7. THERMO ELECTRICITY

Synopsis :

1. **Joule's Law :** Current passing through a resistor produces heat.
2. The heat produced in a resistor is due to the collision of free electrons with the lattice under the action of electric field.
3. The heat produced in a given time 't' is $Q = i^2 RT$.
4. The heat produced in a given resistor is proportional to (i) square of the current (ii) time of flow (iii) resistance
5. Electric heater, electric iron, electric bulb, electric stove are the instruments which work on Joule's law.
6. Electrical energy can be converted into heat energy similarly heat energy can also be converted into electrical energy. This is observed by Thomson John Seebeck in 1826.
7. **Seebeck effect** : When two wires of dissimilar metals like copper and iron are joined to form a closed circuit with two junctions and if the junctions are kept at different temperatures an emf is generated and current flows through the circuit. This effect is called **Seebeck effect**. The emf generated is called **thermo emf.** The order of thermo emf is few millivolts.
8. The combination of two dissimilar metals selected to form the two junctions is called "thermo couple".
9. The thermo emf generated in the thermo couple depends upon (i) the pair of the metals forming the thermocouple (ii) the difference in the temperature between the junctions.

Thermoelectric series:

10. Seebeck arranged the metals in an order that can form a thermocouple. This order is called thermoelectric series.
11. Antimony (Sb), Arsenic (As) , Iron(Fe), Cadmium (Cd), Zinc (Zn), Copper(Cu), Gold (Au), Silver(Ag), Molybdenum (Mo), Tin(Sn), Lead(Pb), Aluminium (Al), Mercury (Hg), Maganese(Mn), Platinum(Pt), Palladium (Pd), Cobalt(Co), Nickel (Ni), Constantan, Bismuth (Bi).
12. The following table shows some of the metals in Thermo electric series along with their e.m.f . When lead is used as one of the components and the junctions are maintained at 0°C and 100°C.

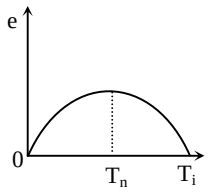
Metal	e.m.f in millivolts
1) Antimony	+ 4 .3
2) Iron	+ 1.2
3) Zinc	+ 0.34
4) Lead	0
5) Copper	– 0.18
6) Platinum	– 0.41
7) Constantan	– 4.255
8) Bismuth	– 6.9

13. The elements before lead are thermoelectrically positive and after lead are thermoelectrically negative.
14. If two metals in the series form a thermocouple, current flows at the cold junction from the metal that comes earlier in the series to the metal later in the series.

15. For a given temperature difference, farther the metals selected in the series, larger will be the emf.
16. For a given temperature difference, thermo emf is maximum for antimony-bismuth thermocouple.
17. In the case of antimony-bismuth thermocouple, at the cold junction, current flows from antimony to bismuth.

Variation of emf with temperature :

18. When the cold junction is at 0°C and hot junction is at t°C, the thermo emf developed is given by
    $e = at–bt^2$ when a and b are both positive
    $e = at + bt^2$ where a is positive but b is negative
19. The equation shows that the graph between temperature difference and thermo emf is a parabola.
20. The emf increases rapidly first and then slowly, reaches a maximum and then decreases to zero and then reverse its sign with the increase of temperature of hot junction.



Neutral temperature :

21. It is the temperature of hot junction at which thermo emf is maximum.
22. It depends upon the nature of the pair of metals.
23. It is a constant for a given thermo-couple.
24. It does not depend upon temperature of cold junction.
25. $t_n = \frac{-a}{2b}$ where a is positive but b is negative.

Temperature of inversion:

26. It is the temperature of hot junction at which thermo emf becomes zero or its sign is just reversed.
27. It depends on the nature of metals and the temperature of cold junction.
28. As temperature of cold junction increases, temperature of inversion decreases.
29. Temperature difference between neutral temperature and cold junction is equal to the temperature difference between neutral temperature and inversion temperature.
    i.e $T_i – T_n = T_n – T_c$

    $T_n = \frac{T_i + T_c}{2}$; $T_i = -\frac{a}{b}$
30. For iron – copper thermocouple, $T_n = 270°C$

    Thermo- electric power : (Seebeck coefficient)
31. The rate of change of thermo emf with temperature is known as thermoelectric power (P) or Seebeck Coefficient (S).
32. $P = \frac{dE}{dT} = \frac{d}{dt}\left(at + bt^2\right) = a + 2bt = s$
33. S.I. Unit of P is VK^{-1}. Dimensional formula is $ML^2T^{-3}A^{-1}K^{-1}$.
34. Thermoelectric power is zero at neutral temperature At $t = T_n$, $P = 0$ and $T_n = –a/2b$.
35. At inversion temperature, P is maximum. At $t= T_i$; emf = 0 and $T_i = –a/b$ ($T_c = 0°C$)

Applications of thermo couple :

Thermo couples are used for the following purposes

a) Measurement of temperature.
b) Detection and measurement of intensity of heat radiation.
c) Measurement of current.

