Unit - 1

Sensor & Transducer:-

→ In field of electrical engineering, the term sensor and transducer both refer to component which convert energy into different forms.

→ Transducer is a device that can convert energy from one form to other where as sensor is device that detect and respond to some type of input from physical environment and input can be light, heat, motion, pressure etc.

Therefore basically sensor is a device that can detect physical quantity and convert the data into an electrical signal.

Ex:- Microphone → Transducer + Sensor
→ convert sound energy to electrical energy

Loudspeaker → Transducer
→ convert electrical energy to sound energy

* Therefore sensor is also a type of transducer.

* Criteria to choose a Sensor:-

Following should be considered while selecting a transducer/sensor for particular application:-

→ a) operating range and type of measurement to maintain range requirement and good resolution.

→ b) Sensitivity and excitation to allow sufficient o/p.

→ c) Mechanical and electrical condition

→ d) Mounting provisions and corrosion resistance

→ e) Environmental condition such as ambient temp. range, corrosive fluid, pressure etc.

Classification of Transducer:-

Transducer may be classified according to their application method of energy conversion, nature of output signal and so on.

Transducer

- On the basis of principle used
  - Capacitive
  - Inductive
  - Resistive
- Active / Passive
- Primary / secondary
- Analog / digi[tal]

a) Primary and Secondary Transducer:-

Some transducer contain mechanical as well as electrical device. The mechanical device converts physical quantity to be measured into mechanical signals. Such mechanical device are called as primary transducer, because they deal with the physical quantity to be measured.

→ The electrical device then convert this mechanical signal into a corresponding electrical signal. Such electrical device are known as secondary transducer.

Ex - For measurement of displacement, diaphragm act as primary transducer converts pressure into displacement (mechanical signals)

→ The displacement is then converted into change in resistance using strain gauge. So strain gauge act as the secondary transducer.

2) Active & Passive Transducer:-

→ Active transducer are those transducer which donot need any external source of power for their operation. Therefore they are also called as self generating type transducer.

→ It operates under the energy conversion principle.

EX:- Piezoelectric Transducer:-
When an external force is applied on to a quartz crystal there will be a change in electrostatic charge 'q' or voltage 'v' generated by crystal.

→ Passive Transducer:- are those transducer which requires an external power source for their operation. They produce an output signal in the form of some variation in resistance, capacitance or any other electrical parameter which then has to converted into equivalent current or voltage.

EX:- Strain gauge → used to measure stress or pressure

As stress on the strain gauge increases or decreases the strain gauge bends or compress causing the resistance of wire bonded on it to increase or decrease. The change in resistance which is equivalent to change in stress is measured with the help of a bridge. Hence stress is measured.

3) Analog & Digital Transducer:-
Analog transducer convert an I/P physical phenomena into an analogous output which is continuous function of time. eg → Strain gauge, LVDT, thermocouple or thermistor

Digital Transducer → convert I/P physical phenomenon into discrete steps of electrical output, which is in the form of pulses eg, digital linear displacement transducer.

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Performance characteristic :-

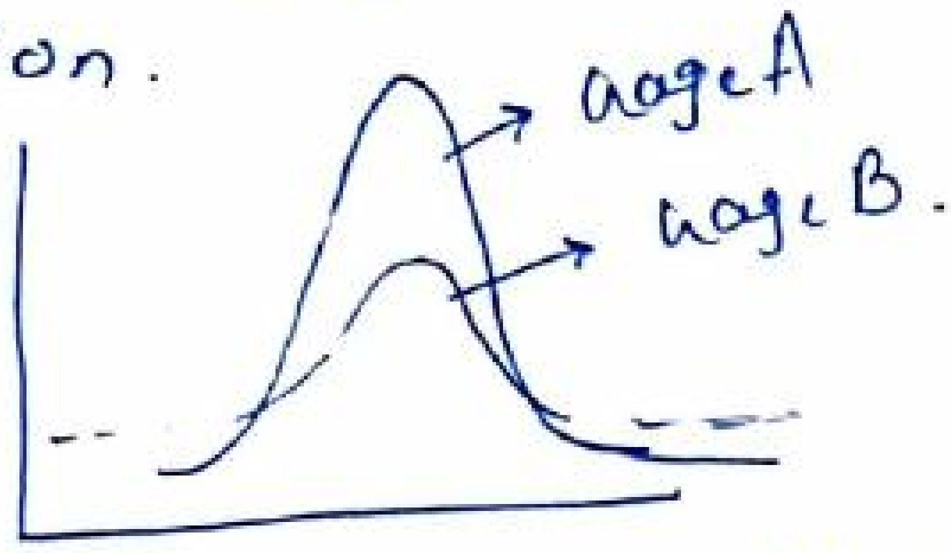
a) Static Characteristic   b) Dynamic Characteristic

a) Static characteristic :- used to measure under unvarying condition

1) Calibration :- It is defined as process for determination by measurement or comparison with standard of correct value of each scale reading on a meter or other measuring instrument.

2) Repeatability

→ Ability of an operator to consistently repeat the same measurement of same part using same gage under same condition.



→ operator 1 measure the single part with gage A 20 time, and then measures the same part with gage B.

3) Reproducibility

→ The ability gage used by multiple operators to consistently reproduce the same measurement of same part under same condition

4) Accuracy

→ Refers to the closeness of a measured value to a standard or known value.

For ex :- If actual or known weight of a substance is 10kg and after measurement we obtain 3.2 kg for given substance then measurement is accurate.

5) Precision

→ Precision refers to closeness of two or more measurement to each other.

For ex :- if we weigh a given substance five time and get 3.2kg each time then measurement is precise but not accurate

→ Precision is independent of accuracy

6) Sensitivity :- Sensitivity can be defined as ratio of change in output to change in input which causes it at steady state condition

7) Drift :- Undesired or gradual variation in output over a period of time that is unrelated to change in output operating condition or load.

Dynamic characteristic:-

In measurement system, if input varies from instant to instant so does the output. The behaviour of such system under such condition is deals by dynamic response of the system.

a) Speed of response:- Speed of response of a physical system refers to its ability to respond to sudden change of amplitude signal.

b) Fidelity:- It is the degree to which an instrument indicates the change in measured variable without dynamic error.

c) Lag - It is the retardation or delay in response of an instrument to change in measured quantity.

d) Dynamic error - It is the difference between true value and value indicated of a quantity changing with time by an instrument

$$\% \text{ error} = \frac{\text{Measure value} - \text{True value}}{\text{True value}} \times 100$$

Note:-

Static characteristic:-

Resolution:- defined as smallest change of magnitude of the measurand that produces a minimum observable output of the instrument.

Q] A wheat stone bridge required a change of 8Ω in unknown ON-OFF Bridge to produce 2.5mm change in deflection of galvanometer. Find the bridge sensitivity.

Sol^n:-

$$\text{Sensitivity; } S = \frac{\text{change in o/p}}{\text{change in i/p}}$$

$$= \frac{2.5mm}{8\Omega} = 0.312\,5mm/\Omega$$

Q] A resistance potentiometer has a total resistance of $10000\,\Omega$ and is rated 4W. If the range of potentiometer is 0 to 100 mm, then its sensitivity in V/mm is -?

Sol^n:-

$R = 10000\,\Omega$

$P = 4W = V_0^2/R$

$V_{max} = \sqrt{PR}$

$= \sqrt{10000 \times 4}$

$= 200V$

$$\text{Sensitivity} = \frac{V_{max}}{100} = \frac{200}{100} = 2V/mm$$

Q] A 0-100 V voltmeter has a 200 scale division which can read up to ½ division. Find the resolution of instrument in volts.

Sol^n:- $1 \text{ scale division} = \frac{\text{Total range}}{\text{No. of division}}$

$$= \frac{100}{200} = 0.5V$$

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$$\text{Sensitivity, } S = \frac{\text{change in o/p}}{\text{change in i/p}}$$

$$= \frac{2.5mm}{8\Omega} = 0.3125 mm/\Omega$$

Q) A resistance potentiometer has a total resistance of 10000Ω and is rated 4W. If the range of potentiometer is 0 to 100 mm, then its sensitivity in V/mm is -?

Sol^n:-

$R = 10000\Omega$

$P = 4W = V_0^2/R$

$V_{max} = \sqrt{PR}$

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Sol^n:- $$1 \text{ scale division} = \frac{\text{Total range}}{\text{No. of division}}$$

$$= \frac{100}{200} = 0.5V$$

device can read up to $\frac{1}{2}$ division;

so Resolution $= \frac{0.5}{2} = 0.25$ (min^m value)

$= 0.25\,V$

Q] thermometer has 100 uniform division, full scale reading is $200°C$ and $\frac{1}{10}$^th of scale division can be estimated accurately. Find resolution of instrument

1 Scale division $= \frac{200}{100} = 2°C$

$\frac{1}{10}$^th of scale $= \frac{2}{10} = 0.2°C$

Resolution $= 0.2°C$

Note:- Accuracy is specified as; → percentage of true value.

$\% \, T.V = \frac{MV}{TV} \times 100$

$$\boxed{\% \text{ True value} = \frac{\text{Measured value}}{\text{True value}} \times 100}$$

→ Accuracy is also defined as percentage of full scale value:-

$$\boxed{\% \, FSV = \frac{\text{Measured value}}{\text{Full scale deflection}} \times 100}$$

Q] True value of a device is 25 unit and measured value is 20 unit then find the accuracy as a percentage of its true value.

Accuracy in % of its true value $= \frac{MV}{TV} \times 100$

$= \frac{20}{25} \times 100$

$= 80\%$

Characterization :-

characterization of sensor can be done in many ways depending on type of sensors.

These are :- a) Electrical
b) Mechanical
c) Optical
d) Thermal
e) Chemical
f) Biological.

→ a) Electrical characterization :-
It consist of evaluation of electrical parameter like
a) Impedance, voltage and current
b) Break down voltage and fields
c) Leakage current.
d) Noise, cross talk.

→ The knowledge of the sensor output impedance is very important for coupling the measuring equipment to it. For voltage sensitive sensor, ratio of input impedance of measuring equipment to output impedance of transducer/sensor should be very high while for current sensitive sensor reverse is true.

→ Break down of insulating part of sensor is very critical

Sol.

a> Here, total length of the wiper = 120 mm and it moves between 20mm to 60mm, so effetive length of resistance $= (60-20)\,mm = 40\,mm$.

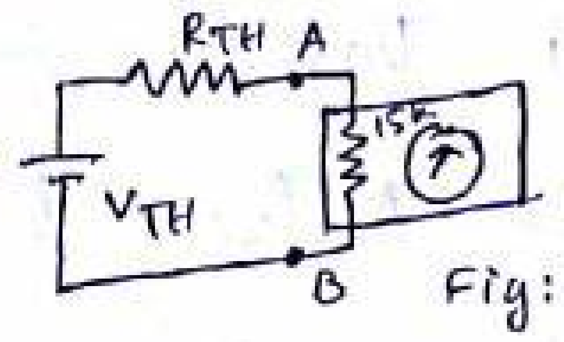


Fig: equivalent ckt.

So, $k = \frac{40}{120} = 1/3$

∴ equivalent internal resistance of or Thevenin's resistance

$$R_{TH} = k(1-k)R_p \quad [R_p = \text{Total resistance of POT}]$$

$$= \frac{1}{3}\cdot\frac{2}{3}\times 24 = \frac{16}{3} = 5{\cdot}33\,k\Omega$$

and $V_{TH} = KE = {\cdot}33E$ [E supply voltage]

in open load condition, output voltage across the terminal AB in given figure would be $V_{TH} = {\cdot}33E$

Now, when loaded, 15kΩ volt meter is connected, voltage drop accross it would be

$$V_L = \frac{15k}{(15+R_{TH})k}\cdot V_{TH} = \frac{15\times{\cdot}33E}{(15+5{\cdot}33)} = {\cdot}24E$$

$$\therefore \text{Error due to loading} = \left(\frac{V_{TH}-V_L}{V_{TH}}\right)\% = \left(\frac{{\cdot}33-{\cdot}24}{{\cdot}33}\times 100\right)\%$$

$$= 26{\cdot}22\,\%$$

b) To keep error within 3%, suppose V_L has to be V_{Lx}

$$\therefore \frac{{\cdot}33 - V_{Lx}}{{\cdot}33}\times 100 = 3$$

~~or ${\cdot}33 - V_{Lx} = {\cdot}99$~~
~~or $V_{Lx} =$~~

$$\left(\frac{{\cdot}33 - V_{Lx}}{}\right)\times 100 = {\cdot}99$$

$${\cdot}33 - V_{Lx} = {\cdot}0099$$

$$V_{Lx} = {\cdot}32E$$

$$\therefore {\cdot}32E = \frac{R_x}{(R_x+5{\cdot}33)}\times{\cdot}33E$$

$$\text{or } {\cdot}97(R_x+5{\cdot}33) = R_x$$

$$\text{or } {\cdot}97\times 5{\cdot}33 = R_x(1-{\cdot}97)$$

$$\text{or } \frac{5{\cdot}33\times{\cdot}97}{{\cdot}03} = R_x$$

$$\text{or } R_x \cong 172\,k\Omega$$

B. Inductive transducers:

This type of transducers can be sub devided into three parts –

i) Variable reluctance type
ii) Mutual Inductance type
iii) Eddy current type.

i) Variable reluctance type:

Self inductance L of a coil can be written as –

$$L = \frac{N^2}{R} \quad \text{where } R = \frac{l}{\mu A} = \frac{1}{\mu G} \left[G = l/A = \text{geometric form factor.}\right]$$

Here N = no. of turns in the coil

l = length of the magnetic path

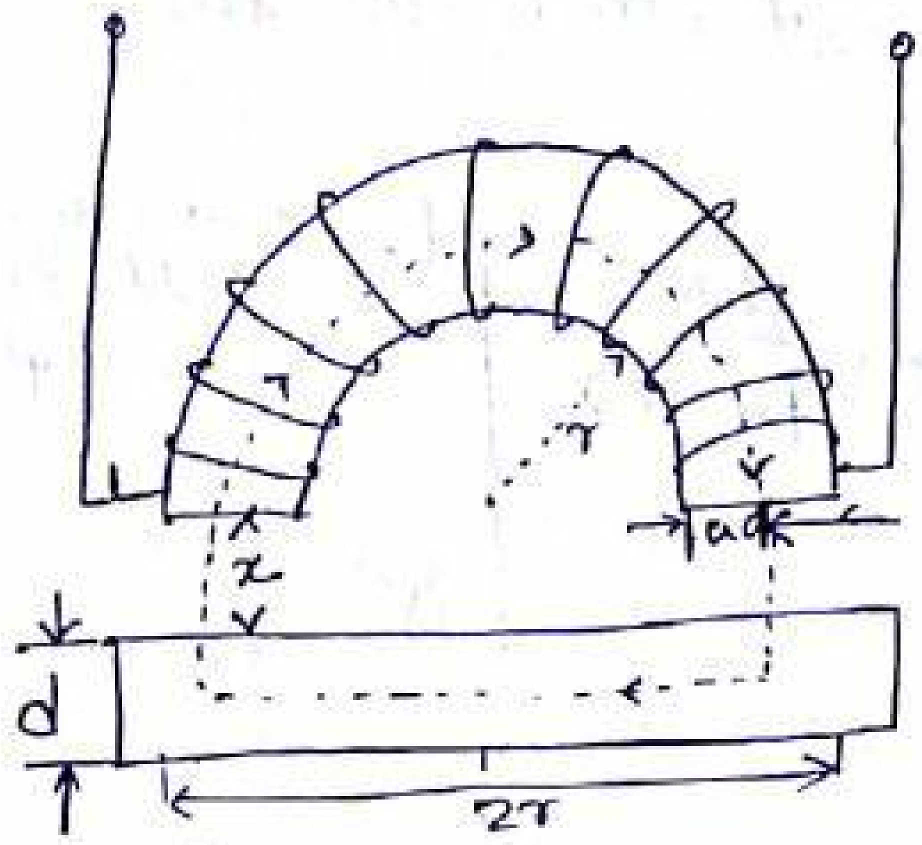
μ = effective permiability of the medium in and around the coil.

A = area of cross section of the magnetic path.

R = Reluctance of the magnetic circuit.

Thus variation in μ, G varries the relactance which in turn varries the inductance. If these varry due to displacement of various part of ~~of~~ magnetic circuit then resulting change in ~~displacement~~ inductance can be measured to find displacement.

Considering a magnetic circuit consisting of i) semi circular ring with an electrical winding, working as an electro magnet ii) air gap iii) a plate of magnetic material as shown in frame.



Let μ_m = Permiability of magnet~~ic material~~

μ_0 = Permiability of air-gap between magnet and plate.

μ_p = Perimabilty of magnetic material (Plate)

~~Then total~~ Since magnetic circuit consist of three components, the total reluctance of the sum of reluctance of individual components. ie

$$R_{Total} = R_{magnet} + R_{gap} + R_{plate}$$

Now,

$$R_{magnet} = \frac{l_{magnet}}{\mu_m A} = \frac{\pi r}{\mu_m \pi a^2} = \frac{r}{\mu_m a^2}$$

r = radius of curvature
a = radius of cross section.

$$R_{airgap} = \frac{2x}{\mu_0 \pi a^2}$$

[x = distance between magnet and plate and it occurs both sides of the ~~cross~~ magnet]

$$R_{plate} = \frac{2r}{\mu_p 2a \cdot d} = \frac{r}{\mu_p ad}$$

$$\therefore R_{total} = \frac{r}{\mu_m a^2} + \frac{r}{\mu_p ad} + \frac{2x}{\mu_0 \pi a^2}$$

$$= \frac{r}{a}\left(\frac{1}{\mu_m a} + \frac{1}{\mu_p d}\right) + \frac{2x}{\mu_0 \pi a^2}$$

$$= R_0 + \frac{2x}{\mu_0 \pi a^2} = \boxed{R_0 + kx}$$

where $R_0 = \frac{r}{a}\left(\frac{1}{\mu_m a} + \frac{1}{\mu_p d}\right)$ = Reluctance with zero air gap

$$K = \frac{2}{\mu_0 \pi a^2}$$

The corresponding change in self-inductance of the circuit

$$L = \frac{N^2}{R_{total}} = \frac{N^2}{R_0 + Kx} = \frac{L_0}{1 + \alpha x} \quad \left[\begin{array}{l} L_0 = \text{inductance with zero air gap} = N^2/R_0 \\ \alpha = \frac{K}{R_0} \end{array} \right]$$

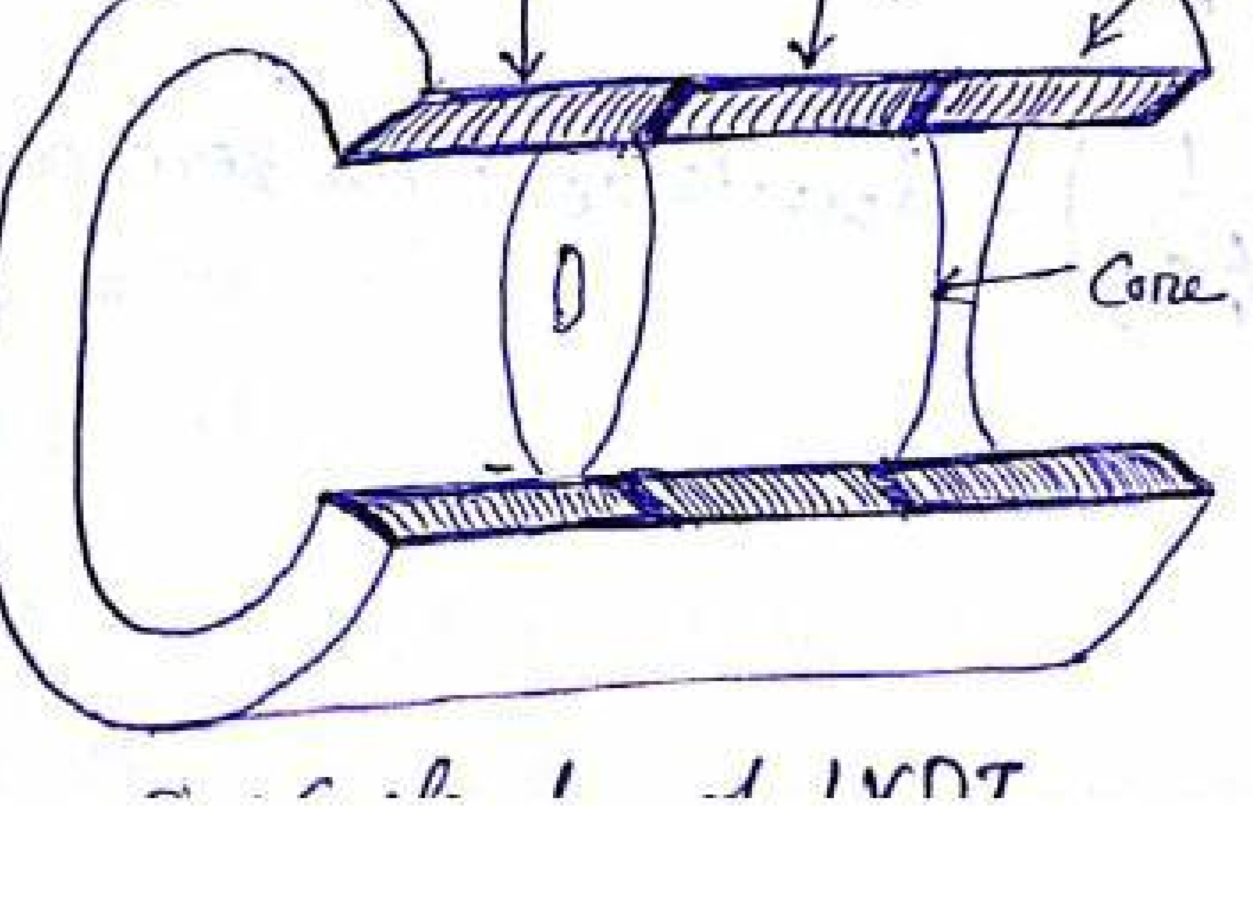
It may be seen that the self inductance has a non linear relationship with the displacement of the plate. This can be converted to linear relation by push pull variable reluctance transducers in ac bridge.

ii) <u>Mutual Inductance type:</u>

One of the most commonly used mutual inductance type trans-ducer is Liner variable Displacement transformer or LVDT. It is an electromechanical device designed to produce an AC voltage output proportional to the relative displacement of a transformer and an iron core.

<u>Construction</u>

Basic construction of LDVT is shown in the given figure.



LVDT

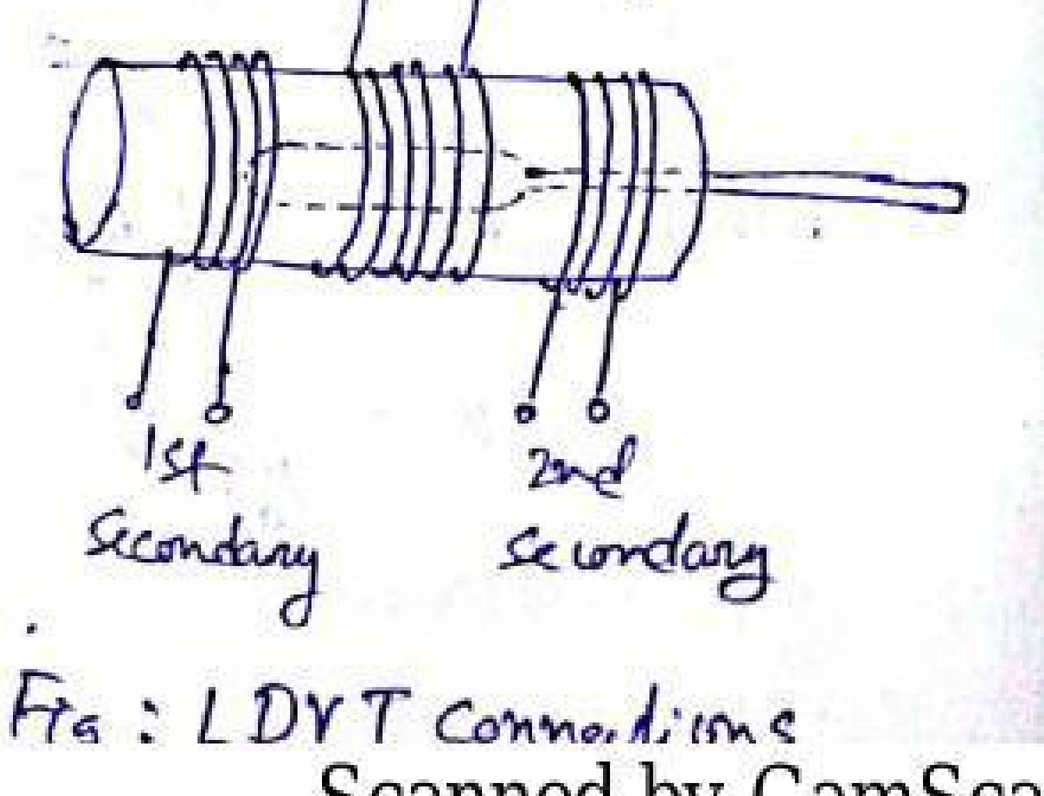


Fig : LDVT Connections

It consists of a primary coil and two secondary coil. Secondary coils are identical in respect of their number of turns and their placement of both sides of the primary winding. A sinosoidal voltage e_i of amplitude 1V to 15V and freq 50 Hz to 20 KHz can be used to excite the primary ~~alt~~ however normally 1 volt, 2-10kHz is ~~normally~~ used. Movable core produces signal proportional to its displacement by changing the mutual inductance between the coils.

Working (Circuit analysis)

When the ~~primary~~ secondary coil is open circuited, the equation of primary can be written as —

$$e_i = L_p \frac{di_p}{dt} + i_p R_p$$

L_p, R_p = Inductance and Resistance component of primary coil.

i_p = Current in primary coil.

e_i = induced e.m.f.

Taking laplas transform,

$$E_i(s) = L_p s I_p(s) + R_p I_p(s)$$

$$\therefore E_i(s) = (sL_p + R_p) I_p(s)$$

$$\text{Now, } \therefore I_p = \frac{E_i(s)}{(sL_p + R_p)} = \frac{E_i(s)/R_p}{1+\tau_p s} \quad \left[\text{Where } \tau_p = \frac{L_p}{R_p} \right]$$

Now if e_s1 and e_s2 are voltage generated in the secondary coils owing to their mutual inductance cofficents as M_1 and M_2 then

$$e_{s_1} = M_1 \frac{di_p}{dt} \qquad e_{s_2} = M_2 \frac{di_p}{dt}$$

taking L.T —

$$E_{s_1}(s) = M_1 s \cdot I_p(s) \quad , \quad E_{s_2}(s) = M_2 s \cdot I_p(s)$$

$$\therefore E_o = E_{s_1}(s) - E_{s_2}(s)$$

$$E_0(S) = (M_1 - M_2)\, I_p(S).S = \frac{(M_1 - M_2)\, S/R_p}{\tau_p S + 1} E_i$$

$$\therefore \frac{E_0(S)}{E_i(S)} = \frac{(M_1 - M_2)\, S/R_p}{\tau_p S + 1}$$

$$\Rightarrow \frac{E_0(j\omega)}{E_i(j\omega)} = \frac{(M_1 - M_2)\, j\omega/R_p}{\tau_p j\omega + 1} = \frac{\omega(M_1 - M_2)/R_p}{\sqrt{(\omega\tau)^2 + 1}} \angle \phi$$

where, $\phi = \frac{\pi}{2} - \tan^{-1}\omega\tau_p$

$\therefore$ Input and output amplitude ratio

$$A = \frac{|E_0|}{|E_i|} = \frac{\omega(M_1 - M_2)/R_p}{\sqrt{(\omega\tau_p)^2 + 1}}$$

$$A = K(M_1 - M_2) \quad \left[K = \text{constant as } \omega, R_p, \tau_p \text{ are constant for a given system} \right]$$

Hence it can be said that output amplitude of the LVDT linearly varies with the mutual inductance in the two secondary coils.

iii) ★ Advantages and disadvantages of LVDT

Advantages

i) Linearity is good upto 5mm.

ii) Output voltage is stepless hence high resolution

iii) Sensitivity is high

iv) Low power, low hysteresis device

Disadvantages

i) Large threshold

ii) Affected by stray electro-magnetic field

iii) AC input generate noise

iv) Sensitivity is lower at higher temperature.

iii) Eddy current transducers

If a conductor is placed near a changing electromagnetic field then some current induces in the conductor which creates its own electromagnetic field that opposes the source field. This induced current in the conductor is known as eddy current. As a result of opposition, flux around the source coil reduces with hence the inductance of the coil. This effect depends on the distance between the target and the coil because nearer the coil, higher the eddy currents and lower the inductance and vice versa.

There are two common types of eddy current sensor arrangement is there —

i) Target placed perpendicularly to the axis of the coil (Fig 1)

ii) Target in form of co-axial cylinder, running over the coil. (Fig 2)

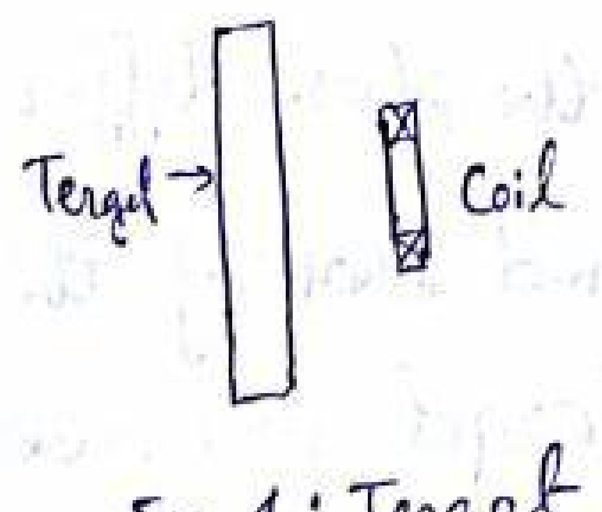


Fig 1: Terget perpendicular to the coil

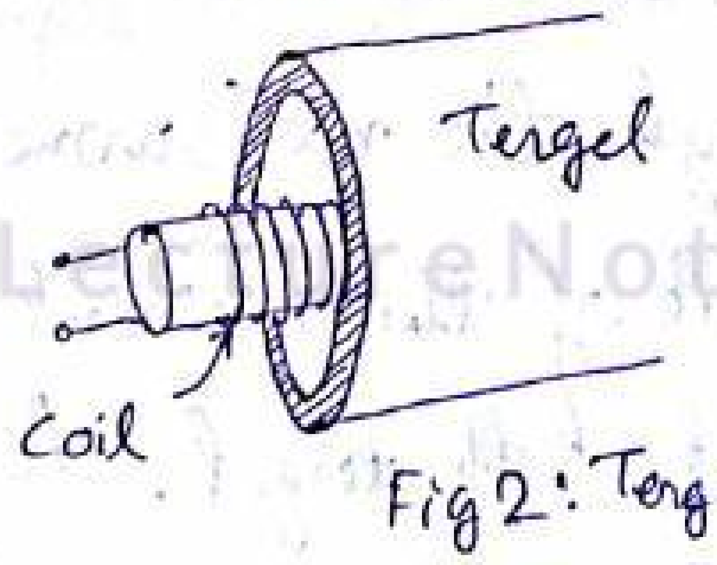


Fig 2: Terget in form of co axial cylinder

In a practical set-up, the probe consists of two coils. One (active) for measurment another (Passive) for temperature compensation and balancing. The two

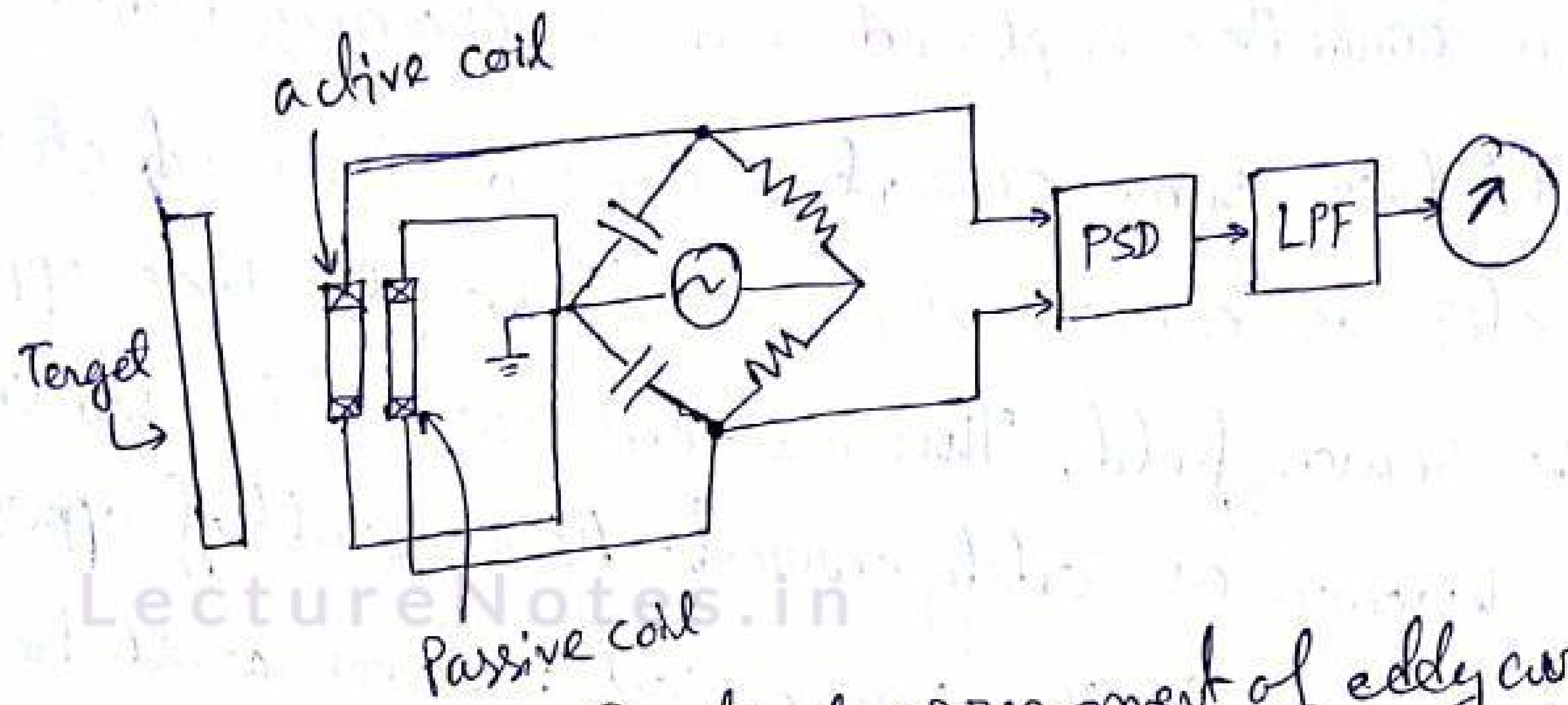


Fig: Practical arrengment of eddy current sensor

coils are connected in parallel with two capacitors forming two arms of a bridge.

