Module IV

① Explain resistivity of a given material determined using two probe method.

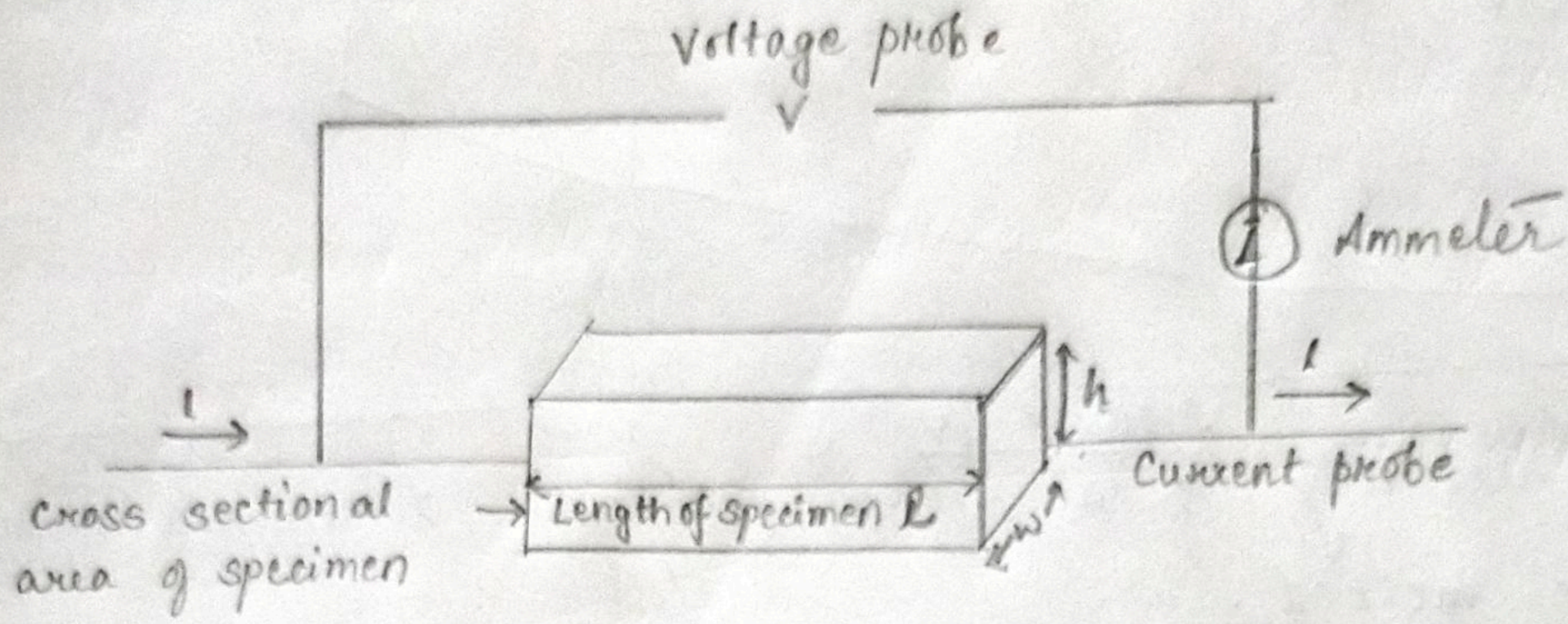
Ans. The two probe method is one of the standard and most commonly used method for the measurement of resistivity of very high resistivity samples like sheets/films of polymers. The resistivity measurements of such samples is beyond the range of four probe method. It has two spring load contact probes.

The two-probe resistance measurement technique consists of the application of an electrical current between two probes a few centimetres apart, and the measurement of the potential difference between these same two probes.

The resistance measured is representative of the volume, defined by 10 times the radius of the concrete - electrode contact area.

The method does not allow the computation of resistivity and the results are expressed in terms of resistance, limiting the comparison of results for different sized devices.

The method can be used as an indicator of variability of surface properties, by relative observation of the variation. For instance, the technique is used in the wood industry to assess moisture variations before use.



Measuring electrical resistivity by two probe method

According to the above diagram, the resistivity is calculated from the voltage drop (V) and current (I) as :

$$\rho = \frac{VA}{IL}$$

$$\rho = \frac{Rwh}{L}$$

Advantages

Two-probe method is a simple and advantageous method for measuring resistance above 1 Ω directly.

Disadvantages

- Error due to contact resistance of the measuring leads
- Materials having random shapes.
- Soldering of the test leads on some materials would be difficult.
- Heating of the leads during soldering may inject additional impurities in materials such as semiconductors and thereby affecting the intrinsic electrical resistivity largely.

② Mention any three advantages of Four Probe over two probe method.

