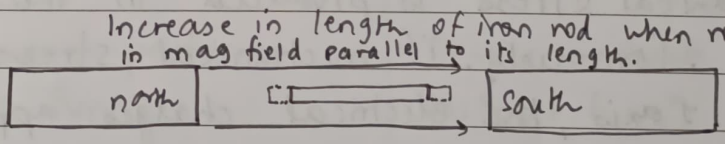
Module 5: Sensors

Q. what are Ultrasonic waves? State magnetostriction effect.

→ Ultrasonic waves are sound waves with frequencies greater than 20kHz. These waves are above upper limit of human's audible range (20Hz - 20kHz)
Magnetostriction is property of ferromagnetic materials that causes them to change their shape or dimension during the process of magnetization. The variation of materials magnetization due to the applied magnetic field changes the magnetostrictive strain until reaching its saturation value. The effect causes energy loss due to frictional heating in susceptible ~~ferro~~ ferromagnetic cores.



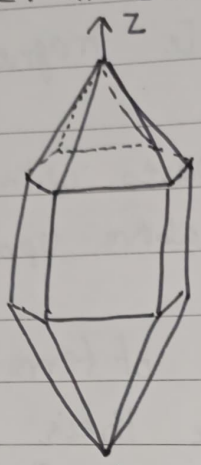
Q. Explain piezoelectric and inverse piezoelectric effect.

→ Piezoelectric effect is the ability of certain materials to generate an electric charge in response to applied mechanical stress.
Direct piezoelectric effect - generation of electricity when stress is applied
Indirect/Inverse piezoelectric effect - generation of stress when an electric field is applied.
When piezoelectric material is placed under mechanical stress, a shifting of the +ve & -ve charge centres in material takes place which results in ext. electric field. When reversed, an outer electric field stretches or compresses the piezoelectric material.

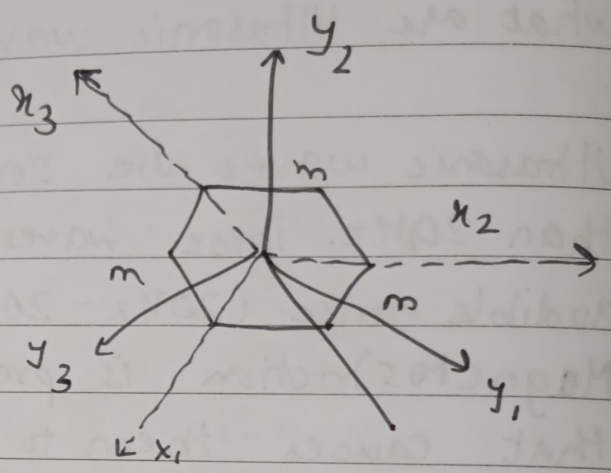
AT, BT, SC, IT, ST Cut

Q. Draw the structure of quartz crystal & explain its various use. axes

→



Quartz in its natural form



section Quartz crystal ⊥ z-axis

In a quartz crystal, if an electric voltage is applied in the direction of electrical axis, mechanical stress is produced in the direction of y-axis. Conversely, if mechanical stress is applied along y axis, the electrical charges appear on the faces of the crystal along x-axis. Consider an X-axis crystal plane thickness 't' & length 'l' (along optic axis). When an ac voltage is applied across the faces of this plate along electrical axis, then alternating stress & strains are set up both in its t & L. If freq. of ac = natural freq of vib of the plate, resonance occurs in large amplitude of oscillation.

$$f_{\substack{\text{along} \\ x\text{-axis}}} = \frac{1}{2t}\sqrt{\frac{y}{\rho}}$$

Q. Explain the production of ultrasonic waves by piezoelectric oscillator.

→ When an electrical signal generator provides a pulse of electrical energy to a piezoelectric crystal in a transducer, the crystal vibrates, converting the electrical pulse into mechanical vibrations then ultrasonic waves are produced. Piezo electric oscillators produce ultrasonic waves at resonance.