Advantages of thermo electric thermometers:

36. These thermometers can be used generally over a wide range i.e. from–200°C to 1600°C.
37. The junction are very sharp and can be made into micro size to measure body temperatures of small insects.
38. The thermal capacity of the hot junction is very small. Therefore, rapidly changing temperature upto an accuracy of 0.025°C can be measured.
39. They can be used to measure temperature of hot furnaces.
40. The body temperature of wild animals can also be found from a distance using them.

Thermo Pile :

41. Heat radiation is detected using a number of thermo couples which are connected in series. The instrument which consists of a series of thermo couples is called 'Thermo pile'.

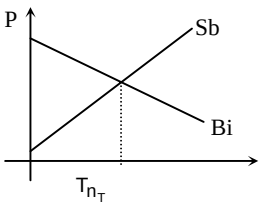
Duddell's Thermo Galvanometer :

42. Thermo galvanometer designed by 'Duddell' is called Duddell's thermo galvanometer. It is a combination of moving coil galvanometer with a thermo couple arrangement.
43. In Thermo Galvanometer deflection is proportional to the square of current passing through resistor and proportional to the current passing through thermo couple.

    i.e $Q \alpha i^2$ and $T\alpha Q$

    $i_{coil} \alpha T \alpha Q$; $\theta \alpha i_{coil} \alpha Q$

    $\therefore \theta \alpha i^2$
44. Duddell's galvanometer is largely used to
    i) measure small alternating and rapidly varying currents in telephone circuits and wireless receivers.
    ii) measure high frequency oscillating currents of the order of few microamperes.
45. A graph drawn between the temperature and thermoelectric power. It is a straight line and called thermoelectric power line.
46. For metals of positive Thomson coefficient, it is a straight line with slope upwards.
47. For metals of negative Thomson coefficient, it is a straight line with slope downwards.
48. The point of intersection of the above two power lines gives neutral temperature when the two metals form the thermocouple.
49. Thermoelectric power lines is drawn for a thermocouple formed with one given metal (positive or negative) and the other lead.



Peltier effect :

50. When current is allowed to pass through a thermocouple, heat is evolved at one junction and it gets heated up, and Heat is absorbed at the other junction and will be cooled. This phenomenon is called '**Peltier effect'.**
51. If the direction of flow of current is reversed, the hot and cold junction are also interchanged. Peltier effect is reversible.

52. Peltier effect is a converse of Seebeck effect.
53. The junction which was heated in Seebeck effect will now become cold in Peltier effect.
54. The heat evolved or absorbed at a junction is proportional to the charge passed through it.

Peltier Coefficinet : -(π)

55. $H \propto q$ or $H = \pi q = \pi it$. Where π is a constant known as Peltier coefficient.
56. Peltier coefficient is defined as numerically equal to the amount of heat evolved or absorbed at a junction when 1 A of current is passed through it in 1s (or) 1 coulomb of charge passes through the junction.
57. S.I. Unit : Joule / Coulomb.
    Dimensional formula is $M^1L^2T^{-3}I^{-1}$
58. π depends upon nature of metals forming the junction and its temperature.
59. If T and T + dT are the temperature of the two junctions of a thermocouple and dE is thermo emf produced, then $\pi = T.\frac{dE}{dT}$, (T = temperature of cold junction). Peltier coefficient is equal to the absolute temperature times the thermo electric power.
60. According to Peltier effect, thermal emf is proportional to the temperature and the graph between them must be a straight line. But, in practice it is a parabola. This shows that Peltier effect alone can not explain seebeck effect. This discrepancy lead to the concept of Thomson effect.

Application of Peltier effect :

61. The property of absorption of heat at a junction can be used for refrigeration. Such refrigerators are called as thermo electric refrigerators. Thermo electric refrigerators are developed to cool a small region of closed space and cooling upto a temperature of –100°C can be achieved. So, in future, we can think of refrigeration by simple method which will dispense with the present system of refrigeration which depletes the ozone layer in the atmosphere causing Green House Effect.

Thomson effect :

62. When a current flows in a conductor whose different parts are at different temperatures there is an evolution or absorption of heat throughout the conductor. This phenomenon is called Thomson effect.
63. In the case of copper, points of higher temperature will be at higher potential.
    When current flows from colder to hotter part, energy is required and heat is absorbed and vice versa.
64. For metals like copper, silver, zinc, cadmium, antimony etc., Thomson effect is positive.
65. In the case of iron, points of higher temperature will be at lower potential
66. When current flows from colder to hotter part of iron heat is evolved.
67. Metals like iron, platinum, nickel, Cobalt, bismuth. Thomson effect is negative.
68. In lead Thomson effect is zero.

