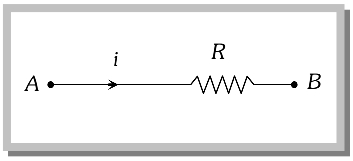
Joules Heating.

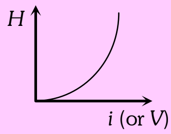
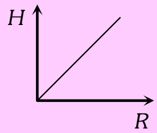
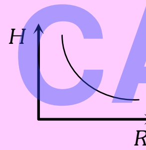
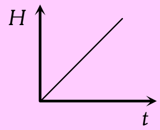
When some potential difference V is applied across a resistance R then the work done by the electric field on charge q to flow through the circuit in time t will be $W = qV = Vit = i^2Rt = \frac{V^2t}{R} Joule$.



This work appears as thermal energy in the resistor.

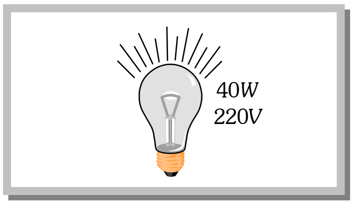
Heat produced by the resistance R is $H = \frac{W}{J} = \frac{Vit}{4\cdot 2} = \frac{i^2Rt}{4\cdot 2} = \frac{V^2t}{4\cdot 2R} Cal$. This relation is called joules heating.

Some important relations for solving objective questions are as follow :

Condition	Graph
If R and t are constant $H \propto i^2$ and $H \propto V^2$	
If i and t are constant (series grouping) $H \propto R$	
If V and t are constant (Parallel grouping) $H \propto \frac{1}{R}$	
If V, i and R constant $H \propto t$	

Electric Power.

The rate at which electrical energy is dissipated into other forms of energy is called electrical power *i.e.* $\boldsymbol{P = \frac{W}{t} = Vi = i^2R = \frac{V^2}{R}}$



(1) **Units :** It's S.I. unit is *Joule/sec* or *Watt*

Bigger S.I. units are *KW*, *MW* and *HP*, remember 1 *HP* = 746 *Watt*

(2) **Rated values :** On electrical appliances (Bulbs, Heater ……. *etc*.)

Wattage, voltage, ……. *etc*. are printed called rated values *e.g.* If suppose we have a bulb of 40 *W*, 220 *V* then rated power (P_R) = 40 *W* while rated voltage (V_R) = 220 *V*. It means that on operating the bulb at 220 *volt*, the power dissipated will be 40 *W* or in other words 40 *J* of electrical energy will be converted into heat and light per second.

(3) **Resistance of electrical appliance :** If variation of resistance with temperature is neglected then resistance of any electrical appliance can be calculated by rated power and rated voltage *i.e.* by using $\boldsymbol{R = \frac{V_R^2}{P_R}}$ *e.g.* Resistance of 100 *W*, 220 *volt* bulb is $R = \frac{220 \times 220}{100} = 484\,\Omega$

(4) **Power consumed (illumination) :** An electrical appliance (Bulb, heater, …. *etc.*) consume rated power (P_R) only if applied voltage (V_A) is equal to rated voltage (V_R) *i.e.* If $V_A = V_R$ so $P_{consumed} = P_R$. If $V_A < V_R$ then $P_{consumed} = \frac{V_A^2}{R}$ also we have $R = \frac{V_R^2}{P_R}$ so $P_{consumed}\text{(Brightness)} = \left(\frac{V_A^2}{V_R^2}\right).P_R$

e.g. If 100 *W*, 220 *V* bulb operates on 110 *volt* supply then $P_{consumed} = \left(\frac{110}{220}\right)^2 \times 100 = 25\,W$

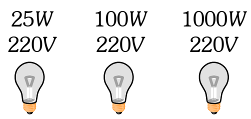
Note : ≅If $V_A < V_R$ then % drop in output power $= \frac{(P_R - P_{consumed})}{P_R} \times 100$

≅ For the series combination of bulbs, current through them will be same so they will consume power in the ratio of resistance *i.e.*, $P \propto R$ {By $P = i^2R$) while if they are connected in parallel *i.e.* V is constant so power consumed by them is in the reverse ratio of their resistance *i.e.* $P \propto \frac{1}{R}$.

(5) **Thickness of filament of bulb :** We know that resistance of filament of bulb is given by $R = \frac{V_R^2}{P_R}$, also $R = \rho\frac{l}{A}$, hence we can say that $\underset{(Thickness)}{\boldsymbol{A}} \propto \boldsymbol{P_R} \propto \boldsymbol{\frac{1}{R}}$ *i.e.* If rated power of a bulb is more, thickness of it's filament is also more and it's resistance will be less.

If applied voltage is constant then $P_{(consumed)} \propto \frac{1}{R}$ (By $P = \frac{V_A^2}{R}$). Hence if different bulbs (electrical appliance) operated at same voltage supply then $\boldsymbol{P_{consumed} \propto P_R \propto \text{thickness} \propto \frac{1}{R}}$

Note : ≅Different bulbs



⇒	Resistance	$R_{25} > R_{100} > R_{1000}$
⇒	Thickness of filament	$t_{1000} > t_{100} > t_{40}$
⇒	Brightness	$B_{1000} > B_{100} > B_{25}$

(6) **Long distance power transmission :** When power is transmitted through a power line of resistance R, power-loss will be i^2R

Now if the power P is transmitted at voltage V $\quad P = Vi$ *i.e.* $i = (P/V)$ $\quad$ So, $\quad$ Power loss $= \frac{P^2}{V^2} \times R$

Now as for a given power and line, P and R are constant so Power loss $\propto (1/V^2)$

So if power is transmitted at high voltage, power loss will be small and vice-versa. *e.g.*, power loss at 22 *kV* is 10^{-4} times than at 220 *V*. This is why long distance power transmission is carried out at high voltage.

(7) **Time taken by heater to boil the water :** We know that heat required to raise the temperature $\Delta\theta$ of any substance of mass *m* and specific heat *S* is $H = m.S.\Delta\theta$

Here heat produced by the heater = Heat required to raise the temp. $\Delta\theta$ of water.

i.e. $p \times t = J \times m.S.\Delta\theta \Rightarrow t = \frac{J(m.S.\Delta\theta)}{p}$ $\{J = 4.18 \text{ or } 4.2\ J/cal)$

for *m kg* water $t = \frac{4180\,(\text{or } 4200)\,m\,\Delta\theta}{p}$ $\{S = 1000\ cal/kg^{o}C)$

Note : ≅ If quantity of water is given *n litre* then $t = \frac{4180(4200)\,n\,\Delta\theta}{p}$

Electricity Consumption.

(1) The price of electricity consumed is calculated on the basis of electrical energy and not on the basis of electrical power.

(2) The unit *Joule* for energy is very small hence a big practical unit is considered known as *kilowatt hour* (*KWH*) or board of trade unit (B.T.U.) or simple unit.

(3) 1 *KWH* or 1 unit is the quantity of electrical energy which dissipates in one hour in an electrical circuit when the electrical power in the circuit is 1 *KW* thus 1 *KW* = 1000 *W* × 3600 *sec* = 3.6×10^6 *J*.

(4) Important formulae to calculate the no. of consumed units is $n = \frac{\text{Total } watt \times \text{Total } hours}{1000}$

Concepts

- *When some potential difference applied across the conductor then collision of free electrons with ions of the lattice result's in conversion of electrical energy into heat energy*
- *If a heating coil of resistance R, (length l) consumed power P, when voltage V is applied to it then by keeping V is constant if it is cut in n equal parts then resistance of each part will be* $\frac{R}{n}$ *and from* $P_{consumed} \propto \frac{1}{R}$, *power consumed by each part* $P' = nP$.
- *Joule's heating effect of current is common to both ac and dc.*

Example

***Example*: 1** The approximate value of heat produced in 5 *min.* by a bulb of 210 *watt* is (*J* = 4.2 *joule/calorie*) **[MP PET 2000; MNR 1985]**

(a) 15,000 (b) 1,050 (c) 63,000 (d) 80,000

Solution : (a) By using $H = \frac{P \times t}{4.2} = \frac{210 \times 5 \times 60}{4.2} = 15000\,Cal$

Example: 2 A heater coil is cut into two parts of equal length and one of them is used in the heater. The ratio of the heat produced by this half coil to that by the original coil is **[NCERT 1972]**

(a) 2 : 1 (b) 1 : 2 (c) 1 : 4 (d) 4 : 1

Solution : (a) If suppose resistance of the coil is R so resistance of it's half will be $\frac{R}{2}$. Hence by using $H = \frac{V^2 t}{R} \Rightarrow H \propto \frac{1}{R}$

$$\Rightarrow \frac{H_{Half}}{H_{Full}} = \frac{R_{Full}}{R_{Half}} = \frac{R}{R/2} = \frac{2}{1}$$

Note : ≅ In general if coil is divided in n equal parts then heat produced by each part will be n times of the heat produced by coil it self *i.e.* $H' = nH$

Example: 3 If current in an electric bulb changes by 1%, then the power will change by **[AFMC 1996]**

(a) 1% (b) 2% (c) 4% (d) $\frac{1}{2}$%

Solution : (b) By using $P = i^2 R \Rightarrow P \propto i^2 \Rightarrow \frac{\Delta P}{P} = 2\frac{\Delta i}{i} \Rightarrow$ change in power = 2%

Example: 4 A constant voltage is applied on a uniform wire, then the heat is produced. The heat so produced will be doubled, if **[IIT-JEE 1980; MP PET 1987; SCRA 1994; MP PMT 1999]**

(a) The length and the radius of wire are halved (b) Both length and radius are doubled

(c) Only the length is doubled (d) Only the radius is doubled

Solution : (b) By using $H = \frac{V^2 t}{R}$ and $R = \rho \frac{l}{A} = \frac{\rho l}{\pi r^2} \Rightarrow H = \frac{V^2 t \pi r^2}{\rho l} \Rightarrow H \propto \frac{r^2}{l}$; on doubling both r and l heat will be doubled.