Distance between target and probe determines the ~~in the~~ inductance of active coil. So any displacement of the target causes ~~imp~~ disbalance in the bridge producing voltage proportional to the displacement. This unbalanced voltage can be demodulated and low pass filtered to produce a DC voltage ~~with~~ which can be calibrated to measure amount of displacement.

There is an alternative method of measurment of displacement through the measurment of the phase difference and the amplitude of the incident ac and that of the induced eddy current at the target. As the target comes closer to the sensor head, the oscillation amplitude becomes smaller and the phase difference from the reference ~~voltage~~ wave form ~~de~~ becomes larger. By detecting amplitude and phase, the sensor can obtain a value approximatly proportional to the distance between sensor and target.

* Advantages and disadvantages of Eddy current transducers

Advantages —

i) Non-contact measurment

ii) High resolution

iii) High frequency responce

Dis advantages —

i) Low range

ii) Displacement vs impedance charecterstics is non linear and temperature dependant.

iii) Works only on conductive materials with sufficent thickness. Not usable for non-conducting materials.

c. Capacitive Transducers :

Capacitive transducers can directly sense varity of things - motion, chemical composition, electric field and indirectly pressure, acclaration, fluid level, and fluid composition. The technology is low cost, stable and uses simple signal conditioning circuit.

Generally parallel plate capacitors are used as transducer. According to theory, Capacitance C of such a capacitor is given by — $C = \varepsilon \frac{A}{x}$ Farad

where $\varepsilon = \varepsilon_0 \varepsilon_r$ dielectric constant, A overlaping area of ~~ove~~plates, x = distance between the plates. Therefore variable capacitance device can be constructed by varning any of the parameters.

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i) <u>By changing d</u> :

Since capacitance varies inversly as x, the plot of C vs x is a rectangular hyperbola which is rather inconvenient for measurement. Here

$$\text{Sensitivity} = S = \frac{dC}{dx} = -\frac{\text{Constant}}{x^2}$$

which means, sensitivity in this case is ~~not e neigther~~ ~~const~~ not constant. Usually linearisation of input-output relation is done by three different techniques —

a) <u>using a charge amplifier</u>

An op-amp configuration, shown in the given figure can be successfully utilised to reduce non-linear relationship between C_x and x. i.e. output voltage and x.

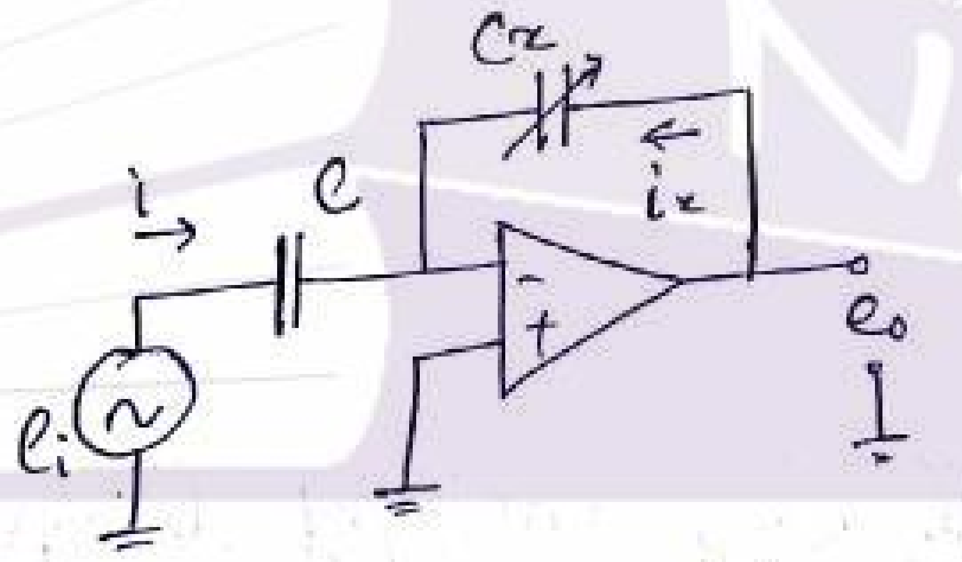


Fig: Charge amplifier

With current i_x and i, capacitors C_x and C and voltage e_i and e_o as show in the figure it can be written that —

$$e_i = \frac{1}{C}\int i\,dt \qquad e_o = \frac{1}{C_x}\int i_x\,dt$$

[where C = fixed capacitance, C_x = variable]

now as op-Amp has the vertual ground at input so, $i = -i_x$

$$\therefore \frac{e_o}{e_i} = -\frac{C}{C_x} \quad \text{or } e_o = -\frac{C}{C_x}e_i = -\frac{Cx}{\varepsilon A}e_i$$

or $e_o = -\frac{Ce_i}{\varepsilon A}x$ as other parameters are constant, the output voltage varries linearly with displacement.

b. By measuring impedance

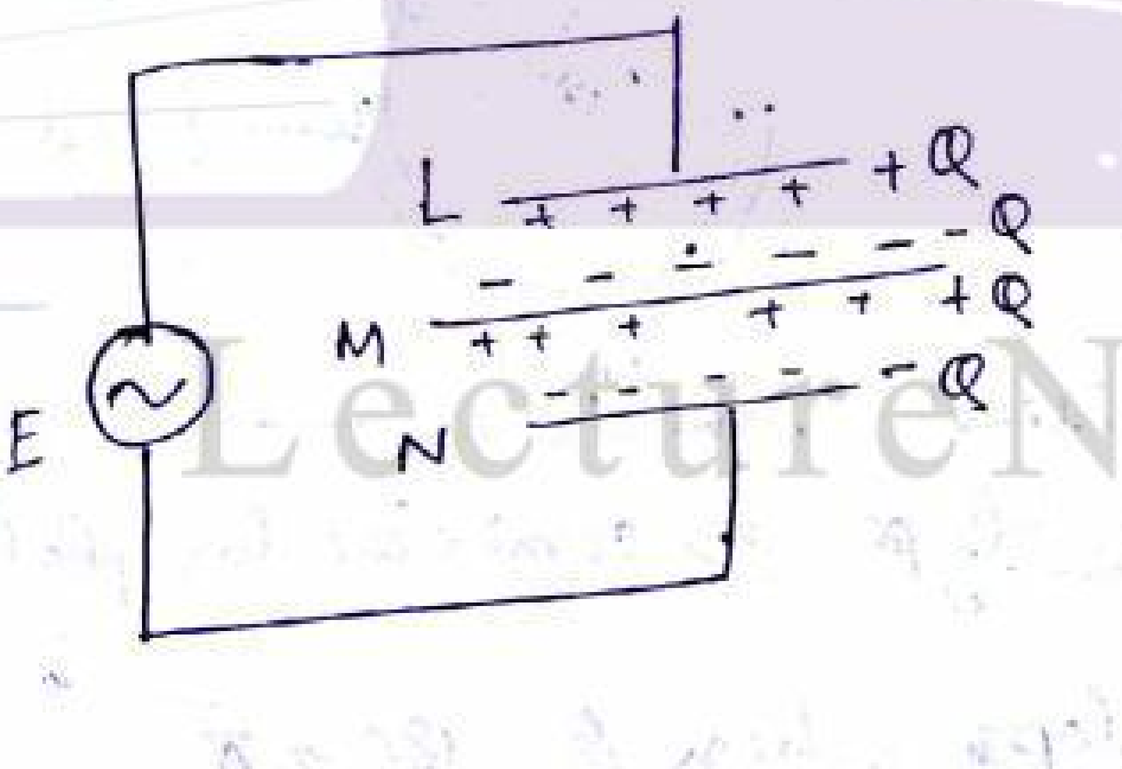
Second way of linearisation is to measure the impedance rather than the capacitance as it is given by —

$$X_C = \frac{1}{2\pi f C} = \frac{x}{2\pi f \cdot \varepsilon_r \varepsilon_0 A}$$

where f = frequency of exciting voltage. As other terms are constant, X_c vs x curve would be linear.

c. By having differential arrangement:

The third technique to produce linear transfer characteristics is a differential arrangement of capacitors as shown in the figure.



Here, third plate capacitor is used, keeping the end plates fixed and allowing middle plate to move. Now, considering M is at the middle position,

Capacitance of the two fixed plates (L, N) $C_L = \varepsilon \frac{A}{2d}$

where, d = distance between two adjacent plates.

If M, moves towards L by an ammount x, then capacitance of two differential capacitance would be

$$C_{LM} = \varepsilon \frac{A}{d-x} \qquad C_{MN} = \varepsilon \frac{A}{d+x}$$

Hence $E_{LM} = E\frac{d-x}{2d}$ and $E_{MN} = E\frac{d+x}{2d}$

which give $\Delta E = \frac{E}{d}x$

it can measure displacement between 10^{-8} mm to 10 mm.

ii) By changing A :

In the x (plate distance) variation motion detectors, ~~ed~~ when the displacement is as large as the dimention of the electrodes, the accuracy of the measurment suffers from varnishing signal level. The area variation measurment is then preferred.

$\therefore$ sensitivity —

As, $C = \varepsilon \frac{A}{dx}$; $\frac{dC}{dA} = \frac{\varepsilon}{x} =$ Constant.

So, output vs area change is linear. No extra circuitry is needed to make calibration linear.

By making parallel plates semicircular, angular dis-placement can also be measured by this methode. In such arrengment, capacitance is maximum when

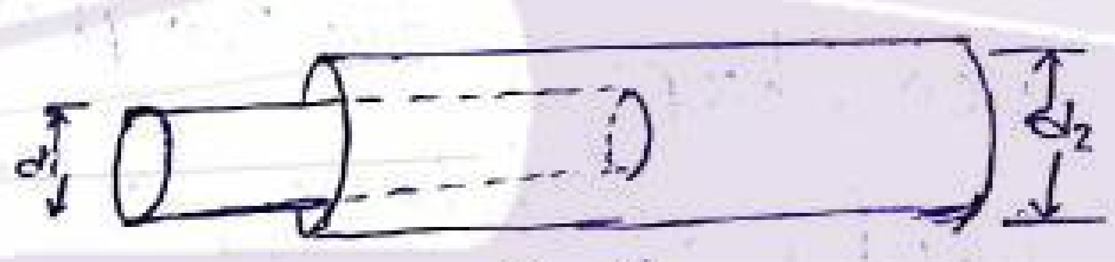


Fig: a

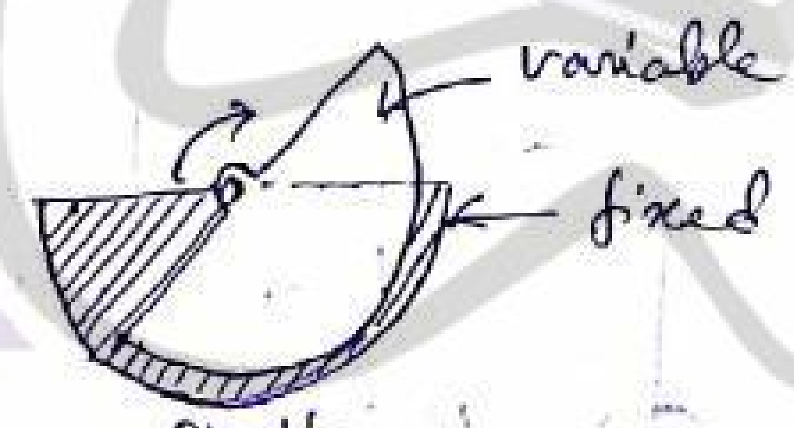


Fig: b

Fig: variable area capacitive transducers —
(a) coaxial cylinder type (b) semi circular plate type.

plates complectly ~~ep~~ over laps when $\theta = 180' = \pi$

Then $C_{max} = \frac{\varepsilon A}{x} = \frac{\varepsilon \pi r^2}{x}$

while at any angle θ degree, the capacitance is $C = \frac{\pi \varepsilon r^2}{360 x}\theta$.

Here also $C \propto \theta$ as all other parameters are constant during ~~rota~~ angular movement.

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iii) By changing ε

Considering a rectangular parallel plate capacitor with each plate of length L and width w and d is the the distance between plates, an initial situation is assumed where an intervening dielectric slab of length L, width w and thickness d is displaced in such a way that only length l of it is within the plates.

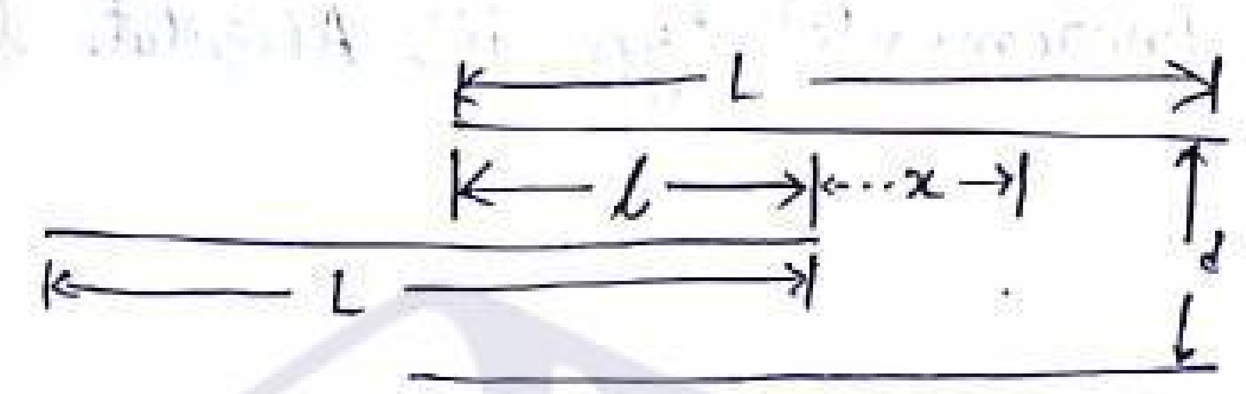


Fig: variable ε type capacitive transducer.

So it canbe written as —

$$\boxed{C = \frac{\varepsilon_0 (L-l)w}{d} + \frac{\varepsilon_0 \varepsilon_r l w}{d}}$$

ε_0 = permittivity of air

Now if any displacement of x occurs in dielectric slab then capacitance will be —

$$C + \Delta C = \frac{\varepsilon_0 (L-l-x) w}{d} + \frac{\varepsilon_0 \varepsilon_r (l+x) w}{d}$$

$$\text{or } \Delta C = \frac{\varepsilon_0 w(\varepsilon_r - 1)x}{d} \quad \text{or } \therefore \Delta C \propto x$$

So, capacitance, i.e. hence output voltage will change linearly with displacement in variable ε type capacitive transducers.

Advantages and Disadvantages

Advantages

- → High sensitivity
- → Good frequency responce
- → High input impedance
- → Minimum Mechanical loading

Disadvantages

- → Noise generation from stray capacitance, from transmission line
- → Temperature sensitivity
- → relatively Complex instrumentation.

Digital Displacement Transducer

Unlike other analog displacement sensors which convert analog signals to digital ones through ADS, digital displacement sensors or encoders directly ~~dro~~ produce digital signal with the suitable electromagnetic or electro optical arrengement.

Encoders can be devided into three catagories —

i) Tachometer type ii) Incremental type iii) Absolute type.

i) Tachometer type:

This type of ~~of~~ transducer produces a single pulse train with incrament of the displacement. This pulses can be couted by a digital couter which in turn can be calibrated in terms of displacement in suitable units.

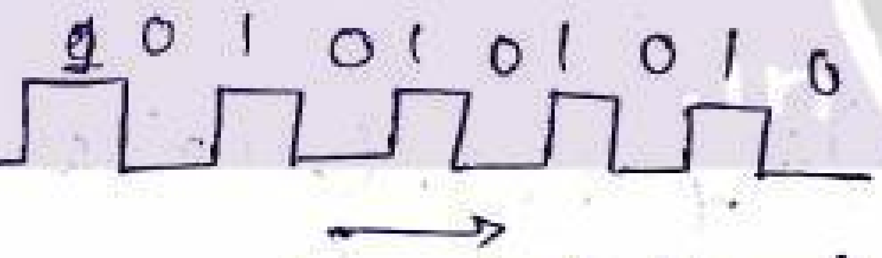


Fig: Coading of tachometer encoder

If motion is in one direction, these encoders are very siriple to measur the corresponding displacement. However any reverse motion will produce identical pulses causing error.

ii) Incremenatal type:

In this type, atleast two or sometimes three, tracks of coding are employed to solve the reverse motion problem.

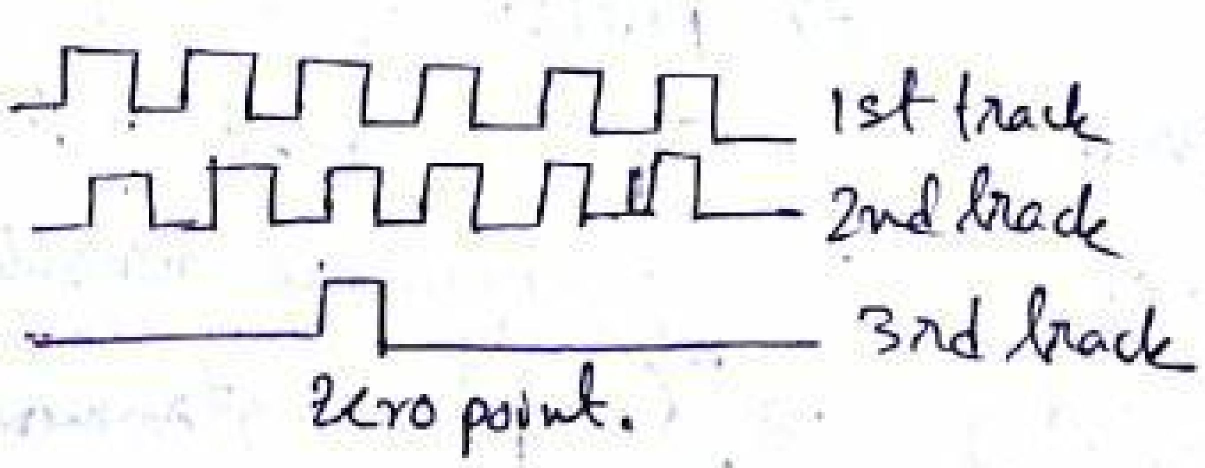


Fig: Coding of an incremental encoder

track 1 and 2 are coded in such a way that there is a phase shift of one-fourth of a cycle relative to other. So the direction of motion can be detected by noting the signal from which track rises first. When third track is incorporated, it is used as a reference track which produces a single pulse per revolution at a distinct point, called zero point.

iii) Absolute type

Such encoders employ four or more bit binary coded strips of or discs ~~as shown~~. Here data from multiple tracks are read out in parallel to produce binary representation of the displacement or angular position.

From measurement point of view, binary code is inconvenient because in this code, a no. of bits change in two consecutive decimal nos numbers. To care of this problem, commercial encoders use grey code where there is only one

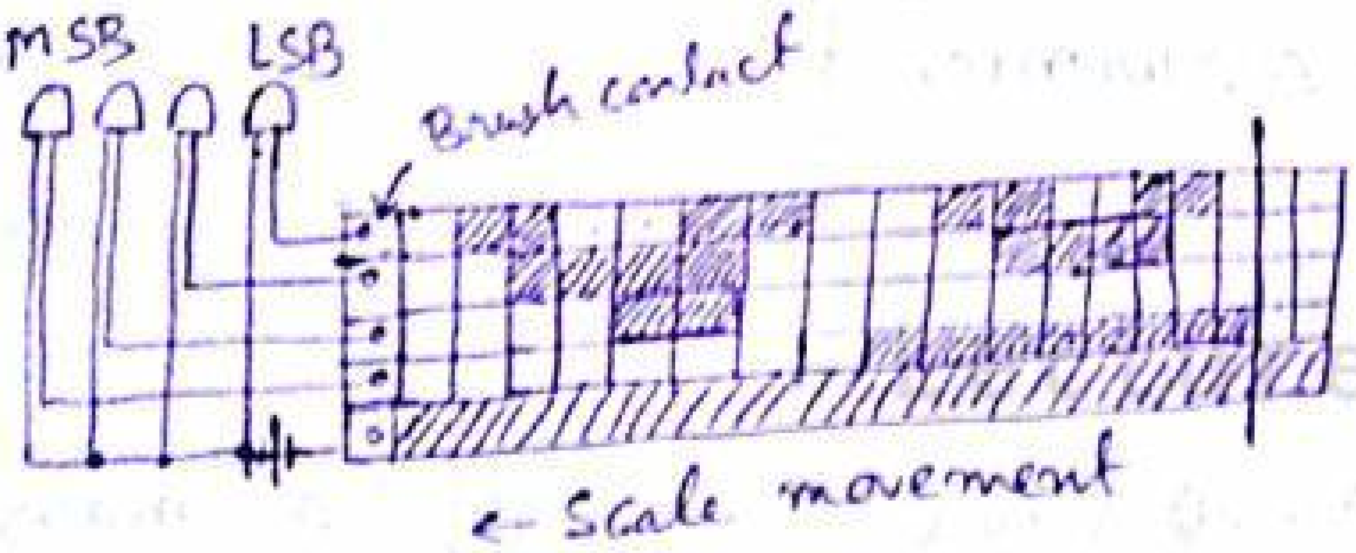


Fig: Digital read out device through brush contact, on a traditional encoder based on Grey code.

bit chang in each transition as a result errors arising due to small misalignment kept small.

Force, Torque, Acceleration and Pressure Sensor

(Acceleration measurment sensors)

The basic instrumentation for measurment of accelera-tion, Force torque and pressure are closely related to the transducers used to measure displacement. Only the configuration and signal processing are different.

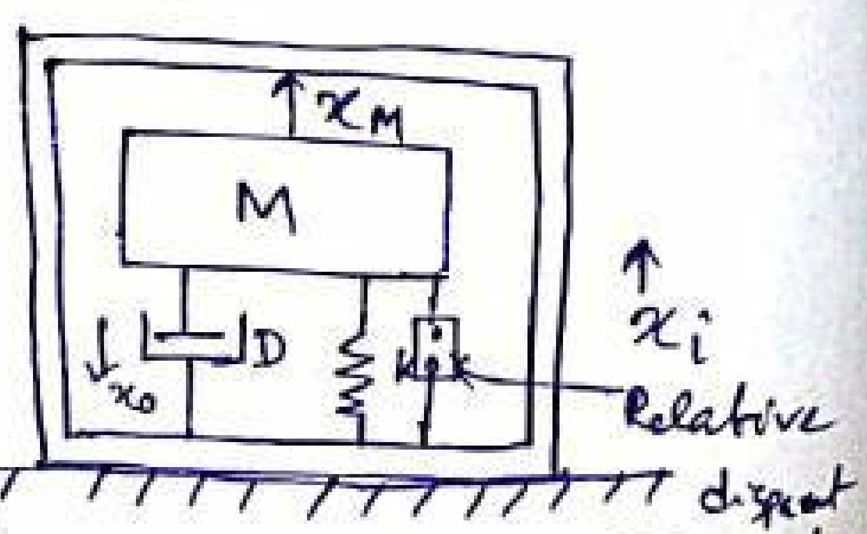
Common practice to measure acceleration is to measure it in multiples of g, the acceleration due to gravity. The product of acceleration and measured mass yields the force. Torque is a twisting force that acts on rotating devices. For the measurment of pressure, it can be easily converted to force by allowing it to act on unit area. There force pressure measurment essentially reduces to force measurment.

Acceleration measurment:

Principle of operation:

In general, accelerometers are consist of a mass M, spring with spring constant K and a damper with damping factor D. Whole ~~sy~~ setup is mounted on the system whose acceleration to be measured as shown

Fig: Spring-mass system accelerometer



At any instance, when the body moves x_i, the displacement of the mass M in the direction of motion is x_M and the relative displacement of the mass in the direction of motion is x_o. By equaling all the given forces acting on M, an equation can be written as –

$$D\frac{dx_o}{dt} + Kx_o = M.\frac{d^2x_M}{dt^2} \quad \text{——} \; (I)$$

Now where $x_o = x_i - x_M$. Substituting $x_M = x_i - x_o$ to eqn-1,

$$M\frac{d^2x_o}{dt^2} + D\frac{dx_o}{dt} + kx_o = M\frac{d^2x_i}{dt^2} \quad \text{——} \; (II)$$

Now, as the accelerometer is attached to the body of measuring subject, displacement (or and thus acceleration) x_i comes in a form of sinosoidal vibration $x_i \sin\omega t$ [ω = freq of vibration]

So, subsequent acceleration becomes $a_i = -x_i\omega^2 \sin\omega t$

Taking the Laplas Transform of equation – II,

$$Ms^2X_o(S) + DsX_o(S) + kX_o(S) = Ms^2X_i(S)$$

or $$\frac{X_o(S)}{X_i(S)} = \frac{Ms^2}{Ms^2 + Ds + K} \quad \text{——} \; (III)$$

$$\frac{X_o(S)}{X_i(S)} = \frac{s^2}{s^2 + D/M\, s + K/M}$$

Substituting $s = j\omega$ (for frequency domain analysis as input is sinosoid)

$$\frac{X_o(j\omega)}{X_i(j\omega)} = \frac{(j\omega)^2}{(j\omega)^2 + D/M(j\omega) + K/M}$$

$$= \frac{(j\omega)^2}{(j\omega)^2 + 2\xi\omega_n(j\omega) + \omega_n^2}$$

where $\omega_n = \sqrt{K/M}$ = Nat freq

$\xi = \dfrac{D}{2\sqrt{KM}}$ = Damping factor

$$\frac{x_0}{x_i}(j\omega) = \frac{(j\omega)^2/\omega_n^2}{(j\omega/\omega_n)^2 + 2\xi(j\omega)/\omega_n + 1}$$

$$\frac{x_0}{x_i}(j\omega) = \frac{j u^2}{-u^2 + j2\xi u + 1} \quad \text{where } u = \frac{\omega}{\omega_n}$$

~~& Solving the~~ From there the amplitude ratio we get is

$$\left|\frac{x_0}{x_i}\right| = \frac{u^2}{\sqrt{(1-u^2)^2 + (2\xi u)^2}}$$

$$\text{or } \left|\frac{\omega_n^2 x_0}{\omega^2 x_i}\right| = \frac{1}{\sqrt{(1-u^2)^2 + (2\xi u)^2}}$$

where $a_i = \omega^2 x_i$ = Amplitude of the acceleration

$$\text{or } \left|\frac{\omega_n^2 x_0}{a_i}\right| = \frac{1}{\sqrt{(1-u^2)^2 + (2\xi u)^2}} \quad \text{--- (IV)}$$

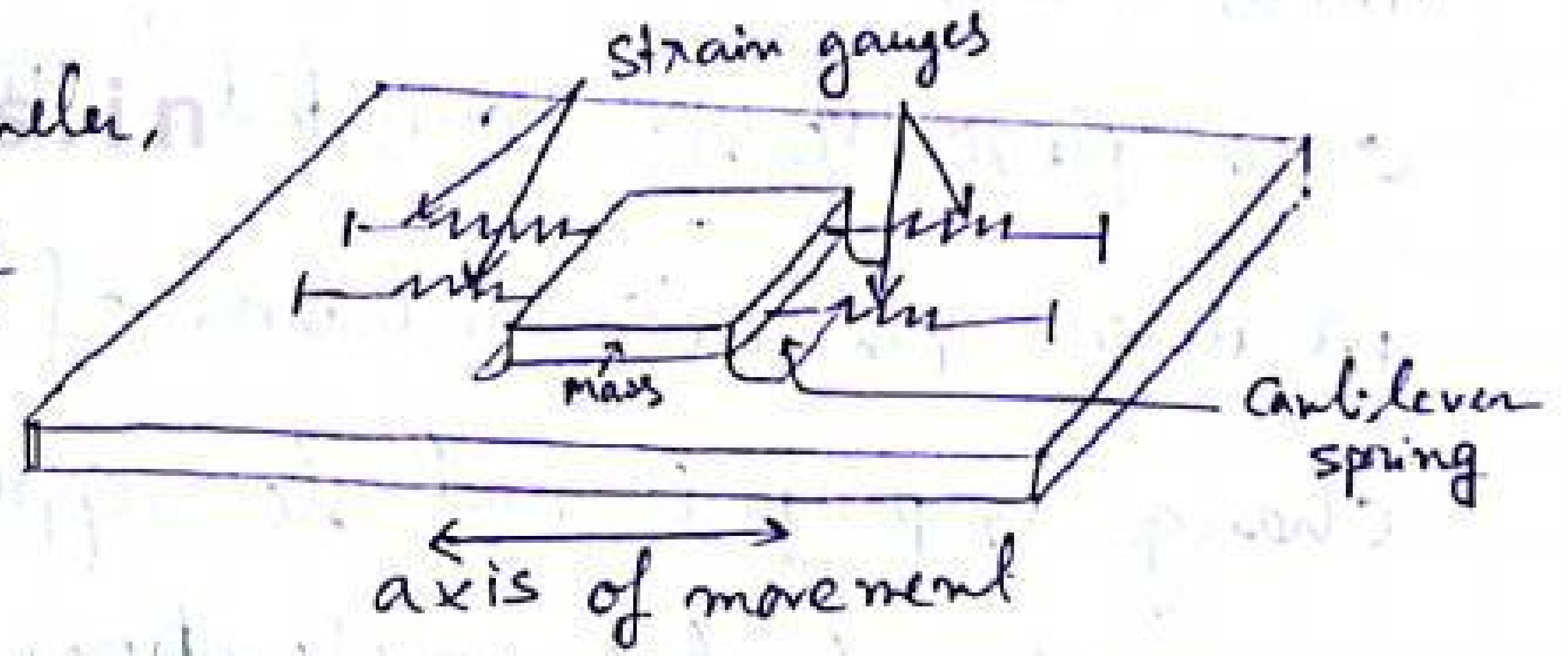
from the equation no. - IV it can be seen that if $\omega < \omega_n$ ie $u < 1$ then it has a little effect on the equation and thus amplitude of acceleration and releative displacement becomes proportional. [Normally u is kept ~~below .4~~ $u < .4$ and $\xi = .7$]. Most of the devices differ in how this displacement is measured.