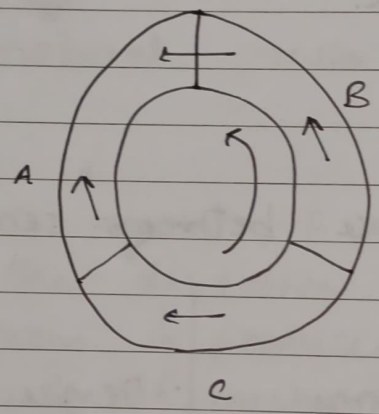
Q. State the difference between sensors and actuators

→

Sensors	Actuators
• Device which performs an input func^n	• Device which performs an output func^n
• Senses physical change, movement, electrical signals, radiant energy, magnetic energy, etc.	• Moves something & control external device
• electrical signals are generated	• Motion or heat is generated
• Convert physical characteristics from their environment to electrical signals for system.	• Convert the electrical ~~system~~ signals from the system to various physical characteristics for their environment.
• Receive input from their environments	• Receive inputs from system's output conditioning unit.

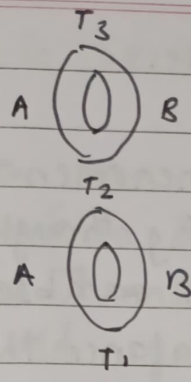
Q. State & explain laws of thermoelectricity.

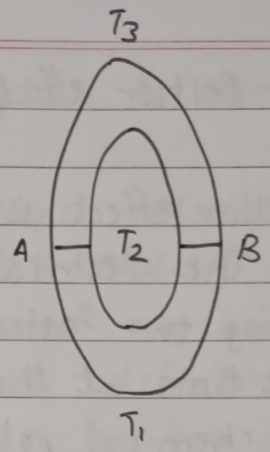
→ Law of Intermediate Metals:
The insertion of an additional metal into any circuit does not alter the whole emf in the circuit provided by that the additional metal is entirely at the temperature of the point of the ckt at which it is inserted.



If in a circuit, all the junctions are at same temp then $V_1 + V_2 + V_3 = 0$. Temp AB change $V_1 \rightarrow V_1'$ & $V_2, V_3 \rightarrow$ remain same
Theroemf $E = V_1' + V_2 + V_3$ & $V_2 + V_3 = -V_1$ so
emf $e = V_1' - V_1$. It shows that if the junction of the thermocouple of elements A & B is opened & C is metal is inserted, emf for the couple AB remain same provided both junctions of metal 'C' are at same temp.

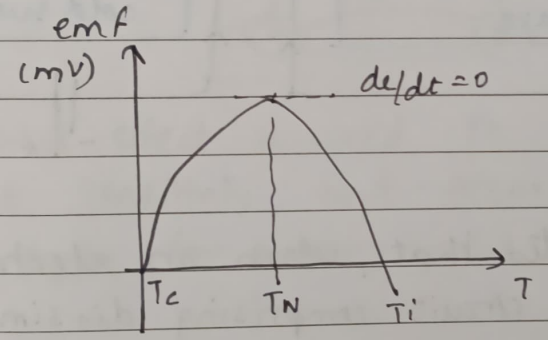
→ Law of Intermediate Temperatures:
Let e(1-2) be the emf for the $T_1 - T_2$ couple and e(2-3) be that for $T_2 - T_3$ couple. If the junctions at the temperature T_2 be placed in contact, no change is observed, because like metals at the same temp are only joined. Then if the junc^n be opened to form the arrangement, there is no change in resultant emf, for contact destroyed, both had the same Peltier effect at temperature T_2.. $e[1-3] = e[1-2] + e[2-3]$





→ Variation of emf with temp:

In a thermocouple, as we increase the temp of the hot junction, keeping the cold junc^n at 0°c, the ⇕ thermo emf ↑ temp ↑ till it reaches max limit. Then ↑ $Temp_{hot\ junc^n}$ ↓ Thermo emf till → 0



Parabola

Neutral temp = T_n = Temp is max hi

Temp of Inversion = T_i = Temp at which reversal of emf takes place.