Example: 5 An electric heater of resistance 6 *ohm* is run for 10 *minutes* on a 120 *volt* line. The energy liberated in this period of time is **[MP PMT 1996]**

(a) $7.2 \times 10^3\ J$ (b) $14.4 \times 10^5\ J$ (c) $43.2 \times 10^4\ J$ (d) $28.8 \times 10^4\ J$

Solution : (b) By using $H = \frac{V^2 t}{R} \Rightarrow H = \frac{(120)^2 \times 10 \times 60}{6} = 14.4 \times 10^5 J$

Example: 6 An electric bulb of 100 *W* is designed to operate on 220 *V*. Resistance of the filament is **[EAMCET 1981, 82; MP PMT 1993, 97]**

(a) 484 Ω (b) 100 Ω (c) 22000 Ω (d) 242 Ω

Solution : (a) By using $P = \frac{V^2}{R} \Rightarrow R = \frac{V^2}{P} = \frac{(220)^2}{100} = 484\,\Omega$

Example: 7 An electric bulb is rated 220 *V* and 100 *W*. Power consumed by it when operated on 110 *volt* is **[AFMC 2000; MP PMT 1986, 94; CPMT 1986]**

(a) 50 *W* (b) 75 *W* (c) 90 *W* (d) 25 *W*

Solution : (d) By using $P_{consumed} = \left(\frac{V_A}{V_R}\right)^2 \times P_R \Rightarrow P_{Consumed} = \left(\frac{110}{220}\right)^2 \times 100 = 25\,W$

Example: 8 A 500 *watt* heating unit is designed to operate from a 115 *Volt* line. If the line voltage drops to 110 *volt*, the percentage drop in heat output will be **[ISM Dhanbad 1994]**

(a) 10.20% (b) 8.1% (c) 8.6% (d) 7.6%

Solution : (c) By using $P_{consumed} = \left(\frac{V_A}{V_R}\right)^2 \times P_R \Rightarrow P_{Consumed} = \left(\frac{110}{115}\right)^2 \times 500 = 456.6\, Watt$

So % drop in heat output $= \frac{P_{Actual} - P_{Consumed}}{P_{Actual}} \times 100 = \frac{(500 - 456.6)}{500} \times 100 = 8.6\%$

Example: 9 An electric lamp is marked 60 *W*, 230 *V*. The cost of 1 *kilowatt hour* of power is *Rs*. 1.25. The cost of using this lamp for 8 *hours* is **[KCET 1994]**

(a) *Rs*. 1.20 (b) *Rs*. 4.00 (c) *Rs*. 0.25 (d) *Rs*. 0.60

Solution : (d) By using consumed unit (n) or $KWH = \frac{\text{Total Watt} \times \text{Total time}}{1000} \Rightarrow n = \frac{60 \times 8}{1000} = \frac{12}{25}$

So cost $= \frac{12}{25} \times 1.25 = 0.60\, Rs$

Example: 10 How much energy in *Kilowatt hour* is consumed in operating ten 50 *watt* bulbs for 10 hours per day in a month (30 days) **[Pb PMT 2000; CPMT 1991; NCERT 1978]**

(a) 1500 (b) 15.000 (c) 15 (d) 150

Solution : (d) By using $n = \frac{\text{Total Watt} \times \text{Total time}}{1000} \Rightarrow n = \frac{(50 \times 10) \times (10 \times 30)}{1000} = 150$

Example: 11 An immersion heater is rated 836 *watt*. It should heat 1 *litre* of water from 20° *C* to 40° *C* in about

(a) 200 *sec* (b) 100 *sec* (c) 836 *sec* (d) 418 *sec*

Solution : (b) By using $t = \frac{4180 \times n \times \Delta\theta}{P} \Rightarrow t = \frac{4180 \times 1 \times (40 - 20)}{836} = 100\, \text{sec}$

Example: 12 The power of a heater is 500 *watt* at 800° *C*. What will be its power at 200° *C* if $\alpha = 4 \times 10^{-4}$ *per* °*C*

(a) 484 *W* (b) 672 *W* (c) 526 *W* (d) 611 *W*

Solution : (d) By using $P = i^2R = \frac{V^2}{R} \Rightarrow P \propto \frac{1}{R} \Rightarrow \frac{P_1}{P_2} = \frac{R_2}{R_1} = \frac{(1 + \alpha t_2)}{(1 + \alpha t_1)} \Rightarrow \frac{500}{P_2} = \frac{(1 + 4 \times 10^{-4} \times 200)}{(1 + 4 \times 10^{-4} \times 800)}$

$\Rightarrow \frac{500}{P_2} = \frac{1.08}{1.32} \Rightarrow 611\, W$

Example: 13 A heater of 220 *V* heats a volume of water in 5 *minute* time. A heater of 110 *V* heats the same volume of water in **[AFMC 1993]**

(a) 5 *minutes* (b) 8 *minutes* (c) 10 *minutes* (d) 20 *minutes*

Solution : (d) By using $H = \frac{V^2 t}{R}$. Here volume of water is same. So same heat is required in both cases. Resistance is also constant so V^2t = constant $\Rightarrow t \propto \frac{1}{V^2} \Rightarrow \frac{t_1}{t_2} = \left(\frac{V_2}{V_1}\right)^2 \Rightarrow \frac{5}{t_2} = \left(\frac{110}{220}\right)^2 = \frac{1}{4} \Rightarrow t_2 = 20\, \text{min}$

Example: 14 Water boils in an electric kettle in 15 *minutes* after switching on. If the length of the heating wire is decreased to 2/3 of its initial value, then the same amount of water will boil with the same supply voltage in **[MP PMT 1994]**

(a) 15 *minutes* (b) 12 *minutes* (c) 10 *minutes* (d) 8 *minutes*

Solution : (c) By using $H = \frac{V^2 t}{R}$ where $R = \rho \frac{l}{A} \Rightarrow H = \frac{V^2 t A}{\rho l}$. Since volume is constant so H is also constant so $t \propto l$

which gives $\frac{t_2}{t_1} = \frac{l_2}{l_1} \Rightarrow \frac{t_2}{15} = \frac{\frac{2}{3} l_1}{l_1} \Rightarrow t_2 = 10 \min$

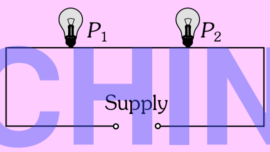
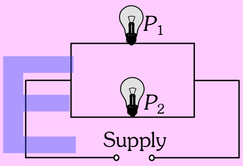
Tricky Example: 1

If resistance of the filament increases with temperature, what will be power dissipated in a 220 V – 100 W lamp when connected to 110 V power supply

(a) 25 W (b) < 25 W (c) > 25 W (d) None of these

Solution : (b) If resistance do not varies with temperature $P_{Consumed} = \left(\frac{V_A}{V_R}\right)^2 . P_R = \left(\frac{110}{220}\right)^2 \times 100 = 25 W$. But actually resistance is increasing with temperature so consumed power will be lesser then 25W.

Combination of Bulbs (or Electrical Appliances).

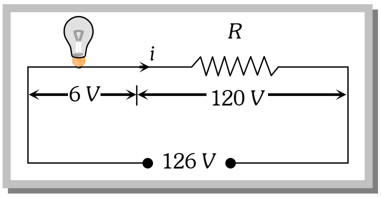
Bulbs (Heater *etc.*) are in series	Bulbs (Heater *etc.*) are in parallel
(1) Total power consumed $\frac{1}{P_{total}} = \frac{1}{P_1} + \frac{1}{P_2} + ...$ 	(1) Total power consumed $P_{total} = P_1 + P_2 + P_3 ...... + P_n$ 
(2) If 'n' bulbs are identical, $P_{total} = \frac{P}{N}$	(2) If 'n' identical bulbs are in parallel. $P_{total} = nP$
(3) $P_{consumed}$ (Brightness) $\propto V \propto R \propto \frac{1}{P_{rated}}$ *i.e.* in series combination bulb of lesser wattage will give more bright light and p.d. appeared across it will be more.	(3) $P_{consumed}$ (Brightness) $\propto P_R \propto i \propto \frac{1}{R}$ *i.e.* in parallel combination bulb of greater wattage will give more bright light and more current will pass through it.

Some Standard Cases for Series and Parallel Combination.

(1) If n identical bulbs first connected in series so $P_S = \frac{P}{n}$ and then connected in parallel. So $P_P = nP$ hence $\frac{\boldsymbol{P_P}}{\boldsymbol{P_S}} = \boldsymbol{n^2}$.

(2) To operate a bulb on voltage which is more then it's rated voltage, a proper resistance is connected in series with it. *e.g.* to glow a bulb of 30 W, 6 V with full intensity on 126 *volt* required series resistance calculated as follows

Bulb will glow with it's full intensity if applied voltage on it is 6 V *i.e.* 120 V appears across the series resistance R current flows through bulb = current flows through resistance



$$i = \frac{30}{6} = 5\, amp$$

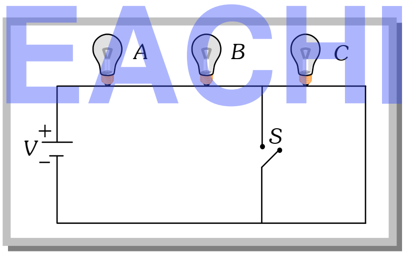
Hence for resistance $V = iR$ *i.e.* $120 = 5 \times R \Rightarrow 5 \times R \Rightarrow R = 24\, \Omega$

Note : ≅ If you want to learn **Short Trick** then remember Series resistance $= \left(\frac{V_{operating} - V_R}{P_R}\right) \times V_R$

(3) An electric kettle has two coils when one coil is switched on it takes time t_1 to boil water and when the second coil is switched on it takes time t_2 to boil the same water.