Based on that, acceleration measurment transducers can be devided into following catagories —

i) Resistive
ii) Capacitive
iii) Inductive
iv) Piezo electric
v) Piezo ~~o~~resistive
vi) Magneto resistive
vii) Thermal.

i> Resistive accelerometer : Resistive accelerometers detect the force imposed on a proof mass when acceleration occurs. The inertia of the mass resists the force of acceleration and thereby causes the physical displacement which can be measured by strain gauges as shown

Fig: Resistive accelerometer, with strain gage sensing the displacement.



When proof mass accelerates, two of the gauges get compressed and other two streched. All four can be connected to ~~four arms~~ form a wheatstone bridge. Damping devices like cantilever spring are used to limit the oscillation.

ii> Capacitive.

In capacitive accelerometers, micro machined capacitive plates form a mass of about 50 µg. As acceleration deforms the plates, a measurable change in ~~eq~~ capacitance results.

iii> Inductive accelerometers An ~~e~~ Inductive type of accelerometer utilises an LDVT to measure mass displacement

In this case LVDT core it self is a sysmic mass. Displacements of the core are directly converted to a linearly proportional ac voltage. These accelero meters generally have a natural freq < 80 Hz and are common ly used for steady state or low freq. vibration measurement.

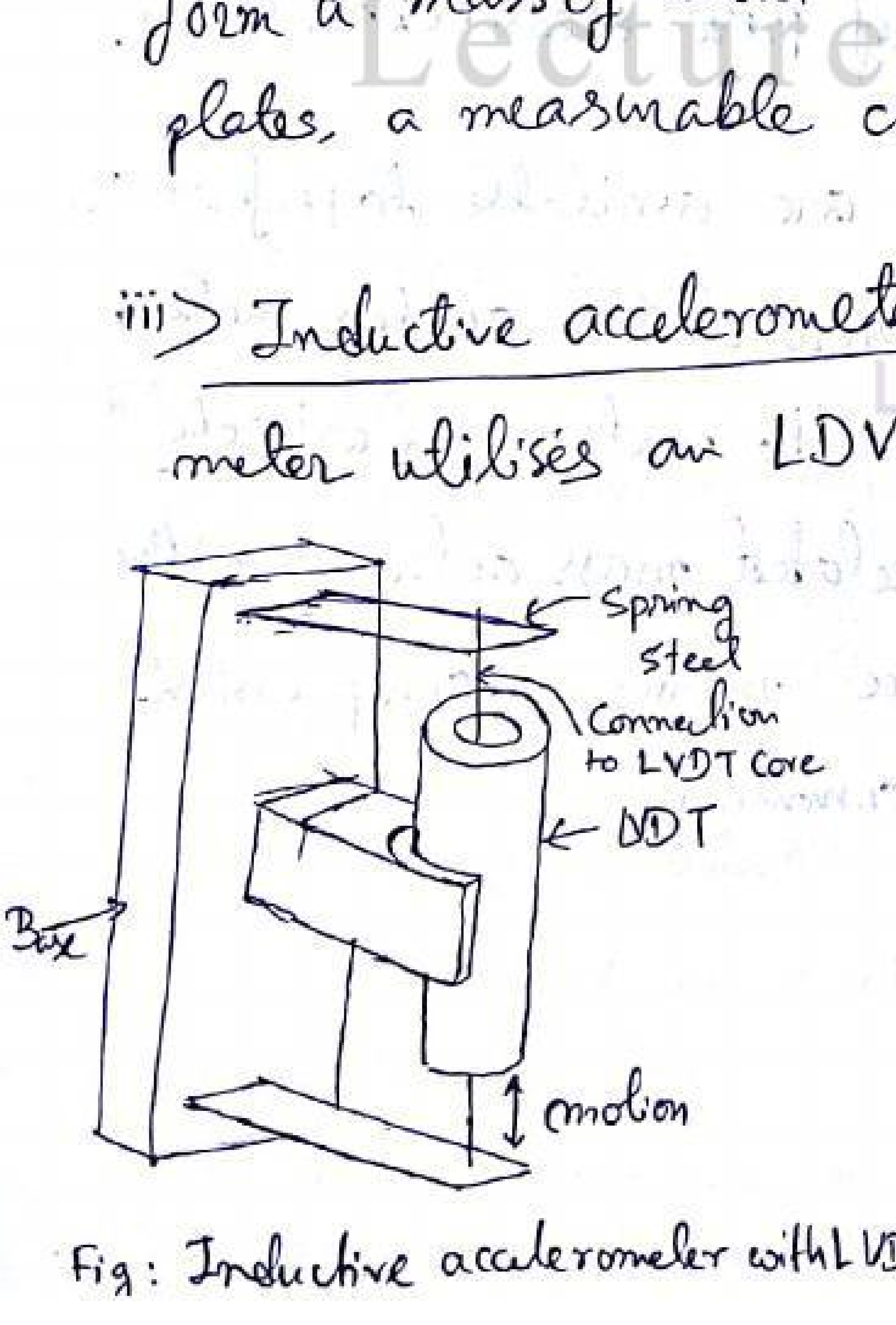


Fig: Inductive accelerometer with LVDT

iv) Piezoelectric Accelerometers:

Piezo electric accelerometers are perhaps the most practical devices for measuring accelerations caused by shock and vibration. The device ~~inde~~ includes a mass that, when accelerated, exerts an inertial force on a piezo electric crystal. The piezo electric effect produces an accumulation of charge on crystal. This charge is proportional to applied force, which in turn is proportional to acceleration.

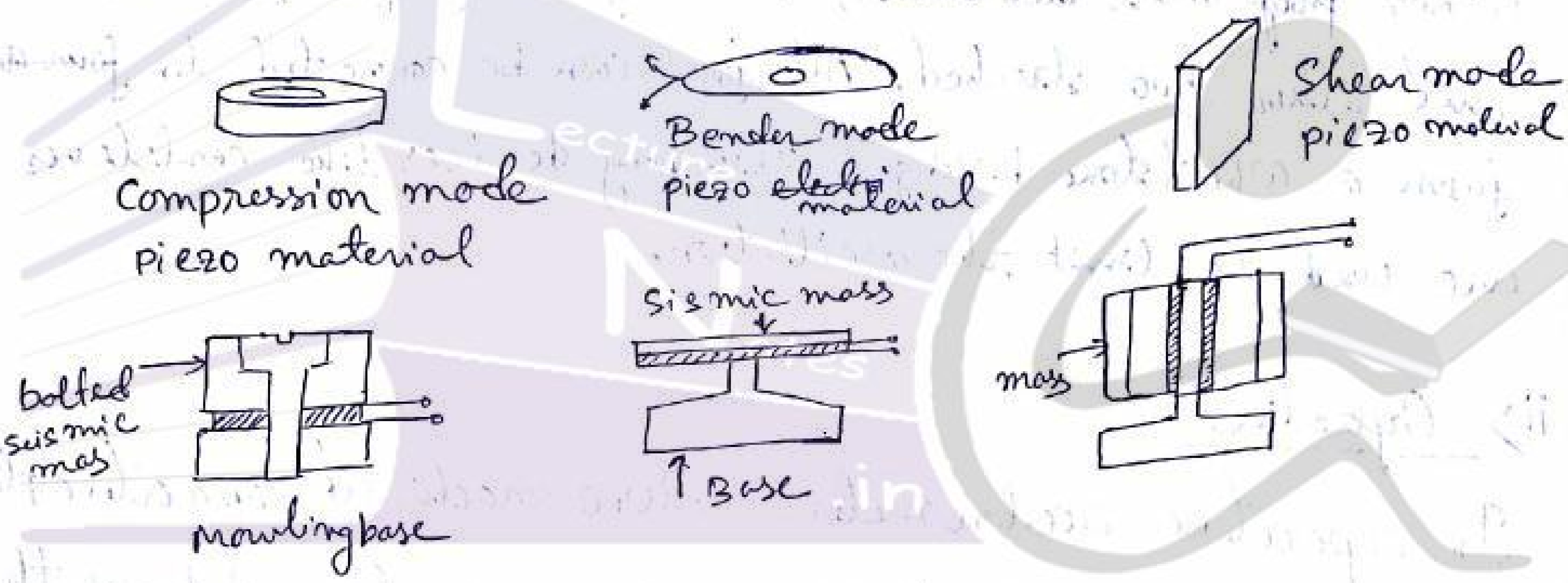


Fig ; Mechanical modes of piezo electric material.

A variety of mechanical modes are available to perform the transduction principles of a piezo electric accelerometers. These modes are defined by the nature in which the inertial force of an accelerated mass acts upon the piezo electric material. Three modes — compression, bending and shear are common.

→ capacitance of a capacitor is directly proportional to the area of plates (A)

$$C \propto A$$

Hence capacitance changes linearly with the change in area of plates, due to this it is used for measurement of moderate to large displacement. [1 mm to 10 mm]

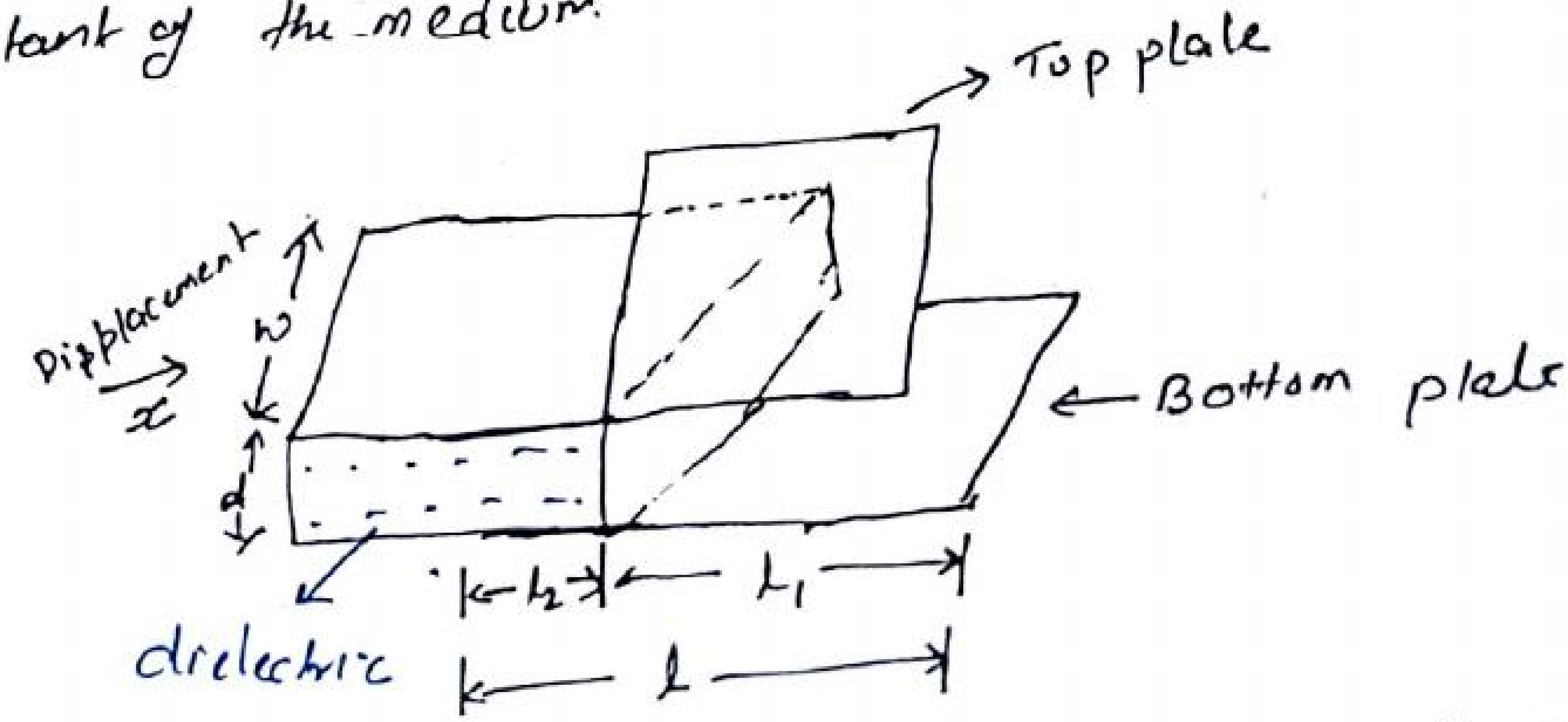
(2) variation of Dielectric constant for Measurement of liquid level:-

The third principle of capacitive transducer is the variation of capacitance due to change in dielectric constant b/w the plates. It is used for measurement of linear displacement.

$$\text{Since} \quad C = \frac{\varepsilon A}{d}$$

$$C \propto \varepsilon$$

Hence capacitance is directly proportional to the dielectric constant of the medium.



dielectric having a refractive permittivity = ε_r

permittivity of free space = ε_0

Initial capacitance of the transducer

$$C = \varepsilon_0 \frac{w l_1}{d} + \varepsilon_0 \varepsilon_r \frac{w l_2}{d}$$

$$= \varepsilon_0 \frac{w}{d} [l_1 + \varepsilon_r l_2]$$

Let the dielectric moved through a distance 'x' in the direction indicated. The capacitance changes from C to C+ΔC;

$$\therefore C + \Delta C = \varepsilon_0 \frac{w}{d}(l_1 - x) + \varepsilon_0 \varepsilon_r \frac{w}{d}(l_2 + x)$$

$$= \varepsilon_0 \frac{w}{d}(l_1 - x + \varepsilon_r(l_2 + x))$$

$$= \varepsilon_0 \frac{w}{d}(l_1 + \varepsilon_r l_2) + \varepsilon_0 \frac{wx}{d}(\varepsilon_r - 1)$$

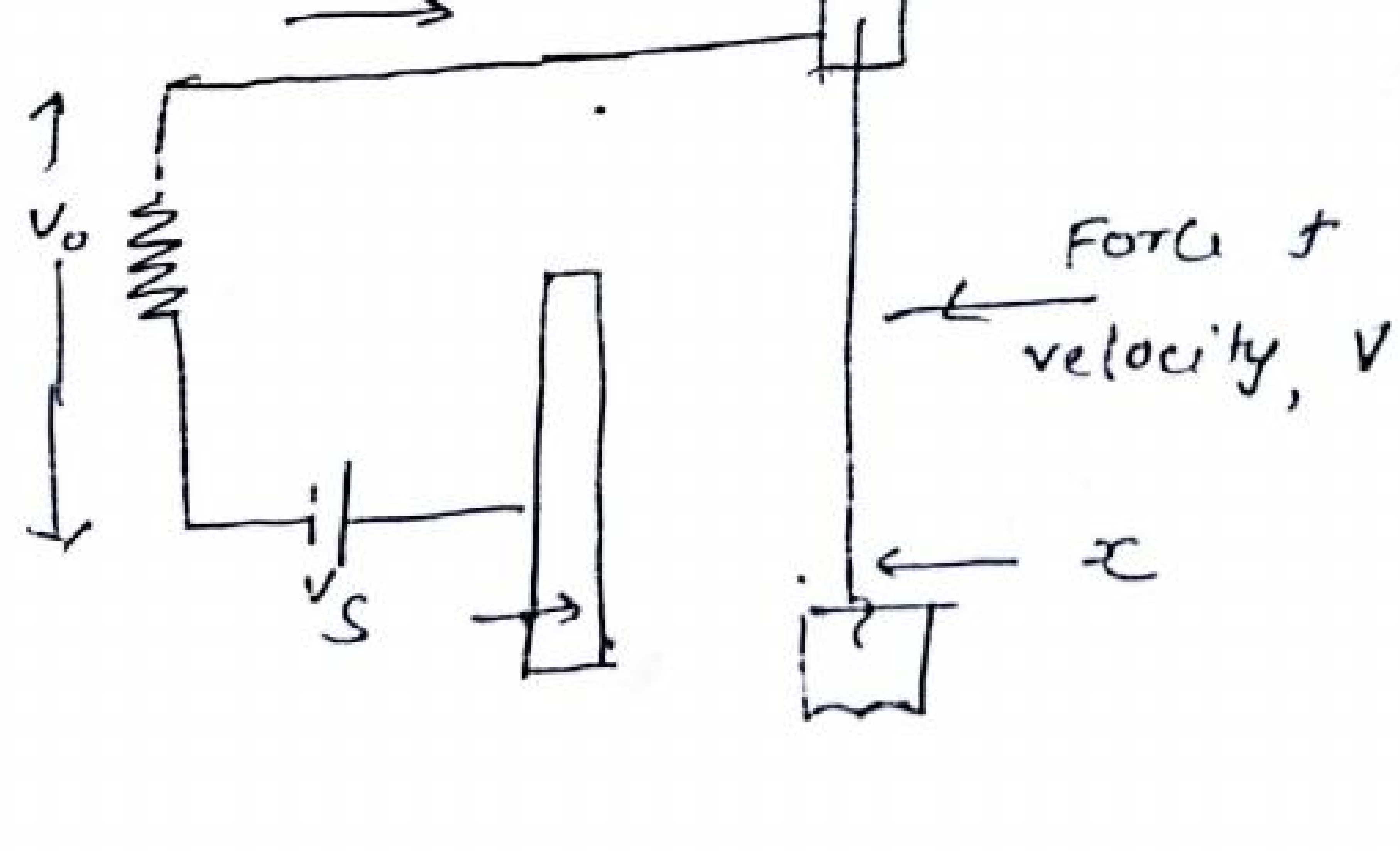
$$= C + \varepsilon_0 \frac{wx}{d}(\varepsilon_r - 1)$$

change in capacitance:

$$\boxed{\Delta C = \varepsilon_0 \frac{wx}{d}(\varepsilon_r - 1)}$$

Hence, it can be seen that change in capacitance is proportional to displacement.

Electrostatic :-



→ This type of transducer is developed with bilateral - characteristic where it is used with dc polarization.

→ A capacitor is formed with a flexible diaphragm which can move due to application of force and rigid plate P_1. There is a bias voltage 'V_s' which is sufficiently large. When the system acts as a transducer, the gap 'x' between the plates changes as by some pressure. This pressure may be considered sinusoidal in nature for analysis purpose. A circuit consisting of a resistance 'R' and capacitance 'C' varying sinusoidally allows 'V_s' to send a sinusoidal current 'i' to flow in it and hence a sinusoidal output 'V_0' across resistance 'R' is obtained.

→ In case of generating action along with bias V_s, a sinusoidal i/p voltage is also applied so that diaphragm undergoes electrostatic vibration.

Piezoelectric and its family:—

→ A piezoelectric material is one in which an electric potential appears across certain surfaces on a crystal if the dimension of crystal are changed by the application of a mechanical force. This potential is produced by the displacement of charges.

The effect is reversible i.e conversely, if a varying potential is applied to the proper axis of the crystal it will change the dimension of crystal thereby deforming it. This effect is known as piezoelectric effect. Elements exhibiting piezoelectric qualities are called as electroresistive element.

→ The piezoelectric effect can be made to respond to (or cause) mechanical deformation of material in many different modes. These modes can be thickness, expansion, transverse expansion, thickness shear. The mode of motion affected depends on the shape of the body relative to the crystal axis and location of electrode. A piezoelectric element used for converting mechanical motion to electrical signal so it may be defined as charge generator.

PZT Family :-

The material that exhibit a significant and useful piezoelectric effect are divided into two categories:-

→ Natural Group
→ Synthetic group.

→ Quartz and Rochelle salt belong to natural group while material like sulphate, ethylene, diamine tartrate belong to synthetic group.

→ The compound of solid solution system $PbZrO_3 - PbTiO_3$ called PZT show strong piezoelectric effect. The piezoelectric properties depend on Ti/Zr ratio.

→ PZT as piezoelectrics are applied in developing ultrasonic motors and ultraprecision grinders

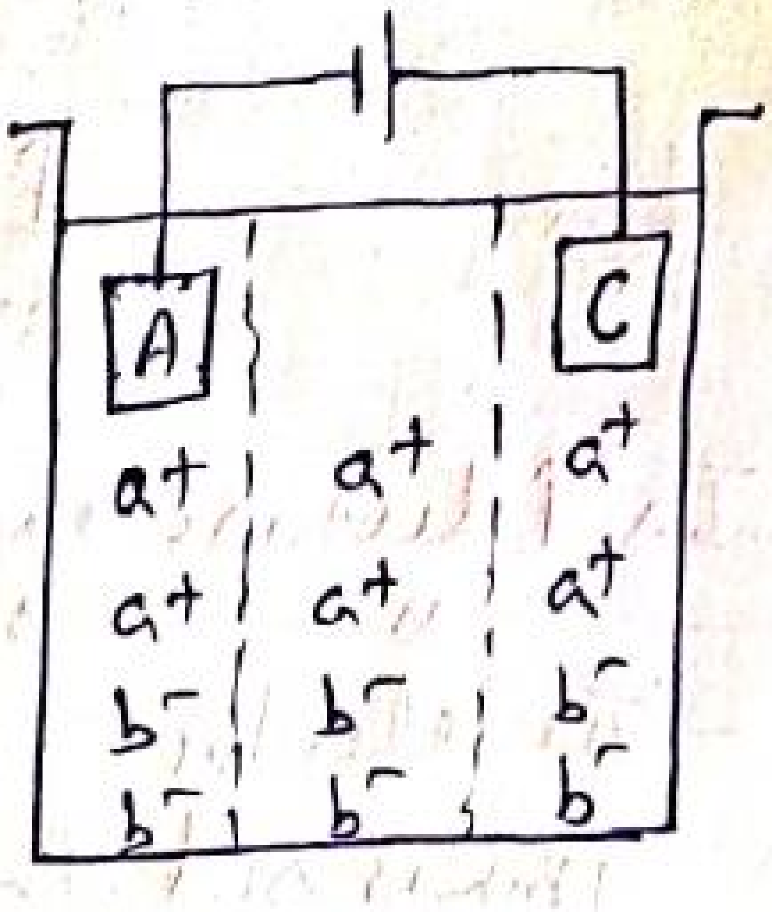
UNIT-III A

Electroanalytical Sensors

The Electrochemical Cell

- The electrochemical cell consists of two electrodes immersed in suitable electrolyte solution. The cell functions if these electrodes are connected externally by metal conductors and internally, the electrolyte solutions are in contact so that ion movement can take place between them.
- Electrodes are known as anode and cathode where oxidation and reduction respectively take place.
- Oxidation and reduction are interfacing mechanisms where the ionic conduction of the solution is coupled to the electronic conduction of electrode (metal) and hence, an electrical circuit completed.
- Each cell consists of two half-cells where each half-cell is said to be consisting of its electrode and electrolyte solution. If the electrolytes of the two half-cells are different in composition, they are not allowed to mix as this would decrease cell efficiency because of deposition, recombination
- Electrolytes in anode & cathode ~~components~~ compartment are often separated by a salt bridge that is created when chemical reaction takes place in cell. ~~Salt~~
- In cell left part contains the anode and its associated solution and cathode with its solution as well as its states are on right.
- Any salt bridge is indicated by a discontinuous line

- The reaction in a cell occur in two phases –
  1) the electronic ones at metal electrode interfaces
  11) ionic ones at the electrolyte level



$a^+ \rightarrow H^+$

$b^- \rightarrow Cl^-$

At cathode $\quad M_1^{k+} + 2e \rightleftharpoons M_1(s)$

At anode $\quad M_2(s) \rightleftharpoons M_2^{k+} + 2e$

Net cell reaction –

$$M_1(s) + M_2^{k+} \rightleftharpoons M_1^{k+} + M_2(s)$$

- At electrolytes, ionic movement takes place. The ions have different mobility. Speed of an ion depends on its relative concentration & also on its inherent mobility.
- In HCl, H^+ being five times more mobile than Cl^- ion, current is largely contributed by it i.e $5/6$th by H^+ and only $1/6$th by Cl^-.
- After current flow, ion distribution will be different in three compartments.
- The direct current flowing in a closed cct cell follows Ohm's law except when polarization occurs.
- For dc current to flow with a dc potential applied between the electrodes, oxidation and reduction at anode & cathode occurs. Such a process is called faradaic process.

- When an ac potential is applied, the process is reversed every half cycle and then either positive or negative ions are attached to the electrode surface. Electrical energy is thus consumed and converted to heat because of this ionic movement.

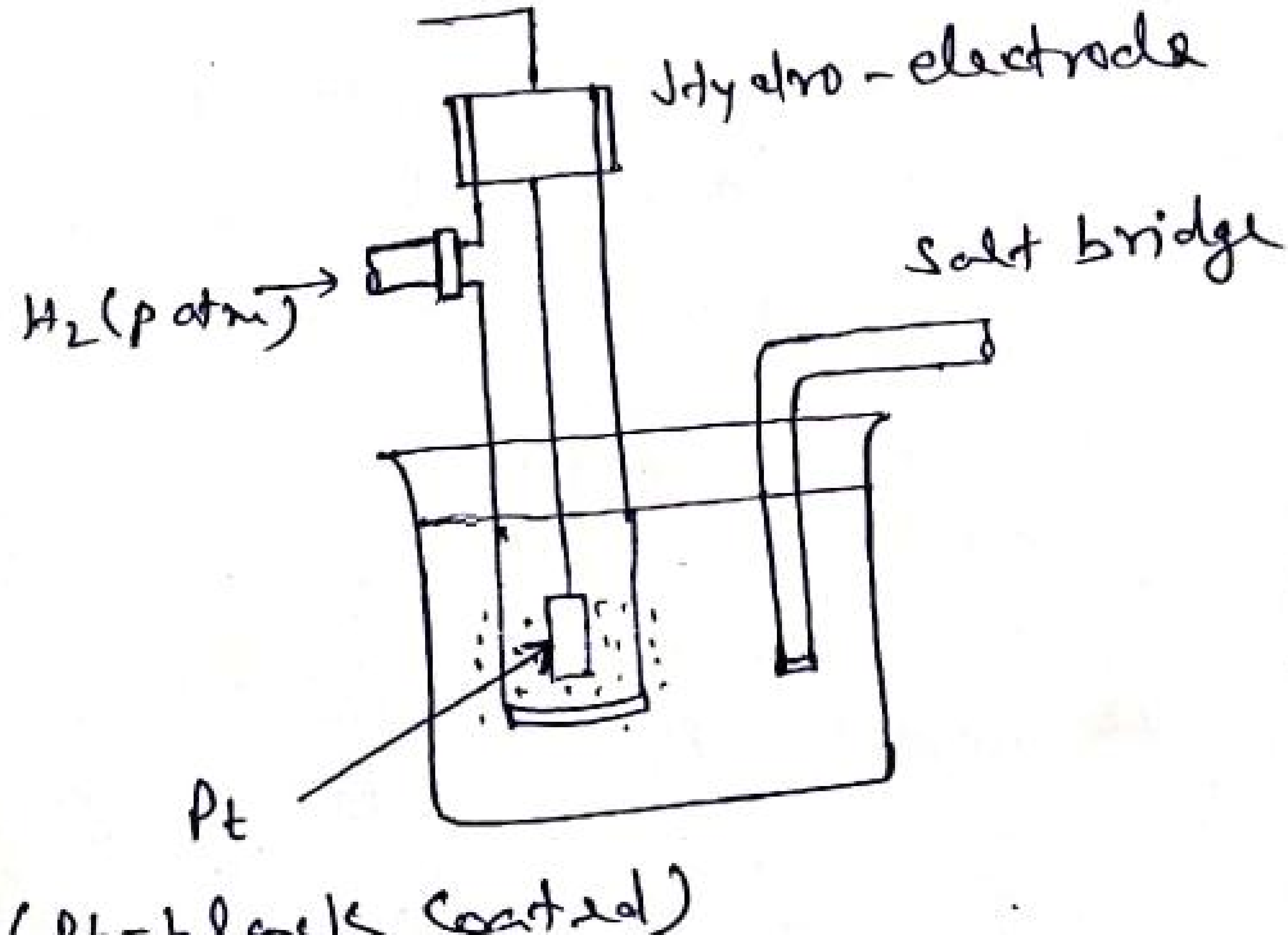
Each electrode surface thus behaves as a capacitor plate with the current increasing with surface area (capacitance) and frequency. This process is a nonfaradaic process.

- Electrochemical cell can be reversible and nonreversible.
- When external source potential is greater than cell voltage E, with negative of source connected to anode, a reversal in electron flow and so reversal of chemical reaction and so cell is called chemically reversible.

SHE

SHE (Standard Hydrogen Electrode)

- Since absolute potential of a half-cell is not
measurable and it is the potential difference
that is measured, a second half-cell has to be
formed. If this second half cell can be made as
a common reference electrode, this measured value
would be available as a relative one but with respect
to ~~relative~~ a standard reference. Such a standard
reference is the standard hydrogen electrode whose
cell potential has been standardized by assignment.
- SHE is not easily reproducible so secondary
standard electrodes or reference electrodes are
used and measured potential are easily converted
to hydrogen reference standards.
- SHE is considered as primary standard. Its
standard half reaction at $25°C$, E^0 has been
assigned a value exactly 0 volts by international
agreement, assuming activity of H^+ and fugacity
(partial pressure) of $H_2(g)$ are 1 and the
relation is $2H^+ + 2\bar{e} \rightleftharpoons H_2(g)$



Structure of Hydrogen electrode

- The platinum electrode uses a platinum foil coated with platinum black to provide a large surface area and a reversible reaction (eq-1) rapidly proceeds, with the solution near electrode kept saturated with respect to the gas.
- Electrode can be either an anode or cathode with hydrogen being oxidized to hydrogen ~~gas~~ ions or vice versa.
- For measurement of potential, two things are of importance i) sign of electrode potential
  ii) value of std. electrode potential
- sign is determined by specific use of electrode anode or cathode. If anode is used from which
- ~~If~~ electrons flows through external ckt to SHE, this would be (-)ve terminal of galvanic cell and its std. electrode potential (SEP) is negative.
- International Union of Pure and Applied Chemistry (IUPAC) specifies that relative external potential is reserved for half reactions as reductions.

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Polarization :-

With electrode potential being constt, cell potential E_{cell} should be linearly related to cell current I.

$$E_{cell} = E_{cathode} - E_{anode} - IR$$

But sometimes nonlinearity arises due to polarization mainly. Due to which (polarization), ~~cur~~ reduction of current or corresponding voltage takes place.

Types - four types

Concentration Polarization :-

- Oxidation - reduction at electrode surface can occur normally when movement of OX and/or Red species across / bulk of electrolyte by mass transfer is normal. If not, reaction rate and correspondingly the current decreases. This is due to concentration polarization.

