RANI CHANNAMMA UNIVERSITY
BELAGAVI

B.Sc. IV Semester

PHYSICS

UNIT-IV

# Thermoelectricity

Thermoelectricity

Thermo electric current

When two dissimillar metals are joined intrensically at thier ends so as to form two junctions. and these two junctions are maintaind that two different temperatures: then a current is formed to flow with in the circuit. the resulting current is called thermo -electric current.

✓ imp

* **seebeck effect :->** The production of emf and hence current by mentaining the junctions of two dissimi -llar metals at different temperatures. is called seebeck effect

The Divice constinting of the pair of dissimillar metals with pair of junction is called "thermo couple"
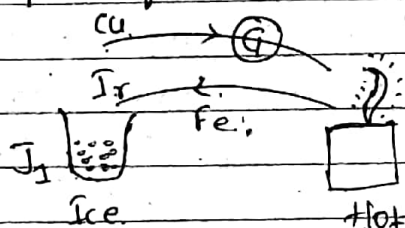
J_1 and J_2 ->cad and hot junction
G -> Galvanomelers

The thermo couple consists of copper & iron as two dissimillor metals Once the thermo couple is maintain let cold and hot junctions then galvanomete -r seg resistor the deflection, indicating a flow of current in the circuit, if the junction are rivense then deflection on G is in opposite Directionst adt seebecks constructed thermo couples with different metals. and arranged them in a series called seebecks series (thermo electric series)

Bi, Ni, co. pt· cu. Mn. Hg. Pb. Sn. cr. Mo. Au, Ag. Zn, Fe. As, Sp, sb.

The list of metals shown above exhibit seebeck effect
and this phenomena can be also observed with some
alloys.

* Variation of thermo emf with temperatures :—
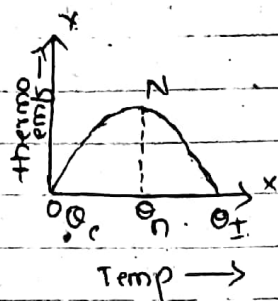
Temp $\rightarrow$

The thermo of emf developed in the thermo couple depe
-nds on the temp difference b/w of the two junctions.
If the temperature of the hot junction is increased
and keeping the cold jaction constant. then emf is
found to increased. The emf is increases until it
reaches maximum at particular temp called θ_n (neutral
temperature):

If the temp of the hot junction is increased further,
the emf is found to decreased till it become zero.
and there after rivers in direction. the correspondi
-ng the temp is called temperature of inversion.

* seebeck - co-efficient :— The temp of the
hot junction of thermo couple at which the thermo
emf becomes maximum is known as neutral
temperature. θ_n

The temperature of hot junction at which reversal
of emf take place is called temp of inversion θ_I
The temp of inversion dependce upoun upon the
temp of cold junction

let θ_n, θ_I and θ_c be the nuetral temp, temp of
inversion & temp of cold junction resp.

then we have. $\theta_s - \theta_n = \theta_n - \theta_c$

since $\theta_c = 0$, then $2\theta_n$

the thermo emf varies with a temp according to
the relation $e = a\theta + b\theta^2$.

where θ is temp difference btwn the two junction
a & b are constants for the given thermo couple
and are called as seebecks co-efficients

* laws of thermo electricity :— as a result of
large no' of experiments laws of thermo electricity
are explained in two ways.
1) law of intermediate metals
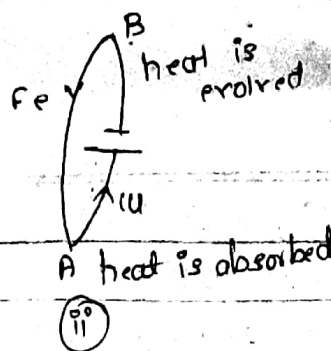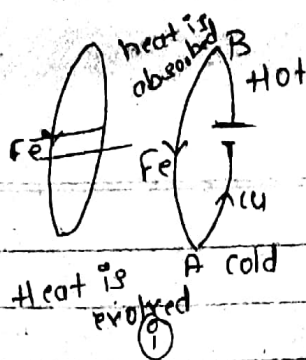2) law of   "   temperatures.