Cold temp Junc^n = T_c

$T_n = \frac{T_c + T_i}{2}$

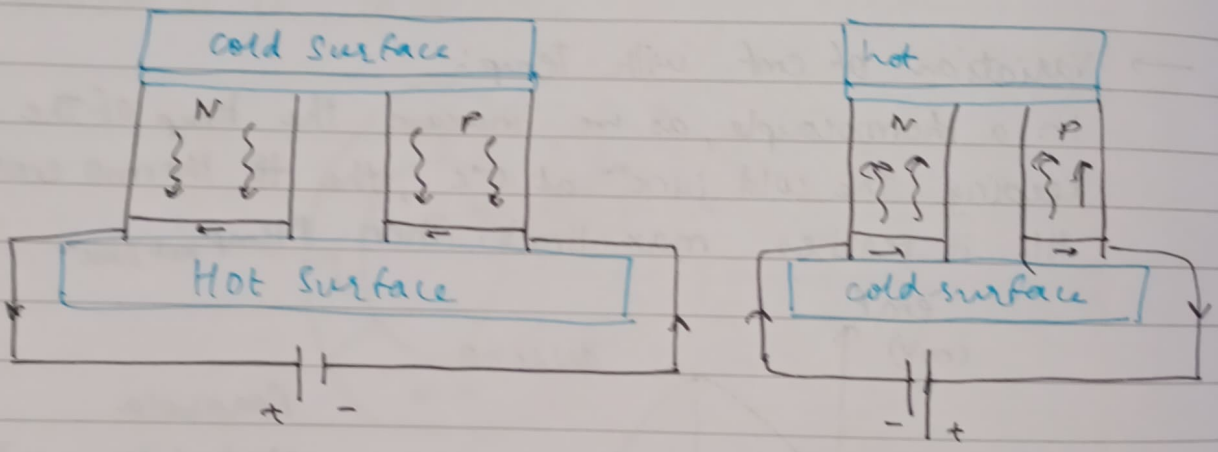
(T_c)

T_N is independent of cold junction temp & inversion temp. (T_i)

T_i depends upon T_c & $T_i >> T_N$ & $T_c << T_n$

8. What is Peltier effect? Explain its use.

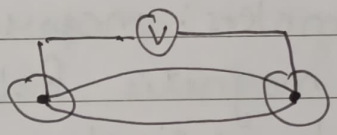
→ The Peltier effect is the reverse phenomenon of Seebeck effect. The electrical current flowing through the junc^n connecting two materials will emit or absorb heat per unit time at the junc^n to balance the difference in the chemical potential of the two materials.



Peltier effect states that, when an electric current flows through a circuit comprising dissimlar conductors, thermal energy is absorbed from one junc^n & is discharged at the other, making former cooler & latter hotter. Thus, a thermal gradient develops from the flowing current, making the Peltier effect inverse of Seebeck effect. Peltier effect occurs due to fact that, the average energy of the e^- involved in the transfer of e^- or electric current is diff for diff conductors. Depending upon the dir^n of flow of electric charge, e^- will transfer from excess energy to the surrounding atoms or absorb energy from them. In former, heat is dissipated while in latter, it is absorbed. Hence, peltier effect is used in heat pumps, which remove heat & transfer it from one side of device to the other.

Q. What is Seebeck effect? Explain its use.

→ Consider two wires of different material joined at their ends to form 2 junc^n A (Hot) & B (Cold). Such an arrangement is called Thermocouple. If one junc^n is kept ~~cold~~ hot & other cold, galvanometer shows deflection. This means emf is generated in the circuit. Emf thus produced is called thermo emf & resulting current is known as thermoelectric current. Hence, the phenomenon of generation of emf in a thermocouple when its two junctions are at different temperature is known as Seebeck Effect.



Seebeck effect is used to measure temperature with great sensitivity and accuracy & to generate electrical power ~~supply~~ for ~~special~~ special applications.

Q. Define neutral temperature & inversion temperature

→ The temperature of hot junc^n at which emf achieves its maximum limit is called Neutral temperature. (T_N) and it is constant for a given pair of dissimilar metals.

The temperature at which the reversal of emf takes place is called Temperature of inversion (T_i) i.e. at T_i the direction of emf is reversed.

$$T_N = \frac{T_c + T_i}{2}$$

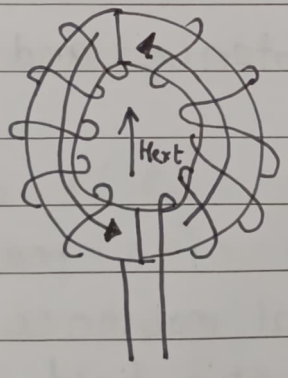
Q. What are vector and total field magnetometers? Give examples. (scalar)