Ans. Advantages of four probe over two probe method are:-

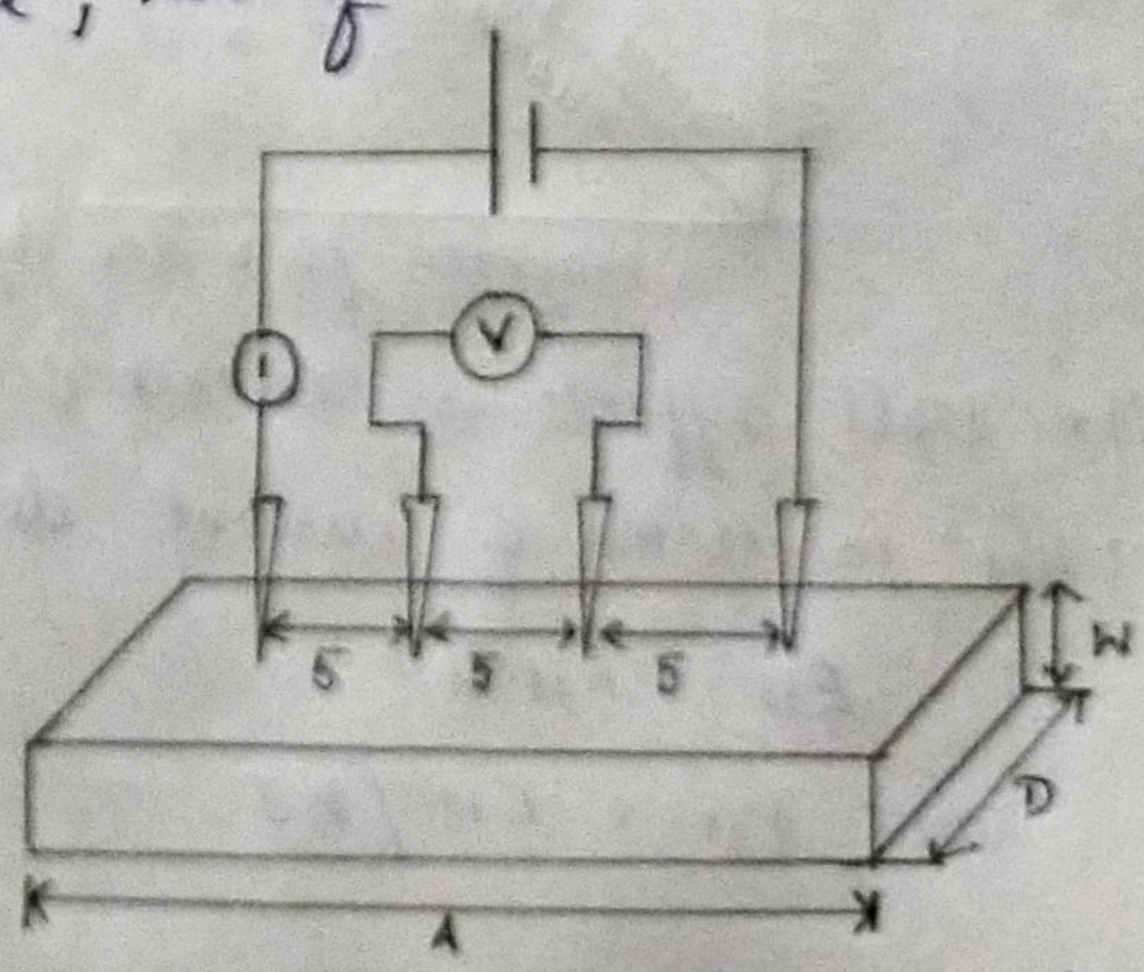
a) Contact and spreading resistance are very low with voltage probes and hence accuracy in measurement is usually very high. To measure very low resistance values, four probe method is used.

b) The contact and spreading resistances in two point probe are large and the true resistivity cannot be actually separated from measured resistivity.

c) The resistance of probe will be not be added to that of sample being tested. It uses two wires to inject current in the resistance and another two wires to measure the drop against the resistance.

③ Explain how the sample is connected to the probes in Four point probe method?

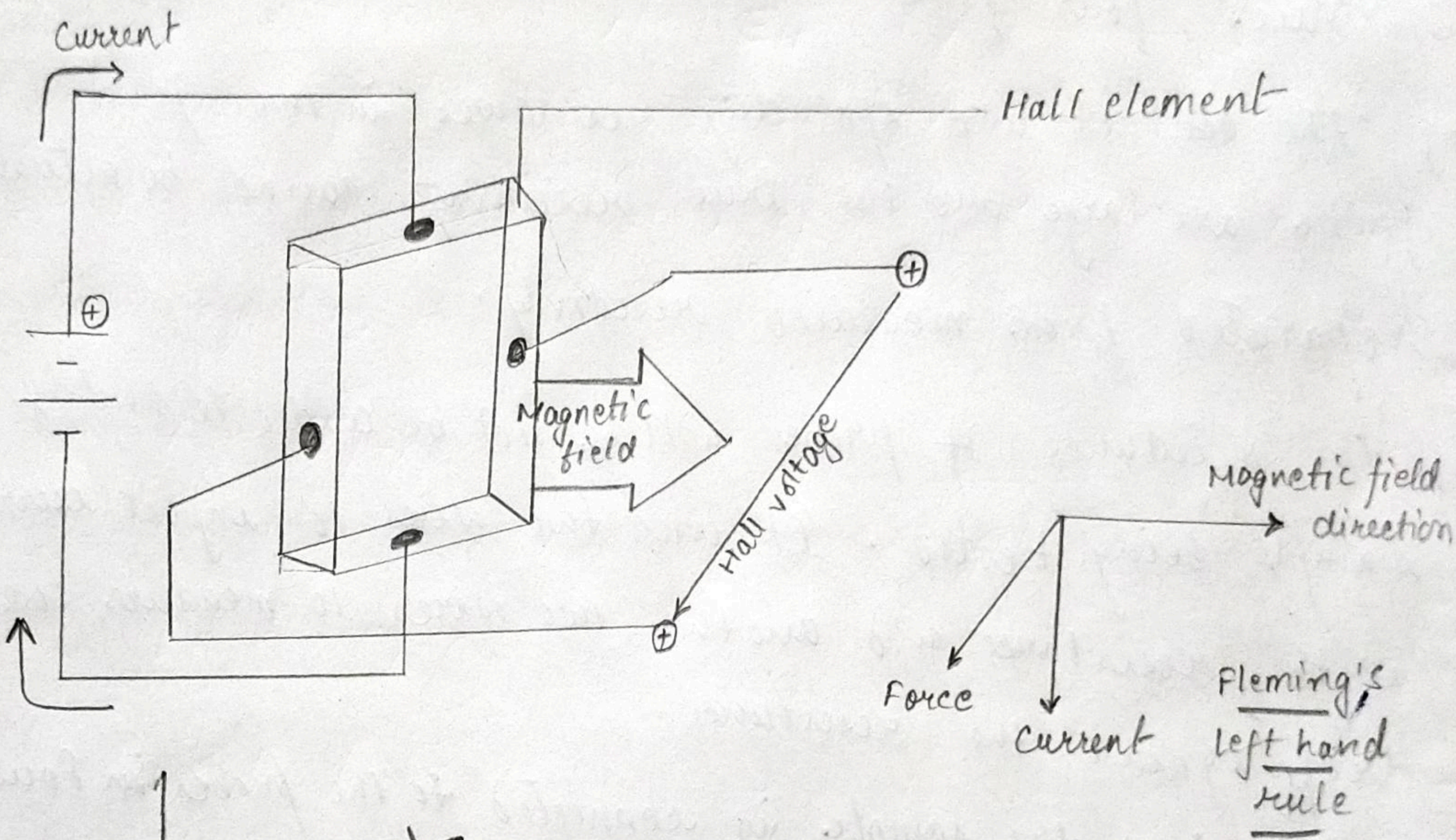
Ans. Here, in the given sample, two of the outer probes are used to send the current from the source meter and other two inner probes are used to measure the voltage drop across the sample.

