MUMBAI UNIVERSITY CBCGS SEM II
APPLIED PHYSICS II DEC 2022 PAPER SOLUTIONS

Q1] a) Explain following terms i) spontaneous emission ii) population

Inversion. **(3)**

ANS : (i) <u>Spontaneous emission</u> : -

After the life time of the state is over, the atom in excited state gets de-excited to lower energy level on its own. This lower energy state may be either ground state or still one of the excited states but having lower energy level. In the process, a photon is emitted. In this emission process, Where the atoms spontaneously goes to a lower energy state through the emission of a photon is called Spontaneous Emission.

(ii) <u>Population Inversion</u>: -

In thermal-equilibrium the population N1 of lower energy level is very large as compared to population N_2 of upper energy level. i.e $N_1 >> N_2$. The non-equilibrium state in which the population N_2 of the upper energy level exceeds to a large extent the population N_1 of the lower energy level is known as the state of population inversion. i.e $N_1 << N_2$.

(1) Thermal Equilibrium   (2) Non-Equilibrium
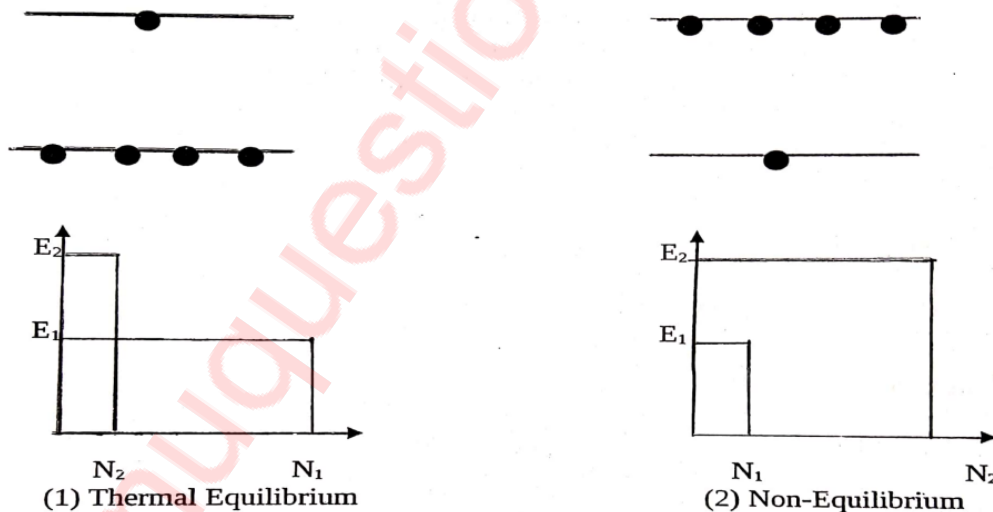
Q1] b) What is nanotechnology ? what is its significance ? **(3)**

ANS : Nanotechnology is the design, characterization, production and application of structure, devices and system. The work is done by controlling

the shape and size at the nanometre scale. In short, nanotechnology is the engineering which deals with the design and manufacture of extremely small component and system.

Using nanotechnology, materials can effectively be made stronger, lighter, more durable, more reactive, or better electrical conductors, among many other traits.

Q1] c) Compare laser source with ordinary optical source. (3)

ANS :

Laser source	Optical source
Light waves emitted from a laser source will be in phase and will be highly coherent	Light waves emitted from a ordinary optical source produces incoherent light and the light waves will not have any common phase relationship
Is a result of Stimulated emission of photons	Is a result of Spontaneous emission of photons
Emits light only in one direction i.e. is highly directional	Emits light in all direction
Light has high intensity	Light has comparatively low intensity

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Q1] d) What is Optical Grating and Grating element? (3)

ANS : Optical grating also known as diffraction grating is the arrangement of large number of parallel slits placed close to each other and separated by equal opaque spaces between them

If 'a' is width of the slit (i.e. space between the lines) and 'b' is the width of the line (i.e. width of opaque space), then (a+b) is called grating element

If there are N lines per cm , Na + Nb = 1cm

$$\therefore \text{grating element } (a+b) = \frac{1}{N} \text{ cm}$$

Q1] e) What are inertial and Non inertial frames of references ? (3)

**ANS :** (i) <u>Inertial Frame of reference</u>

These are those unaccelerated frame of reference in which Newton's law hold good. In these frame of references a body is not acted upon by an external force.

(ii) <u>Non-inertial Frame of reference</u>

Those accelerated frame of references in which Newton's laws do not hold good are called non-inertial frames of references. In these frames the body experiences an additional acceleration due to accelerated motion of the frames of references.