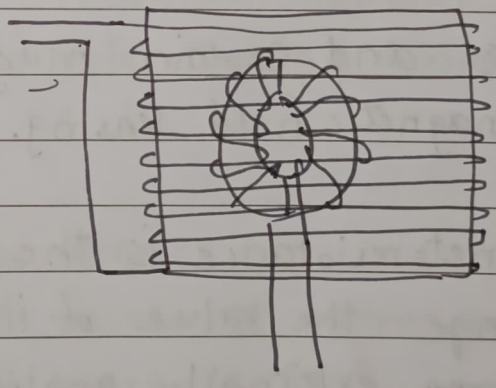
→ Vector and total field magnetometers are devices used to measure and quantify magnetic fields.
Vector magnetometers: measure the 3 components of a magnetic field in 3 orthogonal directions (x, y, z axes)
Example: Fluxgate, Hall effect, MEMS, SQUIDS, Magnetoresistance, magnetostriction

Total field magnetometers: measure the total strength or magnitude of a magnetic field at a specific location. They provide a single numerical value representing the intensity of magnetic field, disregarding its directional information.
Examples: Optically Pumped (spin-based), Over Hauser Magnetometer (proton precession based)

Q. State the working principle of fluxgate magnetometer. Discuss its sensing principle.

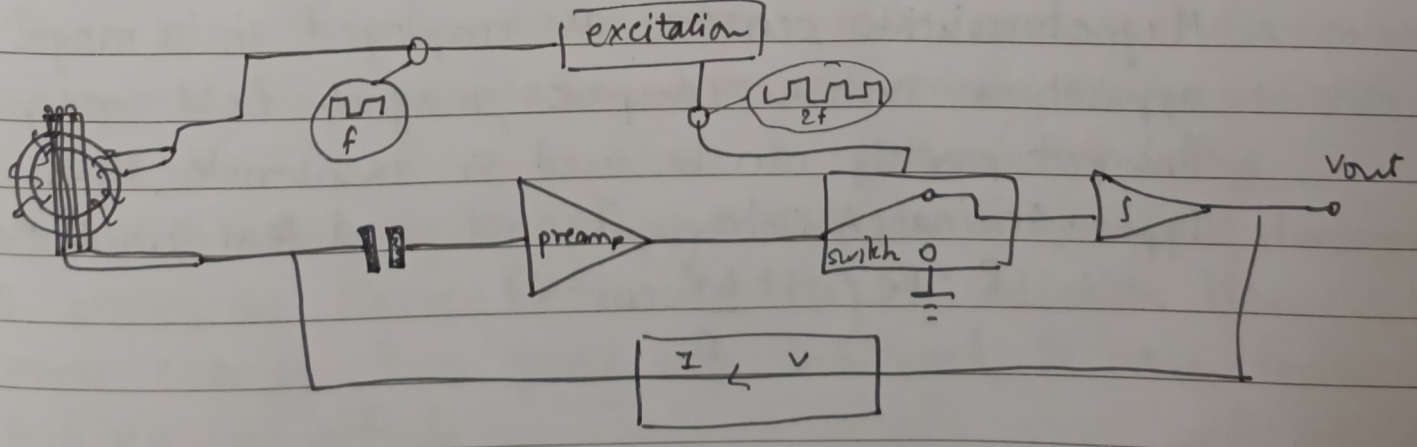
→ The working principal of fluxgate magnetometer is based on electromagnetic induction (EMI). The driver coil operates the ferromagnetic core in to ~~situation~~ saturation. Sensor coil is used to detect the change in current due to external field. Sensitivity can be as low as 10^{-2} nT





Drive Winding

Sense Winding



12. What is Hall effect? Explain the working of Hall effect based ~~xx~~ magnetic sensor.

→ Hall effect is a process in which a transverse electric field is developed in a solid material when the material carrying an electric current is placed in a magnetic field that is ⊥ to the current.

Hall effect sensor is based on Lorentz force. DC current is setup in a semi-conductor thin film. Magnetic ~~fld~~ field acting at right angles generates voltage called Hall voltage.
The principle of the Hall effect states that when a current-carrying conductor/semiconductor is introduced to a ⊥ magnetic field, a voltage can be measured at the right angle to the current path.

13. State and explain magnetoresistance and its use in magnetic field sensing.

→ Magnetoresistance is the tendency of a material to change the value of its electrical resistance in an ~~extorno~~ externally applied magnetic field. The material is called magnetoresistor.
Magnetoresistive sensors are employed in a range of applications such as compasses, magnetic field mapping. This ~~prot~~ property can be used in tachometer, HDD.
Types: Ordinary, Anisotropic, Tunnel and ~~Gxxx~~ Giant Magneto-resistance

$$R = R_0\left(1 + \frac{\Delta R}{R}\cos^2\alpha\right)$$

Anisotropic: Resistance is used related to the orientation between current & mag. field

Tunnel: Change in resistance of 2 ferromagnetic materials are separated by a thin insulator (few nm)

Giant: Large change in resistance between 2 ferromagnetic layers that are sep. by a non-magnetic conductor.