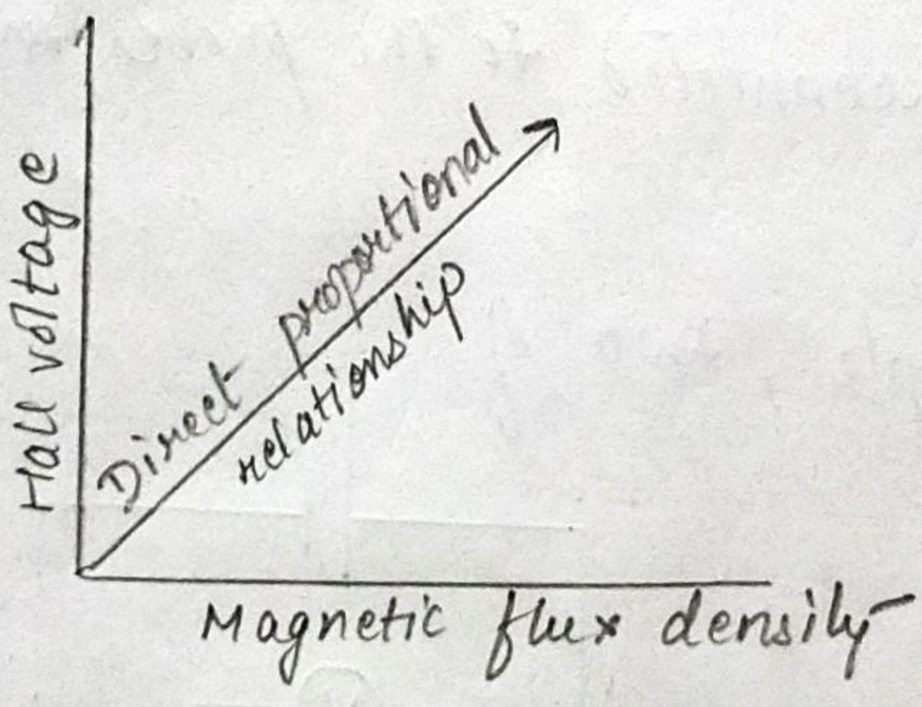


The typical set up of the four-probe method is shown in figure. There are four equally spaced tungsten metal tips supported by springs at one end to mount the sample surface without any damage.

(4) State Hall effect with diagram.

Ans. When a piece of conductor (metal or semiconductor) carrying current is placed in a transverse magnetic field, an electric field is produced inside the conductor in a direction normal to both the current and the magnetic field. This phenomenon is known as the Hall effect and the generated voltage is called the Hall voltage.





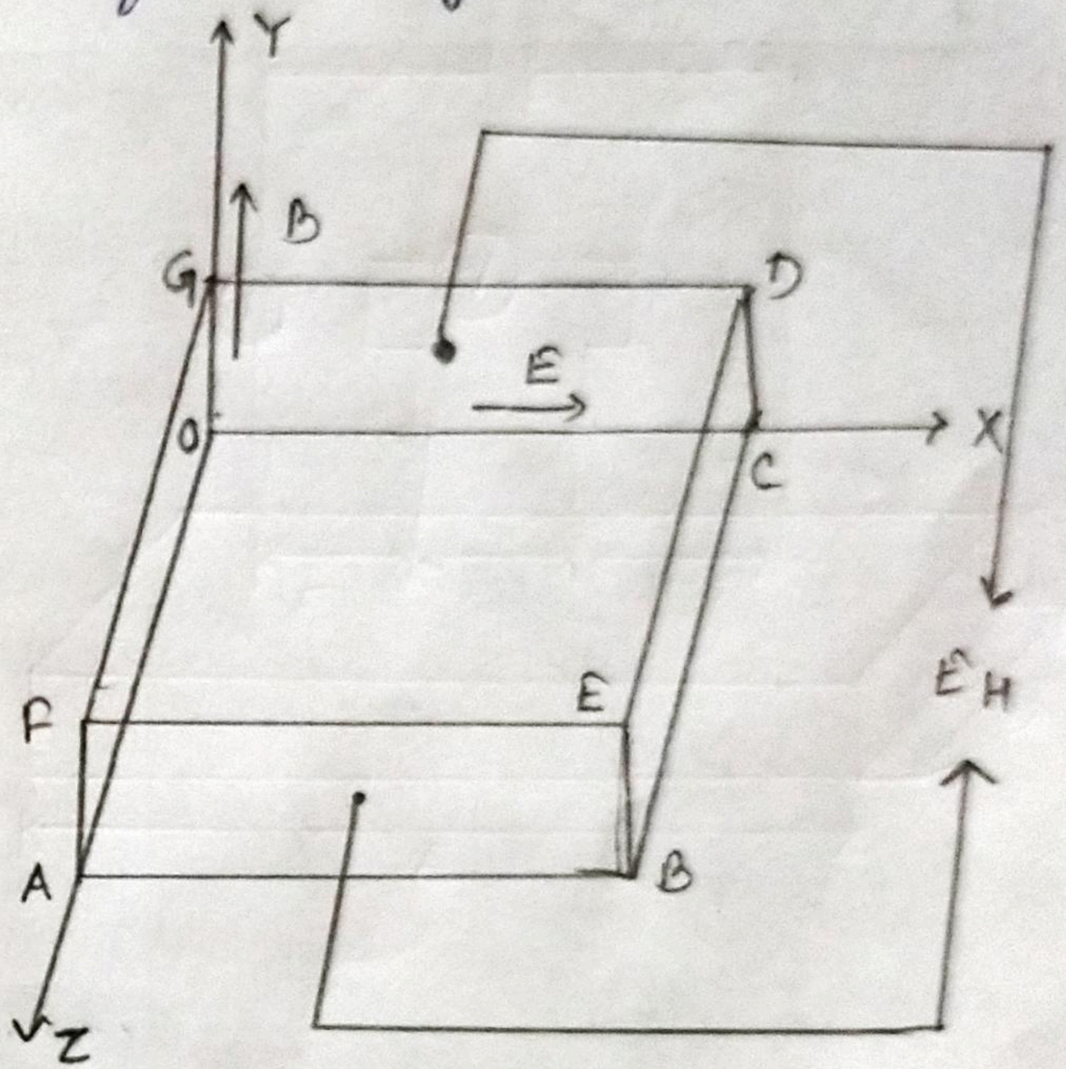
The Hall Effect is described by mans of the Hall coefficient (R_H) in terms of current density 'J' by the relation,

$$E_H = R_H B J$$

(or) $$R_H = E_H / BJ$$

(5) Derive the expression for the Hall coefficient of n type semiconductor.