* law of intermediate metals :—
statements :— It states that the introduction of any
additional metals into any thermo electric circuit
does not ulter the thermo emf provided the metal
intruduced is at the same temperature.

* law of intermediate temperatures :—
statement :- It states that the thermo emf of the thermo
couple btwn two temperatures is equal to the sum of
the emfs corresponding to no' of succesive intervals
into which the given range of temperature may be
Divided

if the thermocouple is maintain the btwn that varias
temperatures, $\theta_1 \theta_2 \theta_3 \theta_4 \ldots$ etc then there
corresponding emfs are $e_1 e_2 e_3 \ldots$ etc.

* Pelter effect :— The process of absorption (or erduction
of heat energy) at a junction between two dissimilar
metals when a current flows through the junction is
called peltier effect

heat is absorbed B | Hot
Fe | Fe | Cu
A cold
Heat is evolved
(i)

B heat is evolved | Fe | Cu
A heat is absorbed
(ii)

explanation :— suppose a battery is intruduced in the circuite and both the junctions are kept at same temp

By passing the current in the circuite (fig(i)) Heat is evolved at junction A, & heat is absorbed at B if the direction of the current is Reversed (fig(ii)) then heat is evolved at B & absorbed at A.

Therefor the peltier effect is reversible

Peltier co-efficient (π) :— peltier co-efficient of a junctions may be defined as the Amount of energy absorbed or evolved when unit quantity of electric charge flows through the junctions. & it is denoted by π & it is depending on

(i) pair of metals in the thermo couple &
(ii) the temp of the junction.

The amount of energy absorbed / evolved $= \pi Q$
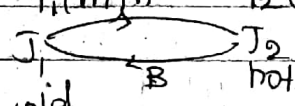where Q is the quantity of charge across the junctions

if E volt is the emf then

$$\pi Q = E Q$$

$$\boxed{\pi = E}$$

SI unit $= J/coulmb$

Thermodynamics of peltier effect :— let J_1 & J_2 be the junctions with temp T_1 & T_2, respectively thus A & B forms a thermocouple.

$T_1 (T_1) A \qquad T_2 (T_2)$
$J_1 \qquad\qquad J_2$
B
cold $\qquad$ hot

Now the heat is absorbed at J_2 & librated at J_1 Amount of heat absorbed at J_2 is more then the amount of heat liberated at J_1

And because of this reason the current in the circuit is observed

Thus thermo act like a heat engine which absorbes the heat at one junction and liberates at colder junction
let 1A current flow for 1sec through the thermo couple
let π_1 & π_2 be the peltier co-efficent at T_1 & T_2

Heat energy absorbed at $T_2 = \pi_2 I t$
$\quad$ for $I = 1A$ & $t = 1s$ then
$$T_2 = \pi_2$$
Heat energy liberated at $T_1 = \pi_1 I t$
$\quad$ for $I = 1A$ & $t = 1s$ then
$$T_1 = \pi_1$$
Net energy absorbed $= \pi_2 - \pi_1$
$\therefore$ This energy is used in setting up of emf e volt
$$e = \pi_2 - \pi_1$$
comparing peltier effect with carnot heat engine.
$$\frac{Q_1}{T_1} = \frac{Q_2}{T_2}$$

