



Chapter 20

Heating and Chemical Effect of Current

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 $W = qV = Vit = iRt = \frac{V^2 t}{R}$ Joule. This work appears as thermal energy in the resistor.

Heat produced by the resistance R is $H = \frac{W}{J} = \frac{Vit}{4.2} = \frac{i^2 Rt}{4.2} = \frac{V^2 t}{4.2R}$ Cal. This relation is called joules heating.

Electric Power

The rate at which electrical energy is dissipated into other forms of energy is called electrical power *i.e.*

$$P = \frac{W}{t} = Vi = i^2 R = \frac{V^2}{R}$$

(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, Geyser *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*.

(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 $R = \frac{V_R^2}{P_R}$.

(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

$$R = \frac{V_R^2}{P_R} \text{ so } P_{Consumed} \text{ (Brightness)} = \left(\frac{V_A^2}{V_R^2} \right) \cdot P_R$$

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

Now if the power P is transmitted at voltage V then $P = Vi$
i.e. $i = (P/V)$ So, 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 $\propto (1/V^2)$

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So if power is transmitted at high voltage, power loss will be small and vice-versa. This is why long distance power transmission is carried out at high voltage.

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 $1 \text{ KWH} = 1000 \text{ W} \times 3600 \text{ sec} = 3.6 \times 10^6 \text{ J}$.

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

Combination of Bulbs

(1) Series combination

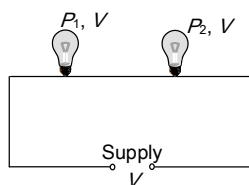


Fig. 20.1

(i) Total power consumed $\frac{1}{P_{total}} = \frac{1}{P_1} + \frac{1}{P_2} + \dots$

(ii) If 'n' bulbs are identical, $P_{total} = \frac{P}{N}$

(iii) $P_{consumed}$ (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.

(2) Parallel combination

(i) Total power consumed $P_{total} = P_1 + P_2 + P_3 \dots + P_n$

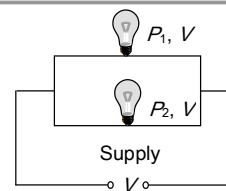


Fig. 20.2

(ii) If 'n' identical bulbs are in parallel. $P_{total} = nP$

(iii) $P_{consumed}$ (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.

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*).

(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.

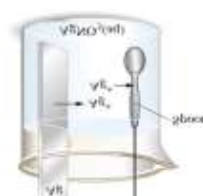
Those liquids which do not allow current to pass through them are called insulators (e.g. vegetable oils, distilled water etc.)

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.

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.

(3) **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

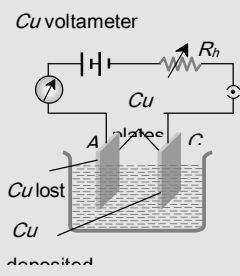
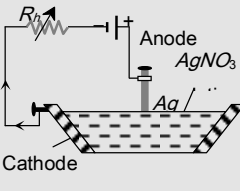
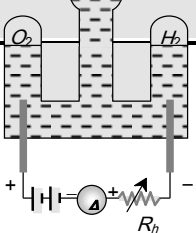


article to be electroplated is made the cathode and the metal to be deposited is made the anode. A soluble salt of the precious metal is taken as the electrolyte. (If gold is to be coated then auric chloride is used as electrolyte).

	are made of platinum (Pt)		collects over the cathode and anode respectively in the ratio of 2 : 1
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(4) **Voltmeter** : The vessel in which the electrolysis is carried out is called a voltmeter. It contains two electrodes and electrolyte. It is also known as electrolytic cell.

Table 20.1 : Types of voltmeters

Volatameter	Anode/ cathode	Electrolyte	Deposition
<p>Cu voltmeter</p> 	Cathode may be of any material but anode must be of Cu	CuSO ₄ or CuCl ₂	At cathode Cu deposited
<p>Ag voltmeter</p> 	Cathode may be of any material but anode must be of Ag	AgNO ₃	At cathode Ag deposited
<p>Water voltmeter</p> 	Both electrode	Acidulated water	H ₂ and O ₂ gases are

Faraday's Law of Electrolysis

(1) **First law** : It states that the mass (m) of substance deposited at the cathode during electrolysis is directly proportional to the quantity of electricity (total charge q) passed through the electrolyte *i.e.* $m \propto q$ or $m = zq = zit$, where the constant of proportionality z is called *electrochemical equivalent (E.C.E.) of the substance*.