Ans Consider a conventional current flow through the strip along OX and a magnetic field of induction B is applied along axis OY.



- If the strip is made of N-type semiconductor, the charge carriers in the strip will be electrons.
- As conventional current flows along OX, the electrons must be moving along XO. If the velocity of the electrons is 'v' and charge of the electrons is '−e', the force on the electrons due

to the magnetic field is,

$F = -Bev$. This causes the electrons to be deflected and so the electrons accumulate at the face ABEF.

Thus, face ABEF will become negative and the face OCDG becomes positive. A potential difference is therefore established across faces ABEF and OCDG, causing a field E_H.

- This field gives rise to a force of '$-eE_H$' on the electrons.

At equilibrium, $eE_H = Bev$ (or) $E_H = Bv$ ——— (1)

If J is the current density, then, $J = -nev$ ——— (2)

where 'n' is the concentration of current carriers,

from equation (2)

$$v = J/-ne \quad \text{——— (3)}$$

substituting the value of v in eqn (1), we get,

$$E_H = BJ/-ne \quad \text{——— (4)}$$

$$R_H = E_H/BJ \quad \text{——— (5)}$$

By substituting the value of E_H from eqn (4), we get

$$\boxed{R_H = BJ/-neBJ = -1/ne} \quad \text{——— (6)}$$

(b) Write any three applications of Hall effect.

Ans Applications of Hall effect :

a) Determination of type of semiconductor :-

For a N-type semiconductor, the Hall coefficient is negative whereas for a P-type semiconductor, it is positive. Thus from the direction of the Hall voltage developed, one can find out the type of semiconductor.

b) Calculation of carrier concentration :-

Once Hall coefficient R_H is measured, the carrier concentration can be obtained from,

$$n = 1/eR_H \quad \text{or} \quad p = 1/eR_H$$

c) Measurement of magnetic flux density :-

Using a semiconductor sample of known 'R_H' the magnetic flux density can be deduced from $R_H = V_H t / BI$ or $B = V_H t / R_H I$

(7) A silicon plate of thickness 1mm, breath 10mm and length 100mm is placed in a magnetic field of $0.5\ Wb/m^2$ acting perpendicular to its thickness. If 10^{-2} A current flows along its length, calculate the Hall voltage developed if the Hall coefficient is $3.66 \times 10^{-4}\ m^3/Coulomb$.

Ans. Given data :-

$t = 1mm$; $W = 10mm$; $L = 100\ mm$; $B = 0.5\ Wb/m^2$

$I = 10^{-2} A$; $R_H = 3.66 \times 10^{-4}\ m^3/coulomb$.

Hall coefficient $R = V_H t / IB$

$$V_H = R_H IB/t$$

$$= 3.66 \times 10^{-4} \times 10^{-2} \times 0.5 / 1 \times 10^{3}$$

$$= 1.83 \times 10^{-3} V$$

$$= 1.83\ mV$$

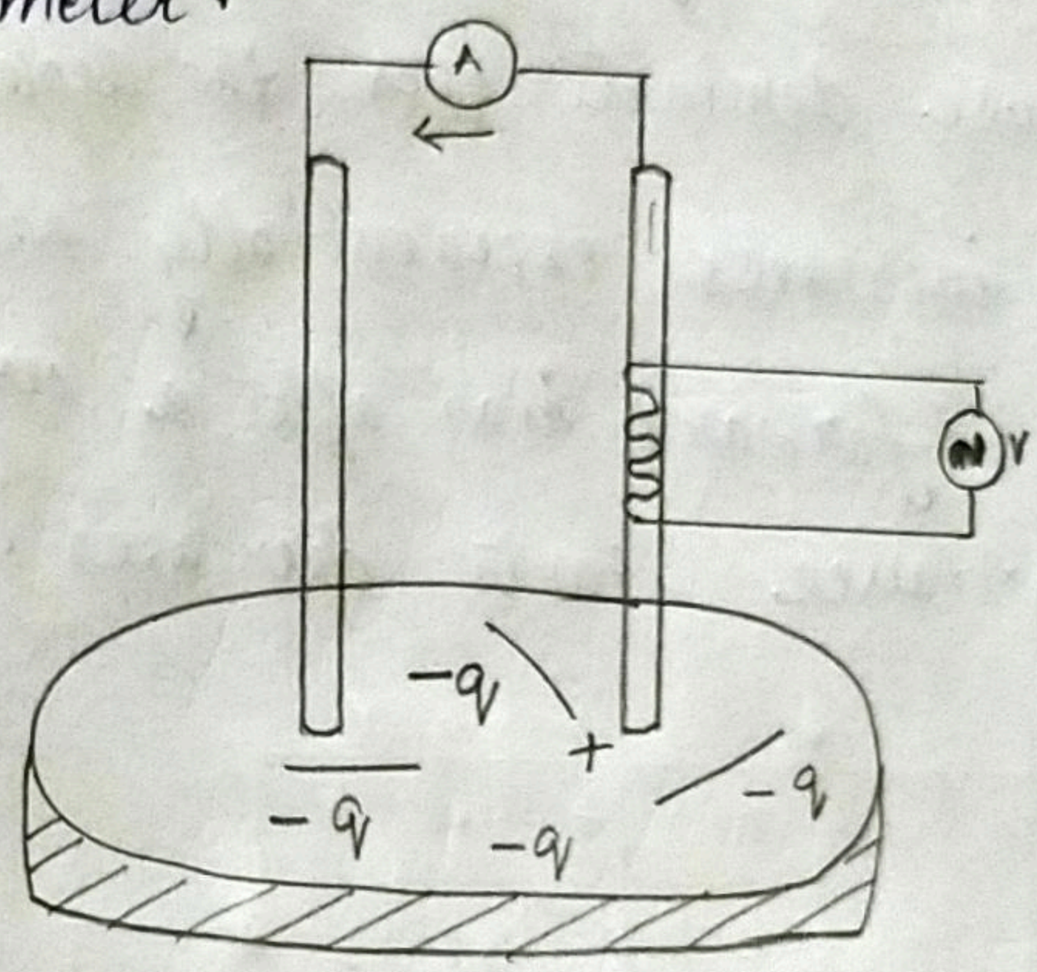
(8) A n-type semiconductor has Hall coefficient $= 4.16 \times 10^{-4} m^3 C^{-1}$. The conductivity is $10^8\ ohm^{-1} m^{-1}$. Calculate its charge carrier density n_e and electron mobility at room temperature.