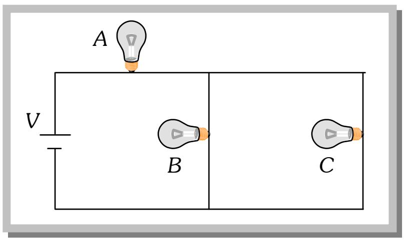
If they are connected in series	If they are connected in parallel
$\frac{1}{P_S} = \frac{1}{P_1} + \frac{1}{P_2}$ $\Rightarrow \frac{1}{H_S/t_S} = \frac{1}{H_1/t_1} + \frac{1}{H_2/t_2}$ $\because H_S = H_1 = H_2$ so $t_s = t_1 + t_2$ i.e. time taken by combination to boil the same quantity of water $\boldsymbol{t_S = t_1 + t_2}$	$P_P = P_1 + P_2$ $\Rightarrow \frac{H_P}{t_p} = \frac{H_1}{t_1} + \frac{H_2}{t_2}$ $\because H_p = H_1 = H_2$ so $\frac{1}{t_p} = \frac{1}{t_1} + \frac{1}{t_2}$ i.e. time taken by parallel combination to boil the same quantity of water $\boldsymbol{t_p = \frac{t_1 t_2}{t_1 + t_2}}$

(4) If three identical bulbs are connected in series as shown in figure then on closing the switch S. Bulb C short circuited and hence illumination of bulbs A and B increases



Reason : Voltage on A and B increased.

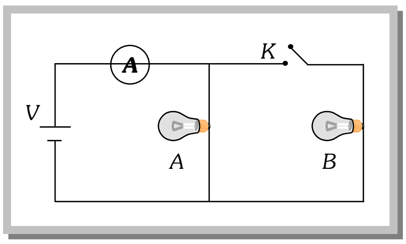
(5) If three bulbs A, B and C are connected in mixed combination as shown, then illumination of bulb A decreases if either B or C gets fused



Reason : Voltage on A decreases.

(6) If two identical bulb A and B are connected in parallel with ammeter A and key K as shown in figure.

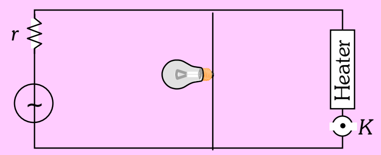
It should be remembered that on pressing key reading of ammeter becomes twice.



Reason : Total resistance becomes half.

Concepts

- *When a heavy current appliance such us motor, heater or geyser is switched on, it will draw a heavy current from the source so that terminal voltage of source decreases. Hence power consumed by the bulb decreases, so the light of bulb becomes less.*



- *If the source is ideal i.e. r = 0, there will be no change in the brightness of the bulb.*

Example

***Example*: 15** An electric kettle has two heating coils. When one of the coils is connected to *ac* source the water in the kettle boils in 10 *minutes*. When the other coil is used the water boils in 40 *minutes*. If both the coils are connected in parallel, the time taken by the same quantity of water to boil will be **[CBSE PMT 2003]**

(a) 4 *min* (b) 25 *min* (c) 15 *min* (d) 8 *min*

Solution : (d) By using the formula $t_p = \frac{t_1 t_2}{t_1 + t_2}$ (as we discussed in theory) $\Rightarrow t_p = \frac{10 \times 40}{(10+40)} = 8\,min$

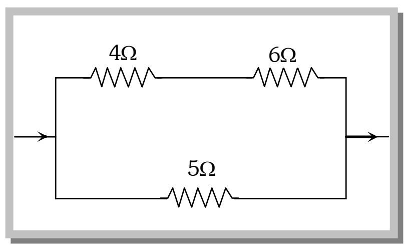
Note : ≅ In this question if coils are connected in series then the time taken by the same quantity of water to boil will be $t_s = t_1 + t_2 = 10 + 40 = 50\,min$

***Example*: 16** If a 30 *V*, 90 *W* bulb is to be worked on a 120 *V* line, a resistance of how many *ohms* should be connected in series with the bulb **[KCET 2003; MP PMT 2002]**

(a) 10 *ohm* (b) 20 *ohm* (c) 30 *ohm* (d) 40 *ohm*

Solution : (c) By using Series resistance $R = \left(\frac{V_{operating} - V_R}{P_R}\right) \times V_R$ (As we discussed in theory) $\Rightarrow R = \frac{(120-30)}{90} \times 30 = 30\,\Omega$

***Example*: 17** In the circuit shown in figure, the heat produced in 5 *ohm* resistance is 10 *calories* per *second*. The heat produced in 4 *ohm* resistance is **[BHU 2003; RPMT 1994; IIT 1981]**



(a) 1 *cal/sec*

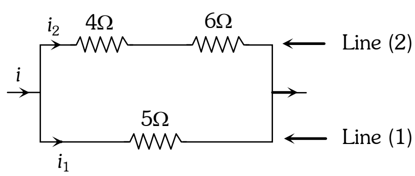
(b) 2 *cal/sec*

(c) 3 *cal/sec*

(d) 4 *cal/sec*

Solution : (b) Ratio of currents $\frac{i_1}{i_2} = \frac{10}{5} = \frac{2}{1}$ by using $H = i^2 Rt$

$\Rightarrow \frac{H_1}{H_2} = \left(\frac{i_1}{i_2}\right)^2 \times \frac{R_1}{R_2} \Rightarrow \frac{10}{H_2} = \left(\frac{2}{1}\right)^2 \times \frac{5}{4} \Rightarrow H_2 = 2cal/sec$



Example: 18 Two heater wires of equal length are first connected in series and then in parallel. The ratio of heat produced in the two cases is **[MP PET 2002, 1999; MP PMT 2001, 2000, 1996; AIIMS 2000; MNR 1987; DCE 1997, 94]**

(a) 2 : 1 (b) 1 : 2 (c) 4 : 1 (d) 1 : 4

Solution : (d) Both the wires are of equal length so they will have same resistance and by using $H = \frac{V^2 t}{R} \Rightarrow H \propto \frac{1}{R}$

$$\Rightarrow \frac{H_s}{H_P} = \frac{R_P}{R_s}; \Rightarrow \frac{H_s}{H_P} = \frac{R/2}{2R} = \frac{1}{4}$$

Example: 19 If two bulbs of wattage 25 and 100 respectively each rated at 220 *volt* are connected in series with the supply of 440 *volt*, then which bulb will fuse **[MP PET 2000; MNR 1988]**

(a) 100 *watt* bulb (b) 25 *watt* bulb (c) None of them (d) Both of them

Solution : (b) In series $V_A \propto \frac{1}{P_R}$ *i.e.* voltage appear on 25*W* bulb will be more then the voltage appears on 100 *W* bulb. So bulb of 25 *W* will gets fused.

Example: 20 Three equal resistors connected in series across a source of *e.m.f.* together dissipate 10 *watt*. If the same resistors are connected in parallel across the same *e.m.f.*, then the power dissipated will be

[KCET 1999; DCE 1998; CBSE 1998; MP PAT 1996]

(a) 10 *W* (b) 30 *W* (c) 10/3 *W* (d) 90 *W*

Solution : (d) In series consumed power $P_s = \frac{P}{n}$ while in parallel consumed power $P_p = nP \Rightarrow P_P = n^2 . P_s$

$$\Rightarrow P_P = (3)^2 \times 10 = 90W$$

Example: 21 Forty electric bulbs are connected in series across a 220 *V* supply. After one bulb is fused, the remaining 39 are connected again in series across the same supply. The illumination will be **[Haryana CEE 1996; NCERT 1972]**

(a) More with 40 bulbs than with 39 (b) More with 39 bulbs than with 40

(c) Equal in both the cases (d) In the ratio of $40^2 : 39^2$

Solution : (b) Illumination $= P_{Consumed} = \frac{V^2}{R}$. Initially there were 40 bulbs in series so equivalent resistance was 40 *R*, finally 39 bulbs are in series so equivalent resistance becomes 39 *R*. Since resistance decreases so illumination increases with 39 bulbs.

Example: 22 Two bulbs of 100 *watt* and 200 *watt*, rated at 220 *volts* are connected in series. On supplying 220 *volts*, the consumption of power will be

(a) 33 *watt* (b) 66 *watt* (c) 100 *watt* (d) 300 *watt*

Solution : (b) In series $P_{Consumed} = \frac{P_1 P_2}{P_1 + P_2} \Rightarrow P_{Consumed} = \frac{100 \times 200}{300} = 66W$

Example: 23 Two wires '*A*' and '*B*' of the same material have their lengths in the ratio 1 : 2 and radii in the ratio 2 : 1. The two wires are connected in parallel across a battery. The ratio of the heat produced in '*A*' to the heat produced in '*B*' for the same time is **[MNR 1998]**

(a) 1 : 2 (b) 2 : 1 (c) 1 : 8 (d) 8 : 1

Solution : (d) Resistance $R = \rho \dfrac{l}{\pi r^2} \Rightarrow R \propto \dfrac{l}{r^2} \Rightarrow \dfrac{R_A}{R_B} = \dfrac{l_A}{l_B} \times \left(\dfrac{r_B}{r_A}\right)^2 \Rightarrow \dfrac{R_A}{R_B} = \dfrac{1}{2} \times \left(\dfrac{1}{2}\right)^2 = \dfrac{1}{8}$

By using $H = \dfrac{V^2 t}{R} \Rightarrow \dfrac{H_A}{H_B} = \dfrac{R_B}{R_A} = \dfrac{8}{1}$

Example: 24 A heating coil is labelled 100 *W*, 220 *V*. The coil is cut in half and the two pieces are joined in parallel to the same source. The energy now liberated per *second* is **[CBSE PMT 1995]**

(a) 200 *J* (b) 400 *J* (c) 25 *J* (d) 50 *J*

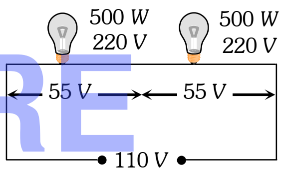
Solution : (b) Let resistance of the heating coil be *R*, when coil cut in two equal parts, resistance of each part will be $\dfrac{R}{2}$.