- Reaction Polarization :-

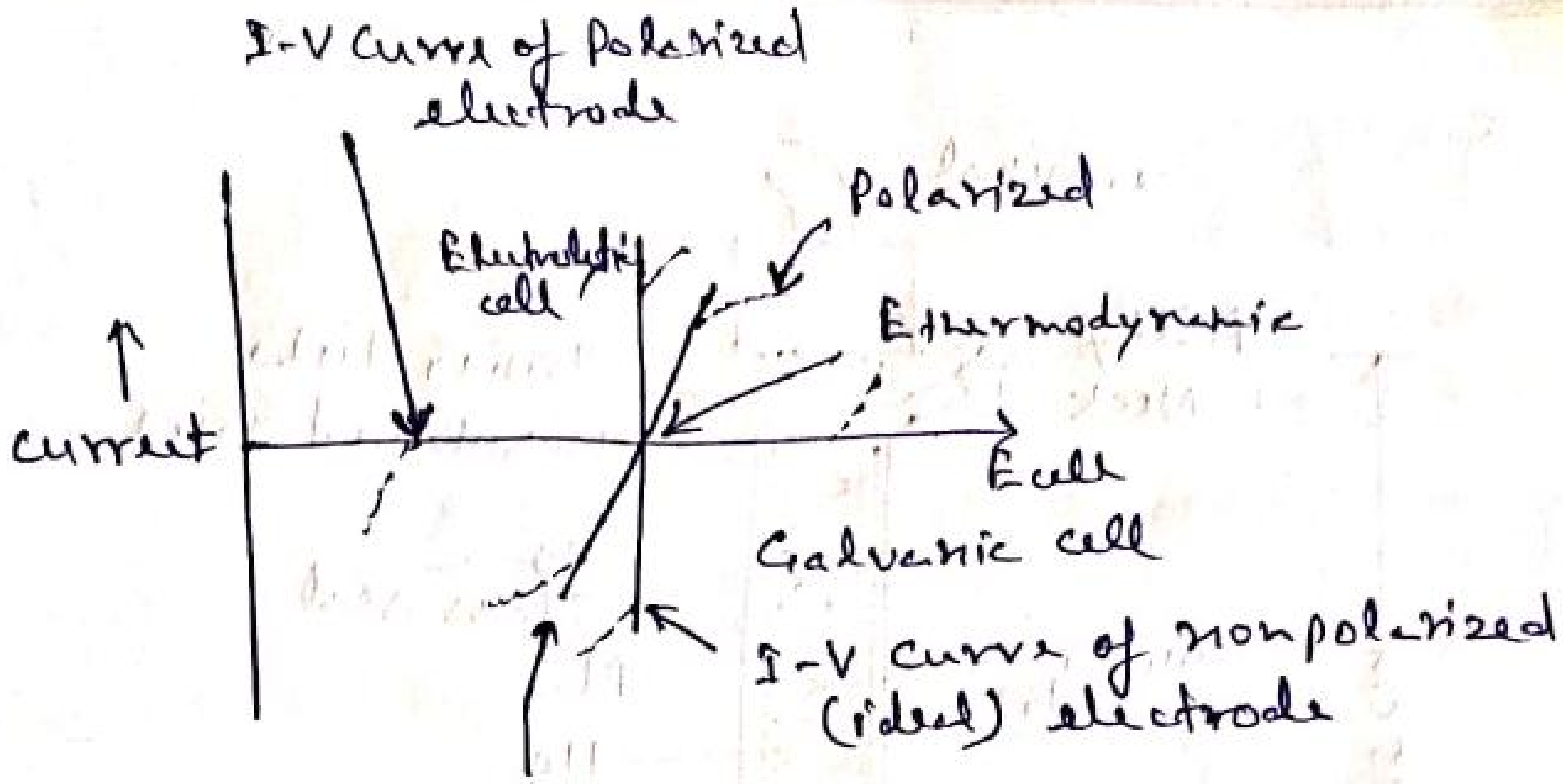
If there is any intermediate chemical reaction in any half-cell for producing 'ox' or 'Red' species that travel to electrodes and participate in electron transfer, this formation of species at intermediate stage is not normal. This is known as Reaction Polarization.

- Adsorption / desorption / crystallization Polarization :-

Sometimes the current is limited by the process as adsorption or crystallization of reactants and hence the name.

- Charge transfer Polarization

Charge transfer takes place from electrode to oxidized species or from reduced species to the electrode. Often, the rate of charge transfer is reduced because of the existance of a charge surface film around the electrodes. This is called charge transfer polarization.



$E_{cell} = E_{thermodynamic} - IR$.

Polarized and Unpolarized Condition of Cell

Reference Electrodes

- Ref. electrodes are required to have a known and constt half-cell potential unaffected by solution composition. Their properties can be listed as they must-
- have known constt potential and follow Nernst eqn.
- have reversible cell reaction
- have little or no hysteresis with temp and small current cycling
- be non polarized

→ Some ~~commonly~~ commercially used electrodes are-

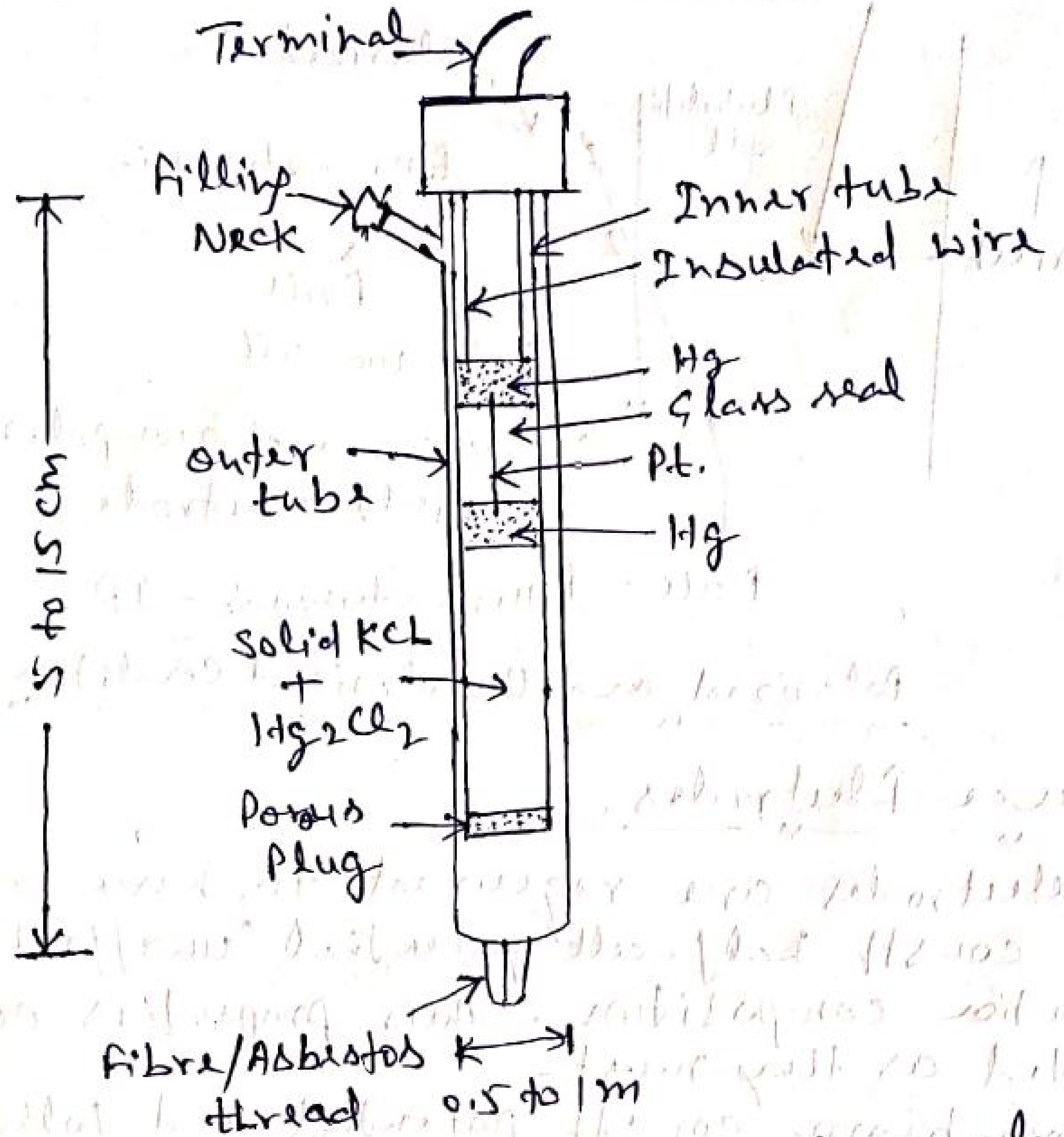
* Saturated calomel electrode (SCE)
* Silver / Silver chloride "
* Thallium / thallouschloride electrode

Fig. shows SCE. The chemists' nomenclature for electrode ~~is~~ junction is given by-

$Hg(l) \,|\, Hg_2Cl_2(std), KCl(aq) \,||$

The corresponding electrode reaction is

$Hg_2Cl_2(s) + 2e \rightleftharpoons 2Hg(l) + 2Cl^-$



The electrode consists of an inner glass/plastic tube containing Hg, Hg_2Cl_2, and KCl. This tube dips into a saturated solution of KCl and Hg_2Cl_2 (calomel) contained in an outer tube made of same glass/plastic material. The junction to the other half-cell for electrical continuity is made through a fibre of quartz or asbestos, a crack a ceramic plug, ~~or~~ a glass sleeve. Pt wire is used for external connections. Provision for refilling with KCl/aqua is also there.

- The glass sleeved or ceramic plug junction type design has lower impedance than fibre type where o/p impedance may be as high as 3kΩ.

The electrode potential at 25°C for different concentrations of KCl is tabulated as -

KCl	Saturated	4.0M	3.5M	1M	0.1M
Eelectro(V)	0.244	0.246	0.250	0.280	0.336

KCl concentration versus electrode potential.

Sensor Electrodes

→ Sensor electrodes or Indicator electrodes are of two kinds - a) Metal b) Membrane

Metal Electrodes

Metal Electrodes are similar to reference electrodes which can be subclassified as

1) First kind Electrode :- Such an electrode is in direct equilibrium with the cation derived from electrode metal. Denoting metal with M,

$$M^{k+} + ke \rightleftharpoons M(s)$$

the electrode potential is given by std. eqn -

$$E = E^0_M - \frac{0.0591}{k} \log \frac{1}{M^{k+}}$$

$$= E^0_M - \frac{0.0591}{k} pM$$

where pM denotes the negative logarith of M-ion concentration.

metals in this category are Cu, Zn, Ag, Hg, Cd, Pb. They show reversible oxidation-reduction behaviour.

II) Second kind Electrode :- This electrode is responsive to concentration of an-ion and its own ion makes precipitate with it or forms a complex ion.

Ag can be used as second kind electrode with respect to halide ion and for measurement purpose, the surface layer of analyte has to be saturated with AgCl.

$$AgCl(s) + e \rightleftharpoons Ag(s) + Cl^-$$

$$E = 0.222 - 0.0591 \log [Cl^-]$$

III) Third Kind Electrode :-

It responds to a different cation under certain circumtances. Hg-electrode can be used to determine the cation concentration in solution containing calcium. This is possible by introducing a complex of calcium and maintaining a certain concentration of the complex for standardization. The chain of process makes electrode a third type.

IV) Redox Electrode :-

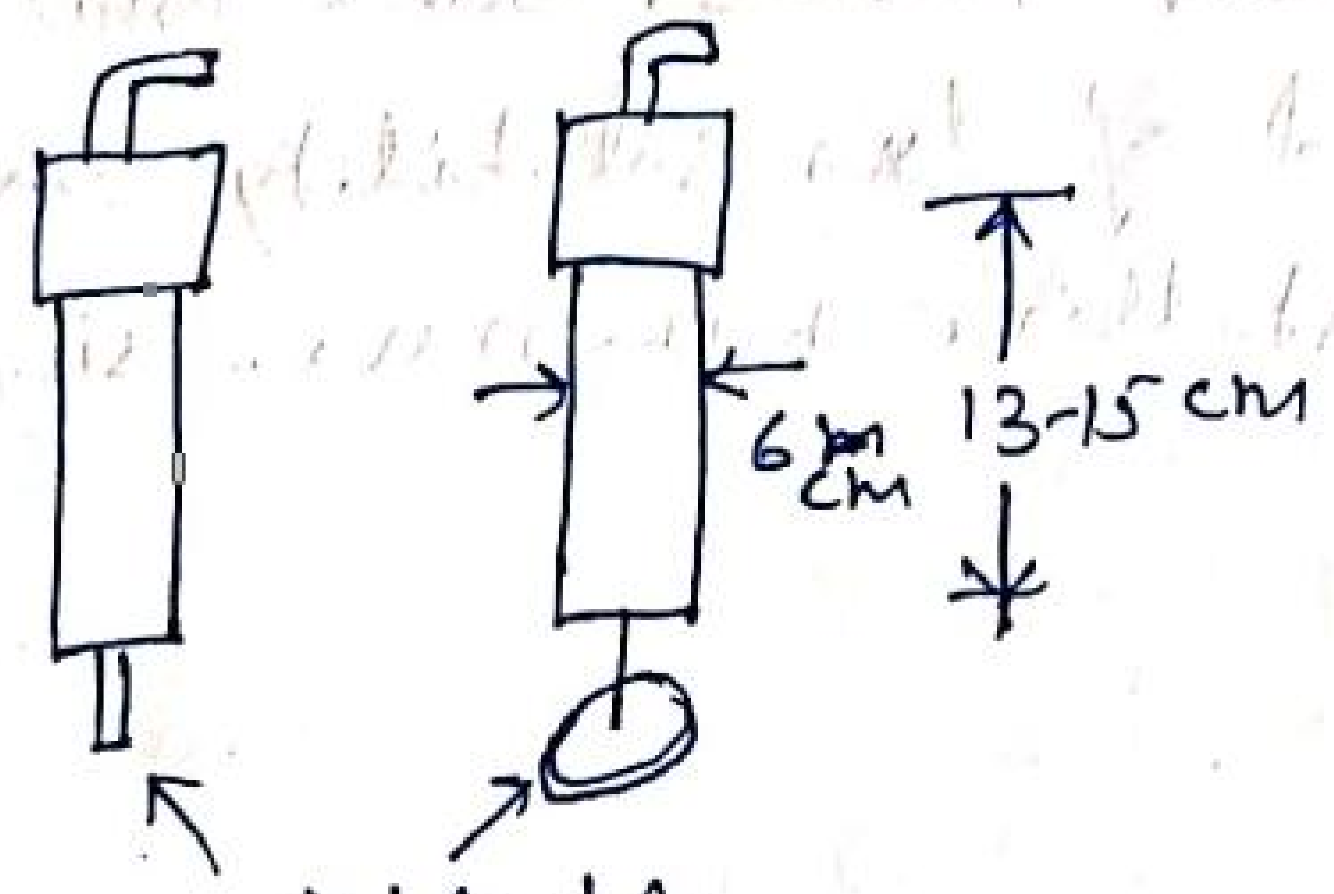
An electrode made of inert metal, is immersed in a solution containing a substance in reduced or oxidized state; the electrode would require a potential depending on the tendency of ion in solution to pass from a higher to a lower state of oxidation or from a lower to a higher state of oxidation.

- If the solution has a reducing property, the ions will tend to be oxidized losing electrons to the electrodes and it becomes negatively charged with respect to the solution.
- The case reversed if the solution has oxidizing property.
- The potential value will be a measure of oxidizing or reducing power of solution whereas sign gives the actual characteristics

With α_+ as the activity of the oxidized ion and α_- that of reduced ion, electrode potential.

$$E = E^0 - \frac{0.0591}{n} \log\left(\frac{\alpha_+}{\alpha_-}\right)$$

- Platinum or gold is often chosen as electrode metal but choice depends on solution concerned.
- Metal should not be attacked by solution, nor should it catalyse side reaction.



Rod type Plate type

Membrane Electrodes:-

- Membrane electrodes are of two different type
  a) Ion-selective b) Molecular Selection type.

→ Ion selective — Non crystaline membrane
- Crystaline "

→ Molecular Selective - Gas sensing type
- Enzyme substrate type

Ion selective membrane electrode

- Ion selective membranes must have some electrical conductivity which occurs due to ion transfer or exchange.
- Membrane should be so constituted that it must be capable of binding the analyte

ion selectivity.

The bindings are three types.

1) Ion-exchange 2) Crystallization 3) Complexation

- Membrane should not dissolve to any extent in analyte solution.

- Membrane should be made of silica glasses, or polymer resins. Some ionic inorganic compound of low solubility can also be used as crystalline membrane, single, poly or mixed.

-

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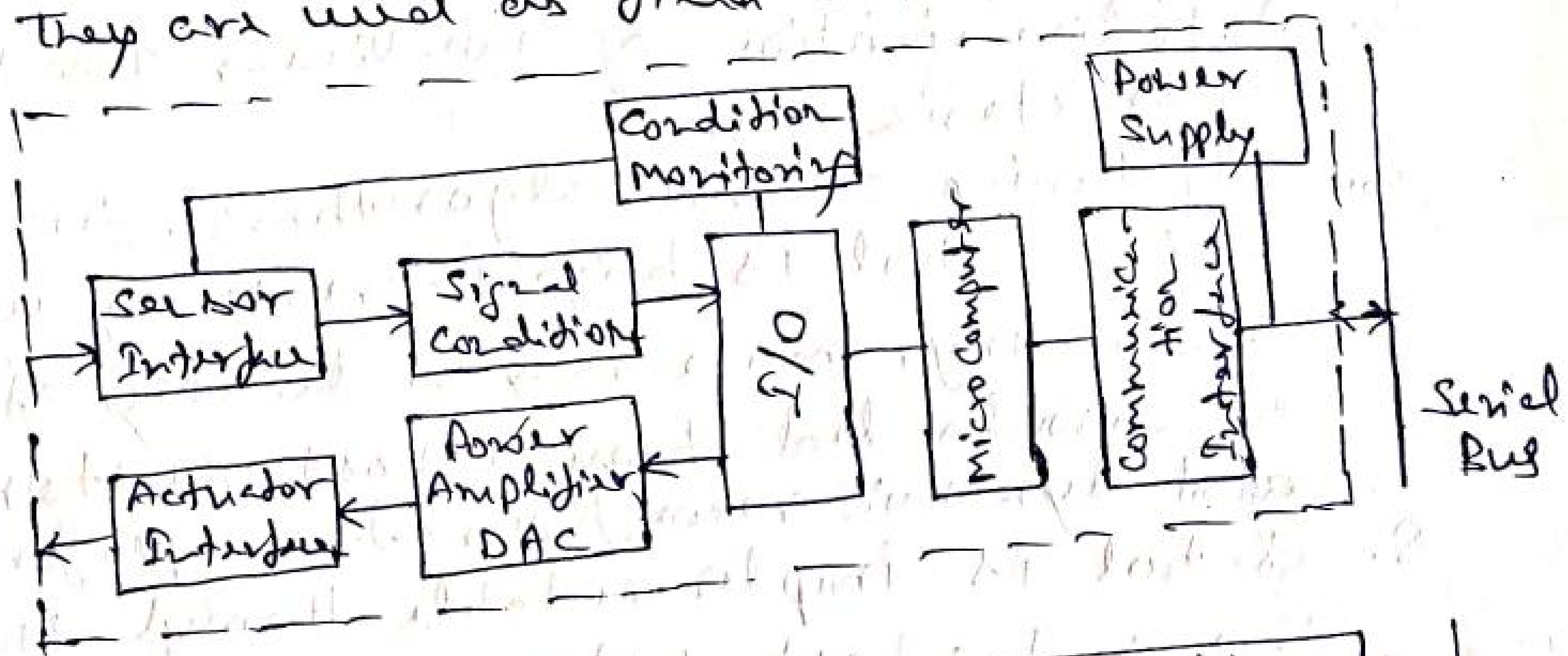
→ Electroceramic - Notes - made self

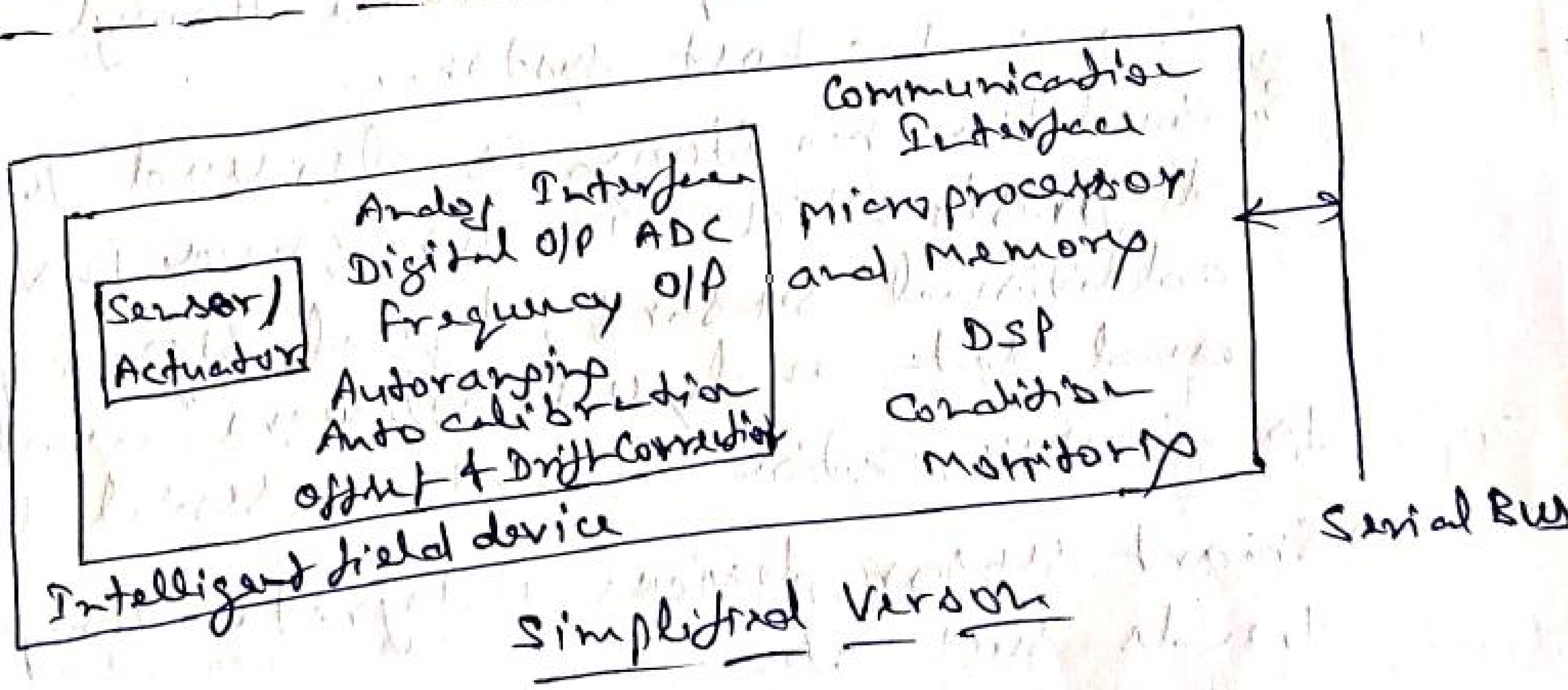
UNIT III B

Smart Sensors

- A sensor producing electrical output when combined with interface electronic circuits is said to be an intelligent sensor / smart sensor if the interfacing circuits can perform
a) ranging b) calibration c) decision making for communication and utilization of data.

Both sensors and actuators are used as intelligent components of instrumentation systems. They are used as field devices.





Simplified Version

- An intelligent field device possesses following properties :-

1. Automatic ranging and calibration through a built-in digital system.
2. Auto-acquisition and storage of calibration constts in local memory of field device
3. Auto configuration and verification of H/Ware for correct operation following internal checks.
4. Autocorrection of offsets, time, and temp drifts.
5. Auto linearization of nonlinear transfer characteristics.
6. Self tuning control algorithms, fuzzy logic control is being increasingly used now.
7. Control programme may be locally stored or downloaded from a host system and dynamic reconfiguration performed.
8. Control is implementable through signal bus and a host system.
9. Condition monitoring is also used for fault diagnosis which, in turn, may involve additional sensors, digital signal processing, and data analysis software and
10. Communication through a serial bus.

→ Smart sensor devices integrate complementary trends such as -

a) new sensing methods
b) improved computing capabilities
c) digital communications.

Film Sensors

Basically such sensors are produced by film deposition of different thickness on appropriate substraits. The deposition techniques used are different for thick and thin film sensors.

- Sensor produced through these techniques have varying electrical and mechanical properties while a variable is being sensed.

Thick film Sensors

- Thick film deposition is a mature technique and there has not been substantial improvement.
- Thick film process of sensor can be expressed as-

Step-1 - Selection and preparation of a substrate

Step-2 - Preparation of the initial coating material in paste or paint form

Step-3 - Pasting or painting the substrate by the coating material or screen printing it.

Step-4 - firing the sample produced in step-3 in an oxidising atmosphere at a programmed temperature format.

- Substrates are alumina (96% or 99.5%) and beryllia (99.5%). These are fired about 625°C.
- Other substrates are low carbon steel coated with low alkali and are fired at 850°C.
- Alumina or beryllia have dielectric constt 9.5 & 7 with dielectric strength 5600 V/mm.
- Thermal expansion constt are 6.5×10^{-6} & 7.5×10^{-6} with bulk resistivity for both $10^{14} \Omega$c
- Thermal conductivity - 0.36 & 2.5 W/cmK

Enamelled steel has better strength & machine (double of Alumina) and has improved thermal conductivity, less costly.

- Sensors which are produced through thick film deposition (~20 μm) are used for sensing temp., pressure, gas concentration & humidity.

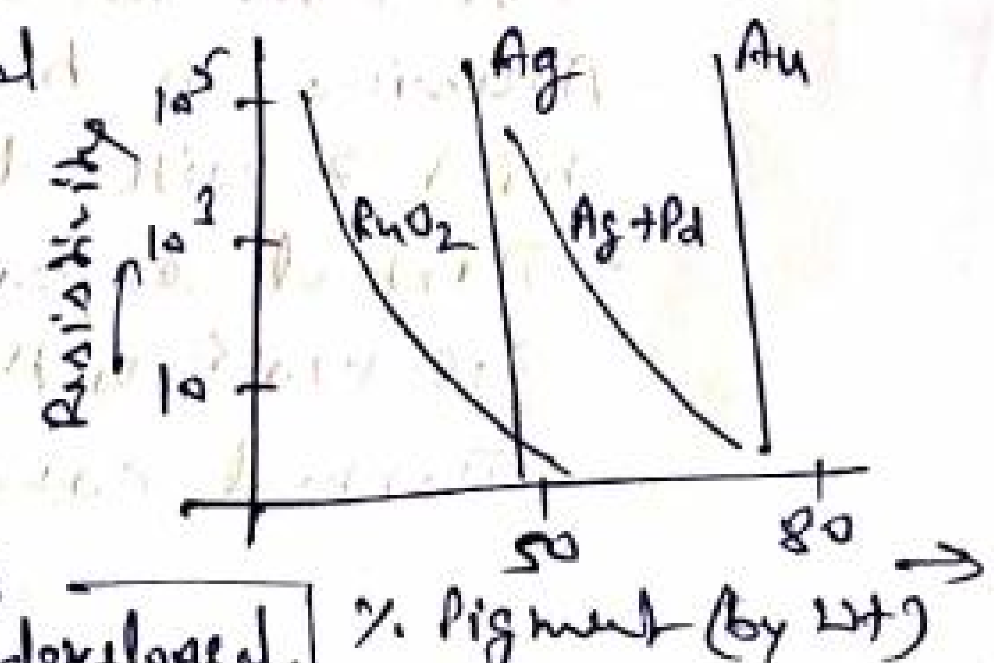
<u>Temp.</u>:- Thick film sensor as (I) Thermopile (Gold and Gold-platinum alloy) (II) Thermistors (oxides of Mg & Cobalt (III) Temp. dependent resistors (Gold, Platinum Nickel)

<u>Pressure</u> - Thick film diaphragms or capacitive devices made with Alumina (Al_2O_3) or Piezoresistive devices

<u>Concentration of gases</u>:- CH_4, CO can be checked for concentration using films of SnO_2 + Pb.

<u>Humidity</u>:- Sensed by (I) Resistive film made of RuO_2 (II) Capacitive films made of Al_2O_3

- For control of the porosity of the film which determine the overall sensor sensitivity, organic materials are added in a selective matter.
- The other thick film variety is ceramic-metal or cermet which consists of gold/silver/palladium based oxides in an insulating medium.
- Thick film resistors of cermet require precise control of heat treatment.
- Pure metal powder and resistor pigments differ in so far as changes in their resistive values are concerned and hence embedding in % wt changes the resistivity of sensor developed.



Thin film Sensors

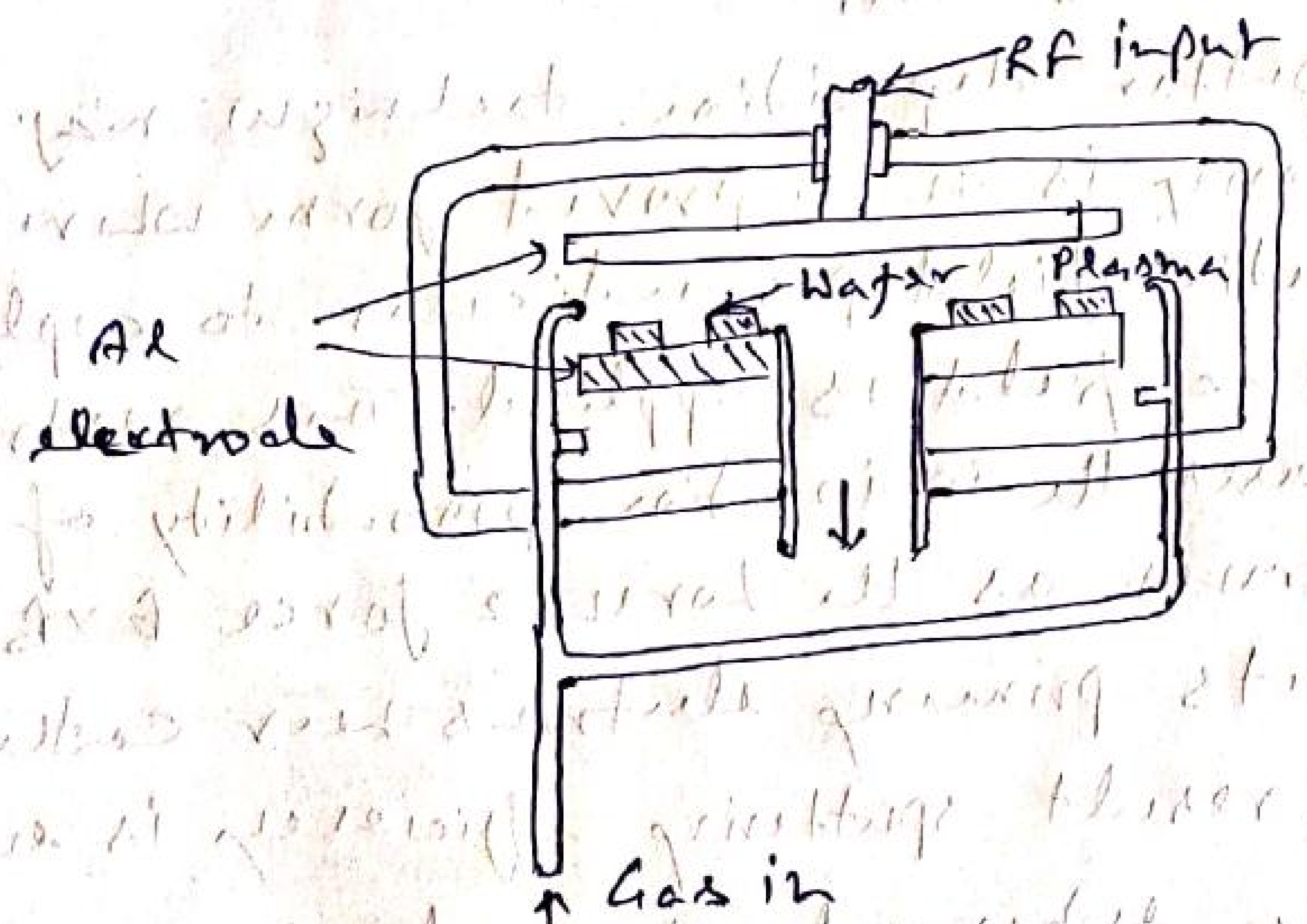
- A no. of techniques are used for thin film deposition such as:-

a) Thermal Evaporation
   i) Resistive Heating   ii) Electron beam Heating
b) Sputter deposition
   i) DC with magnetron   ii) RF with Magnetron
c) Chemical Vapour Deposition (CVD)
d) Plasma enhanced CVD (PECVD)
e) Metallo-organic deposition (MOD)
f) Langmuir-Blodgett technique of monolayer deposition.

- Thermal evaporation and sputter deposition are decades old.
- In sputter deposition technique magnetron sputtering is an improved form where a magnetic field perpendicular to applied electric field is applied. This ~~restricts~~ increases the ionization probability of electrons as the Lorentz force E×B restricts primary electrons near cathode. As a result sputtering efficiency is enhanced.
- Plasma enhanced chemical vapour deposition (PECVD) has been found to be particularly suitable for sensor fabrication.
- This is a low temp. process in which plasma

is introduced into the deposition chamber to enhanced the ~~poly~~ pyrolytic process which in normal CVD process is performed by thermal decomposition that requires high temp.

- In this process, the volatile compound of the material to be deposited is thus vaporized, decomposed and made to react with gaseous species over the substrate to produce a nonvolatile amorphous product on the surface of the substrate.
- The deposition level is controlled by controlling the flow-rates of the vapours.
- A parallel plate, radial flow type PECVD processing chamber is shown in fig.