Ans. $n_e = 1.77 \times 10^{-22}\ m^{-3}$; $\mu_e = 0.0038\ m^2 V^{-1} s^{-1}$

(9) Explain the working principle of hot point probe method.

Ans. Principle of hot point probe method

A conventional hot-point probe experiment enables a simple and efficient way to distinguish between p-type and n-type semiconductors using a hot probe and a stand multimeter.



N - Type Semiconductor

→ While applying the cold and hot probes to an n-type semiconductor, positive voltage read out is obtained in meter whereas for a p-type semiconductor, negative voltage readout is obtained.

(10) Explain the principle of capacitance-voltage measurement method.

Ans. Principle of capacitance-voltage measurement method:

- The capacitance at an p-n or metal-semiconductor junctions depends on the properties of the charge depletion layer formed at the junction
- The depletion regions in the vicinity of the PN junction are "depleted" of free carriers due to the drift field required to maintain charge neutrality.

(11) How does the capacitance of p-n junction diode vary in forward bias and reverse bias.

Ans. In PN diodes, in reverse bias and for small forward voltage, the capacitance is determined by the depletion capacitance, whereas for large forward biases, the diffusion capacitance dominates over the depletion capacitance which increases exponentially with the applied voltage, in forward bias after a certain voltage, the capacitance starts decreases.

(12) Explain forward biasing and reverse biasing of p-n junction diode.

Ans Forward bias → Here, the voltage potential connections are as follows :-
-ve (negative) to the N-type material and +ve (positive) to the P-type material, across the diode. The effect is a decrease in the PN junction diode's width.

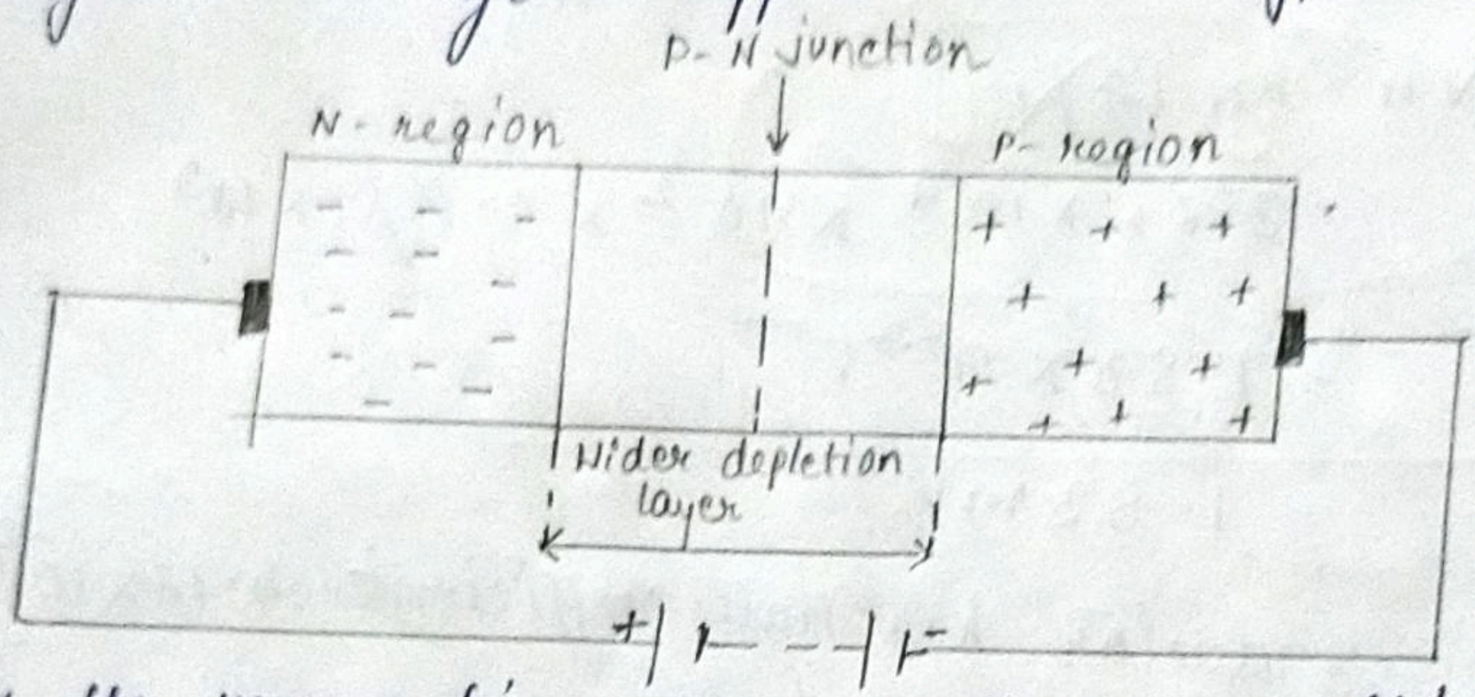
Reverse bias → During this biasing condition, the voltage potential connections are as follows :-
Positive to the N-type material and negative to the P-type material, across the diode. The result of this is an increase in the PN junction diode's width.

(13) Write a short note on I-V characteristics of p-n junction diode in reverse bias.