When these two parts are corrected in parallel, $R_{eq} = \dfrac{R}{4}$ *i.e.* resistance becomes, so according to $P \propto \dfrac{1}{R}$; Power becomes 4 times *i.e.* $P' = 4P = 400\ J/sec$

Example: 25 Two identical electric lamps marked 500 *W*, 220 *V* are connected in series and then joined to a 110 *V* line. The power consumed by each lamp is

(a) $\dfrac{125}{4}\ W$ (b) $\dfrac{25}{4}\ W$ (c) $\dfrac{225}{4}\ W$ (d) 125 *W*

Solution : (a) Both bulbs are identical so voltage across each bulb will be 55*V*.



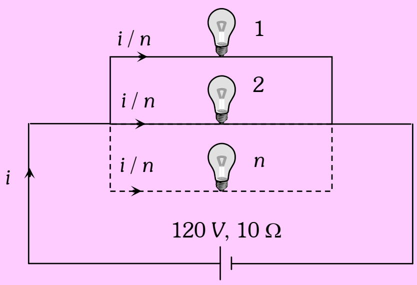
Hence power consumed by each bulb is $\left(\dfrac{V_A}{V_R}\right)^2 \times P_R = \left(\dfrac{55}{220}\right)^2 \times 500 = \dfrac{125}{4}\ W$

Tricky Example: 2

Electric bulb 50 *W* – 100 *V* glowing at full power are to be used in parallel with battery 120 *V*, 10 Ω. Maximum number of bulbs that can be connected so that they glow in full power is **[CPMT 2002]**

(a) 2 (b) 8 (c) 4 (d) 6

Solution : (c) When bulb glowing at full power, current flows through it $\dfrac{i}{n} = \dfrac{P}{V} = \dfrac{50}{100} = \dfrac{1}{2}\ amp \Rightarrow i = \dfrac{n}{2}$ and voltage across the bulb is 100 *V*. If suppose *n* bulbs are connected in parallel with cell as shown in figure then according to the cell equation $E = V + ir \Rightarrow 120 = 100 + \dfrac{n}{2} \times 10 \Rightarrow n = 4$.

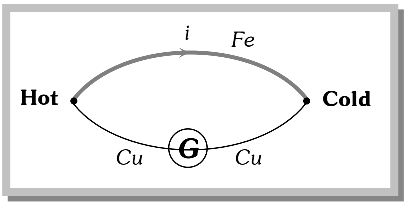


Thermo Electric Effect of Current

If two wires of different metals are joined at their ends so as to form two junctions, then the resulting arrangement is called a "**Thermo couple**".

Seebeck Effect.

(1) **Definition :** When the two junctions of a thermo couple are maintained at different temperatures, then a current starts flowing through the loop known as thermo electric current. The potential difference between the junctions is called thermo electric emf which is of the order of a few micro-volts per degree temperature difference ($\mu V/^{\circ}C$).



(2) **Origin of thermo emf :** The density of free electrons in a metal is generally different from the density of free electrons in another metal. When a metal is brought into intimate contact (say by soldering) with other metal, the electrons tend to diffuse from one metal to another, so as to equalise the electron densities. As an illustration, when copper is brought into intimate contact with iron, the electrons diffuse from iron to copper. But this diffusion cannot go on continuously because due to diffusion, the potential of copper decreases and the potential of iron increases. In other words, iron becomes positive with respect to copper. This is what stops further diffusion. In the case of thermocouple whose junctions are at the same temperature, the emf's at the junctions will be equal in magnitude but opposite in direction. So, the net emf for the whole of thermocouple will be zero.

Let us now consider the case when the temperature of one junction of the thermocouple is raised. Raising the temperature of one junction will affect the electron density in the two metals differently. Moreover, the transfer of electrons at the junction will be easier than the transfer of electrons at the cold junction. Due to both these reasons, the emf's at the two junctions will be different. This produces a net emf in the thermocouple. This emf is known as Seebeck emf.

(3) **Seebeck series :** 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 thermo couple.

Seebeck arranged different metals in the decreasing order of their electron density. Some of the metals forming the series are as below.

Sb, Fe, Ag, Au, Sn, Pb, Cu, Pt, Ni, Bi

(i) **About magnitude thermo emf :** Thermo electric emf is directly proportional to the distance between the two metals in series. Farther the metals in the series forming the thermo couple greater is the thermo emf. Thus maximum thermo emf is obtained for ***Sb-Bi*** thermo couple.

(ii) **Direction of thermo electric current :** If a metal occurring earlier in the series is termed as *A* and the metal occurring later in the series is termed as *B*, then the rule for the direction of conventional current in thermocouple made of elements *A* and *B* is *ABC*. That is, at the cold junction current will flow from *A* to *B*. *e.g.* in *Fe-Cu* thermocouple, at the cold junction current flows from *A* to *B* that is from *Fe* to *Cu*. At the hot junction, the current flows from *Cu* to *Fe*. This may be remembered easily by the **hot coffee.**

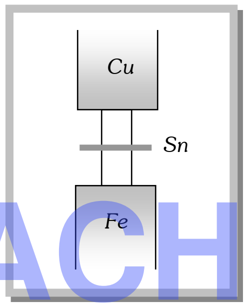
(4) **Law of thermoelectricity**

(i) **Law of successive temperature :** If initially temperature limits of the cold and the hot junction are t_1 and t_2, say the thermo emf is $E_{t_1}^{t_2}$. When the temperature limits are t_2 and t_3, then say the thermo emf is $E_{t_2}^{t_3}$ then $E_{t_1}^{t_2} + E_{t_2}^{t_3} = E_{t_1}^{t_3}$ where $E_{t_1}^{t_3}$ is the thermo emf when the temperature limits are $E_{t_1}^{t_3}$

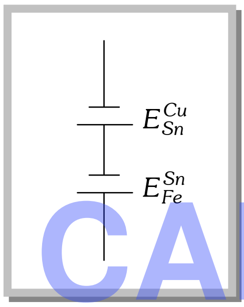
(ii) **Law of intermediate metals :** Let *A*, *B* and *C* be the three metals of Seebeck series, where *B* lies between *A* and *C*. According to this law, $E_A^B + E_B^C = E_A^C$

When tin is used as a soldering metal in *Fe-Cu* thermocouple then at the junction, two different thermo couples are being formed. One is between iron and tin and the other is between tin and copper, as shown in figure (i)

Now iron is thermoelectrically more positive as compared to tin and tin is more positive with respect to copper (the element which occurs earlier in the seebeck series gets positively charged on losing the electrons at the junction), so as clear from the figure below, the thermo emf's of both the thermocouples shown in the figure (ii) are additive



(i)



(ii)

∴ If soldering metal in a thermocouple is an intermediate metal in the series then thermo emf will not be affected.

It is also clear from the above discussions that if the soldering metal does not lie between two metals (in Seebeck series) of thermocouple then the resultant emf will be subtractive.

(5) **Effect of temperature on thermo emf :** In a thermocouple as the temperature of the hot junction increases keeping the cold junction at constant temperature (say 0°C). The thermo emf increases till it becomes maximum at a certain temperature.

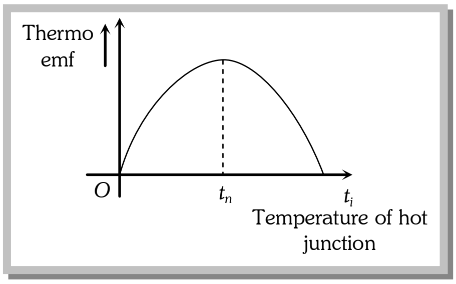
(i) Thermo electric emf is given by the equation $E = \alpha t + \frac{1}{2}\beta t^2$

where α and β are thermo electric constant having units are *volt*/°*C* and *volt*/°C^2 respectively (*t* = temperature of hot junction).

(ii) The temperature of hot junction at which thermo emf becomes maximum is called neutral temperature (t_n). Neutral temperature is constant for a thermo couple (*e.g.* for *Cu-Fe*, t_n = 270°*C*)

(iii) Neutral temperature is independent of the temperature of cold junction.

(iv) If temperature of hot junction increases beyond neutral temperature, thermo emf start decreasing and at a particular temperature it becomes zero, on heating slightly further, the direction of emf is reversed. This temperature of hot junction is called temperature of inversion (t_i).



(v) Graphical representation of thermo emf

(a) $t_n = \dfrac{t_i + t_c}{2}$

(b) Graph is parabolic

(c) For E to be maximum (at $t = t_n$)

$$\frac{dE}{dt} = 0 \;\; i.e. \;\; \alpha + \beta t_n = 0 \Rightarrow t_\eta = -\frac{\alpha}{\beta}$$

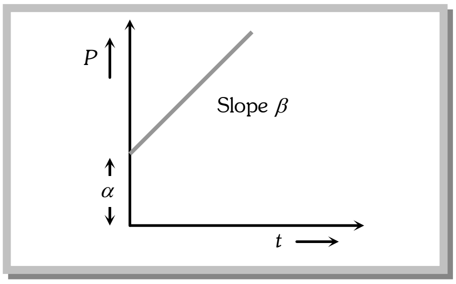
(6) **Thermo electric power :** The rate of change of thermo emf with the change in the temperature of the hot junction is called thermoelectric power.

It is also given by the slope of parabolic curve representing the variation of thermo emf with temperature of the hot junction, as discussed in previous section.

It is observed from the above graph that as temperature of hot junction increases from that of the cold junction to the neutral junction, though the thermo emf is increasing but the slope of the graph, that is the rate of change of thermo emf with temperature of hot junction is decreasing. Note that, at the neutral temperature, the thermo emf is maximum but the slope *i.e.* the thermoelectric power is zero.