14. State differences between Hall resistance and magnetoresistance

→

Hall Resistance	Magnetoresistance
· Resistance along dirⁿ ⊥ to flow of current is measured.	· Resistance along the dirⁿ of current is measured.
· Change in resistance is negligible	· Change in resistance is significant.
· Charge accumulation takes place along dirⁿ ⊥ to magnetic field.	· Charge accumulation does not take place.
· Material is not magnetised	· Material is magnetised
· eg: Si	· eg: Ni-Fe alloy

15. what are diff. types of radiation? Explain on what basis they are classified into ionizing & non-ionizing.

→ Types of Radiation:

- Ionizing: α, β, γ, X-rays, deep UV
- Non-ionizing: UV-A, visible, IR, microwaves, radio waves (photons of energy < 13eV)
- Other: neutrons, cosmic rays, neutrinos, high magnetic field.

The classification of radiation into ionizing & non-ionizing categories is based on the energy of the radiation and its ability to ionize atoms or molecules. Ionizing radiation has higher energy & can cause significant damage to biological tissues, while non-ionizing radiation has lower energy & is generally considered to have fewer biological effects.

16. Define 1 Sievert. State the safety limit of radiation dose for humans.

→ 1 Sievert is equal to quantity of radiation dose that causes biological damage on deposition of 1 J of energy in 1kg of material (tissues)
Safety limit : 2 /hr (MSv)

17. List possible radiation hazards.

→ • Risks from ionizing radiation (non-fatal dose level)
• Nausea, general weakness, skin diseases, cancer, gastrointestinal issues, fertility, weakening of bones & muscles.
• Risks from non-ionizing radiation
• vomiting, eye imitation, restlessness, numbness, psychosomatic diseases.

18. Give classification of radiation ~~dect~~ detectors.

→ ① Gas detectors
• Ionization chamber
• Proportional counter
• Geiger-Muller counter

② Scintillation detectors
• Solid phosphors < Inorganic / organic
• Liquid
• Gases

③ Solid state detectors
• Intrinsic semiconductors
• Photodiodes (p-i-n)
• SDD (FET)

④ CCD
• Directly coupled
• Indirectly coupled.

19. Explain the working principle, construction & working of Geiger-Muller counter. What is dead time?

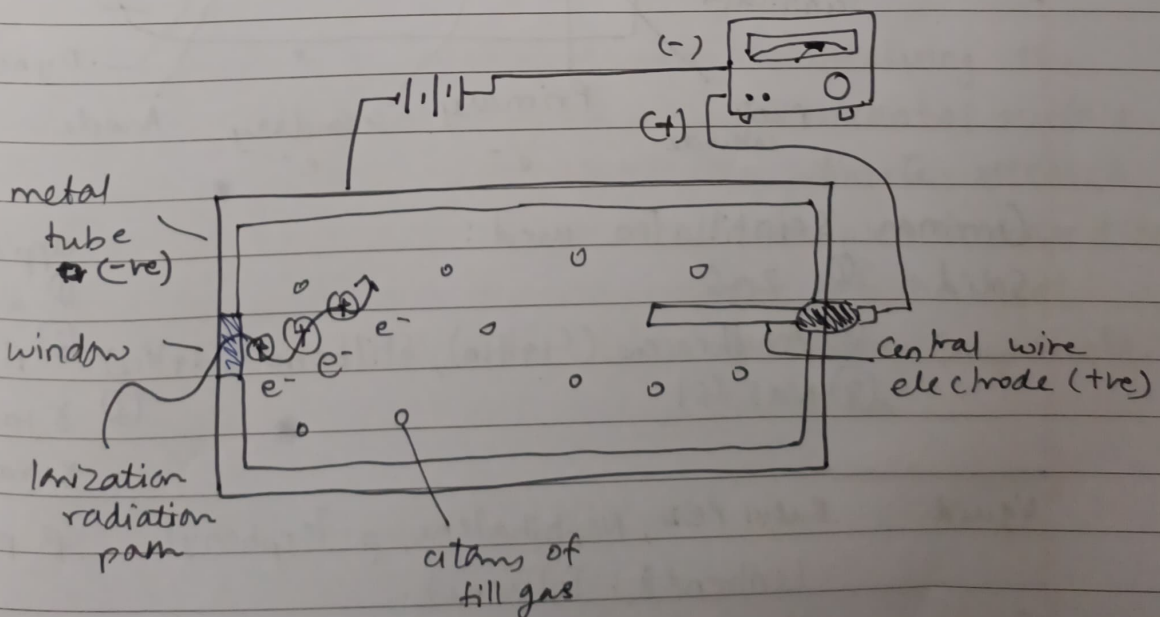
→ The working principle of Geiger-Muller counter is based on electric discharge due to ionization of gas. Mixture of Argon and Ethyl alcohol (90:10) @ 0.01 atm pressure where ethyl alcohol is an active component. When ionizing radiation passes through the counter, it creates ion pairs by knocking electrons off gas atoms or molecules. These ion pairs generate a detectable electrical pluse that is amplified and counted.