Ans. I-V characteristics of p-n junction diode in reverse bias

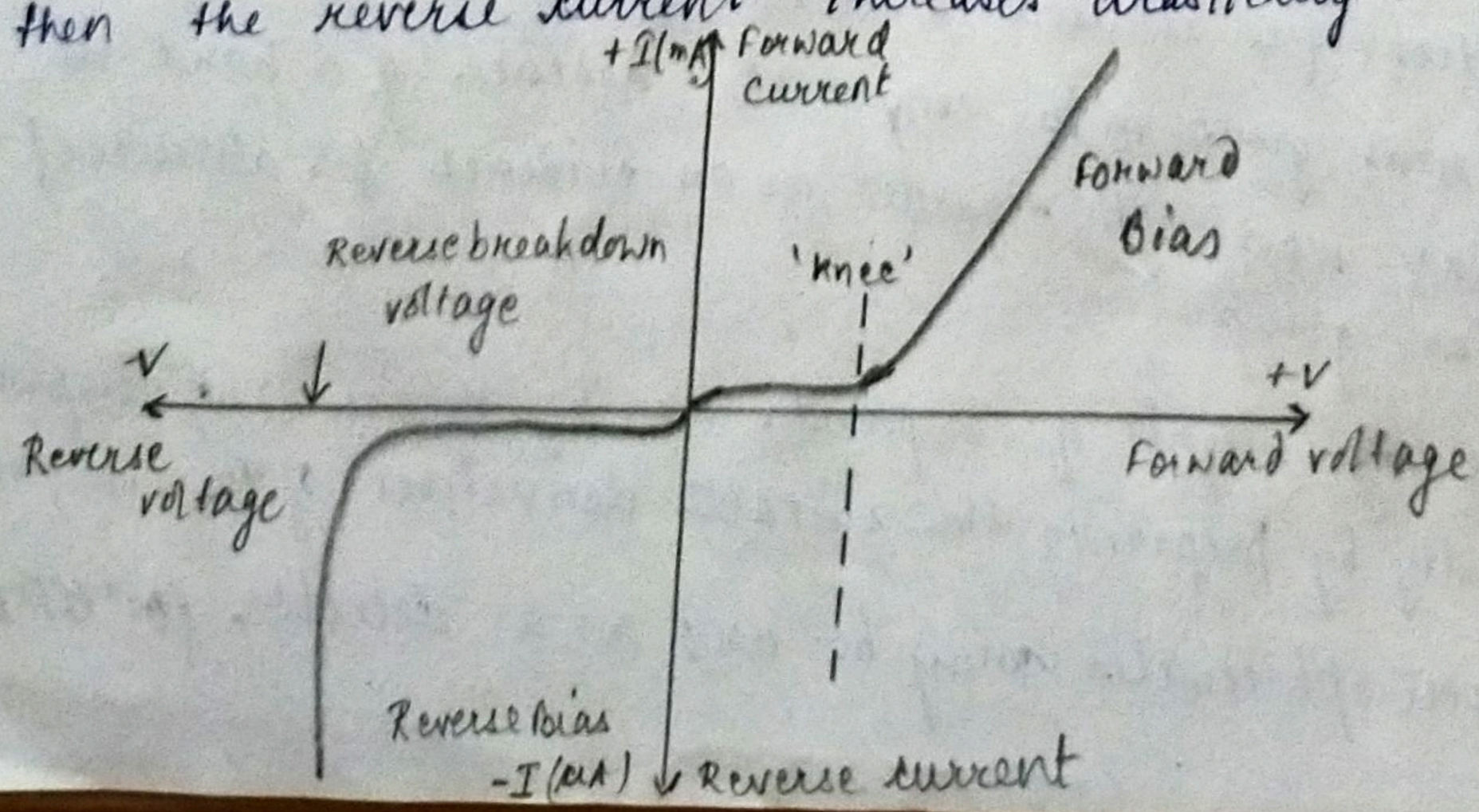
a) By applying a negative voltage (reverse bias) results in the free charges being pulled away from the junction resulting in the depletion layer width being increased. This has the effect of increasing or decreasing the effective resistance of the junction itself allowing or blocking current flow through the diode.

b) When a diode is connected in a Reverse Bias condition, a positive voltage is applied to the N-type material and a negative voltage is applied to the P-type material.



c) If the reverse bias voltage applied to the diode is increased to a sufficiently high enough value, it will cause the diode's PN junction to overheat and fail due to the avalanche effect around the junction. This may cause the diode to become shorted and will result in the flow of maximum circuit current and this shown as a step downward slope in the reverse static characteristics curve below.

d) When the reverse voltage is increased beyond the limit, then the reverse current increases drastically.



(14) What are Shallow Level Traps and Deep Level Traps?

Ans In perfect semiconductors, there exist a band gap (forbidden band) composed of valence band (bottom) and conduction band (top).

When defects are introduced (such as impurities, vacancies, interstitial), there exist allowed energy states somewhere in the band gap.

Deep-level traps or deep-level defects → Deep level defects are a generally undesirable type of electronic defect in semiconductors. They are 'deep' in the sense that the energy required to remove an electron or hole from the trap to the valence or conduction band is much larger than the characteristic thermal energy kT, where k is the Boltzmann constant and T is the temperature.

Shallow-level traps → Those levels ~~in the~~ have very low activation energies so they provide free charge carriers making the semi conductors n- or p-type. Shallow levels are obtained by adding an impurity atom which has, in its outermost shell, one electron in excess or one electron less than in the host atoms electronic configuration.

(15) State combined Beer-Lambert law.

Ans The Beer-Lambert Law is the linear relationship between absorbance and concentration of an absorbing species. The Beer-Lambert law implies that both the type and the concentration of the molecules are important in the process of radiation absorption.

(16) Write any three applications of U-V spectroscopic technique.

Ans Application of UV spectroscopy

a) This technique is used to detect the presence or absence of functional group in the compound. Absence of a band at particular wavelength regarded as an evidence for absence of particular group.

b) Molecular weights of compounds can be measured spectrophotometrically by preparing the suitable derivatives of these compounds.

c) UV spectrophotometer may be used as a detector for HPLC.

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UNIT 5 - Question Bank

① DENSITY OF STATES:

→ In a nutshell, density of states function describes no. of available energy states per unit quantity (length, volume, etc) and is essential for carrier concentration determination and their distribution in a semiconductor.

→ DOS is different for length, volume, etc. because free carrier motion is limited to two, zero, one dimensions.