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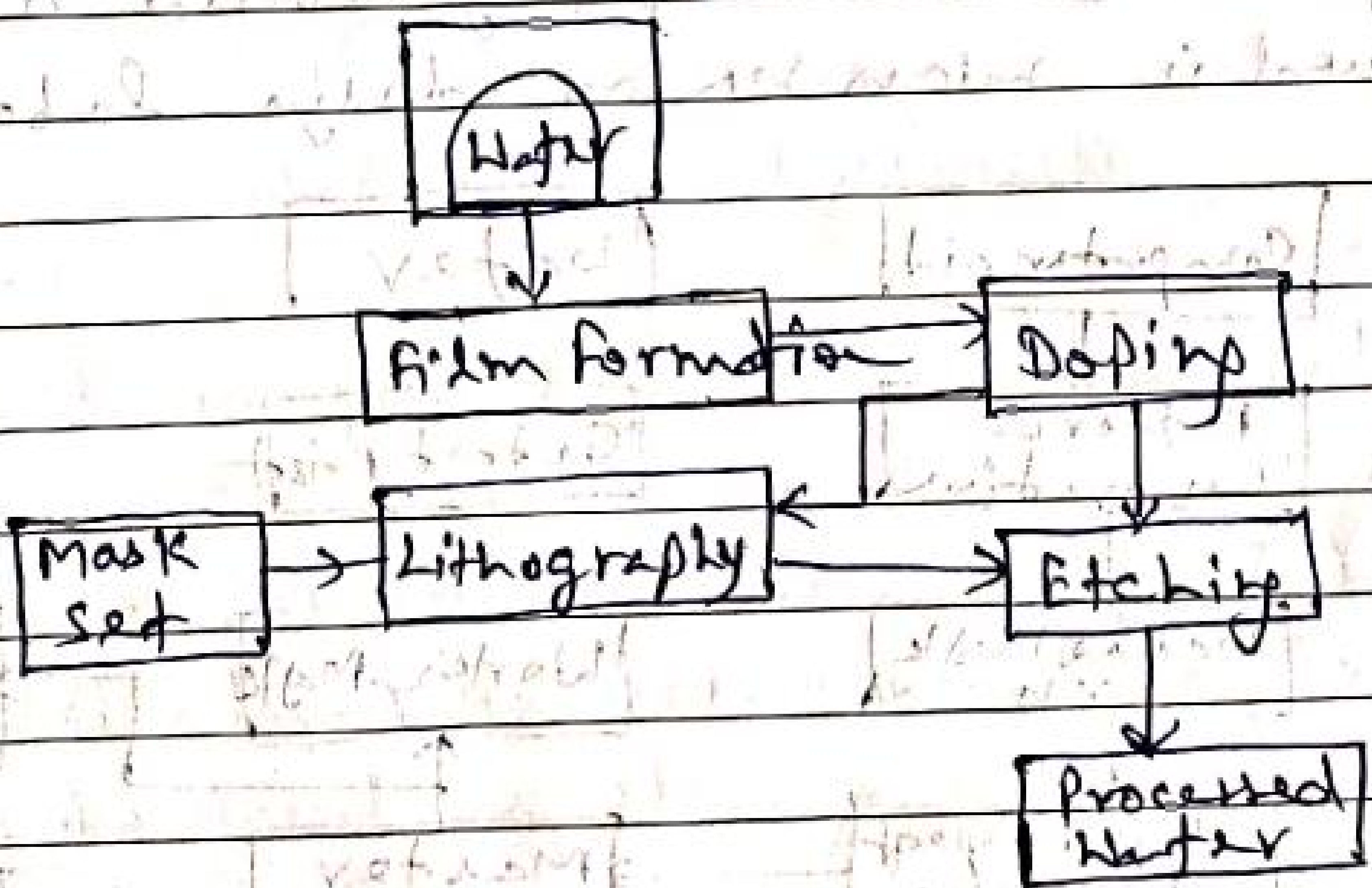
Semiconductor IC Technology - Standard Methods

Solid state sensors are ~~---~~ semiconductor micro and nano-sensors, ceramic and chemical sensors using new materials and optical fibre sensors.

- These sensors are developed through standard IC technology as used in VLSI design and micromatching techniques.
- By precise micromaching technique, the three dimensional structures of sensors are developed for better performance, reliability, sensitivity manufacturing uniformity, ~~and~~ stability and cost reduction.
- In semiconductor sensor fabrication, on polished Si, Ge, or GaAs wafer, film is deposited by a) epitaxial growth, or
  b) oxidation, or
  c) Polysilicon and dielectric deposition, or
  d) metallization.



Processing steps in semiconductor Technology

- Doping (imparting impurity) is done usually by ion implantation or diffusion. At this stage, mask

Date
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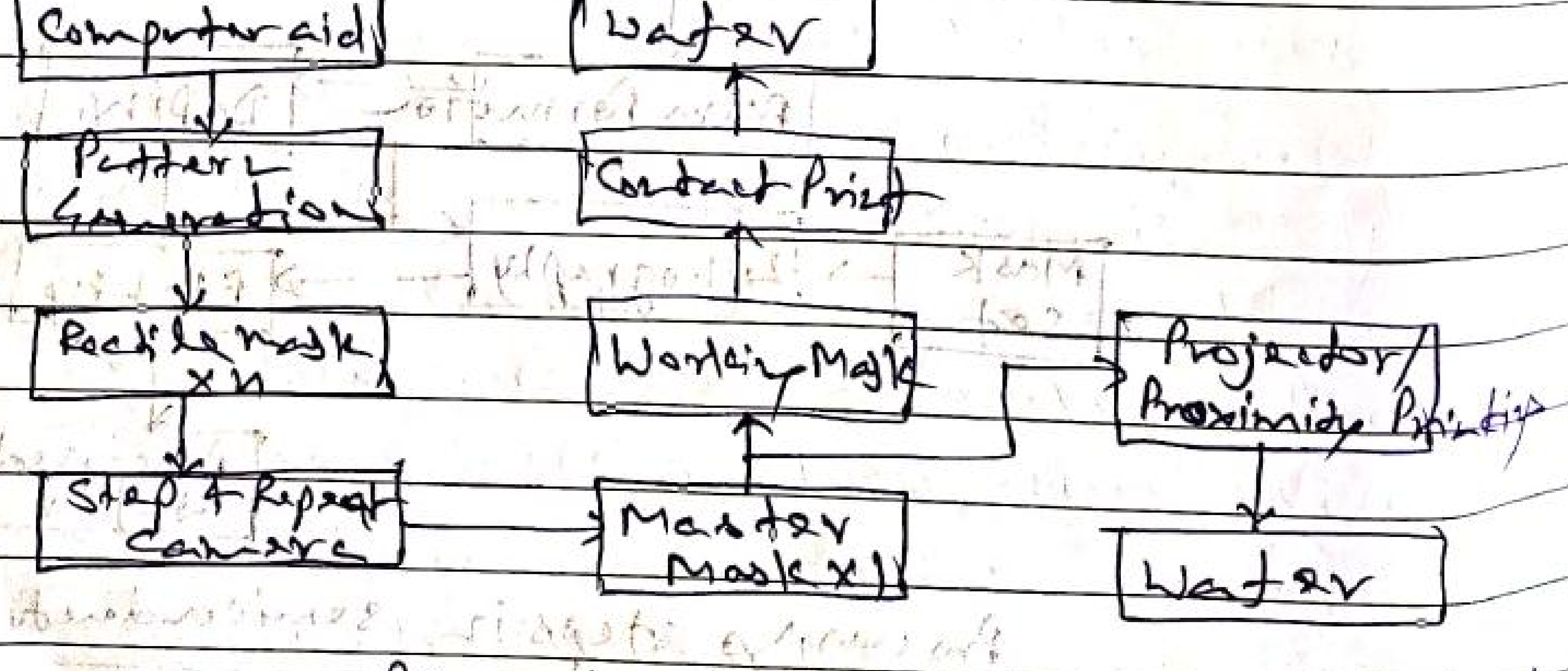
patterns are transferred to the film surface by lithographic process.
- The unwanted film and substrate parts are then removed by etching.
- The process may be repeated for n no. of times for transfer of n-mask patterns.
- A finished wafer would contain thousands of identical chips (features) which are then separated by diamond sawing or laser cut.
- Single crystal and polycrystalline silicon have been grown on insulator surface such as sapphire (Silicon on Sapphire - SOS) and SiO_2. GaAs can also be grown on silicon by epitaxy. The process is important as optical sensors can be developed in this way.

Lithography can be classified as -
1) Photolithography (with optical radiation)
2) X-ray lithography (with X-radiation)
3) E-beam lithography (with electron beam)
4) Ion-beam lithography (with ion-beam radiation)

Fig. shows the steps followed in photolithography used in microsensor design laboratories.



Flowchart - Photolithographic technique

classmate

Date
Page

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Computer aided designs from pattern generator is common now

→ Two methods of pattern transfer are
1) Contact (or shadow) Printing
2) Projection Printing

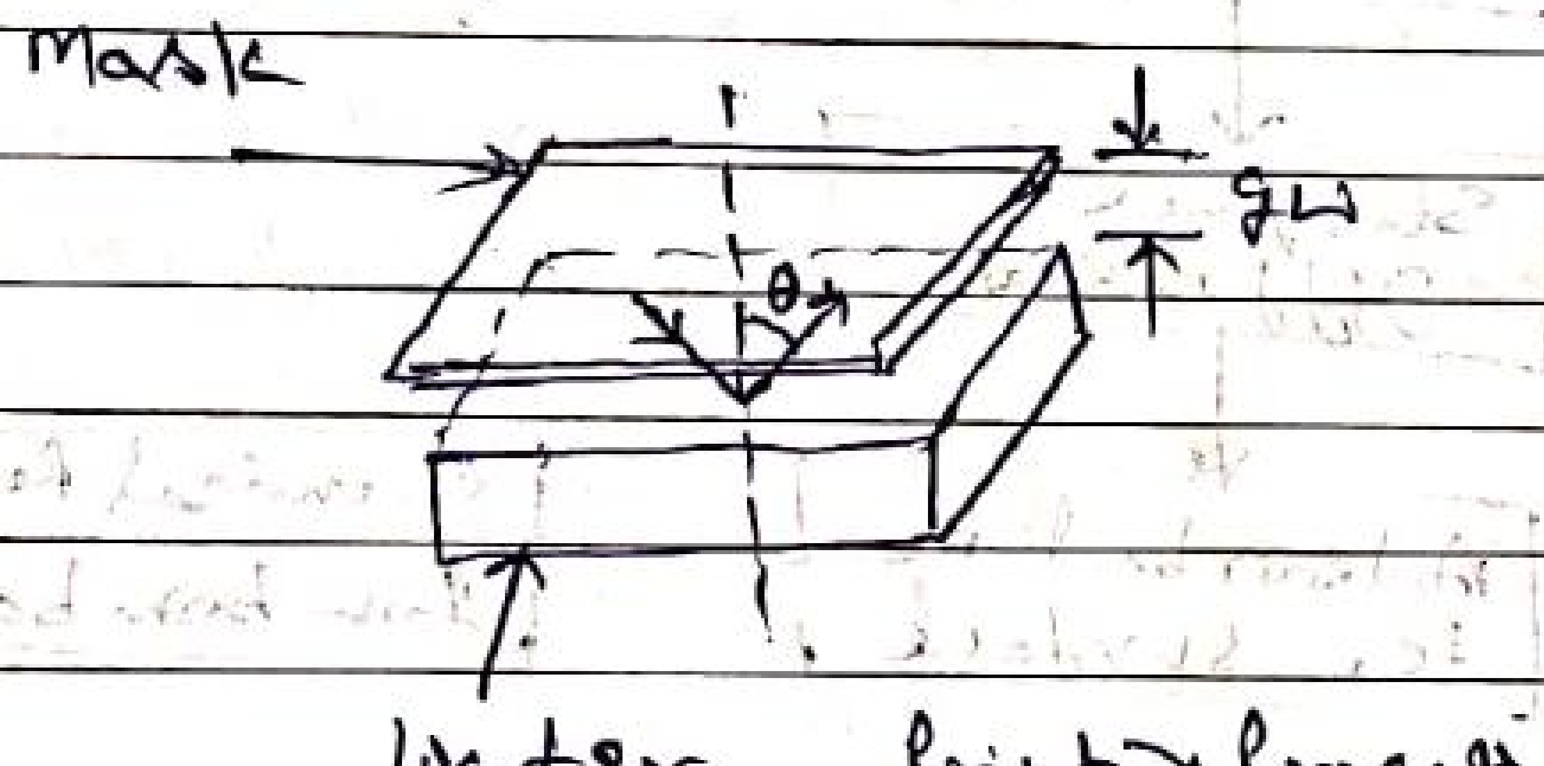
Min line width lw that can be printed by the optical method can be given by

$\boxed{lw\ (shad) = \sqrt{\lambda\, gw}} = \sqrt{450 \times 14 \times 10^{3}} = 2.4 \times 10^{3}$ nm

gw ⇒ gap between mask & wafer plane

For projection printing, numerical aperture $n\sin\theta$ divides λ for the min. line width

$$lw(proj) = \frac{\lambda}{n\sin\theta}$$



Printing Process

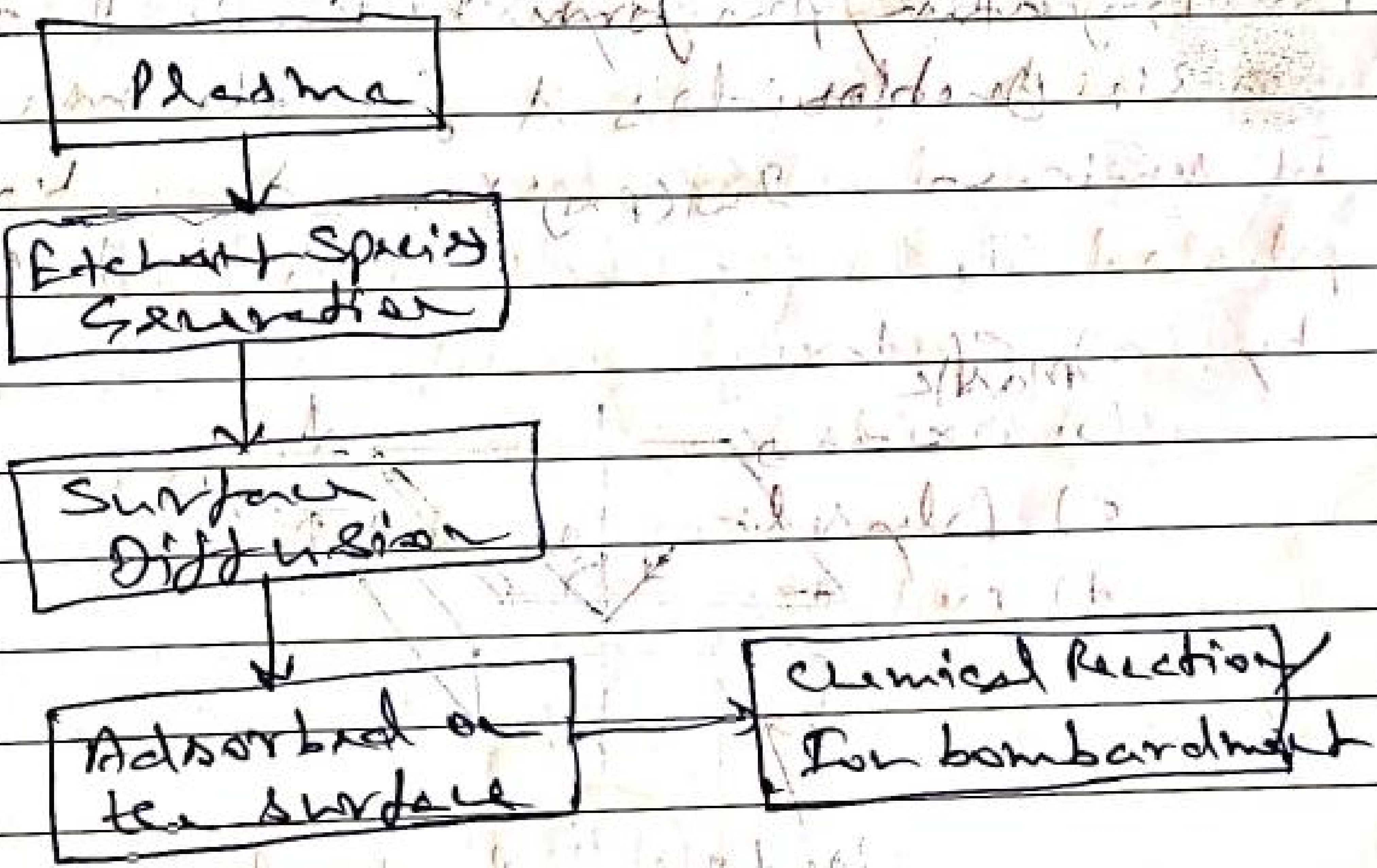
Etching – It is essential for surface polishing, removing contamination, drawing pattern and opening window in-between insulator (SiO_2) and fabrication, by micromachining technique.
- Substrate used for etching are Si, GaAs, metals and insulators.
- Two types → wet and dry.
→ In wet etching, appropriate etchants or reactants are diffused into the reaction

surface for chemical reaction to occur at surface and the reaction products are diffused out.

Etching is controlled by controlling parameters such as temp. and agitation.

→ Dry etching can either be physical or physico chemical. Physical dry etching includes sputtering and ion-milling while physico chemical one includes plasma etching, reactive ion etching and reactive ion beam etching.

→ fig. shows the steps involved in reactive plasma etching (RPE).



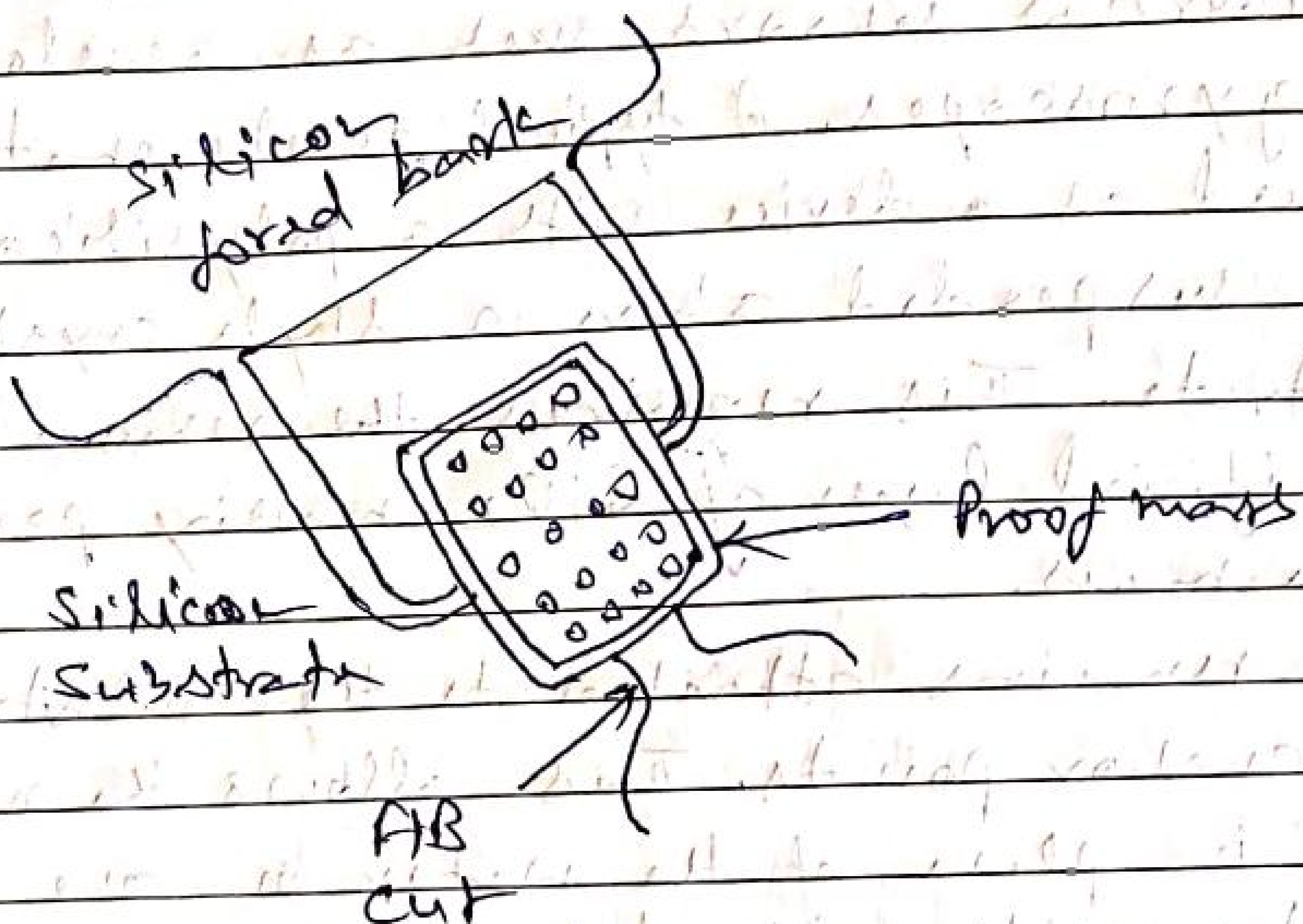
- The basic plasma reactive etcher uses two parallel plates as electrodes.
- the reactive ion etcher has the wafer placed on the RF electrode and
- the reactive ion beam etcher also known as the ion-milling etcher uses the RF to a gas mixture to release special etchant species while the wafers are kept downstream receiving them.

MEMS Sensors

MEMS technology has been used to develop silicon based inertial sensors such as accelerometers and gyroscopes. A typical accelerometer has been produced as a device with a polysilicon proof mass suspended above a single crystal silicon substrate. This requires the removal of a sacrificial layer of SiO_2 making perforations in the mass.

- Mass remains attached to the substrate at two anchor points. This allows the mass to bend in plane of the wafer on one axis. The ~~position~~ position is detected by capacitive effect and the electrostatic force is fed back to operate the device as an accelerometer.
- For obtaining a large proof mass, it is laterally extended to several microns.
- This also provides an appreciable capacitance value. The processing is carried out as in the case of surface micromachining.
- Such Accelerometer structures can be developed through the RSOI technique as well.
- A single crystal silicon is taken as the proof mass in this case which is supported by two silicon beams attached to the substrate.
- The sensitive axis is now perpendicular to the plane of the wafer.
- Instead of capacitive sensing, this design employs electron tunnelling method for sensing. Tunnelling takes place across a narrow oblique gap formed by focused

ion beam (FIB) which machines through a third beam. Fig.1 shows a simplified sketch of such a ~~m~~ non resonant sensor.



Non resonant sensor

Nano-Sensors

- Microelectronics leads to nanoelectronics for realizing nano-devices which are expected to create an impact in the enhancement of energy conversion, control of pollution, production of food etc.
- At present best examples of nano devices are associated with information technology industry.
- The development of nano structures has been accelerated over the past decade because of unexpected breakthroughs in the synthesis and assembly of nanometer scale structures.

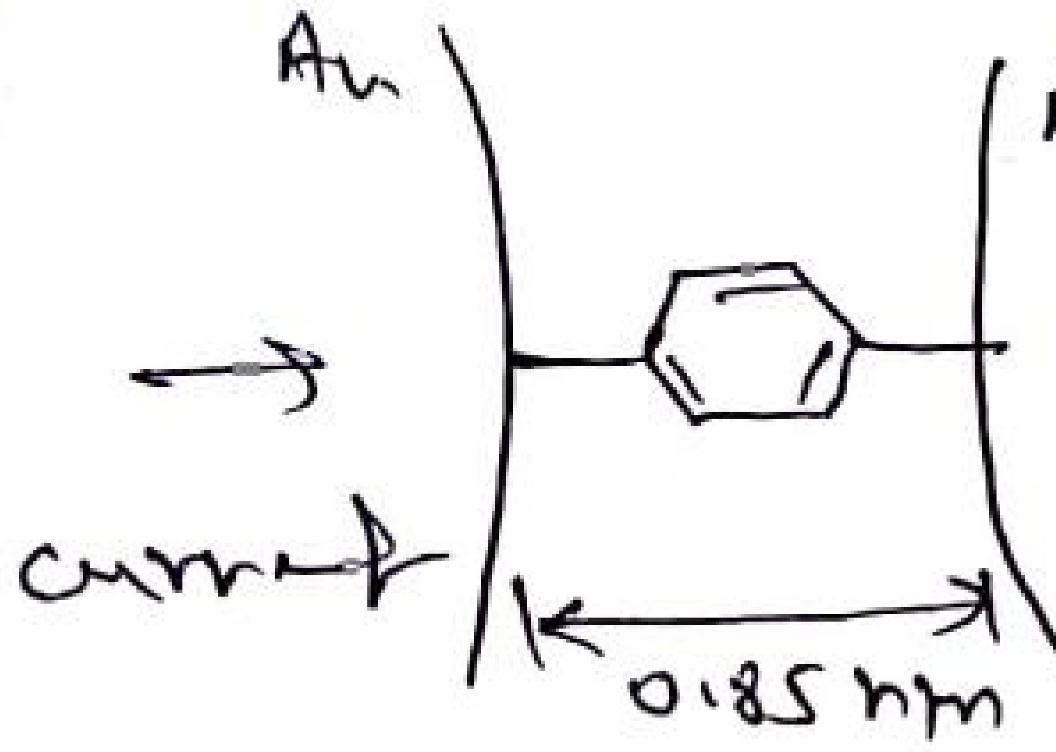
→ Some area that have seen such unexpected developments are -

1) Discovery and controlled production of carbon nanotubes and use of proximal probe and lithographic schemes.
2) Success in placing engineered individual molecules onto appropriate electrical contacts and in measuring transport through these molecules.
3). Availability and use of proximal probe techniques for fabrication of nanometer scale-structures.
4) Development of chemical synthetic methods to realize nanocrystals and also implantation technique for putting these crystals into a variety of larger organised structure and making assembly.
5) Implantation / incorporation of biological motors into nonbiological environments.

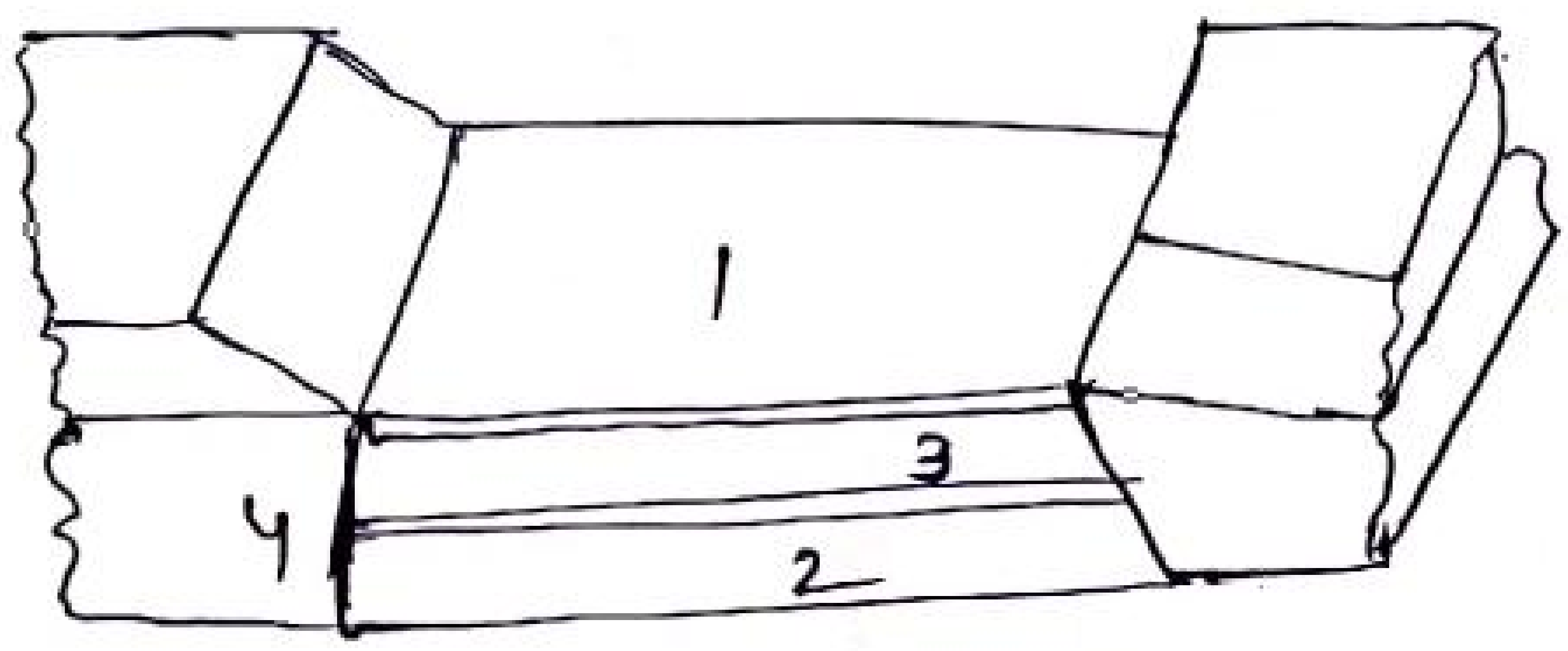
6. Integration of nanoparticles into gas sensors.
7. Fabrication of photonic level band gap structure.
8. Development of quantum effect, single electron memory and logic elements that can operate at room temp.