Its basic components are quartz tube (sensor) with metallic lining inside and counter (electronics). It also has anode wire, cathode, high voltage supply.

Dead time of a GM counter refers to the period during which the counter is unable to detect additional ionizing events immediately after an initial event.

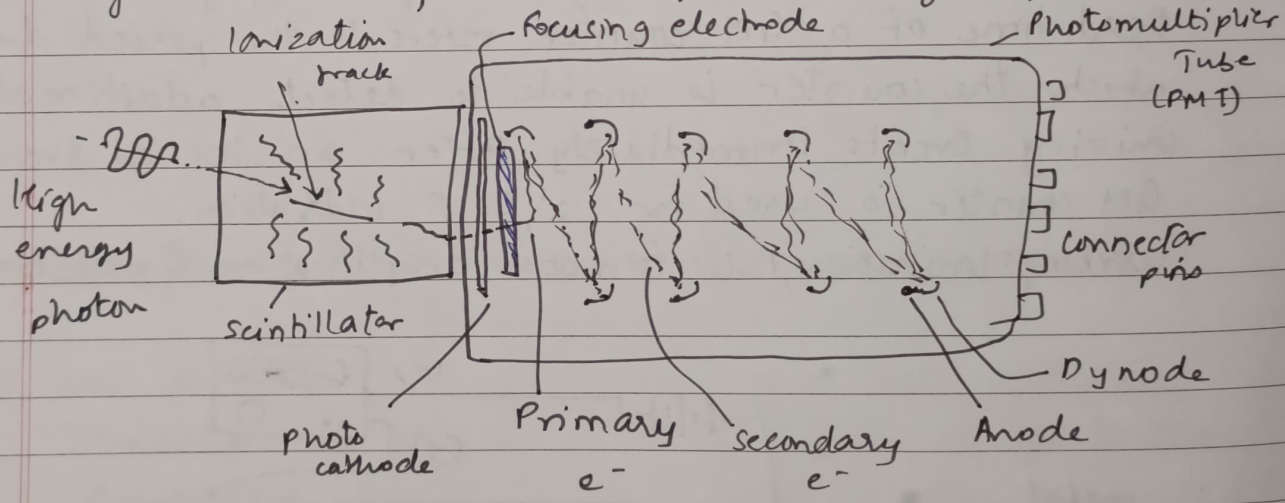
GM counter is used for α, β, γ radiation.

working: Ionization, Pulse formation, amplification & detection



20. Explain the working principal, construction & working of a scintillation counter. State its diff types used.

→ The working principles of scintillation counter is based on Luminescene, Photoelectric effect, Photo multiplication. when ionizing radiation interacts with scintillator material, it deposits energy, exciting the atoms within the material. The emitted light is detected and converted into an electrical signal for measurement.
Basic components used are Phosphor (scintillator) { solid, liquid or gaseous state }, Photomultiplier tube, counter (electronics).
working consists of radiation interaction, light emission, light detection, electron amplification, signal processing.

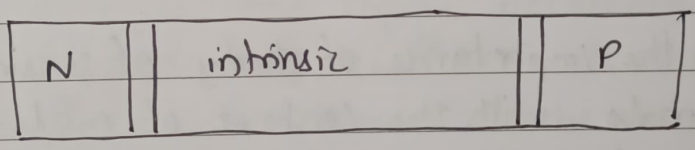


Common scintillators used:

		applications
Solid	① ZnS	① α particles
	② Anthracene ($C_{14}H_{10}$), Stilbene ($C_{14}H_{12}$)	② β particle
	③ NaI, CsI	③ γ radiation, X-rays
liquid	Butyl PBD, Naphthalene, p-Terphenyl (solvent : Toluene)	β particles
Gas	Xenon	γ radiation.