→ DOS in 2D is known as a "quatum well", in 1D - "quantum wire" and in 0D - "quantumdot.

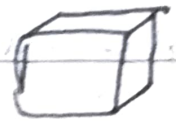
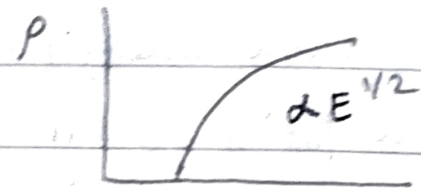
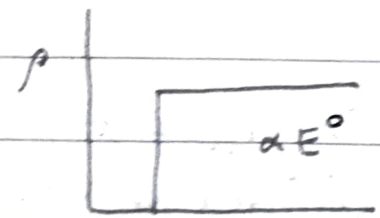
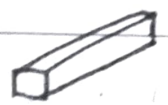
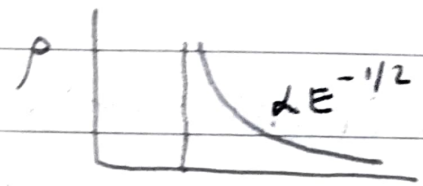
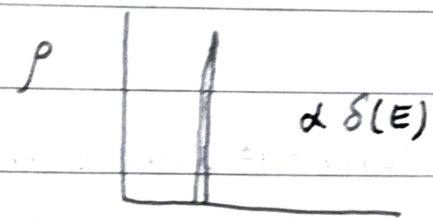
②/③ DENSITY OF STATES IN LOWER DIMENSIONS

→ A lower dimension system is the one where degrees of freedom of microscopic particles like e^-s, p^+s or phonons are restricted

→ This is done because this can give further insight on the material's properties because of the different ways e^-s/etc. interact in 1D, 2D, 0D.

→ This study can give rise to many new types of electronic & photonic devices that make use of these behaviours.

(4) In general,

Degrees of Freedom	representation	ρ vs E
3		
2		
1		
0		

Here 3 dimensions signifies the bulk material.

(5) Quantum wells → A potential well that forces e's to occupy planar region.

Quantum Wire → An electrically conducting wire, in which quantum transport effects are important.

Quantum Dots → A crystals that confines particles to ~~a single~~ 0 dimensions ; a single point.

(6) → Carbon can form different allotropes (different structure) mainly due to its valency.

→ Different allotropes of carbon ~~is~~ are → Diamond, Graphite (pure), Amorphous, Fullerens & nanotubes..

→ Carbon can also form polymer like the linear acetylenic carbon.

(7) CNT: Carbon Nanotubes; allotropes of carbon; variety of applications. Structure-wise, it can be described as a sheet of graphite rolled into a cylinder. Following are its properties:

→ High tensile strength & stiffness (200 GPa & > 1TP respectively) (good for reinforced composites, NEMS)

→ The fibres exhibit high electrical conductivity, Thermal conductivity

→ High chemical reactivity as well because of curved surface.

(8) CNT synthesis by Laser Ablation

→ Graphite is taken and vaporized at around 1200°C by using a pulsed laser, inert gases like Helium / Ar is fed meanwhile.

→ A hot vapour plume forms, expands & cools rapidly as the vaporized carbon condenses.

→ This method's efficiency is ~70% and can produce CNTs with controllable diameter (dependent on the r^n temp.)

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(9) CNT applications :-

→ can be used in Field emmision Transistors.

→ Nanoprobes & sensors also make use of CNTs like scanning probe instruments.

→ predictable time release drug capsules.

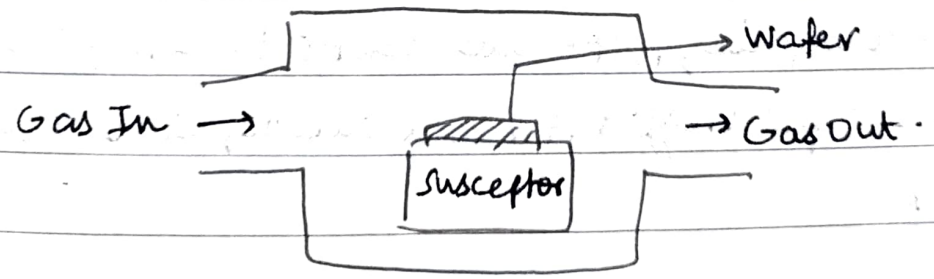
(10) Brief working of CVD:

→ Most widely used method for CNT production

→ A substrate is prepared with a layer of metal catalyst particles.

→ The substrate is heated to ~700°C

→ a process gas (eg NH_3, H_2, etc.) and a carbon gas is fed into into the reactor, and the CNTs are formed at sites of the catalyst.



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(11) Types of CVD reactions

→ Inside the reactor there are 2 types of reactions occuring. The process gas reacts with the substrate surface and the r^n of process gas with the gas phase as well.

→ The former is called Heterogenous reactions and the latter is Homogeneous reactions.

→ The difference lies in the reaction phase. Moreover, Heterogenous reactions are more desireable in the process.

(12) Hot wall & cold wall reactor in CVD.

→ These types of CVDs differ in the activation process of the chemical reaction.

→ As the name implies, Hot-wall reactor have the walls heated along with the wafer itself. In the cold wall one, walls are actively not heated up

→ Due to this, hot walled ones require wall cleaning due to film deposition.

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(13) CVD classification by Pressure

→ APCVD (Atmospheric P CVD) → operate at atmospheric P and therefore simplest design

→ LPCVD (low P CVD) → medium pressure (30-250 Pa) and higher relative temp. ~~than~~ than APCVD.

→ PECVD (Plasma enhanced CVD) → low P operation, also RF induced glow discharge process is used additionally.

(14) Brief working of PVD

→ This process is fundamentally a coating using vapourisation and can be thought as an alternative to electroplating.

→ The process is similiar to CVD but instead the precursor starts out in solid form and heated.

→ Four processes are carried out in order: Evaporation → Transportation → Reaction → Deposition.

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(15) 4 processes of PVD:

→ Evaporation → ~~the~~ target is vapourised (actually atoms dislodging) by a high energy source like beam of e^-s.

→ Transport: → straight line transportation of the vapourised material from ~~the~~ target to the substrate.

→ Reaction → the vapourised target reacts with the substrate to form desired products.