- ~~One other important area~~
- Scanning tunnelling microscopy (STM) or Atomic force microscopy (AFM) are used to manipulate and develop other nanometer scale objects from another type " " " economically & efficiently.
- Fast and miniaturized memory structure have been produced as Giant Magnetoresistive (GMR) structure using Thomson effect. GMR structure consists of layers of magnetic and non-magnetic metal films wherein the critical layers have thickness of order of nanometers. These are used as extremely sensitive magnetic field sensors.
- The spin polarized electrons are transported between the magnetic layers on the nanometer length scale, and this process allows the structure to sense magnetic field. These are in use in sensing magnetic bits stored on computer discs.
- Organic nanostructures have been developed combining chemical self-assembly with a mechanical device. The organic sample is reduced to a size that

consist of a single molecule and this is connected by two gold leads. This has been successfully used to measure the electrical conductivity of a single molecule



a) micro-structure

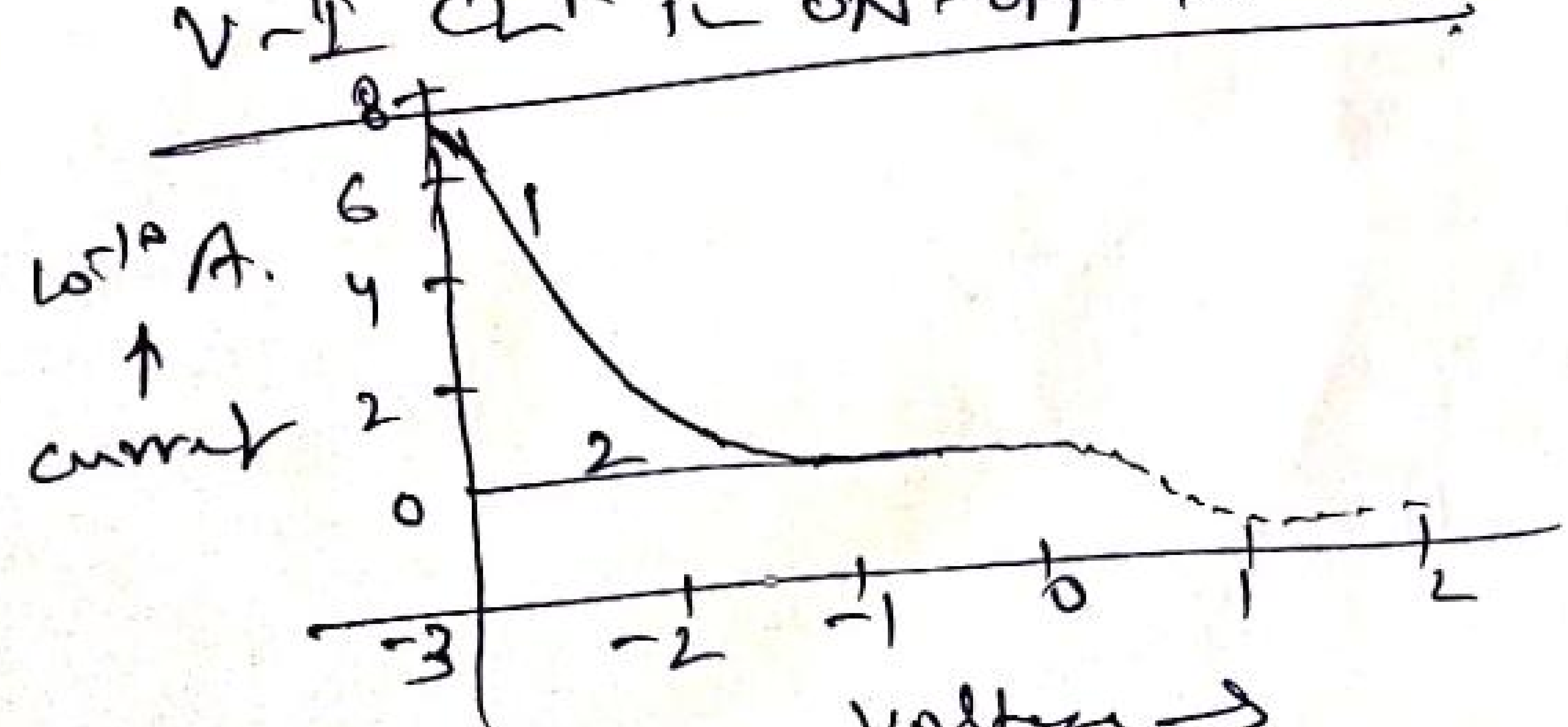


b) Operation mechanism of a GMR

1) Antiferromagnetic exchange film
2) Ni-Fe GMR free film
3) Co-GMR pinned film 4) Cu-spacer

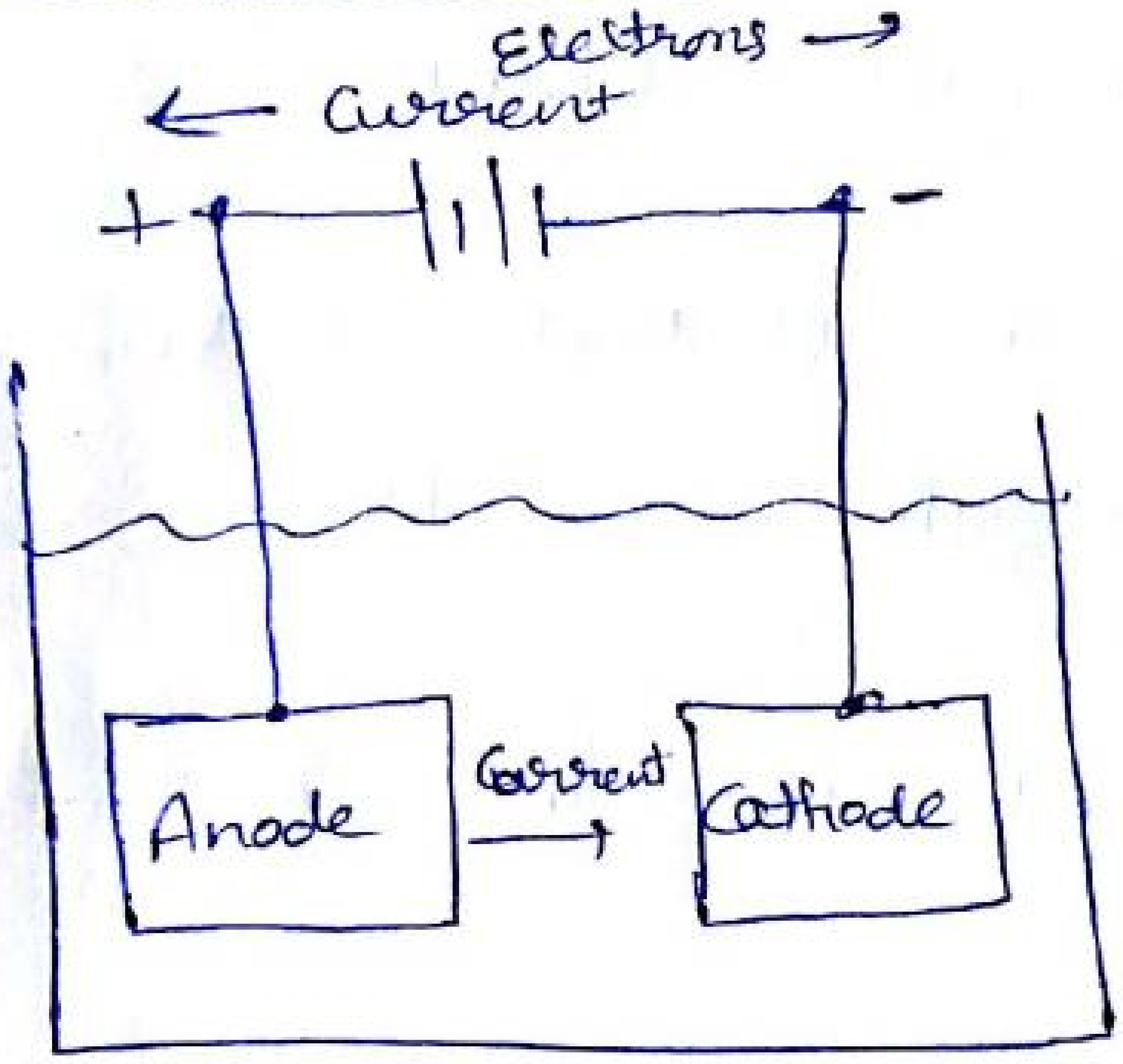
- Molecular switches have been produced.
- Molecular switches use carbon nanotubes as the circuit connecting wires. The operation of switching depends on electronic states of molecules
- The switches are opened by applying an oxidizing voltage across the device.

V-I Ch in ON-off states.



Topics:- Electrochemical cell, SHE, Polarization, Ref. electrode, Metal electrode, Membrane electrodes, Electroceramics

Electrochemical cell :→



Electrochemistry is defined as the branch of chemistry that examines the phenomenon resulting from combined chemical & electrical effects.

Tykes of Sroceu:-

→ Electrolytic Process:- Reactions in which chemical changes occur on the passage of an electric current.

→ Galvanic or Voltaic Process:- chemical reactions that result in the production of electrical energy.

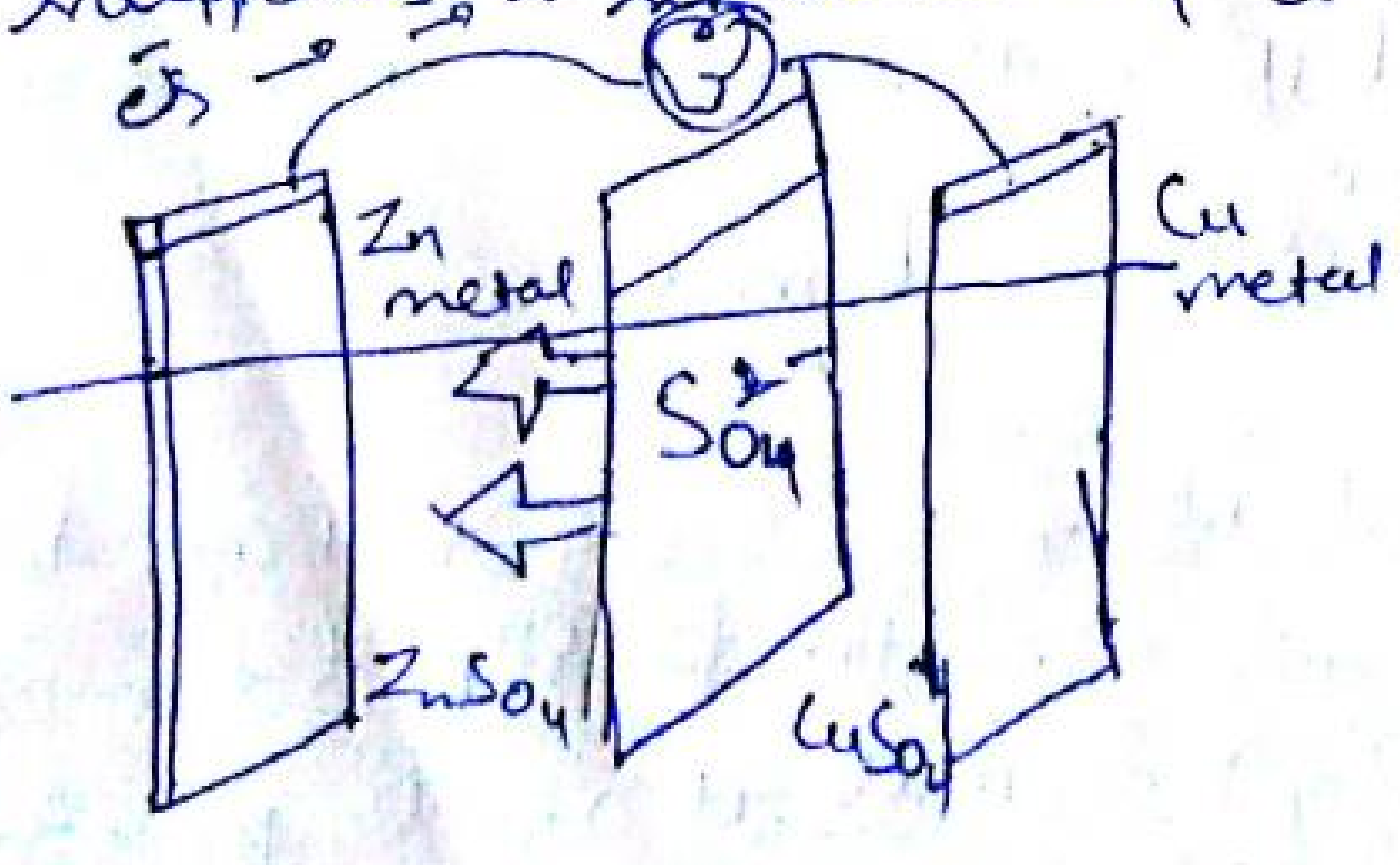
An electrochemical cell typically consists of:

- Two electronic conductors [electrodes].
- An ionic conductor [electrolyte]

→ Charge transport in electrode occurs via the motion of electrons (or holes).

& charge transport in electrolyte occurs via the motion of ions (+ve & −ve)

e.g. Zinc & copper metals placed in a solution of their respective sulfhates, & separated by a semi permable membrane.



$\rightarrow \quad Zn = Zn^{2+} + 2e$ (s)

Zinc metal gets oxidized - goes into soln!

$\rightarrow \quad Cu^{2+} + 2e = Cu$ (s)

Cu ions in soln - reduced; Cu metal deposited on Cu electrode

- Electrons for redn obtained from Zinc electrode - External wire
- Sulfate ions (Rean 2) migrate through the membrane - react with Zn ions - Zinc Sulfate.

$\Rightarrow$ Zn electrode = Anode & Cu electrode = Cathode.

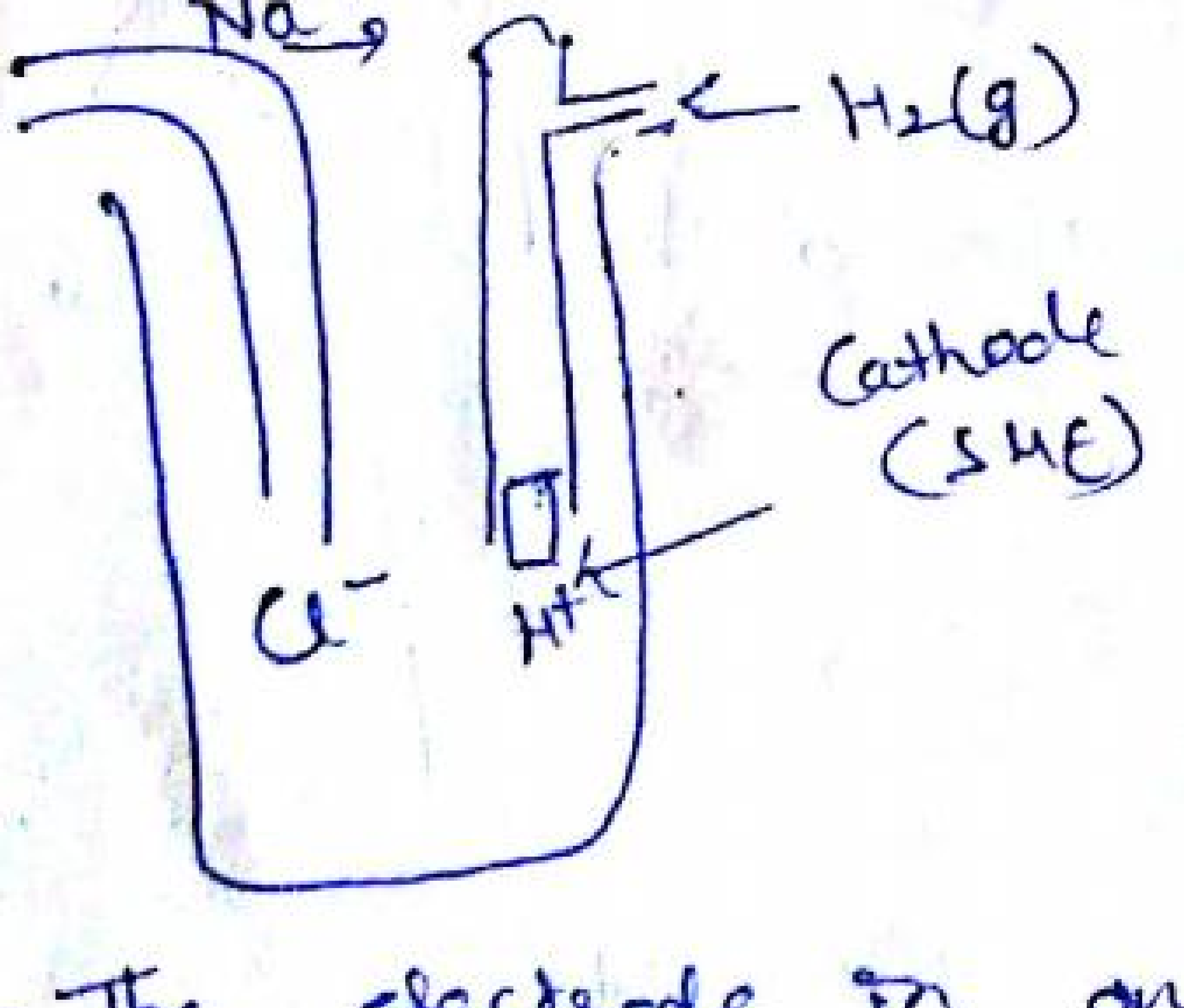
Standard Hydrogen Electrode [SHE]:-

- An electrode must be easy to construct, reversible & highly reproducible in its behaviour. SHE meets these specifications & has been used throughout the world for many years as a universal reference electrode. It is a typical gas electrode.

$$2H^+(aq) + 2e^- \rightleftharpoons H_2(g) \qquad E^\circ_{red} = E^\circ_{1/2} = 0.00V$$

$\Rightarrow$ The electrode potential of SHE is exactly zero.

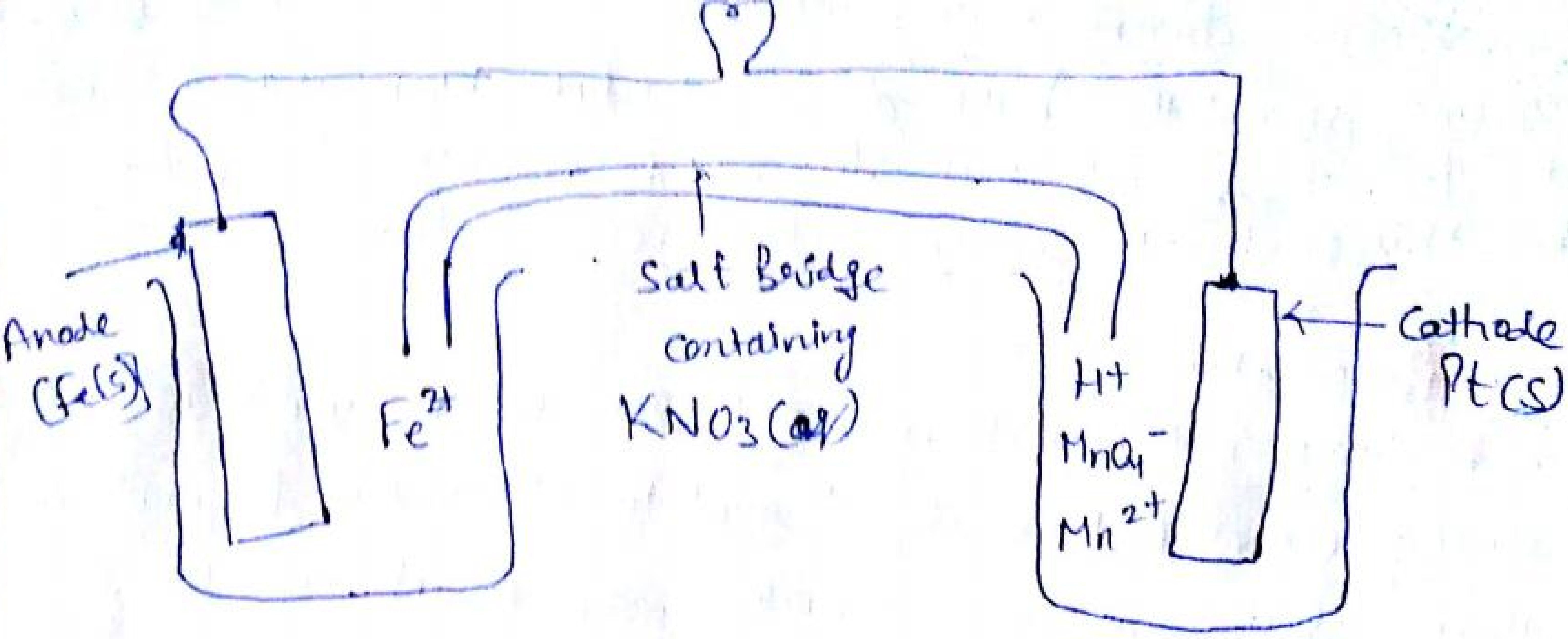
- The electrode in any half-cell with a greater tendency to undergo reduction is +vely charged relative to SHE & hence has a +ve E°.



$\Rightarrow$ Each electrode is assigned a std. redn pot, E°_{red}; also called a std. Half cell pot, $E^\circ_{1/2}$, also known as std. electrode pot.

$$E^\circ_{cell} = E^\circ_{cathode} - E^\circ_{anode}$$

- The electrode in any half cell with a lesser tendency to undergo reduction is -vely charged relative to SHE & has a -ve E°
- Oxidation spontaneously (loss of e's) occurs at anode, the electrode with the more -ve (or less +ve) E°.



oxidation $\Rightarrow$ $Fe(s) \rightarrow Fe^{2+}(aq) + 2e^-$

Reduction $\Rightarrow$ $MnO_4^-(aq) + 5e^- + 8H^+(aq) \longrightarrow Mn^{2+}(aq) + 4H_2O(l)$

$\Rightarrow$ The cell potential of any electrochemical cell (E°_{cell}) is the difference b/w the electrode potentials of cathode & anode.

$$E^\circ_{cell} = E^\circ_{cat} - E^\circ_{an}$$

$\Rightarrow$ E°_{cell} is +ve for spontaneous reactions & -ve for non-spontaneous reactions.

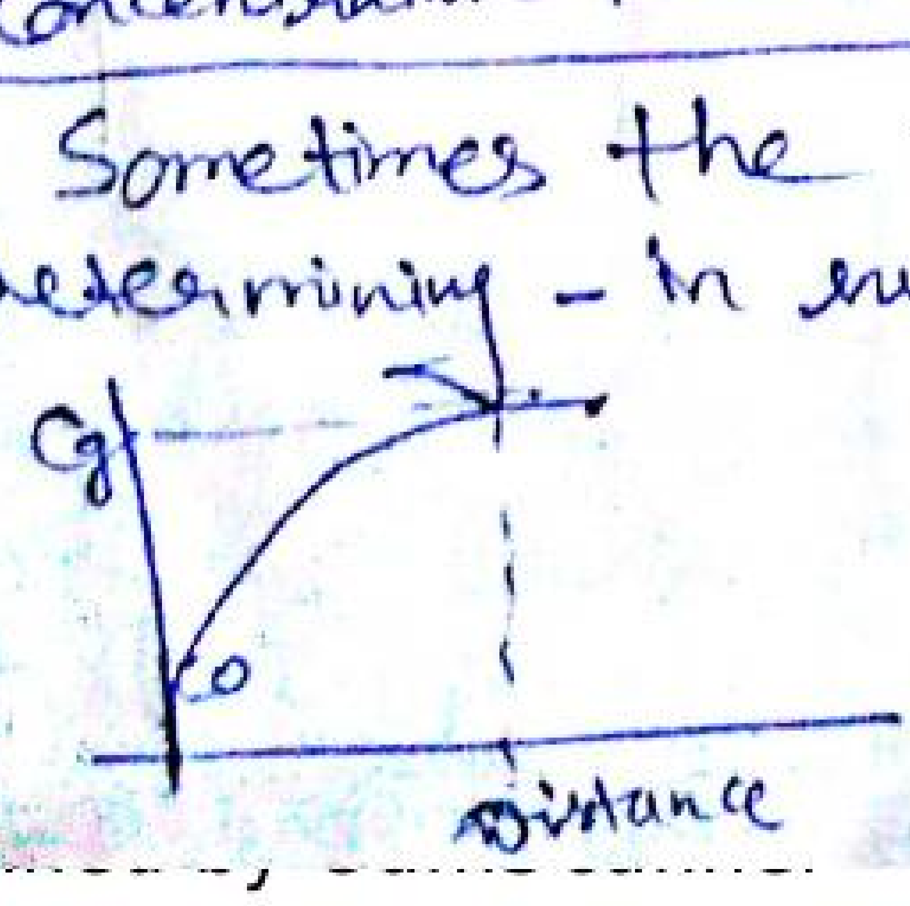
Polarization:→

The non linearity that arises is due to Polarization which is manifested as reduction of current or corresponding voltage.

- concentration Polarization
- Reaction "
- Adsorption | Desorption | Crystallization Polarization
- charge Transfer "

→ Concentration Polarization:→

- Sometimes the mass transport within the soln may be rate determining - in such cases we have Concentration Polarization.



$$O_2 + 4H^- + 4e^- \rightarrow 2H_2O$$

- Oxidn - Redn can occur normally when the movement of Ox +/or 'Red' species across the bulk of electrolyte by mass transfer is normal. If not reacn rate decreases & correspondingly the current. This is due to concentration Polarization.

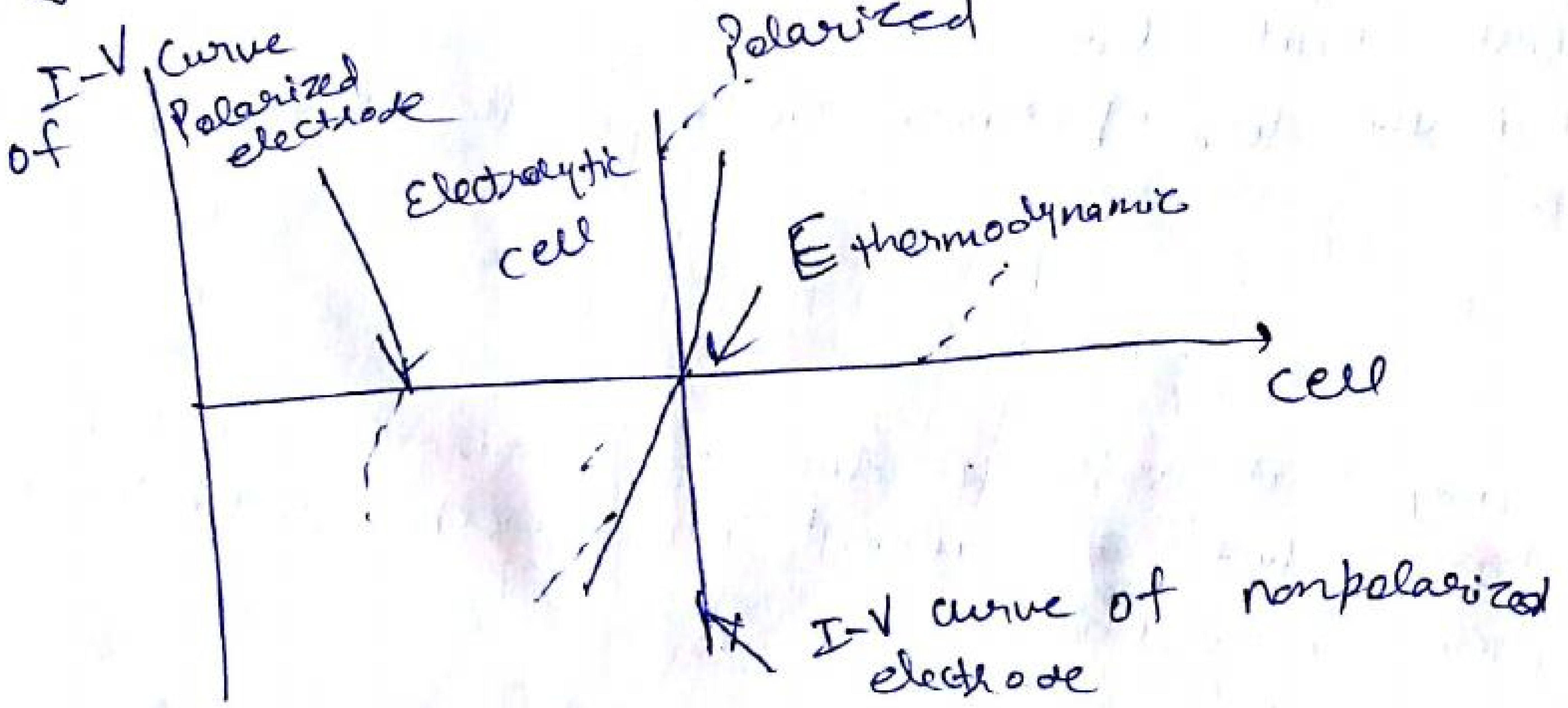
⇒ Reaction Polarization

- If there is any intermediate chemical reaction in any 1/2 cell for producing ox/or Red that travel to electrodes: Formation of these species at intermediate stage is abnormal.

⇒ Adsorption

- current is limited by processes such as adsorption / desorption or crystallization of reactants.

charge Transfer Polarization:- | Electrical Polarization



- charge transfer takes place from electrode to oxidized species or from reduced species to electrode.
- often, the rate of charge transfer is reduced because of existence of a charge surface film around the electrodes.

Reference Electrodes:→

→ Have known constant Potential & follow Nernst eqⁿ

$$E_{ox|red} = E^{o}_{ox|Red} + \frac{RT}{nF} \ln a$$ ← Reaction Quotient

R → Universal Gas const.
n → no. of electrons
F → faraday const.

$$\frac{2.3\,RT}{F} = 0.059, \text{ that}$$

$$E_{ox|Red} = E^{o}_{ox|Red} + \frac{0.059}{n} \log a$$

In general

$$aA + bB \xrightarrow{ne^-} cC + dD$$

The Nernst eqⁿ

$$E_{cell} = E^{o}_{cell} - \frac{2.303RT}{nF} \log \frac{[C]^c [D]^d}{[A]^a [B]^b}$$

At 298K, the eqⁿ becomes

$$E_{cell} = E^{o}_{cell} - \frac{0.059}{n} \log \frac{[C]^c [D]^d}{[A]^a [B]^b}$$

values of a, b, c, d & n are obtained from cell reaⁿ.

→ Have reversible cell reaction.

→ Have little or no-hysteresis with temp. & small current cycling

→ be non-polarized.

1. Saturated calomel Electrode [SCE]
2. Silver | Silver chloride electrode.
3. Thallium | Thallous chloride "

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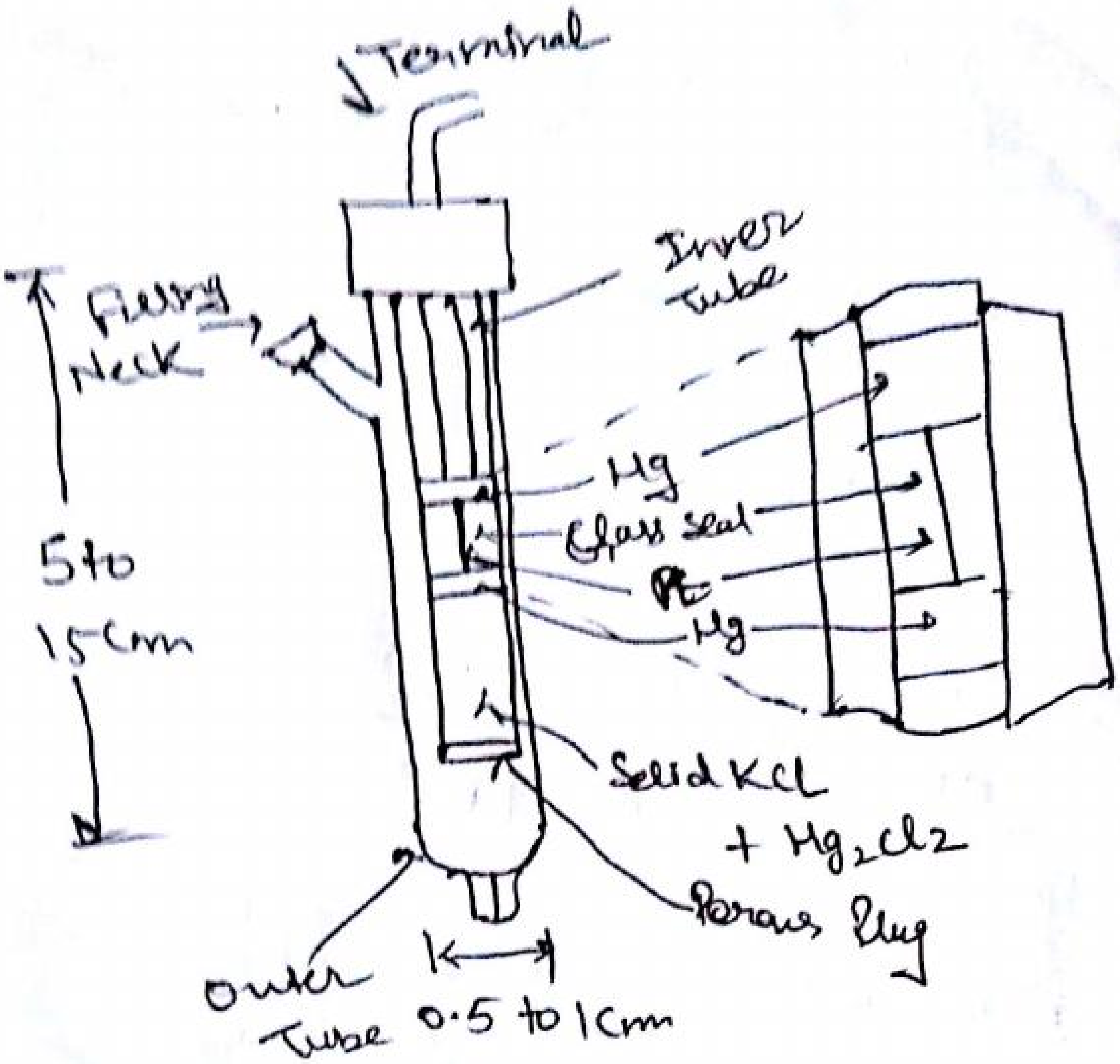
42	40213307715	VISHAL SINGH				
43	40313307715	SANDEEP				



$Hg(l) \mid Hg_2Cl_2(satd), \; KCl(aq) \parallel$

$Hg_2Cl_2(s) + 2e \rightleftharpoons 2Hg(l) + 2Cl^-$

- It consists of an inner glass/plastic tube containing Hg, Hg_2Cl_2 & KCl. This tube dips into a KCL + Hg_2Cl_2 (Calomel) contained in an outer tube. The jn to other half cell is made through a fibre of quartz, a ceramic plug or a glass sleeve.
- Platinum wire is used for external connection

KCL	Saturated	4.0 M	3.5 M	1 M	0.1 M
Electro (V)	0.244	0.246	0.250	0.28	0.336

KCL concentration Vs. Electrode Potential

Metal Electrodes :- → First Kind, Second ", Third ", Redox Type

(i). The First Kind Electrode :-

$$M^{K+} + Ke^- \rightleftharpoons M(s)$$

& the electrode potential is given by std. eqn

$$E = E^0_M - \frac{0.0591}{K} \log \frac{1}{M^{K+}}$$

$$= E^0_M - \frac{0.0591}{K} pM$$

Such an electrode is in direct equilibrium with the cation derived from the electrode metal. For such a case, denoting metal with M.