The thermo electric power $\left(\dfrac{dE}{dt}\right)$ is also called **Seebeck coefficient**. Differentiating both sides of the equation of thermo emf with respect to t, we have $P = \dfrac{dE}{dt} = \dfrac{d}{dt}(\alpha t + \dfrac{1}{2}\beta t^2) \Rightarrow P = \alpha + \beta t$

The equation of the thermo electric power is of the type $y = mx + c$, so the graph of thermo electric power is as shown below.



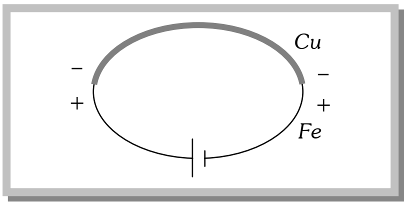
Peltier Effect.

(1) If a current is passed through a junction of two different metals, the heat is either evolved or absorbed at the junction. This effect is known as Peltier effect. It is the reverse of Seebeck effect. Before going into the detailed explanation, we will first revise an important concept about absorption and evolution of energy when electric charge is made to pass through two points having some potential difference.

When a positive charge flows from high potential to low potential, it releases energy and when positive charge flows from low potential to high potential it absorbs energy.

(2) **Explanation of Peltier effect :** In the light of above statement it can be seen that if current is made to flow in *Fe-Cu* thermocouple by connecting it to a battery then the junction at which current goes from *Fe* to *Cu* becomes hot because here positive charge is flowing from high potential to low potential, so energy is released. Remember that, in iron-copper thermocouple, the polarity of the contact potential at each junction is such *iron* is at higher potential. Similarly the junction where current flows from *Cu* to *Fe* becomes colder because at this junction

current is flowing from negative to positive potential, so energy is absorbed. Thus it is observed that on application of potential difference in a thermocouple temperature difference is automatically created. The amount of heat absorbed at cold junction is equal to the heat released at hot junction.



(3) **Peltier co-efficient (π) :** Heat absorbed or liberated at the junction is directly proportional to the charge passing through the junction *i.e.* $H \propto Q \Rightarrow H = \pi Q$; where π is called Peltier co-efficient. It's unit is J/C or *volt*.

(i) If $Q = 1$ then $H = \pi$ *i.e.* Peltier co-efficient of a junction is defined as heat absorbed or liberated at the junction when a unit quantity of electric charge flows across the junction (H is also known as Peltier emf).

(ii) **Relation between π and absolute temperature :** Suppose the temperature of the cold junction is T and that of the hot junction is $T + dT$ and let dE be the thermo emf produced, then it is found that $\pi = T\frac{dE}{dT} = T \times S$; where T is in Kelvin and $\frac{dE}{dT} = P =$ Seebeck coefficient S

(iii) **π-depends on :** (a) Temperature of junction (b) Difference in electron density of the two metal used in thermocouple.

(iv) **Comparison between Joule and Peltier effect**

Joules effect	Peltier's Effect
(a) In joule's effect energy is only released.	(a) In peltier's effect energy is released at one junction and absorbed at the other junction.
(b) Heat produced depends upon i^2, so, heat is always released, whether i is positive or negative.	(b) Heat produced depends upon i^1, $\therefore$ junction at which the heat is released or absorbed changes when the direction of current changes.
(c) It is identically produced by ac or dc	(c) In Peltier's effect if ac is passed, at the same junction heat is released when current flows in one direction and absorbed when the direction of current reverses. The net amount of heat released or absorbed at a junction is therefore zero. Thus, Peltier's effect cannot be observed with ac.
(d) Joules effect is irreversible.	(d) Peltier effect is reversible, its complimentary is Seebeck effect.
(e) In Joule's effect heat is released throughout the length of wire.	(e) In this effect heat is released or absorbed only at the junctions.

Thomson's Effect.

(1) **Definition :** In Thomson's effect we deal with only metallic rod and not with thermocouple as in Peltiers effect and Seebeck's effect. (That's why sometimes it is known as homogeneous thermo electric effect. When a current flows thorough an unequally heated metal, there is an absorption or evolution of heat in the body of the metal. This is Thomson's effect.

(2) **Types of Thomson's effect**

(i) Positive Thomson's effect

In positive Thomson's effect it is found that hot end is at high potential and cold end is at low potential. *e.g. Cu, Sn, Ag, Sb*

Element's occurring before lead in Seebeck series are called thermoelectrically negative but this does not mean that their Thompson effect is negative.

(ii) Negative Thomson's effect

In the elements which show negative Thomson's effect, it is found that the hot end is at low potential and the cold end is at higher potential *e.g. Fe, Co, Bi*

(3) **Thomson's co-efficient :** In Thomson's effect it is found that heat released or absorbed is proportional to $Q\Delta\theta$ *i.e.* $H \propto Q\Delta\theta \Rightarrow \boldsymbol{H = \sigma Q\Delta\theta}$ where σ = Thomson's coefficient. It's unit is *Joule/coulomb°C* or *volt/°C* and $\Delta\theta$ = temperature difference.

(i) If Q = 1 and $\Delta\theta$ = 1 then $\sigma = \boldsymbol{H}$ so the amount of heat energy absorbed or evolved per second between two points of a conductor having a unit temperature difference, when a unit current is passed is known as Thomson's co-efficient for the material of a conductor.

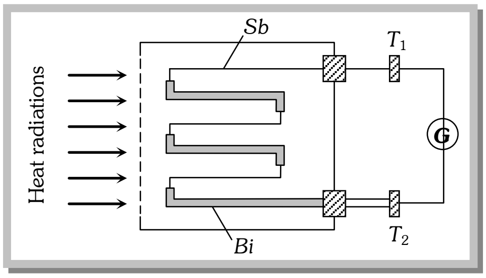
(ii) It can be proved that Thomson co-efficient of the material of conductor $\sigma = -T\frac{d^2E}{dT^2}$ also Seebeck co-efficient $S = \frac{dE}{dT}$ so $\frac{dS}{dT} = \frac{d^2E}{dT^2}$ hence $\sigma = -T\left(\frac{dS}{dT}\right) = T \times \beta$; where β = Thermo electric constant $= \frac{dS}{dt}$

Application of Thermo Electric Effect.

(1) **To measure temperature :** A thermocouple is used to measure very high (2000°C) as well as very low (– 200°C) temperature in industries and laboratories. The thermocouple used to measure very high temperature is called pyrometer.

(2) **To detect heat radiation :** A thermopile is a sensitive instrument used for detection of heat radiation and measurement of their intensity. It is based upon Seebeck effect.

A thermopile consists of a number of thermocouples of *Sb-Bi*, all connected in series.



This instrument is so sensitive that it can detect heat radiations from a match stick lighted at a distance of 50 *metres* from the thermopile.

(3) **Thermoelectric refrigerator :** The working of thermo-electric refrigerator is based on Peltier effect. According to Peltier effect, if current is passed through a thermocouple, heat is absorbed at one junction and is evolved at the other junction of the thermocouple. If on the whole, the heat is absorbed, then the thermocouple acts as thermoelectric refrigerator. It's efficiency is small in comparison to conventional refrigerator.

(4) **Thermoelectric generator :** Thermocouple can be used to generate electric power using Seebeck effect in remote areas. It can be achieved by heating one junction in a flame of kerosene oil lamp and keeping the other junction at room or atmospheric temperature. The thermo emf so developed is used to operate radio receivers or even radio transmitters.

Concepts

- *The emf developed in a thermo couple is rather small i.e. of the order of a few $\mu V/^{o}C$.*
- *A current is passed in a thermocouple formed with dissimilar metals whose one junction is heated and other is cooled. If π_1 and π_2 are the Peltier co-efficient of cold and hot junction respectively then the net emf across the junction is proportional to $(\pi_2 - \pi_1)$*

Example

Example: 26 The smallest temperature difference that can be measured with a combination of a thermocouple of thermo *e.m.f.* 30 μV per *degree* and a galvanometer of 50 *ohm* resistance capable of measuring a minimum current of 3×10^{-7} *ampere* is **[MP PET 2000]**

(a) 0.5 *degree* (b) 1.0 *degree* (c) 1.5 *degree* (d) 2.0 *degree*

Solution : (a) By using $E = a\theta \Rightarrow iR = a\theta \Rightarrow 3 \times 10^{-7} \times 50 = 30 \times 10^{-6} \times \theta \Rightarrow \theta = 0.5$ *degree*

Example: 27 The expression for thermo *e.m.f.* in a thermocouple is given by the relation $E = 40\,\theta - \frac{\theta^2}{20}$, where θ is the temperature difference of two junctions. For this, the neutral temperature will be **[AMU (Engg.) 2000]**

(a) $100^o\,C$ (b) $200^o\,C$ (c) $300^o\,C$ (d) $400^o\,C$

Solution : (d) Comparing the given equation of thermo *e.m.f.* with $E = \alpha t + \frac{1}{2}\beta t^2$ we get $\alpha = 40$ and $\beta = -\frac{1}{10}$. By using $t_n = -\frac{\alpha}{\beta} \Rightarrow t_n = 400^\circ C$.

Example: 28 One junction of a certain thermoelectric couple is at a fixed temperature T_r and the other junction is at temperature T. The thermo electromotive force for this is expressed by $E = K(T - T_r)\left[T_0 - \frac{1}{2}(T + T_r)\right]$ at temperature $T = \frac{1}{2}T_0$, the thermo electric power will be **[MP PMT 1994]**

(a) $\frac{1}{2}KT_0$ (b) KT_0 (c) $\frac{1}{2}KT_0^2$ (d) $\frac{1}{2}K(T_0 - T_r)^2$

Solution : (a) As we know thermo electric power $S = \frac{dE}{dT}$. Hence by differentiating the given equation and putting $T = \frac{1}{2}T_0$ we get $S = \frac{1}{2}KT_0$.