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-C⁻¹).

Table 20.2 : E.C.E. for certain substances

Element	Atomic weight	Atomic number	Valency	E.C.E. (Z) in kg / C
Hydrogen	1.0008	1	1	10.4×10^{-9}
Oxygen	15.999	8	2	82.9×10^{-9}
Aluminium	26.982	13	3	93.6×10^{-9}
Chromium	51.996	24	3	179.6×10^{-9}
Nickel	58.710	28	2	304.0×10^{-9}
Copper	63.546	29	2	329.4×10^{-9}
Zinc	65.380	30	2	338.7×10^{-9}
Silver	107.868	47	1	1118×10^{-9}
Gold	196.966	79	3	681.2×10^{-9}

(2) **Second law** : If same quantity of electricity is passed through different electrolytes, masses of the substance

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deposited at the respective cathodes are directly proportional to their chemical equivalents *i.e.* $m \propto E \Rightarrow \frac{m_1}{m_2} = \frac{E_1}{E_2}$

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

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

(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 $\frac{m_1}{m_2} = \frac{E_1}{E_2}$. Also from Faraday's first law $\frac{m_1}{m_2} = \frac{z_1}{z_2}$

$$\text{So } \frac{z_1}{z_2} = \frac{E_1}{E_2} \Rightarrow z \propto E$$

(4) **Faraday constant** : As we discussed above $E \propto z$
 $\Rightarrow E = Fz \Rightarrow z = \frac{E}{F} = \frac{A}{VF}$. ' F ' is proportionality constant called Faraday's constant.

As $z = \frac{E}{F}$ and $z = \frac{m}{Q}$ so $\frac{E}{F} = \frac{m}{Q}$ hence if $Q = 1 \text{ Faraday}$ then $E = m$ *i.e.* If electricity supplied to a voltmeter is 1 Faraday then amount of substance liberated or deposited is (in gm) equal to the chemical equivalent.

Electro Chemical Cell

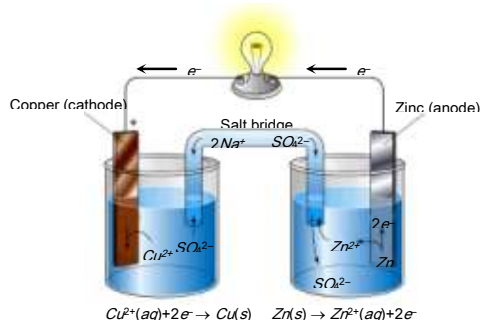


Fig. 20.4

It is an arrangement in which the chemical energy is converted into electrical energy due to chemical action taking place in it.

(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. Examples of primary cells are Voltaic cell, Daniel cell, Leclanche cell and Dry cell *etc.*

(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 reactions are reversible. The secondary cells are also called storage cell or accumulator. The commonly used secondary cells is lead accumulator.

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

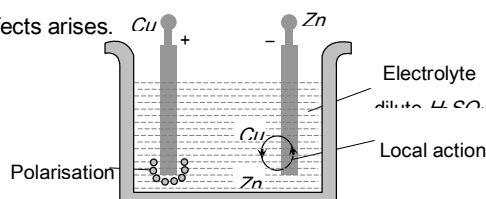


Fig. 20.5

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.

Removal : Either by brushing the anode to 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).

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 ($\mu V/^{\circ}C$).

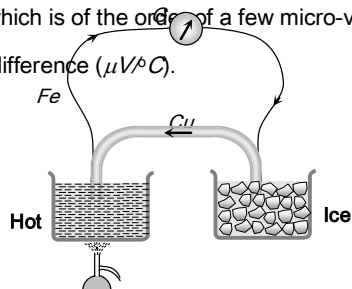


Fig. 20.6

(2) **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.

(i) Seebeck arranged different metals in the decreasing order of their electron density. Few metals forming the series are as below.

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

(ii) 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.

(iii) The current flow at the hot junction of the thermocouple is from the metal occurring later in the series towards that occurring earlier. Thus, in the **copper-iron** thermocouple the current flows from copper (Cu) to iron (Fe) at the hot junction. This may be remembered easily by the **hot coffee**.

