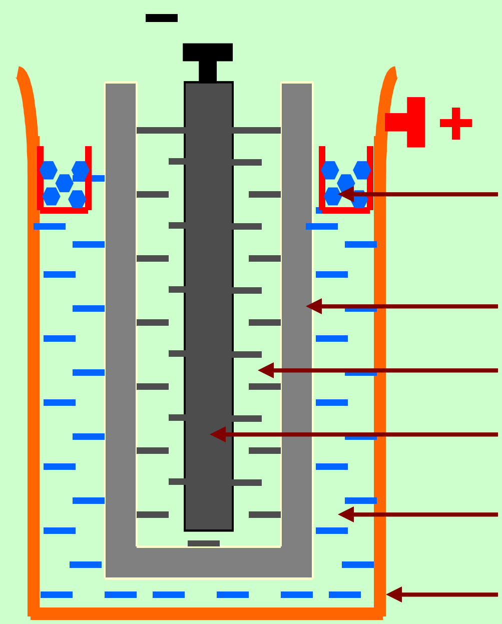



The hydrogen ions so formed diffuse through the porous pot and act on the copper sulphate forming sulphuric acid and liberating $Cu^{++}$ ions.

$$2H^+ + CuSO_4 \rightarrow H_2SO_4 + Cu^{++}$$

## Action at Cu Cathode:

These positive ions are deposited on the copper plate, thereby making copper plate positive with respect the electrolyte.

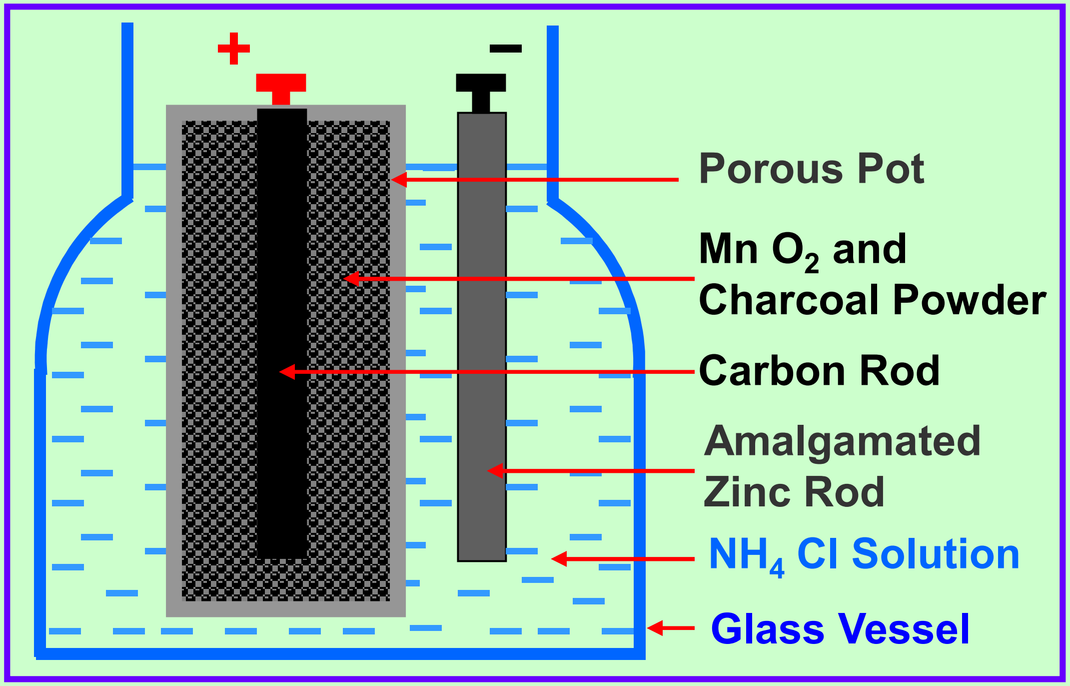
So, there is no polarisation. Thus, $CuSO_4$ acts as depolariser.

The EMF of Daniel cell is 1.12 volt.

# Leclanche cell:

## Action at Zn Anode:

Zn dissociates and Zn ions pass into the solution.




$$Zn \rightarrow Zn^{++} + 2e^-$$

$$2NH_4Cl \rightarrow 2NH_3 + 2H^+ + 2Cl^-$$

$$Zn^{++} + 2Cl^- \rightarrow ZnCl_2$$

$$Zn + 2NH_4Cl \rightarrow 2NH_3 + ZnCl_2 + 2H^+ + 2e^-$$

The ammonium gas escapes. The hydrogen ions diffuse through the pores of the porous pot. Hydrogen ions react with manganese dioxide.

$$2H^+ + 2MnO_2 \rightarrow Mn_2O_3 + H_2O + 2e^+$$

## Action at Carbon Cathode:

These positive charges are transferred to the carbon rod. So, the carbon rod becomes positive with respect to the electrolyte.