Example: 29 The cold junction of a thermocouple is maintained at $10^o\ C$. No thermo *e.m.f.* is developed when the hot junction is maintained at $530^o\ C$. The neutral temperature is **[MP PMT 1994]**

(a) $260^o\ C$ (b) $270^o\ C$ (c) $265^o\ C$ (d) $520^o\ C$

Solution : (b) Given $t_c = 10^oC$ and $t_i = 530^oC$ hence by using $t_n = \frac{t_i + t_c}{2} \Rightarrow t_n = 270^oC$

Example: 30 The thermo emf develops in a *Cu-Fe* thermocouple is 8.6 $\mu V/^oC$. It temperature of cold junction is 0°C and temperature of hot junction is 40°C then the emf obtained shall be

(a) 0.344 *mV* (b) 3.44 μV (c) 3.44 *V* (d) 3.44 *mV*

Solution : (a) By using thermo emf $e = a\theta$ where $a = 8.6\frac{\mu V}{^oC}$ and θ = temperature difference = 40°C

So $e = 8.6 \times 10^{-6} \times 40 = 344\ \mu V = 0.344\ mV$.

Example: 31 A thermo couple develops 200 μV between 0°C and 100°C. If it develops 64 μV and 76 μV respectively between (0°C – 32°C) and (32°C – 70°C) then what will be the thermo emf it develops between 70°C and 100°C

(a) 65 μV (b) 60 μV (c) 55 μV (d) 50 μV

Solution : (b) By using $e_0^{100} = e_0^{32} + e_{32}^{70} + e_{70}^{100} \Rightarrow 200 = 64 + 76 + e_{70}^{100} \Rightarrow e_{70}^{100} = 60\mu V$

Example: 32 A thermo couple is formed by two metals *X* and *Y* metal *X* comes earlier to *Y* in Seebeck series. If temperature of hot junction increases beyond the temperature of inversion. Then direction of current in thermocouple will so

(a) *X* to *Y* through cold junction (b) *X* to *Y* through hot junction

(c) *Y* to *X* through cold junction (d) Both (b) and (c)

Solution : (d) In the normal condition current flows from *X* to *Y* through cold. While after increasing the temperature of hot junction beyond temperature of inversion. The current is reversed *i.e.* *X* to *Y* through hot junction or *Y* to *X* through cold junction.

Example: 33 Peltier co-efficient of a thermo couple is 2 *nano volts*. How much heat is developed at a junction if 2.5 *amp* current flows for 2 minute

(a) 6 *ergs* (b) 6×10^{-7} *ergs* (c) 16 *ergs* (d) 6×10^{-3} *erg*

Solution : (a) $H = \pi i t = (2 \times 10^{-9}) \times 2.5 \times (2 \times 60) = 6 \times 10^{-7} J = 6\, erg$

Example: 34 A thermo couple develops 40 $\mu V/kelvin$. If hot and cold junctions be at 40°C and 20°C respectively then the emf develops by a thermopile using such 150 thermo couples in series shall be

(a) 150 *mV* (b) 80 *mV* (c) 144 *mV* (d) 120 *mV*

Solution : (d) The temperature difference is 20°C = 20 *K*. So that thermo emf developed $E = a\theta = 40\frac{\mu V}{K} \times 20K = 800\mu V$.

Hence total emf = $150 \times 800 = 12 \times 10^4\ \mu V = 120\ mV$

Chemical Effect of Current

Current can produce or speed up chemical change, this ability of current is called chemical effect (shown by *dc* not by *ac*).

When current is passed through an electrolyte, it dissociates into positive and negative ions. This is called chemical effect of current.

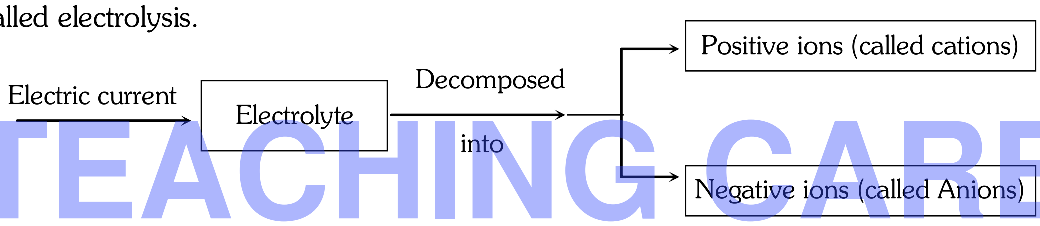
Important Terms Related to Chemical Effect.

(1) **Electrolytes :** The liquids which allows the current to pass through them and also dissociates into ions on passing current through them are called electrolytes e.g. solutions of salts, acids and bases in water, *etc*.

Note : ≅ These liquids which do not allow current to pass through them are called insulators (*e.g.* vegetable oils, distilled water *etc*.) while the liquids which allows the current to pass through them but do not dissociates into ions are called good conductors (*e.g. Hg etc*.)

≅ Solutions of cane sugar, glycerin, alcohol *etc*. are examples of non-electrolytes.

(2) **Electrolysis :** The process of decomposition of electrolyte solution into ions on passing the current through it is called electrolysis.



Note : ≅Practical applications of electrolysis are Electrotyping, extraction of metals from the ores, Purification of metals, Manufacture of chemicals, Production of O_2 and H_2, Medical applications and electroplating.

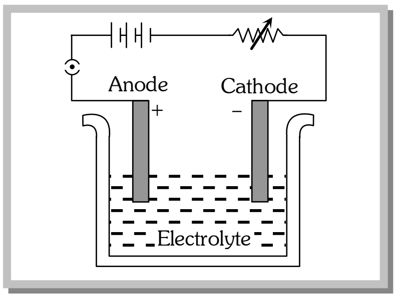
≅ ***Electroplating :*** It is a process of depositing a thin layer of one metal over another metal by the method of electrolysis. The articles of cheap metals are coated with precious metals like silver and gold to make their look more attractive. The article to be electroplated is made the cathode and the metal to be deposited in made the anode. A soluble salt of the precious metal is taken as the electrolyte. (If gold is to be coated then auric chloride is used as electrolyte).

(3) **Electrodes :** Two metal plates which are partially dipped in the electrolyte for passing the current through the electrolyte.

Anode : Connected to positive terminal of battery

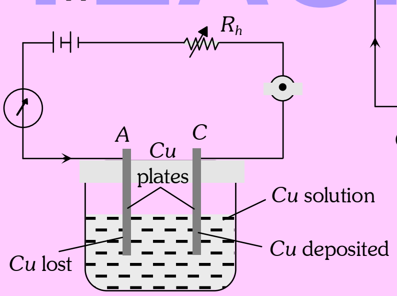
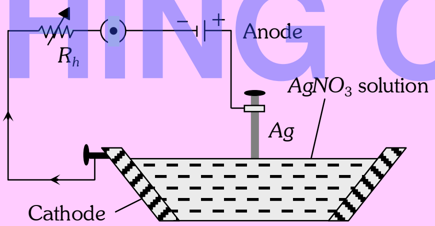
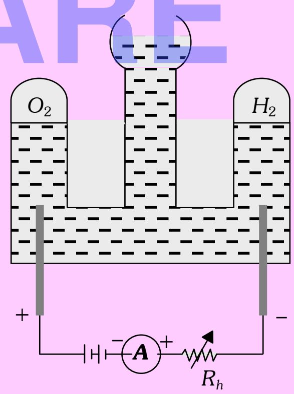
Cathode : Connected to negative terminal of battery

(4) **Voltameter :** The vessel in which the electrolysis is carried out is called a voltameter. It contains two electrodes and electrolyte. It is also known as electrolytic cell.



(5) **Equivalent weight :** The ratio of the atomic weight of an element to its valency is defined as it's equivalent weight.

(6) **Types of voltameter :** Voltameter is divided mainly in following types

***Cu*-voltameter**	***Ag* voltameter**	**Water voltameter**
In copper voltameter, electrolyte is solution of copper *e.g.* $CuSO_4$, $CuCl_2$, $Cu(NO_3)_2$ etc. Cathode may be of any material, but anode must be of copper. $CuSO_4$ in water dissociates as follows $CuSO_4 \rightarrow Cu^{++} + SO_4^{--}$ Cu^{++} moves towards cathode and takes 2 electron to become neutral and deposited on cathode $Cu^{++} + 2e \rightarrow Cu$ SO_4^{--} moves towards anode and looses 2 electrons their. Copper is deposited on the cathode and an equivalent amount of copper is lost by the anode, but the concentration of copper sulphate solution remains the same. In this process, two electrons per reaction are active and valence of copper atom is also two. 	In silver voltameter electrolyte is a solution of silver, *e.g.* $AgNO_3$. Cathode may be of any metal but anode must be of silver. The dissociation reaction is as follows $AgNO_3 \rightarrow Ag^{+} + NO_3^{-}$ The silver dissolves from the anode gets deposited on the cathode. During this process, the concentration of the electrolyte remains unchanged. In this process one electron per reaction is active and valence of *Ag* atom is also one. 	In water voltameter the electrolyte used is acidic water, because it is much more conducting than that of pure water. So acid CH_2SO_4 increases the concentration of free ions in the solution. The electrodes are made of platinum, because it does not dissolve into electrolyte and does not react with the products of electrolysis. When current flows through the electrolyte, hydrogen gas is collected in the tube placed over the cathode (– *ve* electrode) and oxygen is collected in the tube placed over the anode (+*ve* electrode). Hydrogen and oxygen are liberated in the proportional in which they are found in water *i.e.* the volume ratio of hydrogen and oxygen is 2 : 1. 

Faraday's Law of Electrolysis.

(1) **First law :** It states that the mass of substance deposited at the cathode during electrolysis is directly proportional to the quantity of electricity (total charge) passed through the electrolyte.