~~& the~~ where pM denotes the -ve logarithm of M-ion concentration. The metals in this category are Cu, Zn, Ag, Hg, Cd & Pb. They show reversible oxidation-reduction behaviour.

(ii). The Second Kind Electrode :-

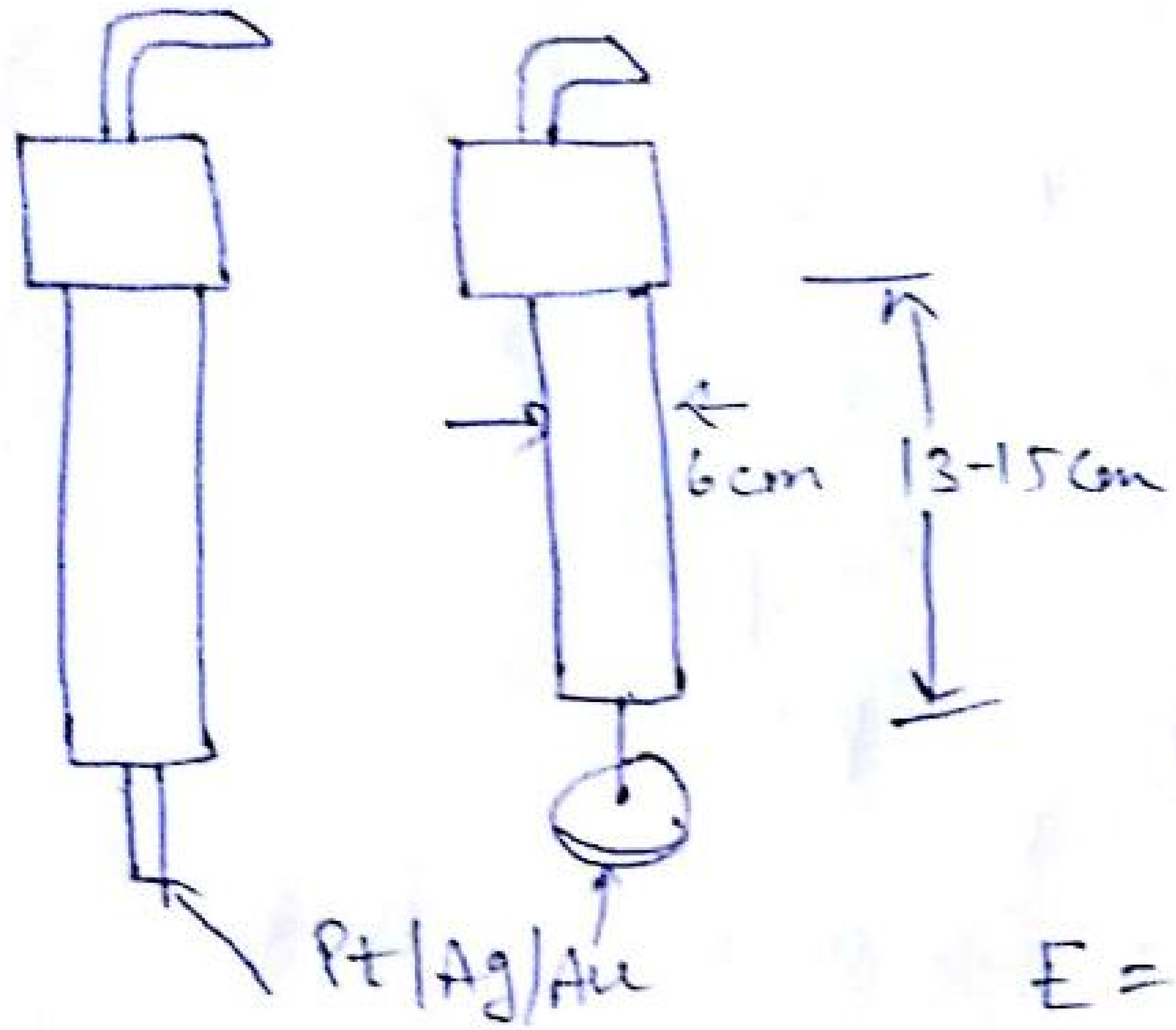
— This electrode is responsive to the concentration of an anion & its own ion makes ~~prec~~ precipitate with it or forms a complex ion.

$$AgCl(s) + e \rightleftharpoons Ag^+(s) + Cl^-$$

$$\& \ E = 0.222 - 0.0591 \log [Cl^-]$$

(iii). Third Kind Electrode :-

— It responds to a different cation under certain circumstances. Hg electrode can be used to determine the Ca ion concentration in soln (iv). Redox Electrode:-



— An electrode made of inert metal is immersed in a solⁿ containing a substance in the reduced or oxidized state, the electrode would aquire a potential depending on tendency of ions in solution to pass from a higher to lower state of oxidation or from a lower to higher state of oxidation.

$$E = E^\circ - \frac{0.0591}{n} \log \left[\frac{\alpha +}{\alpha -}\right]$$

⇒ If solⁿ has reducing property, the ions will tend to be oxidized losing e⁻s to the electrode & Pt becomes -vely charged wrt solution. The case reverses if solⁿ has oxidizing property.

⇒ with α+ as the activity of oxidized ion & α- that of the reduced ion.

⇒ The electron transfer process must not also be too slow for a reproducible behaviour.

Membrane Electrodes:-

- Glass Membrane Electrode
- Solid State
- Liquid Junction
- Permeable

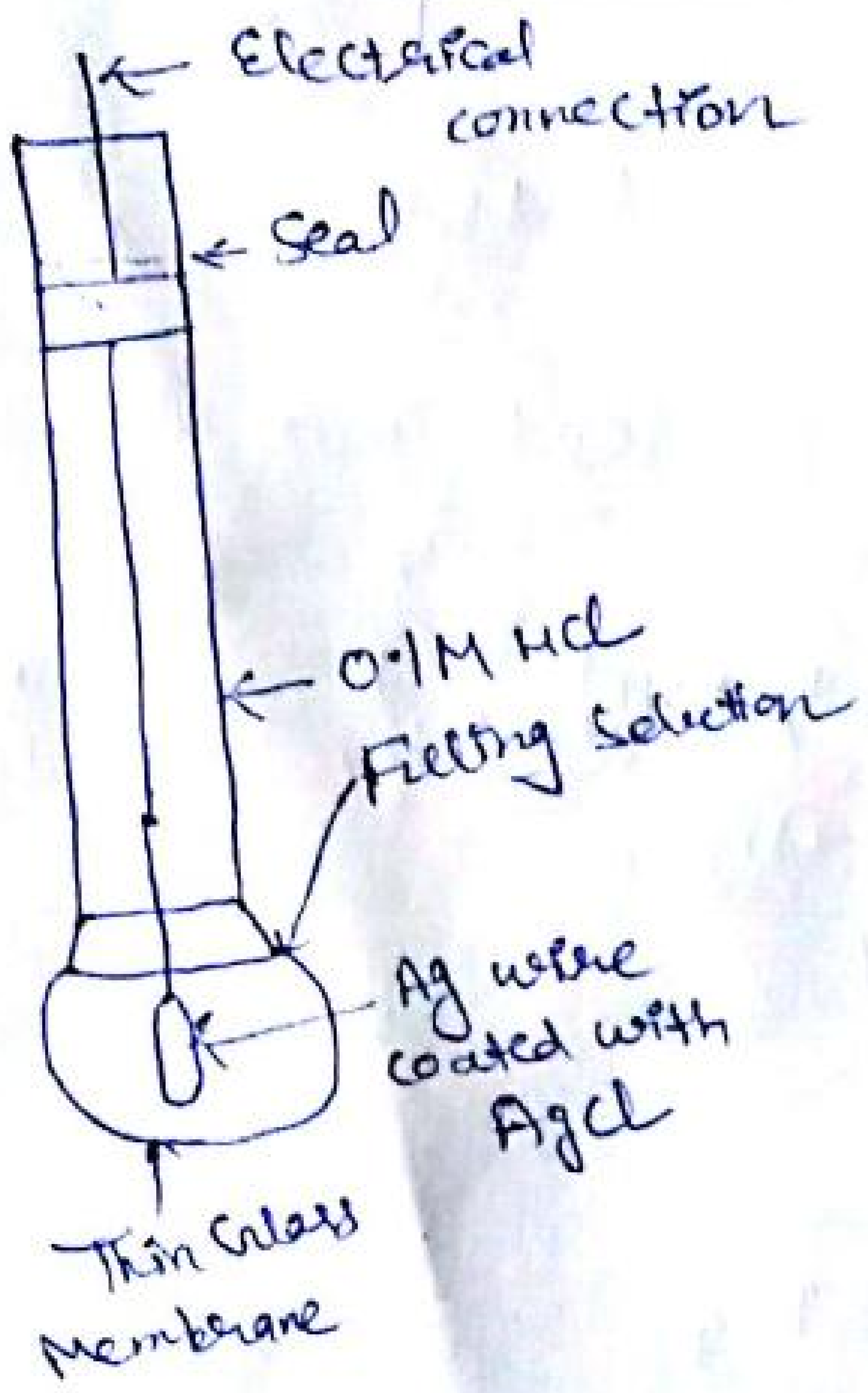
thin Glass Membrane

$[H^+] = a_1$ | $[H^+] = a_2$

solution 1 | Solution 2

Potential develops across Membrane.

Glass pH Electrode:-

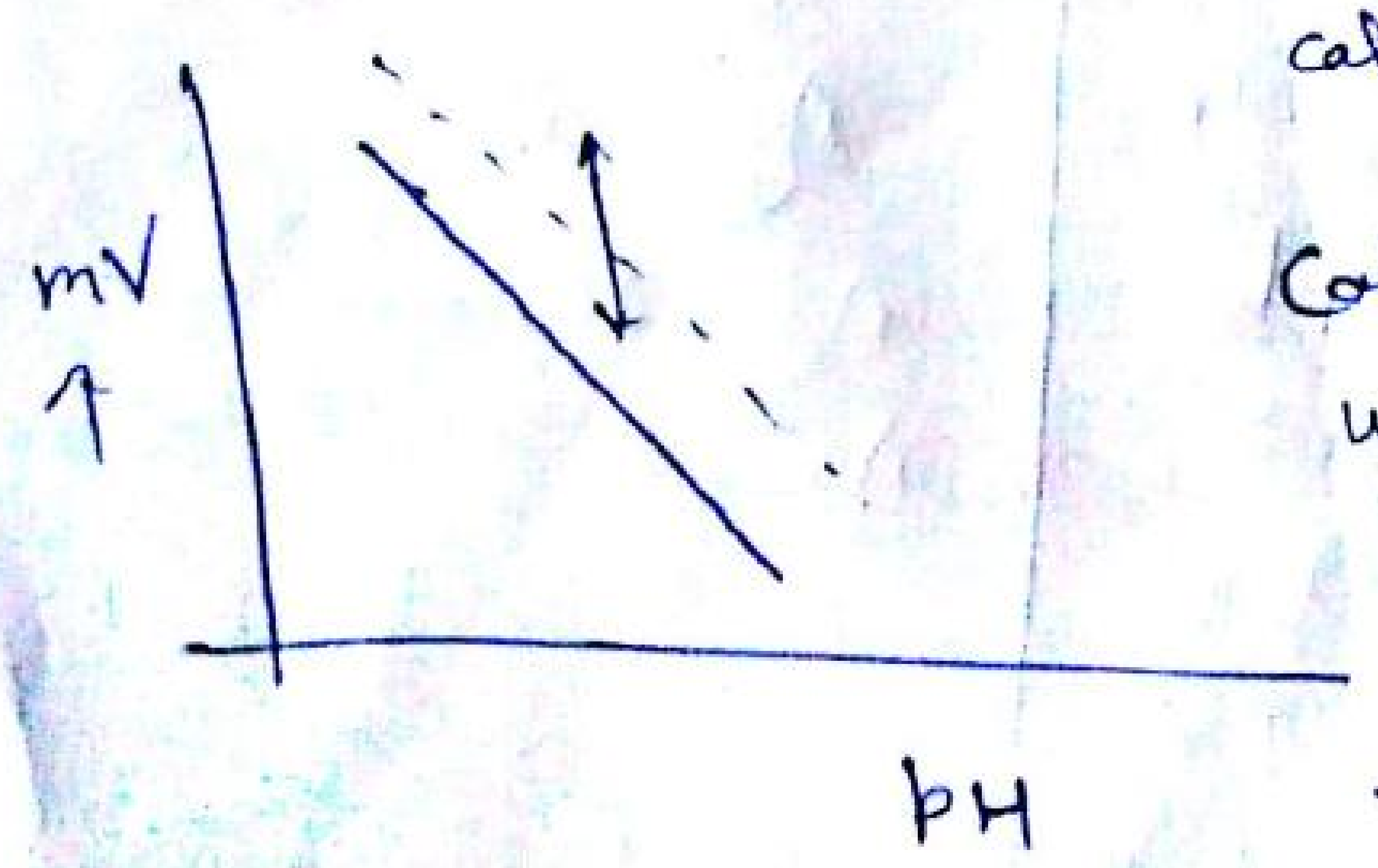


$$E = K' - 0.0591\ pH$$

- Combine with Reference electrode & meter
- Half cell voltage $\propto$ to pH.
- Nernstian slope
- Intercept is K', no E°
- Calibrate with buffers

Proper pH Calibration

- $E = K' - 0.0591\ pH$
- Meter measures E vs pH - must Calibrate both slope & Intercept on meter with buffers
- Meter has two controls - Calibrate & slope.
- 1st use pH 7.00 buffer to adjust calibrate knob.



Calibrate knob raises & lowers the line without changing slope.

- 2nd step is to use any other pH buffer
- Adjust slope/temp control to correct pH value

- This will pivot the calibration line around the isopotential which is set to 7.00 in all meters.

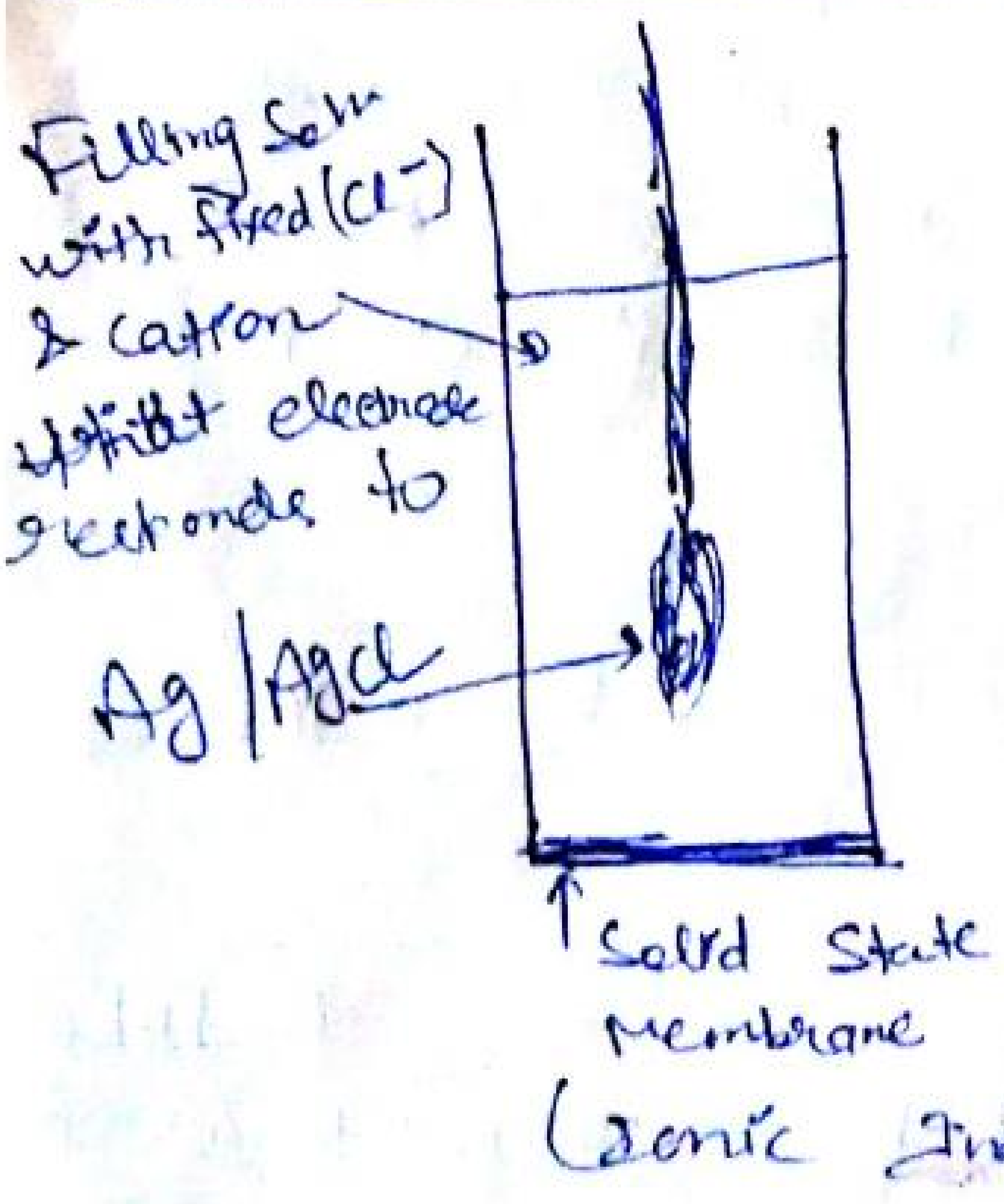
slope/temp control pivots line around isopotential without changing it.

$Ag_{(s)} | AgCl_{(s)} | Cl^-_{(aq)} || H^+ || HCl\ (0.1M) | AgCl\ (solid) | Ag_{(s)}$

Ref. electrode — Test soln — Glass Electrode

- Glass Membrane electrodes are very good indicator electrodes in potentiometry.
- Glass electrodes available for Na^+, K^+, NH_4^+, Rb^+, Cs^+, Li^+, Ag^+ (cations only) by varying glass composition.
- Combination electrodes combine pH & Ref.

Solid State Membrane Electrodes:→



membrane	Ion determined
LaF_3	F^-, La^{3+}
$AgCl$	Ag^+, Cl^-
$AgBr$	Ag^+, Br^-
AgI	Ag^+, I^-
Ag_2S	Ag^+, S^{2-}
$Ag_2S + CuS$	Cu^{2+}
$Ag_2S + CdS$	Cd^{2+}
$Ag_2S + PbS$	Pb^{2+}

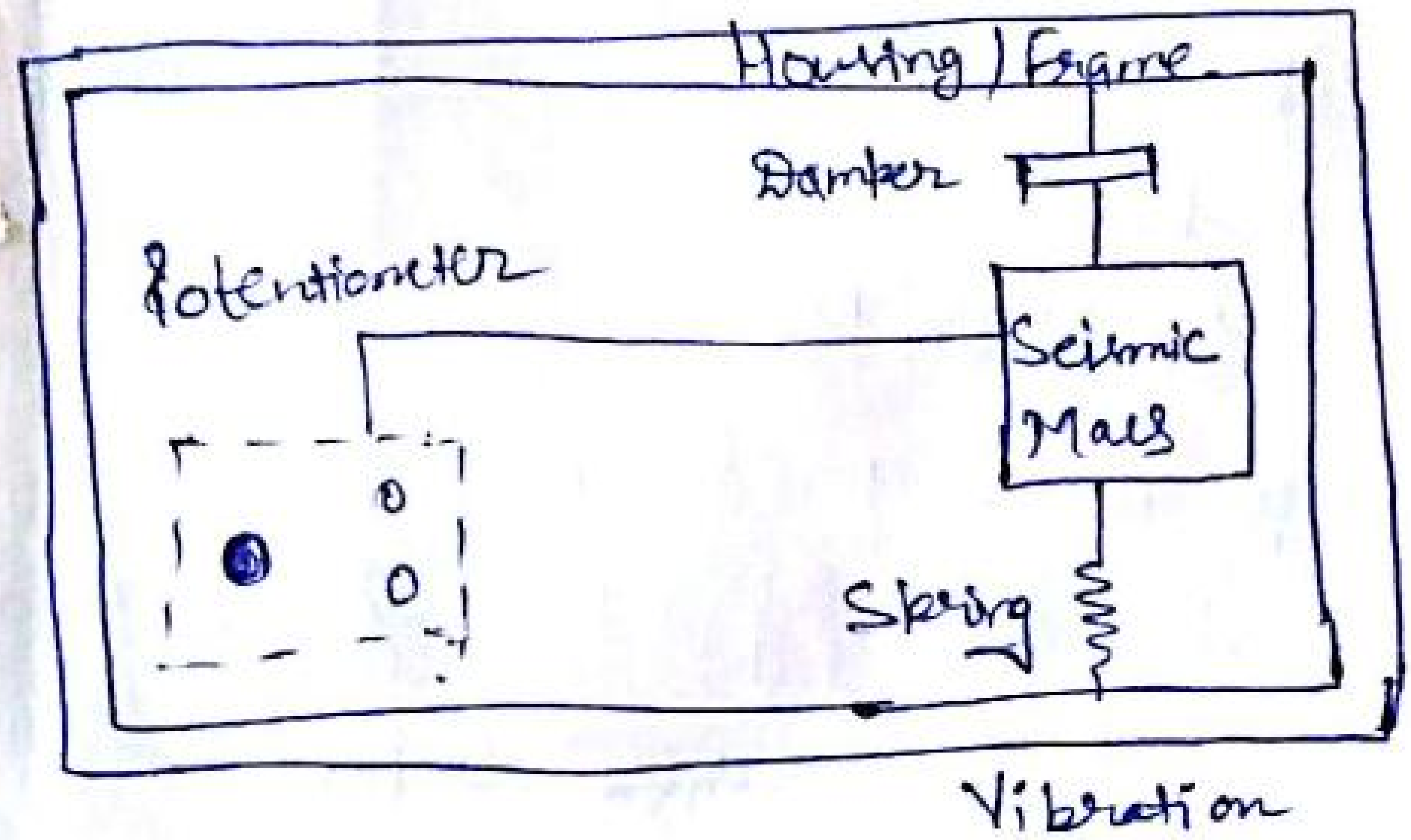
solid state

- Detection limits depend on solubility of solid state membrane
- K_{sp} for $AgCl$ = approx. 10^{-10}
- Solubility is 10^{-5} M or membrane starts to produce ions of interest in soln.
- Mixed crystals improve this somewhat but it is still a limitation.
- Selectivity coefficient = electrode response ratio

Seismic Mass Transducer:-

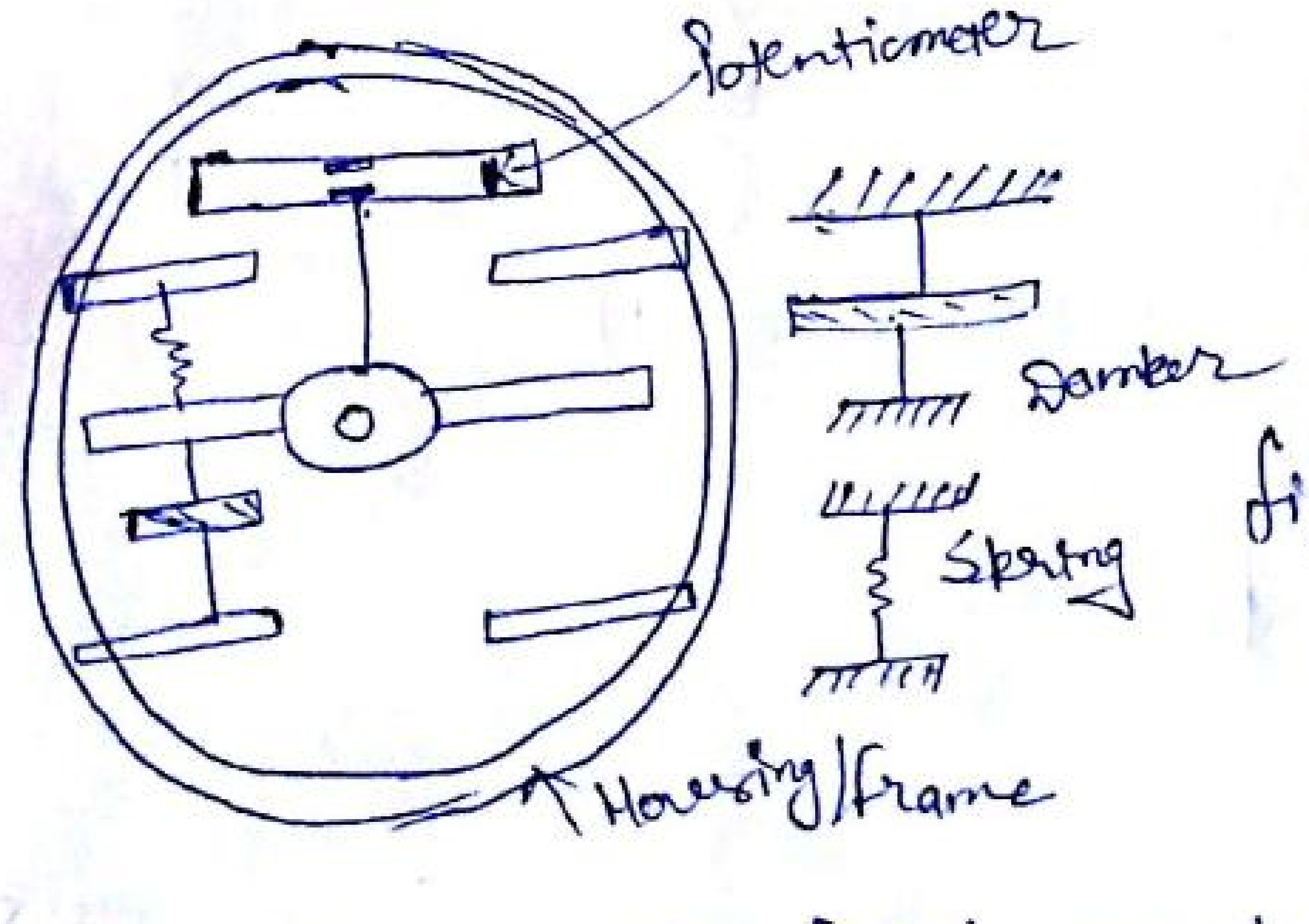
⇒ It is a device which is based on a mass attached to the transducer base, usually with a linear spring. The base is attached to the surface whose motion is desired, & the motion of seismic mass relative to base is recorded with a motion transducer.

⇒ It is used to measure motion of the ground including those of seismic waves generated by earthquakes, volcanic eruptions & other seismic sources.



- A seismic mass is suspended from the housing of the accelerometer through a spring.
- A damper is connected between the seismic mass & housing of the accelerometer.
- Seismic mass is connected to electric displacement transducer.

fig(1) Linear Seismic Displacement Sensing Accelerometer



fig(2)- Rotational Seismic Accelerometer

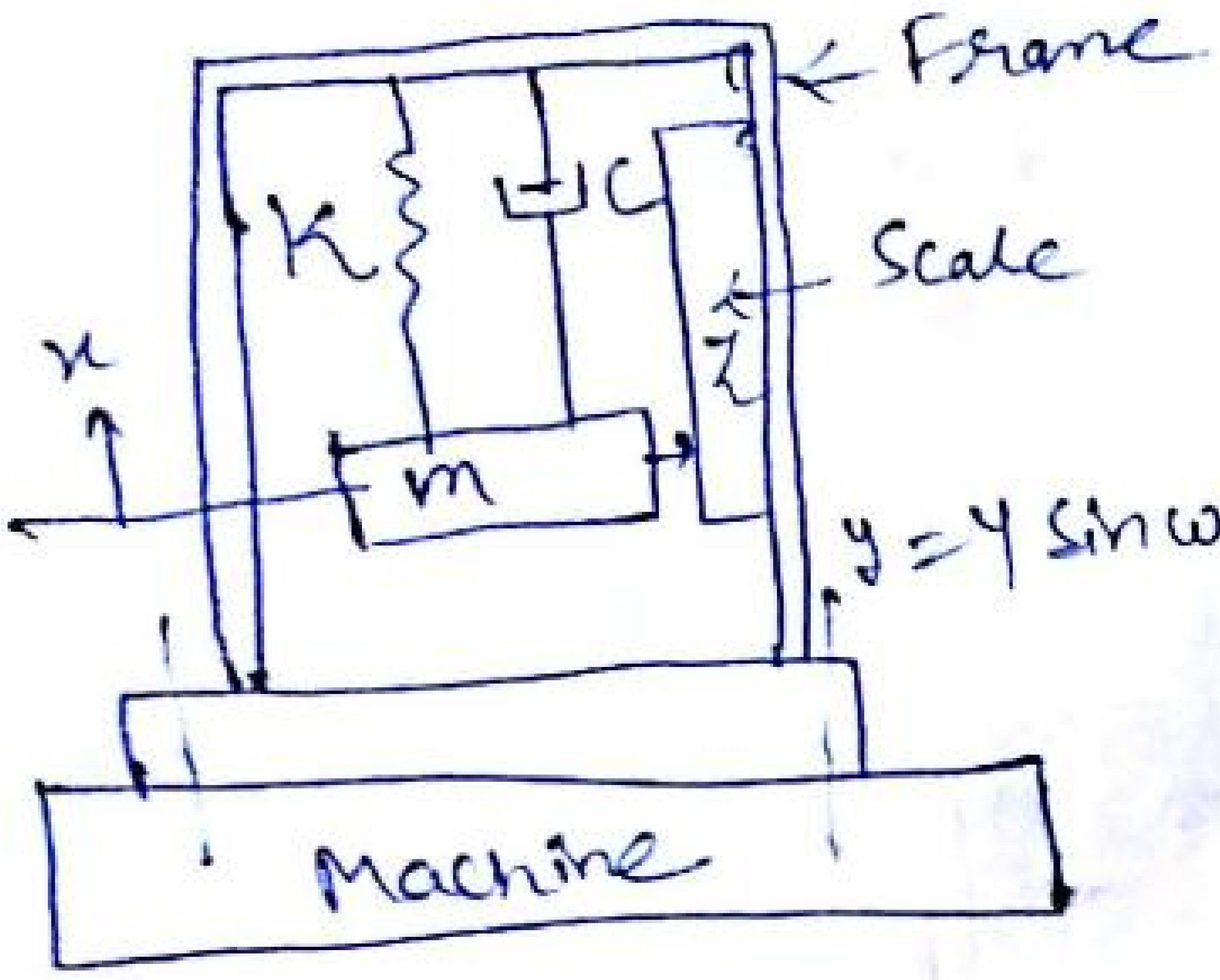
- The accelerometer is fitted on to the structure where acceleration is to be measured.
- Due to acceleration, the seismic mass experience a displacement & this displacement of mass is proportional to acceleration.
- As the mass is connected to an electric displacement transducer, the o/p of transducer depends on the extent to which the mass is displaced.

P. T. O.

- Hence the o/p of transducer is calibrated to give a direct indication of the acceleration characteristics of structure.

Seismic Transducer are of two types:-
- Vibrometer – used to measure displacement of vibrating body
- Accelerometer – " " " acceleration " " " .

⇒ Vibrometer is designed with low natural frequency so known as low frequency transducer.
⇒ Accelerometer is designed with high natural frequency so known as high frequency transducer.