When the cell is allowed to rest for some time by keeping the porous pot outside the cell, $Mn_2O_3$ is once again converted into $MnO_2$

$$2Mn_2O_3 + O_2 \rightarrow 4MnO_2$$

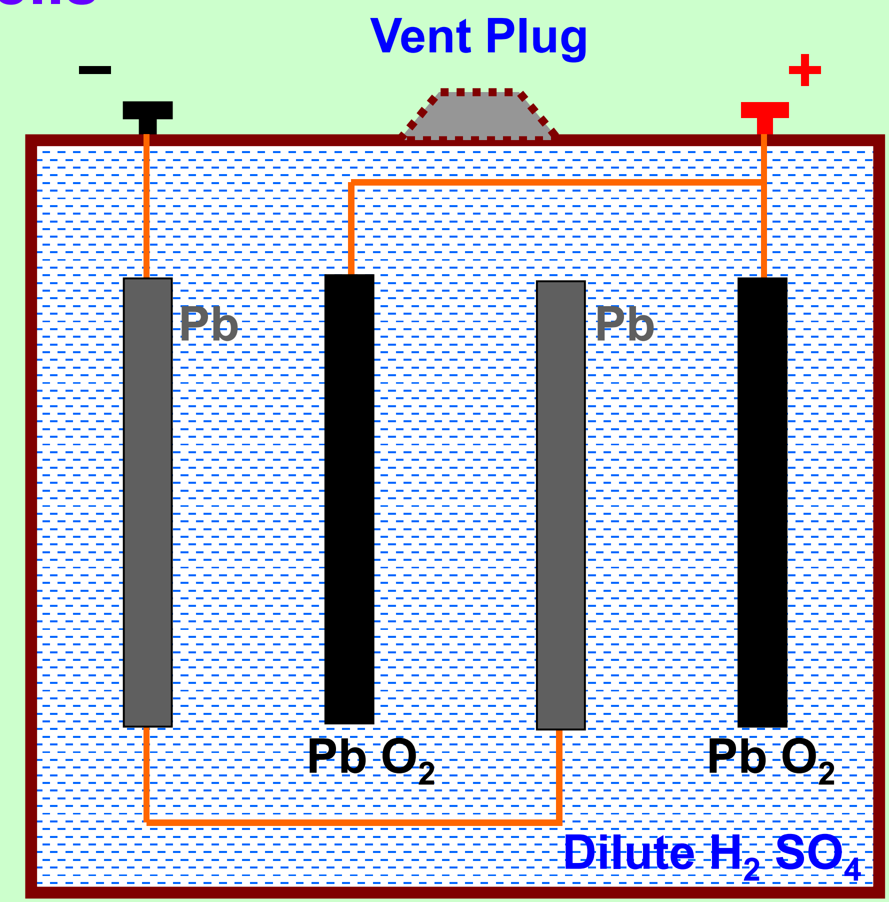
EMF of Leclanche cell is 1.5 volt.

# Secondary Cells

## Lead Acid Cell:

### Discharging:

When the cell is connected to an external resistance, current begins to flow. The sulphuric acid dissociates into hydrogen ($H^+$)and sulphate ($SO4^{--}$) ions.




The hydrogen ions move towards the positive plate. The sulphate ions move towards the negative plate.

While delivering charges to the plates, the ions convert the active materials of each to lead sulphate.

**Action at the negative plate (Pb):**

$$Pb + SO_4^{--} - 2\,e^- \rightarrow PbSO_4$$

**Action at the positive plate ($PbO_2$):**

$$PbO_2 + 2H^+ + 2\,e^- \rightarrow PbO + H_2O$$

$$PbO + H_2SO_4 \rightarrow PbSO_4 + H_2O$$

$$PbO_2 + H_2SO_4 + 2H^+ + 2\,e^- \rightarrow PbSO_4 + 2\,H_2O$$

But $H_2SO_4$ molecules do not exist in the solution. These are dissociated into $2H^+$ and $SO_4^{--}$ ions. So, the net reaction at the positive plate is:

$$PbO_2 + SO_4^{--} + 4H^+ + 2e^- \rightarrow PbSO_4 + 2H_2O$$

The lead sulphate produced in these reactions is a soft form. It is chemically more active than the hard lead. When the emf of cell falls 1.9 V, it requires to be charged.