$$\frac{\pi_1}{T_1} = \frac{\pi_2}{T_2}$$

$$\frac{T_2}{T_1} = \frac{\pi_2}{\pi_1}$$

substract 1 on both sides
$$\frac{T_2}{T_1} - 1 = \frac{\pi_2}{\pi_1} - 1$$

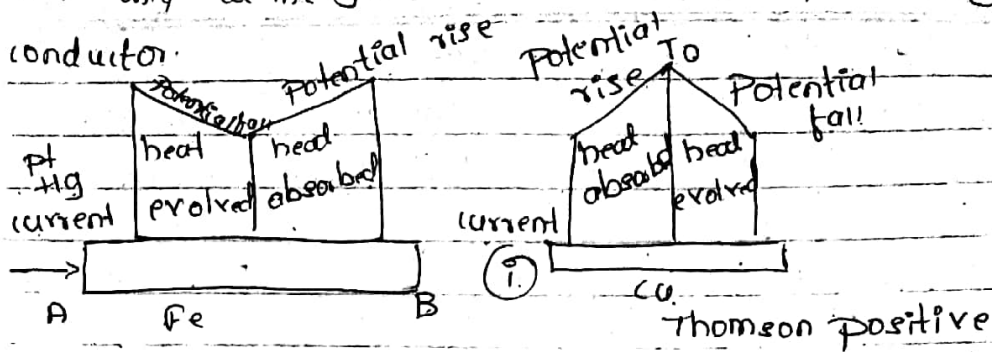$$\frac{T_2 - T_1}{T_1} = \frac{\pi_2 - \pi_1}{\pi_1}$$

$$\frac{\pi_1 (T_2 - T_1)}{T_1} = (\pi_2 - \pi_1)$$

$$\frac{\pi_1 (T_2 - T_1)}{T_1} = e$$

$$\therefore e \propto T_2 - T_1$$
The thermo emf directly propartional to temp difference btw two junction

Thomson effect :—/ when a current flows through unequally
Heated conductor there is a evolution & absorption heat
Not only at the junction but it takes place throughout the
conductor.

Potential rise

Potential rise

Potential fall

Pt
+Ig
current | evolved absorbed
A   Fe   B

heat | heat
Potential

current

heat absorbed | heat evolved
cu.
Thomson positive

(ii) **Thomson Negative :—**
Consider a thick copper both AB heated at its
centre of No current flows through the
conductor. the points A&B are at the same
·temp. Now let us pass the current
through the conductor.
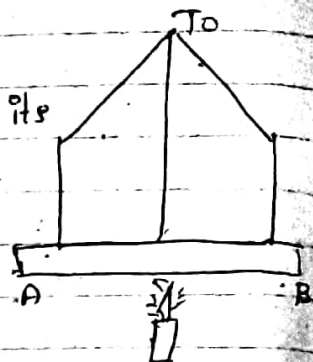
ⓐ Heat is absorbed from A to its centre &
ⓑ heat is evolved from centre to B
Thus the transfer of heat in the direction of current
is known as "+ve thomson effect"
i.e— cd, Zn. Ag. sb

In case of iron both if the current flows from A to B
then
ⓐ heat is evolved from A to centre &
ⓑ Heat is absorbed from to B
Thus the transfer of heat in the direction of current is
opposite to flow of current & is known as "Negative
thomson effect"
ex :— Pt. Bi. co. Ni, +Ig
In case of lead pb thomson effect is zero &
therefore lead to is used to make thermo-couples.

✓
Explanation of thomson effect :—
* it is on the bases of free election theory of metals
when metalic bar is unequally Heated temp gradient
is set up in the bath

As electron are more energetic at hot region which starts moving towards cooler parts. This causes higher potential of the hotter portions & lower potential at the cooler portions. If the electric charge is sent through the conductor then work is to be done along the conductor. are opposite to it as a result heat energy is absorbed or evolved. due to the difference of these two energies Thomson emf is produce

Thomson coefficient (σ) :-

It is the heat energy absorbed or evolved when 1A current flows for 1sec btw² two points of a conductor at a temp difference of $1°$

or

" It is also defined as the potential difference set up btw² true points for unit temp difference

if two points are at temp T_1 & T_2 when 1 Ampere flows for 't' seconds.