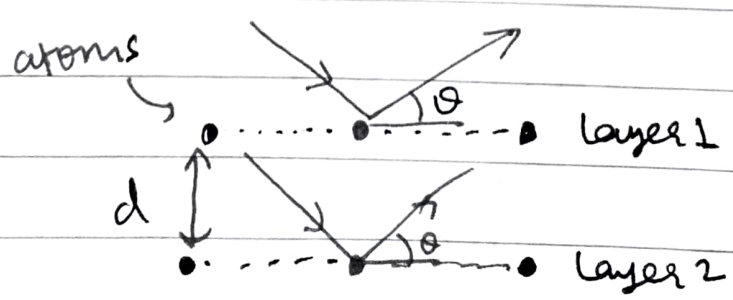
→ Deposition → The result of the reaction; the solid product forms at the reaction site.

(16) → In a highly regular crystal structure, X rays can actually scatter at the surface.

→ If it doesn't at one layer, X rays can pass to the next layer of the structure. This causes an overall diffraction pattern.

→ This phenomenon is represented numerically as

$2d\sin\theta = n\lambda$, and is called Bragg's law.



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(17) Powder XRD:

→ The main aim of the exp is to get a diffraction pattern that is different for different materials. Moreover we can also calculate lattice properties.

→ An x ray is made to fall on the specimen (through a monochrome filter as well as sheets). Due to the structure x-rays emerge in all directions and give a pattern.

→ By using some mathematical relationships b/w distances, radii, angles (like Bragg's law) crystalline structure can be deduced.

(18) SEM principle

→ We can get clear images of very small specimens by using electron interactions and detecting them.

→ Electrons are fired and reach the specimen through different lenses. upon striking the electrons interact and these interactions are recorded.

→ These interactions are also used to generate pixels in CRT monitors to form a frame. The intensity of the pixel is dependent on number of reactions.

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(19)

→ Backscattered e^-s are the ones which are scattered at exactly 180°. Since no. of such e^-s is directly related to the atomic number, these e^-s gives differentiation b/w different parts of the specimen (with different average atomic number)

→ Secondary e^-s are the ones which gets ejected due to the e^- gun electron imparting its energy. This also causes path change. Generally, changes in topography yields secondary e^-s.

→ Auger electrons are produced because of energy surplus in the atom which has produced secondary e^-s. Since Auger e^- energy is a characteristic feature of elements, it gives elemental composition information of the specimen.

(20) TEM Principle

→ Very similiar to SEM, it uses electron gun through a series of condensor lenses that hit the specimen, photo is obtained on a screen

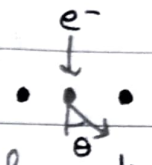
→ The behaviour of the transmitted electrons after interaction gives the idea of structure, spacing and composition properties

→ electrons can either be unscattered, elastically scattered or inelastically scattered.

(21)

→ unscattered are the ones that simply didn't interact and gives idea of thickness of the specimen. ~~*~~ no. of such e⁻s vary inversely with the thickness.

→ Elastical collision means e⁻s are scattered at some θ without any energy loss. when such e⁻s are recorded, each spot on the photographic plate represents atomic spacing.



→ Inelastically scattered e⁻s loose energy upon interaction with the material. This energy loss is characteristics of different elements. Moreover, ~~Bright~~ alternate dark & bright bands can be obtained which gives further info about atomic spacing. (less energ → dark, etc.)

(22) AFM principle:

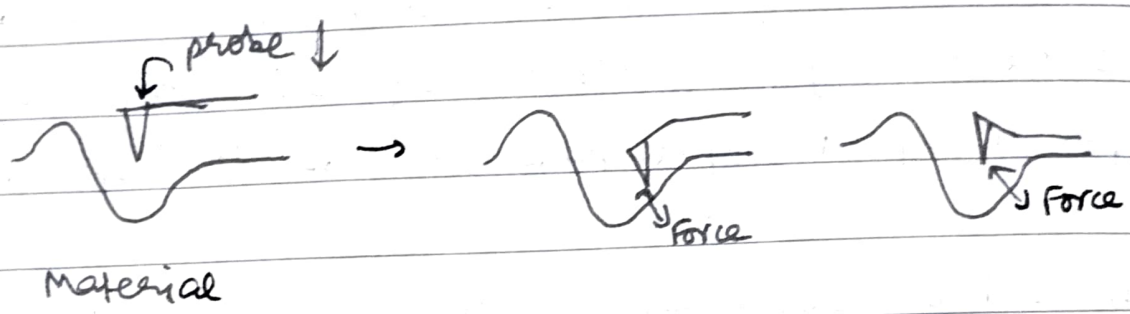
→ The main idea of this device is that at different topologies, there is a change in force experienced by the tip & the sample.

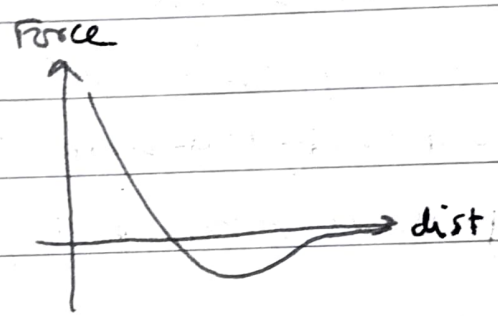
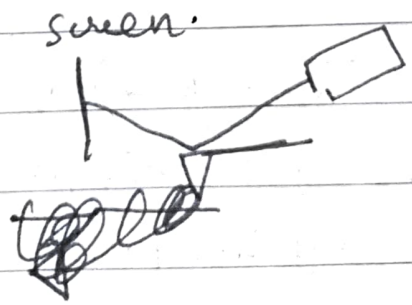
→ These forces can be ionic, repulsion, vander walls, capilliary, etc. The image is generated by recording the force changes as the probe is ~~can~~ scanned in the x & y directions.

→ The structure consists of a cantilever with a sharp tip and is controlled by a piezo electric tube scanner.

(23) Working principle of AFM:

→ The probe is connected to a piezo electric scanner which ensure precise movement of the probe. The probe is made to approach the sample vertically and the trend of force is recorded as the probe can bend according to the force





→ A laser beam is also made to fall on the probe, as the reflected ray is a consequence of the bending of probe and can be fed into a microprocessor.