21. Explain the construction & working of a p-i-n photodiode.

→ P-i-n photodiode works on the principle of reverse bias (photoconductive mode). Construction:
P - Type layer - doped with a material that introduces +ve charge carriers (holes) into semi-conductor material.
Intrinsic layer (i) - lightly doped region between p & n type layer. This layer allows generation of e⁻-hole pairs.
N - Type layer - doped with a material that introduces -ve charge carriers (e^-) into semiconductor material.
Its working consists of absorption of photons, generation of e^--hole pairs, separation & collection of charge carriers, electrical signal output.



22. what is pyranometer? what is its use? Explain its working principle.

→ A pyranometer is a device used for measuring the total solar radiation received on a horizontal surface. They are used for solar radiation, climate research, environmental studies. Its working principle is based on thermo emf (Cr-Al) and measurement of the heat generated by the incident solar radiation. Components: Thermopile, environmental shield, electronics.

23. Briefly explain the recording and retrival of image from a charge couple device (CCD).

→ The recording & retrieval of images from a CCD involve the capture, storage & readout of electrical signals representing the image. Explanation of process:
Recording - Photons capture, Charge Transfer, Charge Accumulation
Retrieval - Readout Register, analog-to-digital conversion, Image reconstruction, image storage.
The process of recording and retrieving images from CCD allows for the efficient capture & preservation of visual information for various applications.

24. Discuss the importance of study of sensing in plants and animals with the context of modern science and technology. Give a suitable example.

→ The study of sensing in plants and animals is of great importance in modern science and technology as it provides valuable insights into the mechanisms and adaptations that allow organisms to perceive and respond to their environment. In plants, gravitropism increases the probability of roots to encounter water and minerals, and stems and leaves will be able to intercept light for photosynthesis. Heliotropism decreases the temperature of leaf & minimizes desiccation. for "compass" plants.
In animals, Sharks use sensing to locate its prey by smell over long distances. They can also pick up small electrical fields by other animals. They can use this electromagnetic sense when their vision is impaired to locate prey. Sharks can use their ampullae to magnate the globe by tracking earth's electromagnetic field.

25. Discuss in brief sensing of Shark.
Same as 64.

26. List the various tropisms in plants.

→ ① Phototropism - is a growth response of plants to light coming from one direction. Positive tropism of stems results from cells on the shaded side of a stem growing faster than cells along the illuminated side, as a result, the stem curves toward light.
② Gravitropism - is a growth response to gravity. The +ve gravitropism involves the root cap that covers the tip of roots. Decapped roots grow but do not respond to gravity, indicating that the root cap is necessary. Gravitropism increases the probability of ① Roots to encounter water & minerals & ② stems and leaves will be able to intercept light for photosynthesis.
③ Thigmotropism: is a growth response of plants to touch. Thigmotropism is the coiling exhibited by organs called tendrils. Tendrils are common on twining plants such as morning glory & bindweed.
④ Hydrotropism: Growth of roots toward soil moisture
⑤ Heliotropism (solar tracking): is the process by which plants' organs track the relative position of sun. Diff plants have diff types of heliotropism. The "compass" plants that grow in deserts orient their leaves parallel to sun's rays, thereby decreasing leaf temp. & minizing desiccation.

27. Define:

→ ① Differential growth - means that one side of the responding organ grows faster than the order side of the organ. This growth curves organ toward or away from the stimulus.

② Negative Tropism - Curvature of an organ away from a stimulus.

③ Time required for tropism - Tropism begin within 30 mins after a plant is exposed to the stimulus & are usually completed within 5 hrs.

28. What are MEMs & NEMs? Give some main points of diff.

→ MEMS (Microelectromechanical system): is a process used to create tiny devices or systems that combine mechanical and electrical components.

→ NEMS: (Nano-electromechanical systems) are made of electromechanical devices that have critical dimensions from hundreds to a few nanometers.

MEMS	NEMS
· Dimension 10^{-6} to 10^{-3} m	· Dimension 10^{-9} m
· Fabrication - silicon micromachining, bulk micromachining	· Nanofabrication - e⁻ beam lithography, molecule self assembly.
· Rely on macroscopic physical effects	· Rely on nanoscale phenomena
· Commercially successful	· early stages of development.