· Then Thomson emf :-

$$= \int_{T_2}^{T_1} (\sigma dt) \times I \times t$$

if $t = 1s$, $I = 1$

Thomson emf $= \int_{T_2}^{T_1} \sigma dt$

Problems :-

✳ For a certain thermo couple $a = 20 \mu v/°C$ & $b = \frac{-1}{30} \mu v/°C$
find the Neutral temp & the temp of inversion

Given :- $a = 20 \times 10^{3} v/°C$ $b = -0.03334 \mu v/°C$

$e = a\theta + b\theta^2$

$\frac{de}{d\theta} = a + 2b\theta$

if $\frac{de}{d\theta} = 0$

$\theta = \frac{-a}{2b} = \frac{20}{2 \times 1/30}$ $a + 2b\theta = 0$

$\theta_n = \frac{20 \times 30}{2} = 300°C$ $\theta_I = 2\theta_n$

$\boxed{\theta_n = 600}$

Expression $(\sigma_A - \sigma_B)$ for $\pi = T \dfrac{de}{dT}$

Differenting the following eq^n w.r.t 'T'

$$\pi = T \dfrac{de}{dT}$$

$$\dfrac{d\pi}{dt} = T \dfrac{d^2e}{dt^0} + \dfrac{de}{dT}$$

Then rearrange tho eq^n

$$\dfrac{de}{dT} = \dfrac{d\pi}{dT} = -T\dfrac{d^2e}{dT^2} \longrightarrow \text{①}$$

BH we h.T

$$d\pi + (\sigma_A - \sigma_B) dT = de$$

Dividing this $equal^t$ by 'dT'

$$\dfrac{d\pi}{dT} + (\sigma_A - \sigma_B) = \dfrac{de}{dT}$$
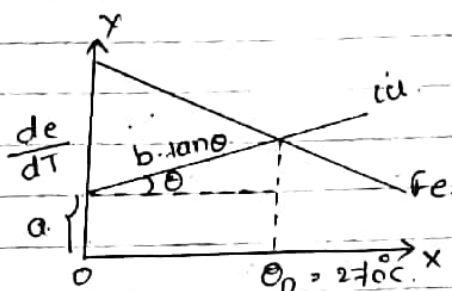
then rearrange this eq^n

$$\dfrac{de}{dT} - \dfrac{d\pi}{dT} = (\sigma_A - \sigma_B) \longrightarrow \text{②}$$

comparing eq^n ① & ② we get

$$(\sigma_A - \sigma_B) = -T \dfrac{d^2e}{dT^2}$$

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* Thermoelectric diagrams.

② definations:- $T \longrightarrow$

The diagram showing the relation btw\ thermoeledric power at the temp of the hot junction is called as Thermo electric diagram   these diagram first constructed by tait. and hence is known as 'tails' diagram

W. h T   from the relation

$$e = a\theta + b\theta^2$$

which represents varied of emf with Temp

diff w.r.t θ

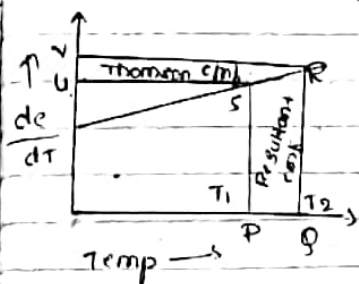$$\dfrac{de}{d\theta} = a + 2b\theta.$$

$$P = a + 2b\theta.$$

'a' from the above eq^t slope $= ab$ and intercept is given by

* **Applications of thermodedric diagram :-**
① It is used to find the total thermoemf
② It " " to " emf due to peltier effect
③ " " " " " " thomson effect
④ To determine the neutral temp
⑤ " . " temp of inversion.

① **Total Thermo emf :—**

The total emf develop in a thermocouple with junctions of absolute temperatures T_1 & T_2 is given by

$$E = \int_{T_1}^{T_2} \frac{de}{dT} \, dT$$

The area of PQRS in the figure gives the total-thermo dedric emf.

$$E = Area\ PQRS.$$

② **EMF due to Peltier effect :—** The peltier emf at the cold junction of absolute temp. T_1 is given by.

$$\pi_2 = T_1 \left(\frac{dE}{dT}\right)_{T_1}$$

$$= OP \times PS.$$

$$= Area\ OPSU.$$

similarly at the hot junct^t (T_2) is.
Peltier emf is given by.