Q1] f) What are transducers ? What is there significance of transducers in

modern technology ? (3)

ANS : A transducer is an electronic device that converts energy from one form to another. The process of converting energy from one form to another is known as transduction. Some common examples of transducers include loudspeakers, microphones, thermometers and LEDs.
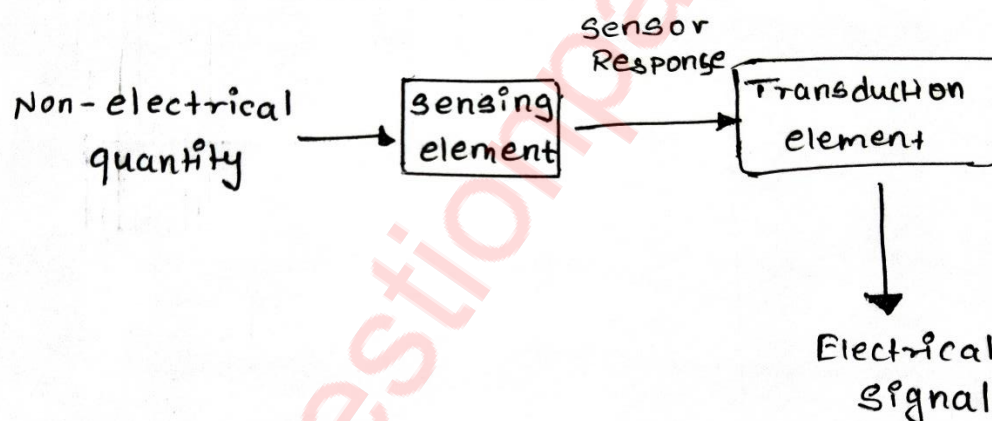
The significance of transducers in modern technology is to determine the exact magnitude of physical forces such as temperature and pressure is difficult. But, if these physical forces are converted into an electrical signal, then their values can be easily determined using a meter. The primary function of transducers is to convert a physical force into an electrical signal so that it can be easily handled and transmitted for measurement.

Q1] g) State application of lasers in Industry and medicine. (3)

ANS :

<u>Medical Applications</u>

1. Many surgical procedures are now completely painless or comparatively less painful with the help of 'laser scalpel' which is absolutely sterile and does not introduce any secondary infection.
2. Because of its high intensity laser light can be used to burn tumours etc.

<u>Industrial Applications</u>

1. LASER CUTTING :- Laser cutting works by directing the output of a high power laser, by computer at the material to be cut. The material then melts, burns, vaporizes away or is blown away by a jet gas, leaving an edge with a high quality surface finish.
2. LASER HEAT TREATMENT :- A powerful laser output rapidly warms up the surface layer in an item it hits. As the beam moves away to other areas the heated spot cools down as rapidly. This procedures is used for heat treatment of surface layers of metal items, which considerably enhances the item strength.


Q2] a) Explain the physical significance of Divergence and Curl of a vector field with suitable Example ? **(5)**

ANS : <u>Physical significance of Divergence</u> : -

Divergence of a vector function $\vec{v}$ (i.e. $\vec{\nabla} \cdot \vec{v}$) is a measure of how much the vector $\vec{v}$ spreads out from the given point.

Example :- If fluid is flowing into a point → divergence is negative

If fluid is flowing out from a point → divergence is positive
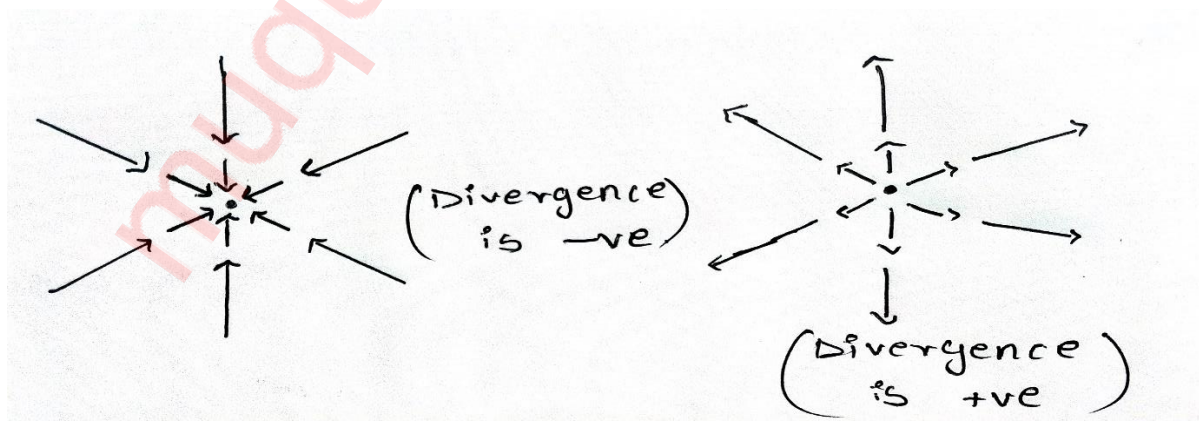
Physical significance of Curl : -