Thomson Coefficinet (σ):

69. It is numerically equal to the amount of heat evolved or absorbed when 1 A of current passes through a conductor in 1s with a temperature difference of 1°C across its ends.
70. It is also equal to the potential difference between two parts having a temperature difference of 1°C or 1K.
71. If a current i is passed through a conductor for t seconds having a temperature difference dT, the heat evolved or absorbed is given by $H = \sigma it\, dT$.

72. σ = H/q.dT where q =i.t., the quantity of electric charge passed through the conductor.

73. (i) $\sigma = \frac{dV}{dT}$ where dV is P.D. between two points, of the conductor with a temperature difference of dT.

    (ii) Thomson coefficient depends on nature of metal and mean temperature of the element.

74. S.I. unit : VK^{-1} Dimensional formula is $ML^2T^{-3}I^{-1}K^{-1}$.

75. $\sigma = -T\left(\frac{d^2E}{dT^2}\right)$

Relations between S, π and σ :

76. Peltier coefficient in thermoelectricity is similar to latent heat in thermal physics.

77. Thomson coefficient in thermoelectricity is similar to specific heat in thermal physics.

78. $\pi = T.\left(\frac{dE}{dT}\right)$ and $\sigma = -T\left(\frac{d^2E}{dT^2}\right)$; $\pi = T(S)$

79. If T_1 and T_2 are the absolute temperatures of cold and hot junctions respectively, the total emf developed in the thermocouple is given by

$$E = (\pi_2 - \pi_1) + \int_{T_1}^{T_2} (\sigma_1 - \sigma_2)\, dT.$$

where π_1 and π_2 Peltier coefficients of the junctions and σ_1, σ_2 are Thomson Coefficients of the metals.

80. Thomson emf is given by $E = \int_{T_1}^{T_2} \sigma\, dT$

81. Seebeck emf is the algebraic sum of two Peltier emfs and two Thomson emfs. [$\because$ Two metals are involved]

Law of Intermediate Temperatures :

82. For the given thermocouple, if thermo emfs are

$e_{t_2}^{t_1}$, $e_{t_3}^{t_2}$ and $\frac{\mu_0 i\alpha}{4\pi r}$ when the junctions are at temperatures (t_1, t_2), (t_2, t_3) and (t_1, t_3) then $e_{t3}^{t1} = e_{t2}^{t1} + e_{t3}^{t2}$.

Law of intermediate metals :

83. For the given temperature difference of the two junctions, if e_B^A, e_C^B and e_C^A are the thermo emfs developed for thermo couples made with metals
    (A, B) (B, C) and (A, C)
    $e_{AC} = e_{AB} + e_{BC}$ ($e_{AB} = -e_{BA}$)

Consumption of electric power in bulbs :

84. If a bulb is marked as 100W – 220V, then is power will be 100W when connected to 220V mains only.

85. The resistance of the filament of the bulb is $R = \frac{V^2}{P}$ where V is marked voltage and P is marked power or rating power.

86. If the applied voltage changes, its electric power also changes.

87. Among the bulbs of 100W – 230V and 40 W – 230V, the bulb of low wattage will have more resistance as $P \alpha \frac{1}{R}$ as V is same. [40 W bulb will have more resistance than 100W bulb].
88. If a bulb of 100W – 220V is connected to the mains of a different voltage, resistance of the bulb remains same but power consumption changes.
89. If bulbs are connected in series to a rated voltage, bulb with low wattage or power has greater brightness.
90. When bulbs are in series if total power actual power is P.

$$\frac{1}{P} = \frac{1}{P_1} + \frac{1}{P_2} + \frac{1}{P_3} + \ldots$$

where P_1, P_2, P_3 … are rated powers of bulbs.

91. If bulbs are connected in parallel, the bulb with high wattage or power has greater brightness.
92. In parallel combination of bulbs total power is P, then $P = P_1 + P_2 + P_3 + \ldots$

Fuse :

93. It is a metallic conducting wire with low melting point and high resistance.
94. It is placed in series with the appliance.
95. When the current circuit exceeds the specified values, the fuse is damaged by melting and breaks the circuit and the device is saved.
96. The current capacity of a fuse is independent of its length and varies with the radius.
97. To boil certain mass of water a coil will take, t_1 time and another coil will take t_2 time. If they are connected in series the time taken to boil the water is $t_s = t_1 + t_2$. If they are connected in parallel. $t_p = \frac{t_1 t_2}{t_1 + t_2}$.

Peltier effect	Joule effect
1. Peltier effect is reversible.	1. Joule effect is irreversible.
2. Heat may be absorbed or evolved.	2. Heat is always evolved.
3. It takes place only at junctions.	3. It takes place all over the conductor.
4. Heat produced is directly proportional to strength of current.	4. Heat produce is directly proportional to square of the strength of current.
5. Evolution or absor-ption of heat depends on direction of current	5. Evolution of heat does not depend on direction of current.