Let m be the mass of the substance liberated, when a charge q is passed through the electrolyte. Then, according to the Faraday's first law of electrolysis $m \propto q$ or $m = zq$, where the constant of proportionality z is called *electrochemical equivalent* (E.C.E.) *of the substance.* If a constant current i is passed through the electrolyte for time t, then the total charge passing through the electrolyte is given by $q = it$

Therefore we have $m = zit$. If q = 1 *coulomb*, then we have $m = z \times 1$ or $z = m$

Hence, the electrochemical equivalent of substance may be defined as the mass of its substance deposited at the cathode, when one *coulomb* of charge passes through the electrolyte.

S.I. unit of electrochemical equivalent of a substance is *kilogram coulomb*$^{-1}$ ($kg\text{-}C^{-1}$).

(2) **Second law :** If same quantity of electricity is passed through different electrolytes, masses of the substance deposited at the respective cathodes are directly proportional to their chemical equivalents.

Let m be the mass of the ions of a substance liberated, whose chemical equivalent is E. Then, according to Faraday's of electrolysis, $m \propto E$ or m = constant $\times E$ or $\frac{m}{E}$ = constant

Note : ≅ Chemical equivalent E also known as equivalent weight in *gm* *i.e.* $E = \frac{\text{Atomic mass } (A)}{\text{Valance } (V)}$

(3) **Relation between chemical equivalent and electrochemical equivalent :** Suppose that on passing same amount of electricity q through two different electrolytes, masses of the two substances liberated are m_1 and m_2. If E_1 and E_2 are their chemical equivalents, then from Faraday's second law, we have $\frac{m_1}{m_2} = \frac{E_1}{E_2}$

Further, if z_1 and z_2 are the respective electrochemical equivalents of the two substances, then from Faraday's first law, we have $m_1 = z_1 q$ and $m_2 = z_2 q \Rightarrow \frac{m_1}{m_2} = \frac{z_1}{z_2}$

So from above equation $\frac{z_1}{z_2} = \frac{E_1}{E_2} \Rightarrow z \propto E \Rightarrow z_2 = z_1 \times \frac{E_2}{E_1}$

(4) **Faraday constant :** As we discussed above $E \propto z \Rightarrow E = Fz \quad \Rightarrow z = \frac{E}{F} = \frac{A}{VF}$

'F' is proportionality constant called Faraday's constant.

As $z = \frac{E}{F}$ and $z = \frac{m}{Q}$ (from I law) so $\frac{E}{F} = \frac{m}{Q}$ hence if Q = 1 *Faraday* then $E = m$ *i.e.* If electricity supplied to a voltameter is 1 Faraday then amount of substance liberated or deposited is (in *gm*) equal to the chemical equivalent. *e.g.* to deposit 16 *gm* O_2; 2 *Faraday* electricity is required.

Note : ≅Remember Number of *gm* equivalent $= \frac{\text{given mass}}{\text{atomic mass}} \times$ valency

≅ 1 *Faraday* = 96500 *C*

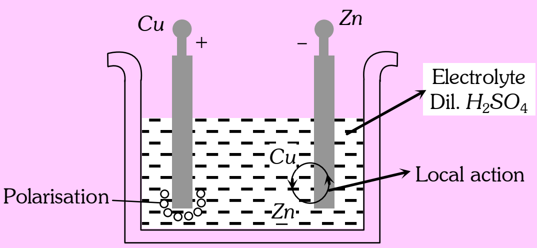
≅ Also $F = Ne$ {where N = Avogrado number}

Electro Chemical Cell.

It is an arrangement in which the chemical energy is converted into electrical energy due to chemical action taking place in it. The total amount of energy that can be provided by this cell is limited and depends upon the amount of reactants. Electro chemical cells are of two types.

(1) **Primary cell :** Is that cell in which electrical energy is produced due to chemical energy. In the primary cell, chemical reaction is irreversible. This cell can not be recharged but the chemicals have to be replaced after a long use examples of primary cells; Voltaic cell, Daniel cell, Leclanche cell and Dry cell *etc*.

(i) Voltaic cell



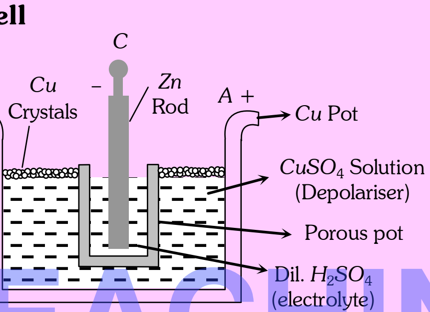
Positive electrode	–	*Cu* rod
Negative electrode	–	*Zn* rod
Electrolyte	–	dil. H_2SO_4
Emf	–	1.08 *V*

Main chemical reactions

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

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

(ii) Daniel cell



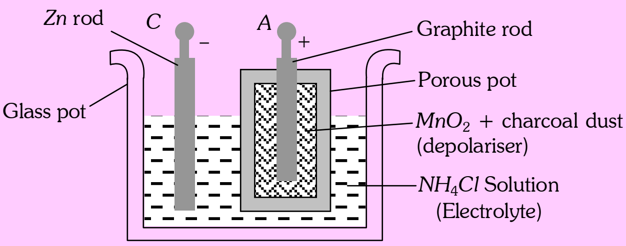
Positive electrode	–	*Cu* rod
Negative electrode	–	*Zn* rod
Electrolyte	–	dil. H_2SO_4
Emf	–	1.1 *V*

Main chemical reactions

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

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

(iii) Lechlanche cell



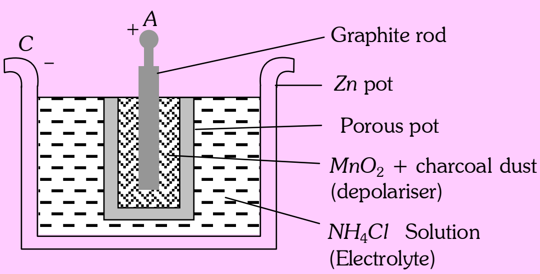
Positive electrode	–	Carbon rod
Negative electrode	–	*Zn* rod
Electrolyte	–	NH_4Cl solution
Emf	–	1.45 *V*

Main chemical reactions

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

$2H^+ + 2MnO_2 \rightarrow Mn_2O_3 + H_2O$ + 2 unit of positive charge

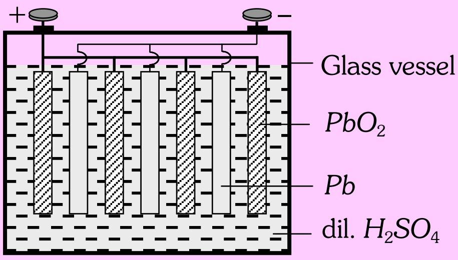
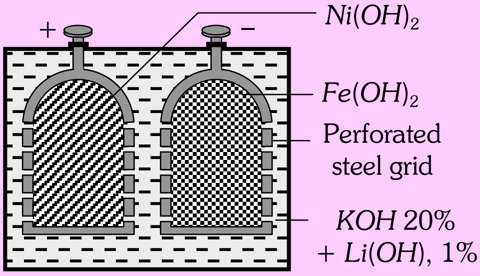
(iv) Dry cell



Leclanche cell

Positive electrode	–	Carbon rod with brass cap
Negative electrode	–	*Zn* vessel
Electrolyte	–	Paste of NH_4Cl and saw dust
Emf	–	1.5 *V*
Main chemical reactions	–	Similar to

(2) **Secondary cell :** A secondary cell is that cell in which the electrical energy is first stored up as a chemical energy and when the current is taken from the cell, the chemical energy is reconverted into electrical energy. In the secondary cell chemical reaction are reversible. The secondary cells are also called storage cell or accumulator. The commonly used secondary cells are

In charged	**Lead accumulator**	**Alkali accumulator**
		
Positive electrode	Perforated lead plates coated with PbO_2	Perforated steel plate coated with $Ni(OH)_4$
Negative electrode	Perforated lead plates coated with pure lead	Perforated steel plate coated with Fe
During charging	**Chemical reaction** At cathode : $PbSO_4 + 2H^+ + 2e^- \rightarrow Pb + H_2SO_4$ At anode : $PbSO_4 + SO_4^{--} + 2H_2O - 2e^- \rightarrow PbO_2 + 2H_2SO_4$ Specific gravity of H_2SO_4 increases and when specific gravity becomes 1.25 the cell is fully charged. Emf of cell : When cell is full charged them $E = 2.2$ *volt*	**Chemical reaction** At cathode : $Fe(OH)_2 + 2OH^+ - 2e^- \rightarrow Ni(OH)_4$ At anode : $Fe(OH)_2 + 2K^+ + 2e^- \rightarrow Fe + 2KOH$ **Emf of cell :** When cell is fully charge then $E = 1.36$ *volt*
During discharging	**Chemical reaction** At cathode : $Pb + SO_4^{--} - 2e^- \rightarrow PbSO_4$ At anode : $PbO_4 + 2H^+ - 2e^- + H_2SO_4 \rightarrow PbSO_2 + 2H_2O$ Specific gravity of H_2SO_4 decreases and when specific gravity falls below 1.18 the cell requires recharging. Emf of cell : When emf of cell falls below 1.9 *volt* the cell requires recharging.	**Chemical reaction** At cathode : $Fe + 2OH^- - 2e^- \rightarrow Fe(OH)_2$ At anode : $Ni(OH)_4 + 2K^+ + 2e^- \rightarrow Ni(OH)_2 + 2KOH$ Emf of cell : When emf of cell falls below 1.1 V it requires charging.
Efficiency	80%	60%

(3) **Defects In a primary cell :** In voltaic cell there are two main defects arises.

Local action : It arises due to the presence of impurities of iron, carbon etc. on the surface of commercial Zn rod used as an electrode. The particles of these impurities and Zn in contact with sulphuric acid form minute voltaic cell in which small local electric currents are set up resulting in the wastage of Zn even when the cell is not sending the external current.

Removal : By amalgamating Zn rod with mercury (*i.e.* the surface of Zn is coated with Hg).