$$\pi_2 = T_2 \left(\frac{dE}{dT}\right)_{T_2}$$

$$= OQ \times QR.$$

$$= Area\ Area\ OQRV$$
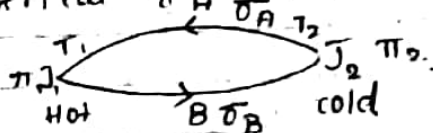
So emf setup due to peltier emfeffect $= \pi_2 - \pi_1$

$$= \text{Area } OPRV - \text{Area } OPSU.$$
$$= \text{Area } PQRS \text{ (Approximate)}$$

* Application of thermodynamics to thermocouple
① Derivrade of the Peltier $\pi = Tx \frac{dE}{dT}$

consider a thermocouple with metals A & B, J_1 & J_2 are hot & cold junctions having temp T_1 & T_2 respectively let σ_A & σ_B one thomson's co-efficients & π_1 & π_2 one Peltier co-efficients

The energy absorbed due to peltier effed at the hot junction $= \pi_2 I t$

the energy liberated due to peltier effect ad energy absorbed at the cold junction $= - \pi_1 I t$

similarly energy absorbed in a metal A due to thomson effed $= \int_{T_1}^{T_2} (\sigma_A dT) I_1.$

energy absorbed in metal 'B' due to thomson effed $= \int_{T_1}^{T_2} (\sigma_B dT)$

Total gain in the energy for the complete thermocouple
$$= \left[(\pi_2 - \pi_1) + \int_{T_1}^{T_2} (\sigma_A - \sigma_B) dT \right] I t \to ①$$

Total emf produced in the circuit then energy produced
$$= eIt \to ②$$

∴ from eq^s ① & ②
$$eIt = \left[(\pi_2 - \pi_1) + \int_{T_1}^{T_2} (\sigma_A - \sigma_B) dT \right] I t$$

$$e = (\pi_2 - \pi_1) + \int_{T_1}^{T_2} (\sigma_A - \sigma_B) dT \to ③$$

According to 2nd law of thermodynamics for the carnot reversible heat engine
$$\frac{Q_1}{T_1} = \frac{Q_2}{T_2}$$

q_1 = The quantity of heat absorbed at T_1

q_2 = " " " " " rejected " T_2.

The energy absorbed at hot junction due to peltier effect = $(\pi + d\pi) I t$

q energy liberated at cold junction = $\pi I t$

similarly, energy absorbed due to Thomson effect $= \dfrac{(\sigma_A - \sigma_B)}{dT\, It}$

Applying II law of thermodynamics

$$\dfrac{(\pi + d\pi)\, It}{T + dT} + \dfrac{(\sigma_A - \sigma_B)dT\, It}{T} = \dfrac{It}{T}$$

$$\dfrac{(\pi + d\pi)}{T + dT} - \dfrac{\pi}{T} + \dfrac{(\sigma_A - \sigma_B)}{T}\, dT = 0$$

$$\dfrac{T\pi + Td\pi - T\pi + \pi dT}{T(T + dT)} + \dfrac{(\sigma_A - \sigma_B)dT}{T} = 0$$

$$\dfrac{Td\pi - \pi dT}{T(T + dt)} + \dfrac{(\sigma_A - \sigma_B)\, dT}{T} = 0$$

$$\dfrac{Td\pi}{T^2} - \dfrac{\pi dT}{T^2} + \dfrac{(\sigma_A - \sigma_B)\, dT}{T} = 0$$

$$\dfrac{d\pi}{T} - \dfrac{\pi dT}{T^2} + \dfrac{(\sigma_A - \sigma_B)\, dT}{T} = 0$$

multiplying 'T' througout

$$\dfrac{d\pi - \pi dT}{T} + (\sigma_A - \sigma_B)\, dT = 0$$

$$d\pi + (\sigma_A - \sigma_B)\, dT = \dfrac{\pi dT}{T}$$

substitute LHS as de

$$\boxed{de = \dfrac{\pi dT}{T}}$$

But $\dfrac{de}{dT}$ = Thermo electric power

$$\therefore \pi = \dfrac{de}{dT}\, T$$

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