## Charging:

When the cell is to be charged, it is connected in opposition to a supply of greater emf. The hydrogen ions are carried to the negative plate and sulphate ions to the positive plate.

### Action at the negative plate (Pb):

$$PbSO_4^{--} + 2H^+ + 2e^- \rightarrow Pb + H_2SO_4$$

### Action at the positive plate ($PbO_2$):

$$PbSO_4 + SO_4^{--} - 2e^- \rightarrow PbO_2 + 2SO_3$$

$$2SO_3 + 2H_2O \rightarrow 2H_2SO_4$$

$$PbSO_4 + 2H_2O + SO_4^{--} - 2e^- \rightarrow PbO_2 + 2H_2SO_4$$

EMF of freshly prepared cell is 2.2 volt.

# THERMOELECTRIC EFFECT OF CURRENT

The phenomenon of production of electricity with the help of heat is called thermoelectricity and this effect is called thermoelectric effect.

Or

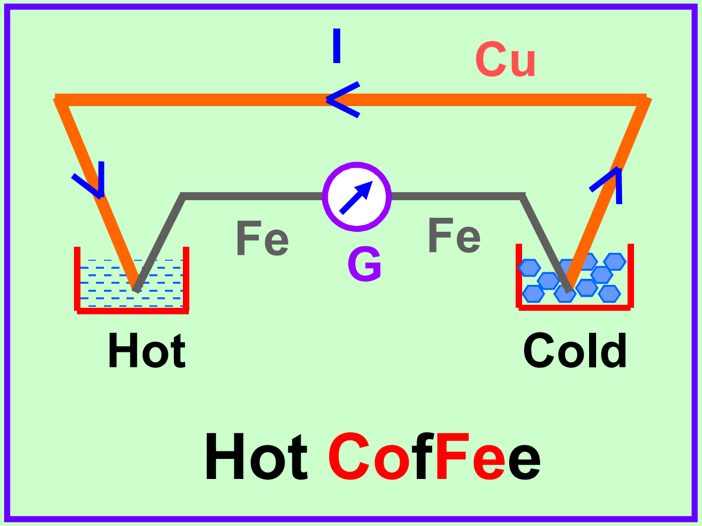
The phenomenon of generation of an electric current in a thermocouple by keeping its junctions at different temperatures is called thermoelectric effect.

An arrangement of two wires of different materials (conductors) joined at their ends to form two junctions is called thermocouple.

## Seebeck Effect:

$$E = \alpha t + \tfrac{1}{2} \beta t^2$$

where α and β are thermoelectric constants




The current produced in this effect is called thermoelectric current and the emf is called thermoelectric emf.

Thermoelectric emf is usually in the order of μV.

## Seebeck Series (Cold Junction):

The magnitude and direction of thermo emf in a thermocouple depends not only on the temperature difference between the hot and cold junctions but also on the nature of metals constituting the thermocouple.

Sb, As, Fe, Cd, Zn, Ag, Au, Mo, Sn, Pb, Hg, Mn, Cu, Pt, Co, Ni, Bi

1. The magnitude of thermo emf in a thermocouple depends on the extent of separation of the metals in the series.

2. The thermoelectric current flows from a metal earlier in the series to a metal later in the series across the cold junction.

Note: For hot junction, just reverse the series.

## Origin of Seebeck Effect:

The density of free electrons in a metal is generally different from the density of free electrons from another metal. When a metal is brought into contact with another, the free electrons tend to diffuse so as to equalise the electron densities. If the temperatures of both the junctions are the same, then the emfs at the junctions will be equal and opposite and hence net emf is zero.

However, if the junctions are maintained at different temperatures, the densities of the metals will be affected and differently. Further, it is easy to transfer the electrons at the hot junction than at the cold junction. Therefore, emf at the two junctions will be different causing the net emf.