(3) **Variation of thermo emf with temperature** : In a thermocouple as the temperature of the hot junction increases keeping the cold junction at constant temperature (say $0^{\circ}C$). The thermo emf increases till it becomes maximum at a certain temperature.

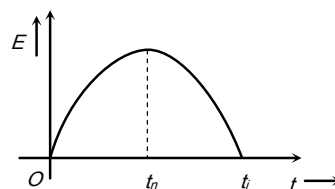


Fig. 20.7

(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 $\text{volt}/^{\circ}C$ and $\text{volt}/^{\circ}C^2$ respectively ($t =$ temperature of hot junction). For E to be maximum (at $t = t_n$)

$$\frac{dE}{dt} = 0 \quad \text{i.e. } \alpha + \beta t_n = 0 \Rightarrow t_n = -\frac{\alpha}{\beta}$$

(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 $Cu-Fe$, $t_n = 270^{\circ}C$)

(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) Relation between t_n, t_i and t_c is $t_n = \frac{t_i + t_c}{2}$

(4) **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.

The thermo electric power $\left(\frac{dE}{dt}\right)$ is also called **Seebeck coefficient**. Differentiating both sides of the equation of thermo emf with respect to t , we have thermoelectric power

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

$$\Rightarrow P = \alpha + \beta t$$

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

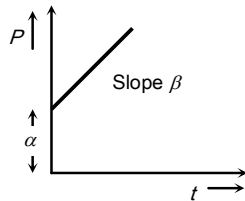


Fig. 20.8

(5) **Laws 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 t_1 and 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

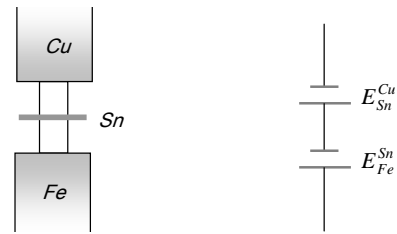


Fig. 20.9

If the soldering metal does not lie between two metals (in Seebeck series) of thermocouple then the resultant emf will be subtractive.

Peltier Effect

When 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. (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.)

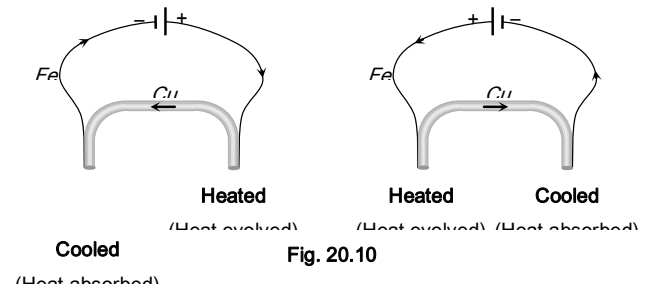


Fig. 20.10

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*.

Peltier co-efficient of a junction is the amount of heat absorbed or liberated per sec. When 1 amp of current is passed to the thermo couple.

It is found that $\pi = T \frac{dE}{dT} = T \times S$; where T is in Kelvin and

$$\frac{dE}{dT} = P = \text{Seebeck coefficient } S$$

Thomson's Effect

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 through an unequally heated metal, there is an absorption or evolution of heat in the body of the metal. This is 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. Heat is evolved when current is passed from hotter end to the colder end and heat is absorbed when current is passed from colder end to the hotter end. The metals which shows positive Thomson's effect are *Cu, Sn, Ag, Cu, Zn... etc.*

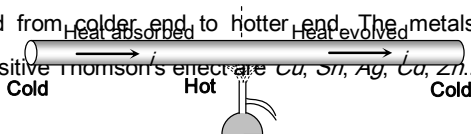


Fig. 28.11

(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. Heat is evolved when current is passed from colder end to the hotter end and heat is absorbed when current flows from hotter end to colder end. The metals which shows negative. Thomson's effect are *Fe, Co, Bi, Pt, Hg ... etc.*

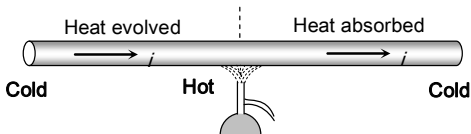


Fig. 20.12

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

If $Q = 1$ and $\Delta\theta = 1$ then $\sigma = H$ 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.