Vibrating body is having Harmonic motion

$y = Y \sin \omega t$ — (1)

eqn of motion for mass m

$m\ddot{x} + c(\dot{x} - \dot{y}) + k(x - y) = 0$ ⇒ (2)

Defining relative displacement

$z = x - y$ → (3)

$\Rightarrow x = y + z$

$$m\ddot{z} + c\dot{z} + kz = -m\ddot{y}$$

$$m\ddot{z} + c\dot{z} + kz = m\omega^2 Y \sin \omega t \quad \text{— (4)}$$

steady state eqn for eqn (4)

$$z = Z \sin(\omega t - \phi)$$

$$\frac{Z}{Y} = \frac{\left[\frac{\omega}{\omega_n}\right]^2}{\sqrt{\left[1 - (\omega/\omega_n)^2\right]^2 + \left[2\xi(\omega/\omega_n)\right]^2}} = \frac{r^2}{\sqrt{[1 - r^2]^2 + (2\xi r)^2}}$$

where $r = \omega/\omega_n$

$$\phi = \tan^{-1}\left[\frac{2\xi(\omega/\omega_n)}{1 - (\omega/\omega_n)^2}\right] = \tan^{-1}\left[\frac{2\xi r}{1 - r^2}\right]$$

For vibrometer, the eqn is

$$\frac{Z}{B} = \frac{(\omega/\omega_n)^2}{\sqrt{\{1-(\omega/\omega_n)^2\}^2 + [2\xi\,\omega/\omega_n]^2}} = \frac{r^2}{\sqrt{[1-r^2]^2 + (2\xi r)^2}}$$

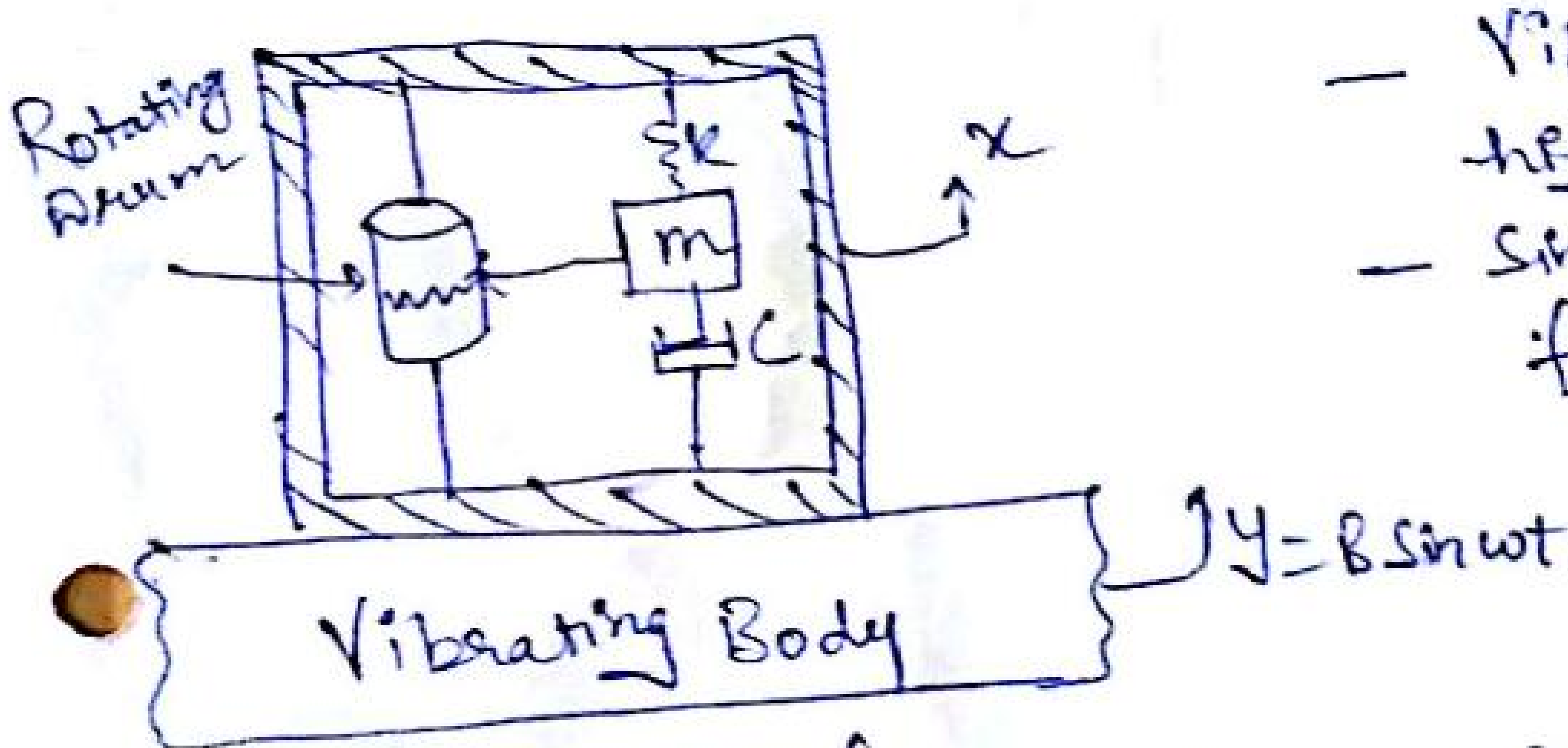
when r is very high (more than 3), the above eqn is

$$\frac{Z}{B} = \frac{r^2}{\sqrt{(1-r^2)^2}} = 1 \Rightarrow Z = B$$

amplitude of vibrating body

[as $2\xi r$ is very small term, so it is neglected for a wide range of damping factors].

⇒ Though Z & B are not in the same phase but B being in single harmonic, will result in the o/p signal as true reproduction of i/p quantity.



- Vibrometer is used to measure the high frequency ω of vibrating body.
- Since r is very high, so natural frequency of instrument is low.

- Low natural frequency means heavy mass of the body of instrument which makes its rare application in practice specially in systems which require much sophistication.
- Natural frequency 1 Hz to 5 Hz.

Interferometer Transducer:→

⇒ Interferometry is a technique in which waves [i.e. EM] are superimposed in order to extract information.

→ It is an investigative technique in fields of astronomy, fibre optics, engg. metrology, oceanography, seismology, spectroscopy, quantum mechanics, nuclear & particle physics, plasma physics, remote sensing etc.

— used for high precision measurements (distance, angle ... etc.)

— It uses very small, stable & accurately defined wavelength of laser as a unit of measure.

OCT 08, 2016 — DEVRAT

Sensors & Transducers

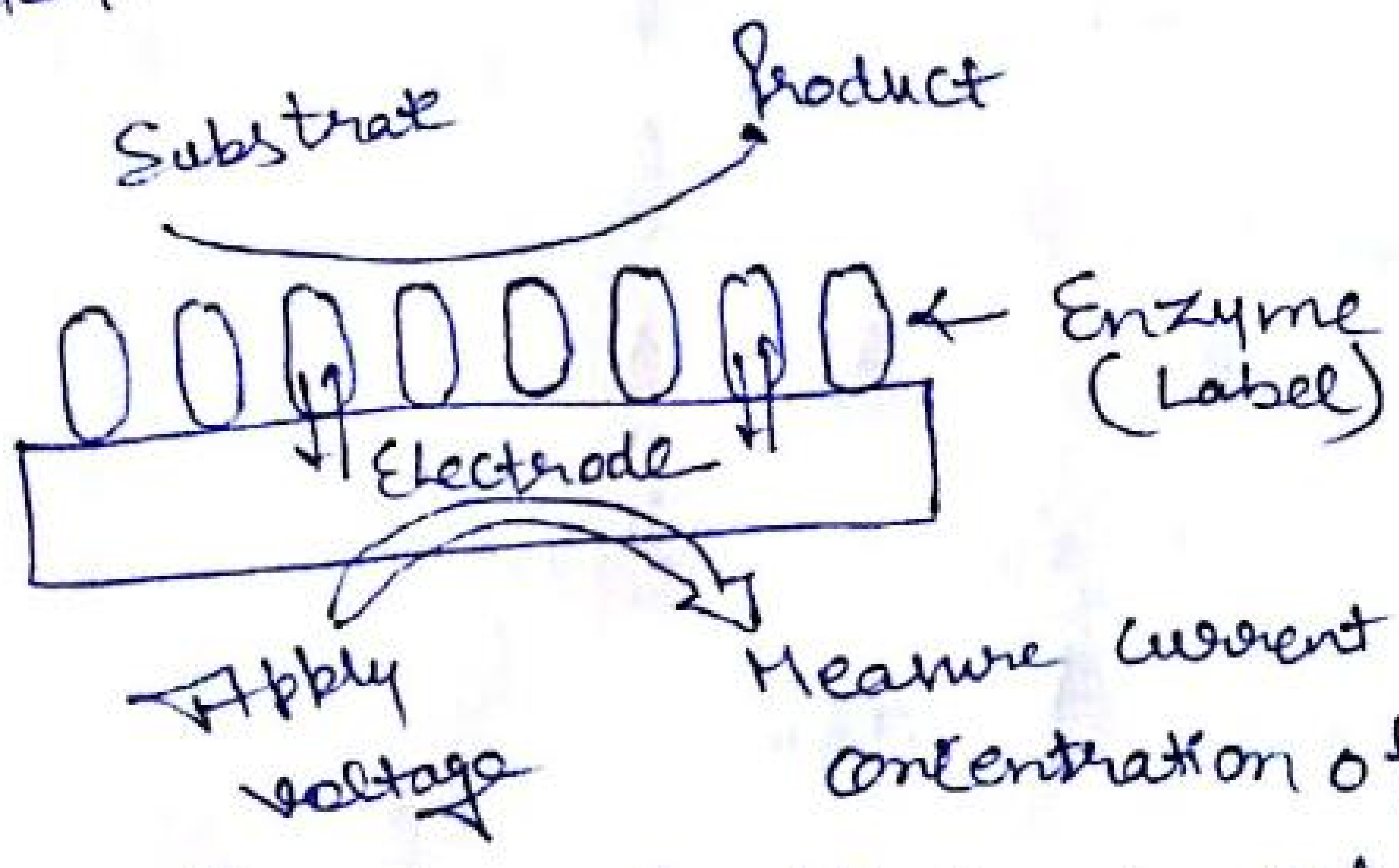
Bio-Sensors :→ [Prof. Leland Clark Inn, 1918-2005]

It is a self-contained integrated device that is capable of providing specific quantitative or semi-quantitative analytical information using a biological recognition element which is in direct spatial contact with a transduction element.

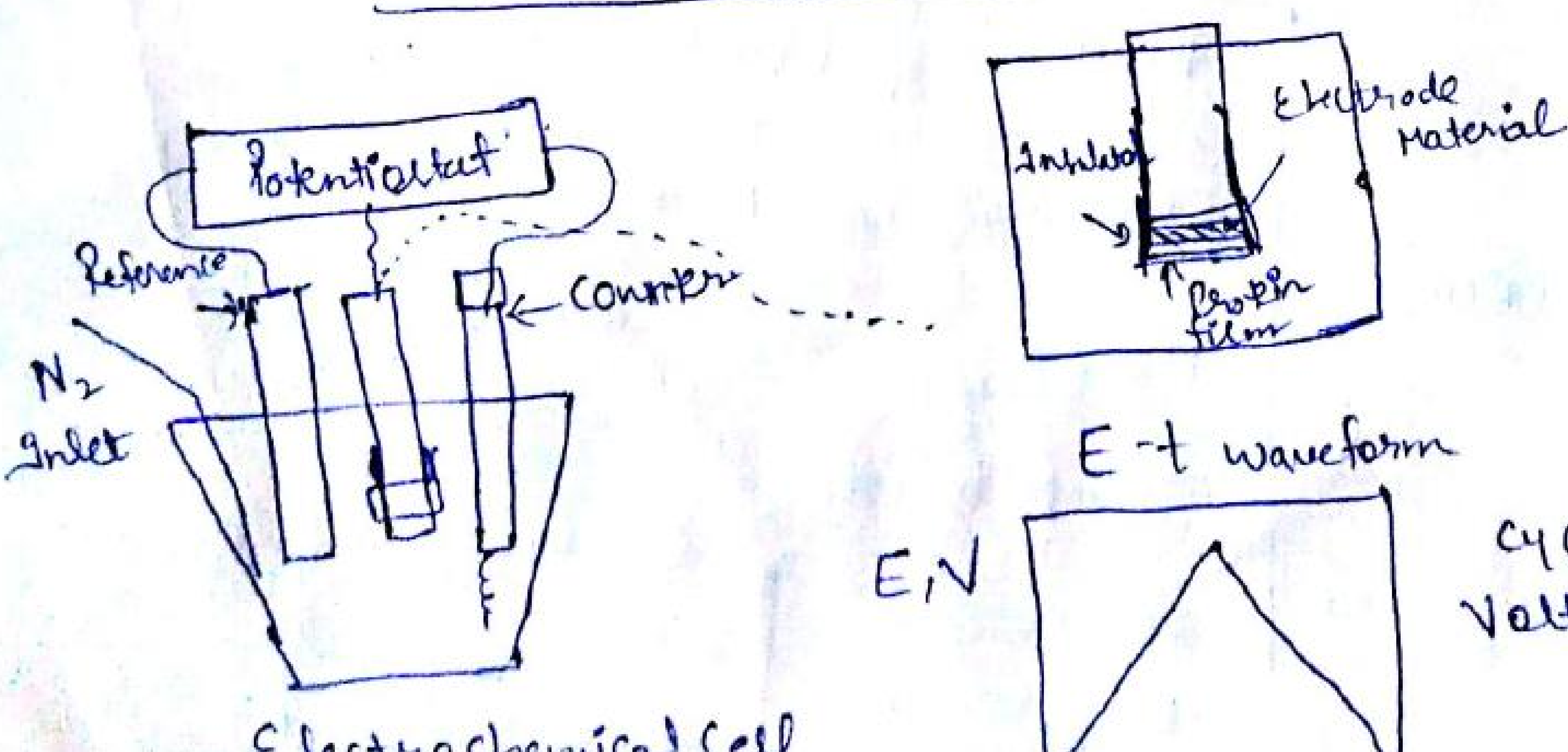
- Biosensor ≠ Bioanalytical System
- An enzyme electrode is a biosensor.

— Any device that uses specific biochemical reactions to detect chemical compounds in biological samples.

— A sensor that integrates a biological element with a physico chemical transducer to produce an electronic signal proportional to a single analyte which is then conveyed to a detector.

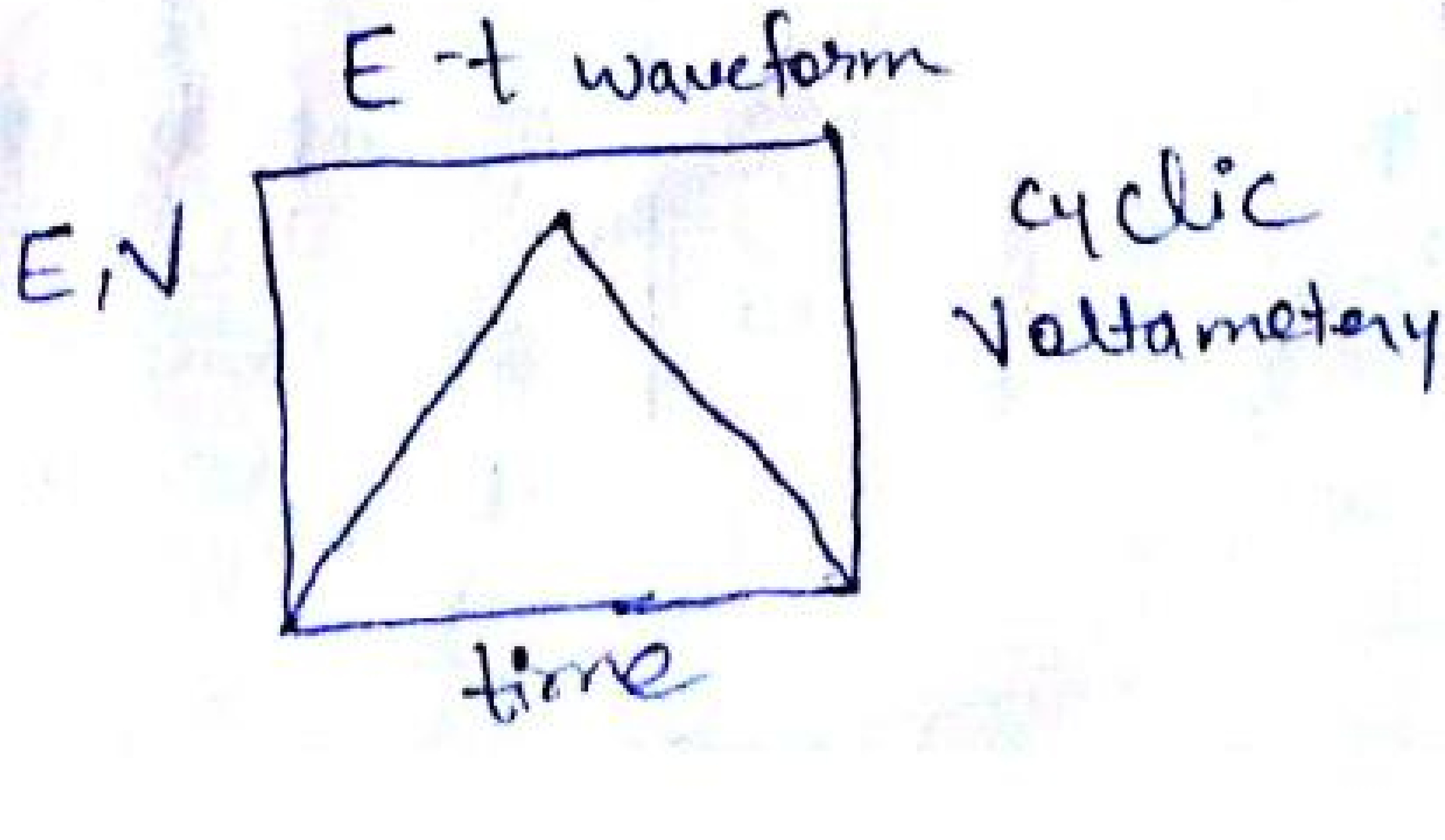


Principle of Electrochemical biosensors



Electrochemical cell

E-t waveform



=> A device that utilizes biological components e.g. enzymes to detect the amount of a biomaterial

(Bio-reaction)

Sample Handling → Bio-Recognition → Transduction → Signal detection

Sample Handling ← Interference usually means a need for sample pre-treatment

Signal detection ← Requires suitable read out & data interpretation

Biosensor System

External | Bio-Recognition | Transduction, Data Processing | External

Sample | Wet | Dry | Observer

Potentiometry - Pot. diff at zero current

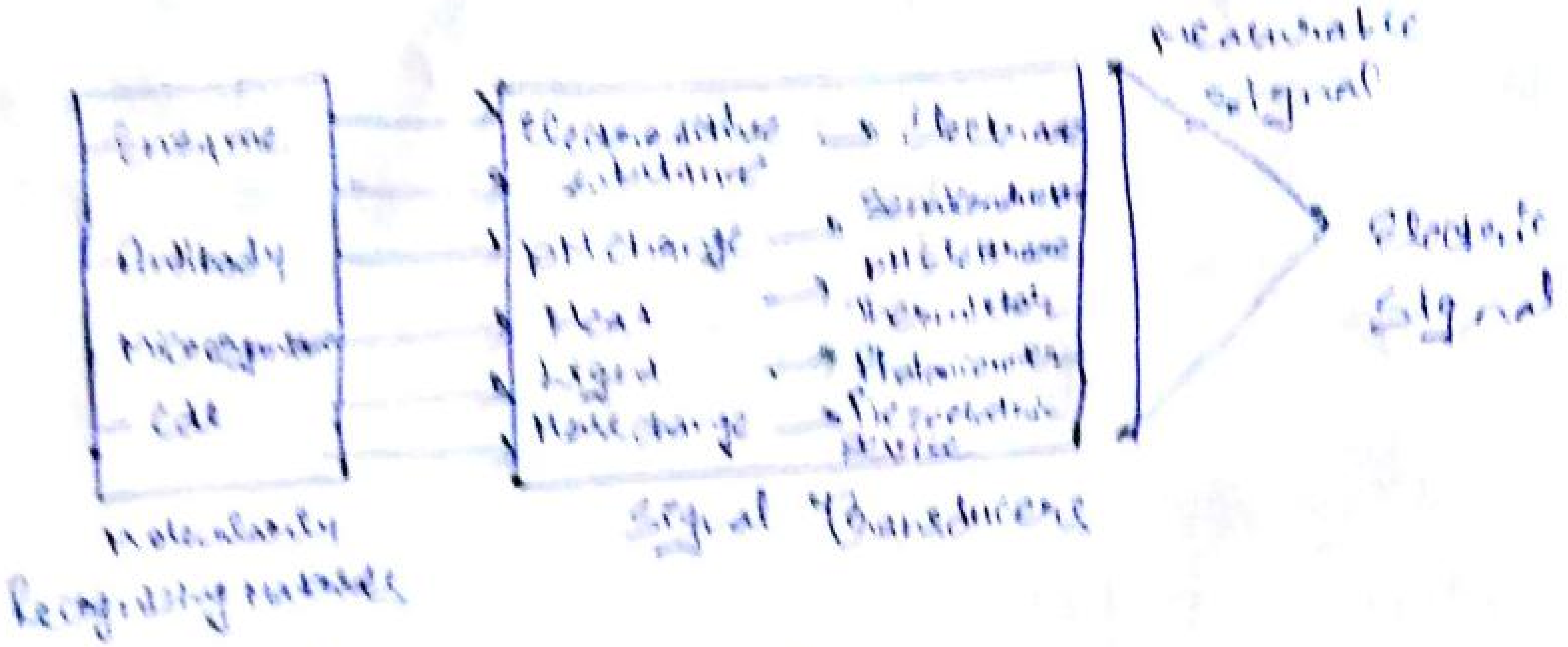
Voltammetry - current with voltage change

Amperometry - current at const. voltage

Conductimetry - 1/solution Resistance

Bio-Receptor
- Antibody
- Enzyme
- Nucleic Acid (DNA)
- Cell
- MIP (Molecular Imprinted Polymer)

Transducer
- Optical
  - Absorption
  - Fluorescence
  - Interference
- Electrochemical
  - Potentiometric
  - Amperometric
  - Conductimetric
- Mass Based
- Temp based
- Electric & Magnetic
  - Dielectric Properties
  - Permeability "
  - Voltage or current



1. The Analyte [What to detect]
Molecule - Protein, toxin, Peptide, Vitamin, Sugar, metal ions

2. Sample Handling [How to transfer analyze to sensitive region]?
Micro fluidics - Concentration increase / decrease, filtration / selection

3. Detection / Recognition - How to recognize the analyte.

4. Signal - How to know there was a detection

Example :-

1. Pregnancy test - Detect the hCG protein in urine.

2. Glucose monitoring device [for diabetes patients]
   - Monitors the glucose level in blood.

3. Infectious disease bio sensor from RBS

4. Bia core Biosensor platform

Types :-

1. Calorimetric Biosensors
2. Potentiometric "
3. Amperometric "
4. Optical "
5. Piezo - electric "

Nanosensors:-

- An extremely small device capable of detecting & responding to physical stimuli with dimensions on the order of one billionth of a meter.
- Physical stimuli - Biological & chemical substances

Current Nanosensors device:

→ Nano structured Materials. (e.g. Porous Silicon)
→ Nano Particles
→ Nano Probes
→ Nanowire Nanosensors
→ Nanosystems [- Cantilevers, NEMS, mostly theoretical]

[A nanometer is a billionth of a meter]

⇒ These are the sensors with atleast one of their sensing dimensions being not greater than 100nm]

3 broad categories
- Optical Nanosensors
- Electromagnetic "
- Mechanical/Vibrational "

MEMS Sensors:→

Micro Electro Mechanical Systems
↓ Small [0.1–100 μm]
↓ Electrical Components
↓ Mechanical components
↓ Integrated

used in Printers [High DPI ~~Inkjets~~ Inkjets], Projectors (Micro-Mirrors from Texas Instruments), Cell Phones, Automobiles

— Human hair thickness [50mm], Red Blood cells – 10 μm.

Why MEMS:-

- Low cost, high yields [use existing IC fabrication technology]
- Made on Si wafers [Silicon Dioxide, Silicon Nitride]
- Favourable scaling for a lot of applications i.e.
  - → Flow rate Sensors
  - → Electrostatics
  - → Magnetism
  - → Many others

Typical Applications

- Accelerometers
- Magnetometers
- Microphones
- Micro-Fluidics
- RF-MEMS
- Bridge to Nanotechnology

Automotive MEMS:-

⇒ MEMS sensors & Actuators used to control various elements of automobile.

- Power train & Chasis control [e.g. Manifold Air Temp.]
- Comfort & Convenience [e.g. - Air Temp. control]
- Communications [e.g. Wireless]

⇒ Two groups i.e. Delco Electronics Group (General Motors) used Piezo resistive sensing & Ford used capacitive sensing.

MEMS Packaging:-

- Most important & extensive part of MEMS sensors
- ≃45% of cost of designing a MEMS device is spent on packaging.

⇒ MEMS is combination of mechanical functions [Sensing, moving & heating] & electrical functions [switching, deciding] on same chip using microfabrication technology.

Materials for MEMS:-
- Metals, Polymers, ceramic materials, Semiconductors, composite materials

Q.1 A seismic accelerometer has a seismic mass $M = 0.005$ kg, stiffness, $K = 8$ N/m & damping ratio, $\xi = 0.1$. If I/P acceleration is $a_i(t) = 50 \sin 30t$ m/s²; find the displacement $x(t)$ of mass?

Solⁿ:- Given
$$M = 0.005 \text{ kg}$$
$$K = 8 \text{ N/m}$$
$$\xi = 0.1$$
$$\omega = 30 \text{ rad/sec}$$
$$a_o = 50 \text{ m}$$

$$\omega_n = \sqrt{\frac{K}{M}} = \sqrt{\frac{8}{0.005}} = 40 \text{ rad/sec}$$

$$U = \frac{\omega}{\omega_n} = \frac{30}{40} = 0.75$$

$$\left|\frac{x_o}{x_i}\right| = \frac{U^2}{\sqrt{(1-U^2)^2 + (2\xi U)^2}}$$

$$\left|\frac{x_o}{x_i U^2}\right| = \frac{1}{\sqrt{(1-U^2)^2 + (2\xi U)^2}}$$

since $U = \omega/\omega_n$

$$\left|\frac{\omega_n^2 x_o}{\omega^2 x_i}\right| = \frac{1}{\sqrt{(1-U^2)^2 + (2\xi U)^2}}$$

& $a_o = \omega^2 x_i$ = amplitude of acceleration of subject

$$\left|\frac{\omega_n^2 x_o}{a_o}\right| = \frac{1}{\sqrt{(1-U^2)^2 + (2\xi U)^2}}$$

$$x_o = \frac{a_o}{\omega_n^2 \sqrt{(1-U^2)^2 + (2\xi U)^2}}$$

$$x_o = \frac{50}{(40)^2 \sqrt{(1-0.75^2)^2 + (2\times 0.1\times 0.75)}}$$

$$= 0.0676 \text{ m} = \underline{6.76 \text{ cm}}$$

$$\left|\frac{x_0}{x_i}\right| = \frac{r^2}{\sqrt{(1-r^2)^2 + (2\xi r)^2}} = \frac{0.75^2}{\sqrt{(1-0.75)^2 + (2\times0.1\times0.75)^2}}$$

$$\left|\frac{x_0}{x_i}\right| = 1.3163$$

$$x_0 = 1.3163 \times x_i$$

$$\Rightarrow x_i = 5.56\,cm$$

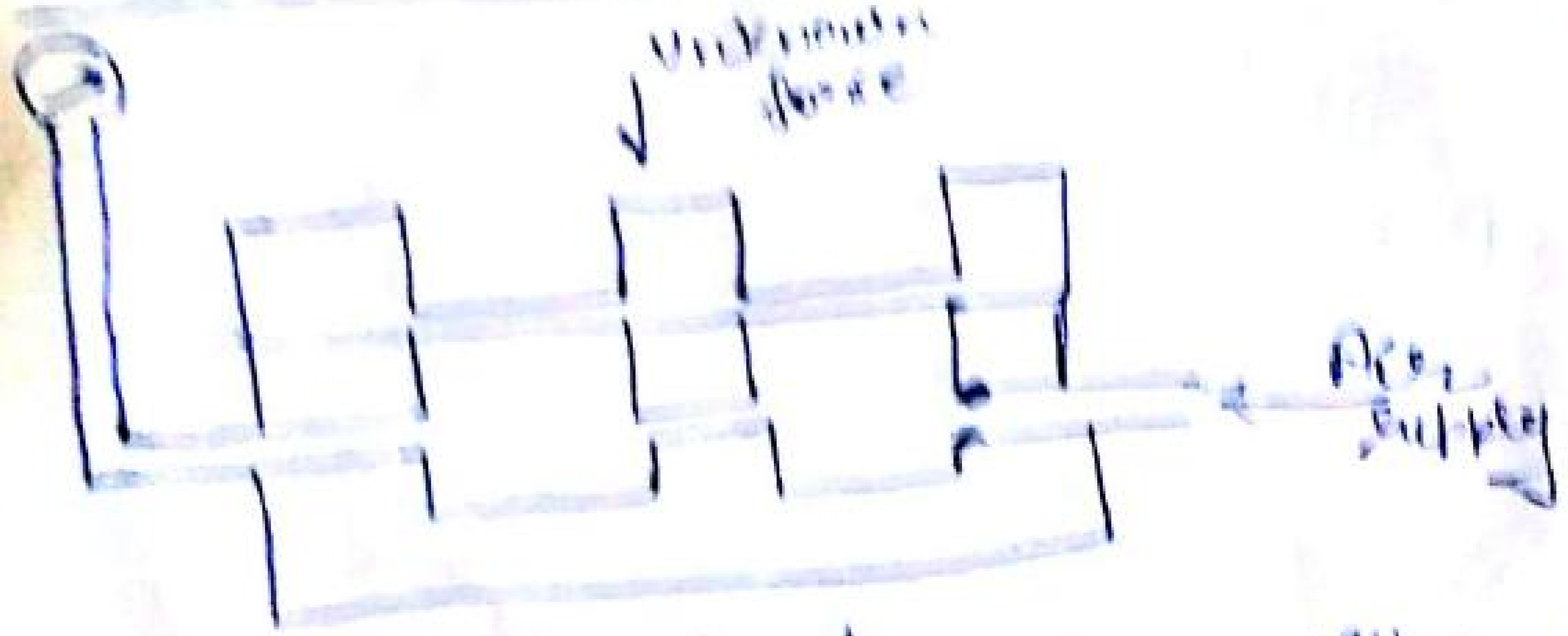
$$|x_m| = |x_i - x_0| = |5.56 - 6.76| = \underline{1.2\,cm}$$

Hydraulic & Pneumatic Load cells

⇒ A load cell is a transducer that converts a force or load acting on it into an analog electrical signal. It is achieved by physical deformation of strain gauges which are bonded into the load cell beam & wired into a wheatstone bridge configuration.

- Mechanical
  - Hydraulic
  - Pneumatic
- Strain Gauge load cells

Pneumatic load cells



- operates on the force-balance principle. These devices are
- These devices use multiple dampener chambers to give higher accuracy than can a hydraulic device
- Explosion proof & not sensitive to temp variations
- Contain no fluids like the hydraulic type that might contaminate the process if diaphragm destroyed
- relatively slow speed of response & need for clean, dry, regulated air or nitrogen

— Force to be measured is applied to top side of diaphragm. Due to this force, diaphragm deflects & causes the flapper to shut off the nozzle opening. Air supply is provided at bottom of diaphragm. As the flapper closes, the nozzle opening, a back diaphragm. This back pressure acts on the diaphragm producing an upward force. Air pressure is regulated until the diaphragm returns to pre-loaded position which is indicated by air which comes out of nozzle.

$= 5 \times 10^{-2}$ kg f   accuracy $= 0.5\%$.

Measurement of Humidity :→

⇒ Atm. Humidity is the ratio of atm. water vapour pressure to the saturated water vapour pressure at that air temperature.

Term	Definition	Unit (SI)
Mixing Ratio	Mass, Water Vapour / Mass, Dry Air	Kg/Kg
Absolute Humidity	Water Vapour (Mass, Volume)	Kg/m^3
Relative Humidity	Actual water vapour Pressure / Saturation water vapour pressure	%
Dew Point	Temp. of condensation (saturation)	K

Humidity Sensors

- Absolute Humidity Sensors - PPMV (Hygrometer)
- Relative Humidity Sensors - %RH (Materials)
  - Ceramics (Metal oxides)
  - Al_2O_3, SnO_2, TiO_2, ZrO_2, $MgFe_2O_4$
  - Polymers
  - Electrolyte