Polarisation : It arises when the positive H_2 ions which are formed by the action of Zn on sulphuric acid, travel towards the Cu rod and after transferring, the positive charge converted into H_2 gas atoms and get deposited in the form of neutral layer of a gas on the surface of Cu rod. This weakens the action of cell in two ways.

Removal : Either by brushing the anode the remove the layer or by using a depolariser (*i.e.* some oxidising agent MnO_2, $CuSO_4$ *etc* which may oxidise H_2 into water).

Note : ≅The end point voltage of dry cell is 0.8 V.

Concepts

- *Electrolysis takes place for dc and low frequency ac, as at high frequency, due to inertia (i.e. mass) ions cannot follow the frequency of ac.*
- *Electrolytes are less conducting then the metallic conductors because ions are heavier than electrons.*
- *If ρ is the density of the material deposited and A is the area of deposition then the thickness (d) of the layer of the material deposited in electroplating process is $d = \frac{m}{\rho A} = \frac{Zit}{\rho A}$; where m = deposited mass, Z = electro chemical equivalent, i = electric current.*

Example

***Example*: 35** In an electroplating experiment, *m gm* of *silver* is deposited when 4 *ampere* of current flows for 2 *minute*. The amount (in *gm*) of *silver* deposited by 6 *ampere* of current for 40 *second* will be **[MNR 1991; MP PET 2002]**

(a) 4 *m* (b) *m*/2 (c) *m*/4 (d) 2*m*

Solution : (b) By using $m = zit \Rightarrow \frac{m_1}{m_2} = \frac{i_1 t_1}{i_2 t_2} \Rightarrow \frac{m}{m_2} = \frac{4 \times 2 \times 60}{6 \times 40} \Rightarrow m_2 = m/2$

***Example*: 36** A current of 16 *ampere* flows through molten *NaCl* for 10 *minute*. The amount of metallic sodium that appears at the negative electrode would be **[EAMCET 1984]**

(a) 0.23 *gm* (b) 1.15 *gm* (c) 2.3 *gm* (d) 11.5 *gm*

Solution : (c) By using $m = zit = \frac{A}{VF} it \Rightarrow m = \frac{23}{1 \times 96500} \times 16 \times 10 \times 60 = 2.3\, gm$

***Example*: 37** For depositing of 1 *gm* of *Cu* in *copper* voltameter on passing 2 *amperes* of current, the time required will be (For *copper* $Z = 0.00033\, gm/C$)

(a) Approx. 20 *minutes* (b) Approx. 25 *minutes* (c) Approx. 30 *minutes* (d) Approx. 35 *minutes*

Solution : (b) By using $m = zit \Rightarrow 1 = 0.00033 \times 2 \times t \Rightarrow t = 1515.15\, sec \approx 25\, min$.

***Example*: 38** Two electrolytic cells containing $CuSO_4$ and $AgNO_3$ respectively are connected in series and a current is passed through them until 1 *mg* of *copper* is deposited in the first cell. The amount of *silver* deposited in the second cell during this time is approximately (Atomic weights of *copper* and *Silver* are respectively 63.57 and 107.88) **[MP PMT 1996]**

(a) 1.7 *mg* (b) 3.4 *mg* (c) 5.1 *mg* (d) 6.8 *mg*

Solution : (b) By using $\frac{m_1}{m_2} = \frac{E_1}{E_2} \Rightarrow \frac{1}{m_2} = \frac{63.57/2}{107.88/1} = \frac{31.7}{107.88} \Rightarrow m_2 = 3.4\, mg$

***Example*: 39** When a *copper* voltameter is connected with a battery of *emf* 12 *volts*, 2 *gms* of *copper* is deposited in 30 *minutes*. If the same voltameter is connected across a 6 *volt* battery, then the mass of *copper* deposited in 45 *minutes* would be **[SCRA 1994]**

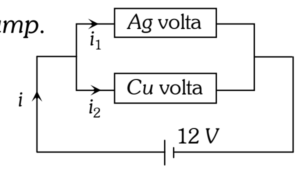
(a) 1 *gm* (b) 1.5 *gm* (c) 2 *gm* (d) 2.5 *gm*

Solution : (b) By using $m = zit = \frac{zVt}{R} \Rightarrow \frac{m_1}{m_2} = \frac{V_1 t_1}{V_2 t_2} \Rightarrow \frac{2}{m_2} = \frac{12 \times 30}{6 \times 45} \Rightarrow m_2 = 1.5\, gm$

***Example*: 40** *Silver* and *copper* voltameter are connected in parallel with a battery of *e.m.f.* 12 *V*. In 30 *minutes*, 1 *gm* of *silver* and 1.8 *gm* of *copper* are liberated. The energy supplied by the battery is ($Z_{Cu} = 6.6 \times 10^{-4}\, gm/C$ and $Z_{Ag} = 11.2 \times 10^{-4}\, gm/C$) **[IIT 1975]**

(a) 24.13 *J* (b) 2.413 *J* (c) 0.2413 *J* (d) 2413 *J*

Solution : (a) By using $m = zit$, for *Ag* voltameter $1 = 11.2 \times 10^{-4} \times i_1 \times 30 \times 60 \Rightarrow i_1 = 0.5\, amp$.



For *Cu* voltameter $1.8 = 6.6 \times 10^{-4} \times i_2 \times 30 \times 60 \Rightarrow i_2 = 1.5\, amp$

Main current $i = i_1 + i_2 = 1.5 + 0.5 = 2A$.

So energy supplied $= Vi = 12 \times 2 = 24\, J$

***Example*: 41** Amount of electricity required to pass through the H_2O voltameter so as to liberate 11.2 *litre* of hydrogen will be

(a) 1 Faraday (b) $\frac{1}{2}$ *Faraday* (c) 2 Faraday (d) 3 Faraday

Solution : (a) Mass of hydrogen in 11.2 litres of hydrogen $= \left(\frac{11.2}{22.4}\right) \times M = \left(\frac{11.2}{22.4}\right) \times 2 = 1 gm$

We know that 1 *gm* of hydrogen is equal to 1 *gm* equivalent *wt.* of hydrogen. It means that 11.2 *litre* of hydrogen at NTP represents 1 *gm* equivalent of hydrogen, so for liberation it requires 1 *Faraday* electricity.

Example: 42 Amount of electricity required to liberate 16 *gm* of oxygen is

(a) 1 *Faraday* (b) 2 *Faraday* (c) $\frac{1}{2}$ *Faraday* (d) 3 *Faraday*

Solution : (b) Number of *gm* equivalent $= \frac{\text{Given mass}}{\text{gm equivalent weight}} = \frac{16}{16/2} = 2$. Hence 2 *Faraday* electricity is needed.

Example: 43 Total surface area of a cathode is 0.05 m^2 and 1 *A* current passes through it for 1 *hour*. Thickness of nickel deposited on the cathode is (Given that density of nickel = 9 *gm/cc* and it's ECE = 3.04×10^{-4} *gm/C*)

(a) 2.4 *m* (b) 2.4 *cm* (c) 2.4 μm (d) None of these

Solution : (c) Mass deposited = density × volume of the metal

$m = \rho \times A \times x$ ...... (i)

Hence from Faraday first law $m = Zit$ ......(ii)

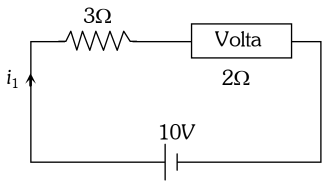
So from equation (i) and (ii) $Zit = \rho \times Ax \Rightarrow x = \frac{Zit}{\rho A} = \frac{3.04 \times 10^{-4} \times 10^{-3} \times 1 \times 36 \times ......}{9000 \times 0.05} = 2.4 \times 10^{-6} m = 2.4 \mu m$

Example: 44 Resistance of a voltameter is 2 Ω, it is connected in series to a battery of 10 *V* through a resistance of 3 Ω. In a certain time mass deposited on cathode is 1 *gm*. Now the voltameter and the 3Ω resistance are connected in parallel with the battery. Increase in the deposited mass on cathode in the same time will be

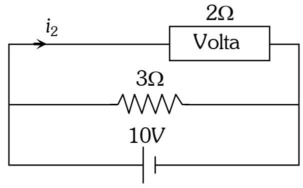
(a) 0 (b) 1.5 *gm* (c) 2.5 *gm* (d) 2 *gm*

Solution : (b) Remember mass of the metal deposited on cathode depends on the current through the voltameter and not on the current supplied by the battery. Hence by using $m = Zit$, we can say $\frac{m_{Parallel}}{m_{Series}} = \frac{i_{Parallel}}{i_{Series}} \Rightarrow m_{Parallel} = \frac{5}{2} \times 1 = 2.5 gm$.

Hence increase in mass = 2,5 – 1 = 1.5 *gm*



$i_1 = \frac{10}{5} = 2A$



$i_2 = \frac{10}{2} = 5A$

Tricky Example: 3

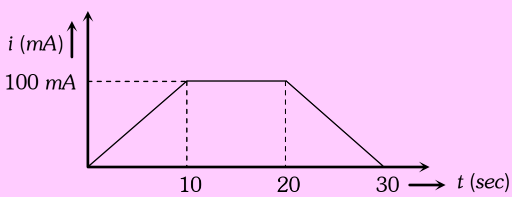
In a copper voltameter, the mass deposited in 30 *s* is *m gram*. If the current time graph is as shown in the figure, the e.c.e. of copper, in *gm/coulomb*, will be **[Pantnagar 1987]**

(a) *m*

(b) $\frac{m}{2}$

(c) 0.6 *m*

(d) 0.1 *m*



Solution : (b) Area of the given curve on *x*-axis $= it = \frac{1}{2}(10 + 30) \times 100 \times 10^{-3} = 2 \, Coulomb$

From Faraday's first law $m = zit \Rightarrow z = \frac{m}{it} = \frac{m}{2}$.