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

Application of Thermo Electric Effect

(1) **To measure temperature** : A thermocouple is used to measure very high ($2000^\circ C$) as well as very low ($-200^\circ C$) 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

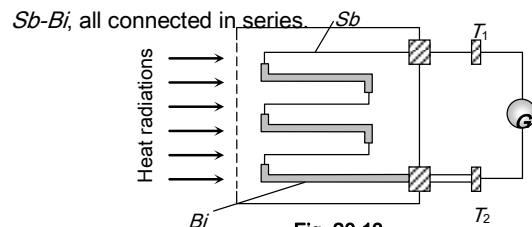


Fig. 20.13

Table 20.3: Heating effect and Thermo-electric effects

S.No.	Joule's effect	Peltier's effect	Seebeck effect	Thomson's effect
1.	Heat produced is directly proportional to the square of the current passing through a	Heat produced or absorbed at a junction is proportional to the current through the junction.	Here temperature difference of junction is used to produce thermo e.m.f. and vice versa.	Thomson's heat is proportional to the current passing through the conductor.

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	conductor.			
2.	This effect is produced due to collision of free electrons with positive ions of the current carrying conductor.	This effect is produced when current is passed through junction of suitable materials.	This effect produced when junctions of a thermocouple are kept at different temperatures.	This effect is produced when parts of same conductor are kept at different temperature.
3.	It is not a reversible effect.	It is a reversible effect	It is a reversible effect	It is a reversible effect
4.	Heat produced depends upon resistance (and thus temperature also) of the conductor.	Heat exchange depends upon nature of conductors and temperature of the junctions.	This effect depends upon nature of materials used to form junctions and temperature of junctions.	This effect depends upon nature of conductor and temperature difference of different parts of the conductor.
5.	It is basically a heating effect	It can be heating as well as cooling effect.	Different junctions are at different temperature.	It is heating as well as cooling effect.

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 thermoelectric refrigerator is based on Peltier effect.

(4) **Thermoelectric generator** : Thermocouple can be used to generate electric power using Seebeck effect in remote areas.

(5) **Thermo-couple meter** : The current to be measured passes through a resistance where heat is generated in the amount of $i^2 R$ joule/sec. The hot junction of the thermocouple is in contact with this resistance, and resulting thermoelectric current gives deflection in the galvanometer G .

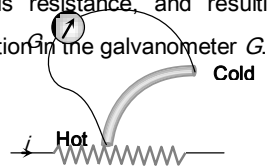
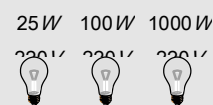


Fig. 20.14

If $V_{Applied} < V_{Rated}$ then % drop in output power of electrical device = $\frac{(P_R - P_{consumed})}{P_R} \times 100$

☞ Different bulbs



⇒ Resistance $R_{25} > R_{100} > R_{1000}$

⇒ Thickness of filament $t_{1000} > t_{100} > t_{25}$

⇒ Brightness $B_{1000} > B_{100} > B_{25}$

☞ Time taken by heater to raise the temperature by $\Delta\theta$ of m kg (or m litre) water is given by $t = \frac{4180 \text{ (or } 4200) m \Delta\theta}{p}$

☞ Necessary series resistance to glow a bulb, if $V_{Applied} > V_{Rated}$

$$R = \left(\frac{V_{Applied} - V_{Rated}}{P_R} \right) \times V_R \quad (P_R = \text{Rated power of bulb})$$

☞ 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 constant if it is cut in n equal parts then resistance of each part will be R/n and from $P_{consumed} \propto \frac{1}{R}$, power consumed by each

Tips & Tricks

part $P' = nP$.

✎ In series a device of higher power rating consumes less power.

✎ Consider that n bulbs are connected in series across V volt supply. If one bulb gets fused and $(n - 1)$ bulbs are again connected in series across same supply, the illumination will be more with $(n - 1)$ bulbs than n bulbs but risk of fusing of bulbs will increase.

✎ When a heavy current appliance such as 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 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.

✎ Charging current for a secondary cell

$$= \frac{\text{e.m.f. of charger} - \text{e.m.f. of cell}}{\text{Total resistance of the circuit}}$$

✎ Efficiency of a cell is given by $\eta = \frac{R}{r + R}$ where R is external resistance and r is internal resistance.

✎ The efficiency of cell is 50% when the power dissipated in the external circuit is maximum.

✎ Thermo couple can be compared to a heat engine. It absorbs heat at the junction (source) converts heat into electric energy (which appears as the circulating electric current) and rejects the remaining heat to cold junction (Sink).