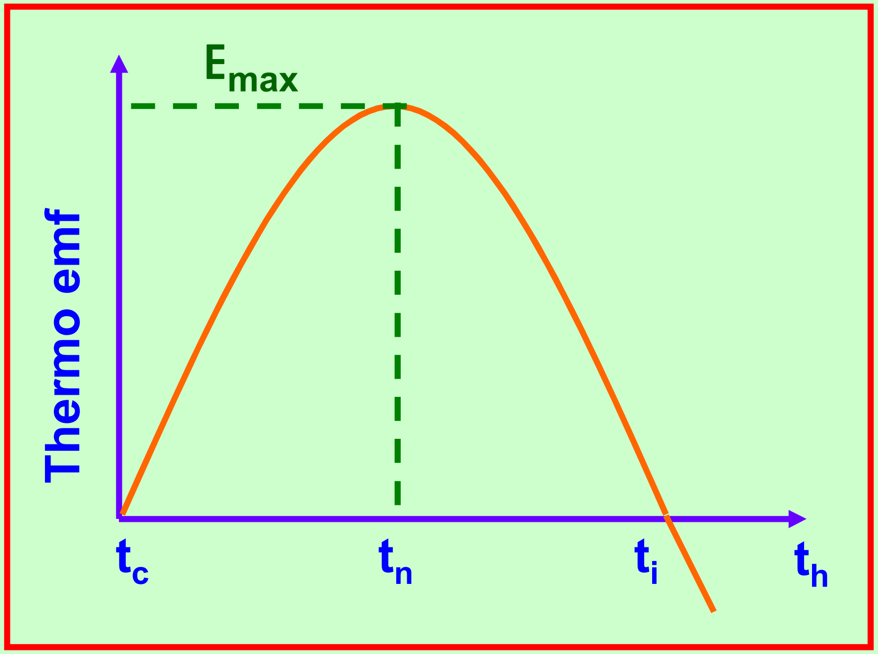
## Variation of Seebeck EMF with Temperature:

### Neutral Temperature:

The temperature of the hot junction at which the thermo emf becomes maximum is called the neutral temperature.

It is independent of the temperature of the cold junction.

It depends only upon the nature of the metals forming the thermocouple.




### Temperature of Inversion:

The temperature of the hot junction at which the thermo emf becomes zero and then changes direction is called the temperature of inversion.

It depends on the temperature of the cold junction.

It also depends on the nature of the metals forming the thermocouple.

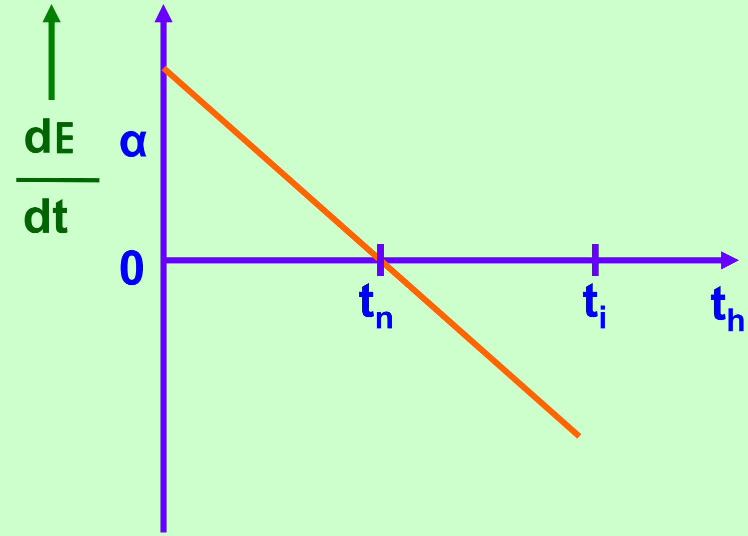
$t_i - t_n = t_n - t_c$ or $t_n = (t_i + t_c) / 2$

## Thermoelectric Power (S):

The rate of change of thermoelectric emf with temperature is called thermoelectric power.

It is also known as 'Seebeck coefficient'.

$$E = \alpha t + \tfrac{1}{2} \beta t^2$$




$$\text{Thermoelectric power} = \frac{dE}{dt}$$

$$S = \frac{d}{dt}\left( \alpha t + \tfrac{1}{2} \beta t^2 \right)$$

$$S = \alpha + \beta t$$

The graph between Seebeck power and temperature is a straight line and is called 'thermoelectric power line'.

When $t = t_n$, $\frac{dE}{dt} = 0$ or $S = \alpha + \beta t_n = 0$

or $$t_n = -\frac{\alpha}{\beta}$$

## Laws of Thermoelectricity:

### 1. Law of successive temperatures:

For a given thermocouple, the emf for any specified temperature difference is equal to the sum of the emfs corresponding to any smaller intervals into which the given range of temperature may be sub-divided.

$$E_{t_1}^{t_n} = E_{t_1}^{t_2} + E_{t_2}^{t_3} + E_{t_3}^{t_4} + \ldots\ldots\ldots + E_{t_{n-1}}^{t_n}$$

### 2. Law of successive metals:

The insertion of an additional metal or metals into any thermoelectric circuit does not change the effective emf of the circuit, provided that both the ends of each such conductor are at the same temperature.

$$E_A^G = E_A^B + E_B^C + E_C^D + \ldots\ldots\ldots + E_F^G$$

End of Thermal, Chemical and Thermoelectric Effect