Curl of a vector function $\vec{v}$ (i.e. $\vec{\nabla} \times \vec{v}$) is a measure of how much the vector $\vec{v}$ curls or twists around the given point.
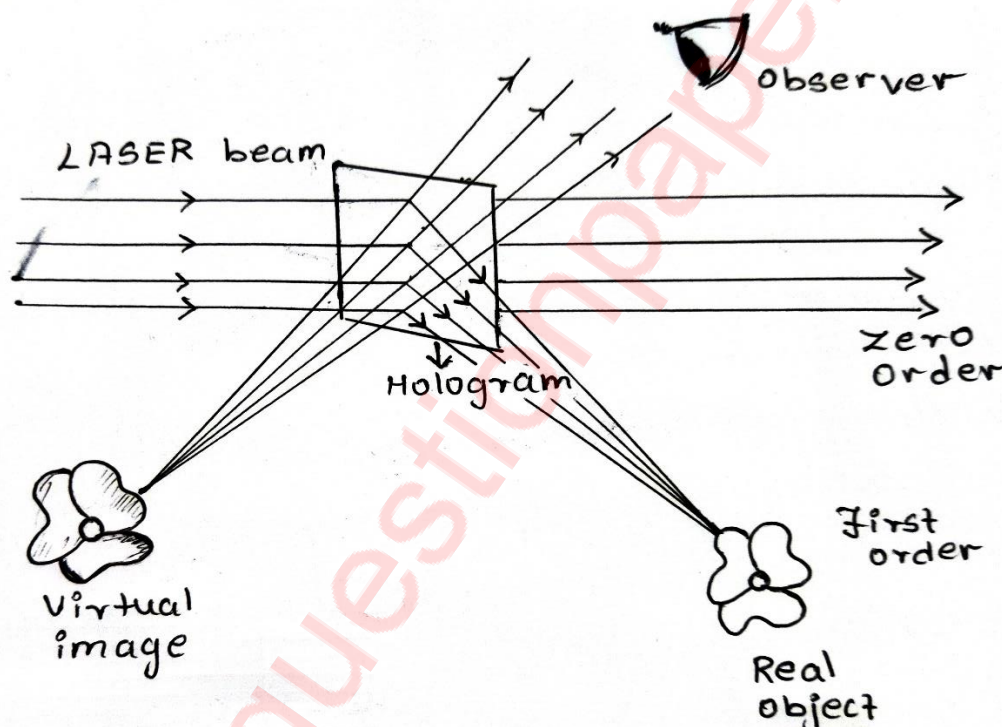
If zero curl that means no rotation

Example :- Consider a water going down the drain. In this motion water swirls in rotation. The curl of the velocity field of water describes its local rotation.

Q2] b) With appropriate schematic diagram explain Method of

reconstruction of the Hologram ? **(5)**

ANS :

- A laser beam identical to the reference beam is used for the reconstruction of the object. The reconstruction beam (laser beam) illuminates the hologram at the same angle as that of the reference beam.
- The hologram acts as a diffraction grating and secondary waves from the hologram interfere constructively in certain directions and destructively in other directions.

- They form a real image in front of the hologram and a virtual image behind the hologram at the original site of the object.
- An observer sees light waves diverging from the virtual image. An image of the object appears where the object once stood and that image is identical to what our eyes would have perceived in at its details.
- If the observer tilts his head other objects behind the first one or new details of the object which were not noticed earlier would be observed.

Q2] c) Find the fractional increase in mass of a particle moving at velocity given by 0.2c and velocity of particle when mass of a particle will be 1.5 times it's rest mass. **(5)**

ANS :

Given : - (i) velocity = 0.2 c

(ii) M = 1.5 m_0

To find :- (i) Increase in mass?

(ii) Velocity when M = 1.5 m_0

Formulae :- $$M = \frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}}$$

Solution : -

(I)   In the given formula M is the mass of the particle , m_0 is the rest mass of the particle , v is the velocity of the particle and c is the velocity of Light .

Substituting the given values in $M = \frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}}$

$$M = \frac{m_0}{\sqrt{1-\frac{(0.2\ c)^2}{c^2}}} = \frac{m_0}{\sqrt{1-0.44}} = \frac{m_0}{\sqrt{0.96}}$$

$$M = \frac{m_0}{0.9797}$$

Therefore $M = 1.02062\ m_0$ --------(i)

Increase in mass = M - m_0

$= 1.02062\ m_0 - m_0$ --------from(i)

$= m_0$ (1.02062 - 1)

$= 0.020262\ m_0$

$\therefore$ Increase in mass = 0.020262 m_0

$\therefore$ The increase in mass of a particle at 0.2c is $0.02062 m_0$

(II) To find the velocity of a particle when mass of a particle will be 1.5 times its rest mass.

i.e. $M = 1.5m_0$ ------(ii)

$$\therefore M = \frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}}$$

$$1 \cdot 5m_0 = \frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}} - - - - - from(ii)$$

$$1 \cdot 5 = \frac{c}{\sqrt{c^2-v^2}}$$

$$(\sqrt{c^2-v^2})^2 = (\frac{c}{1.5})^2 \quad \textbf{Taking square on both sides}$$

$$v^2 = c^2 - (\frac{c}{1.5})^2 \quad \textbf{Taking square roots on both sides}$$

$$v = \sqrt{c^2 - \left(\frac{c}{1\cdot5}\right)^2} = \sqrt{\frac{2.25\ c^2 - c^2}{2.25}} = \frac{\sqrt{2.25\ c^2 - c^2}}{1.5} = \frac{\sqrt{1.25\ c^2}}{1.5} = \frac{1.011803}{1.5}\ \text{c}$$
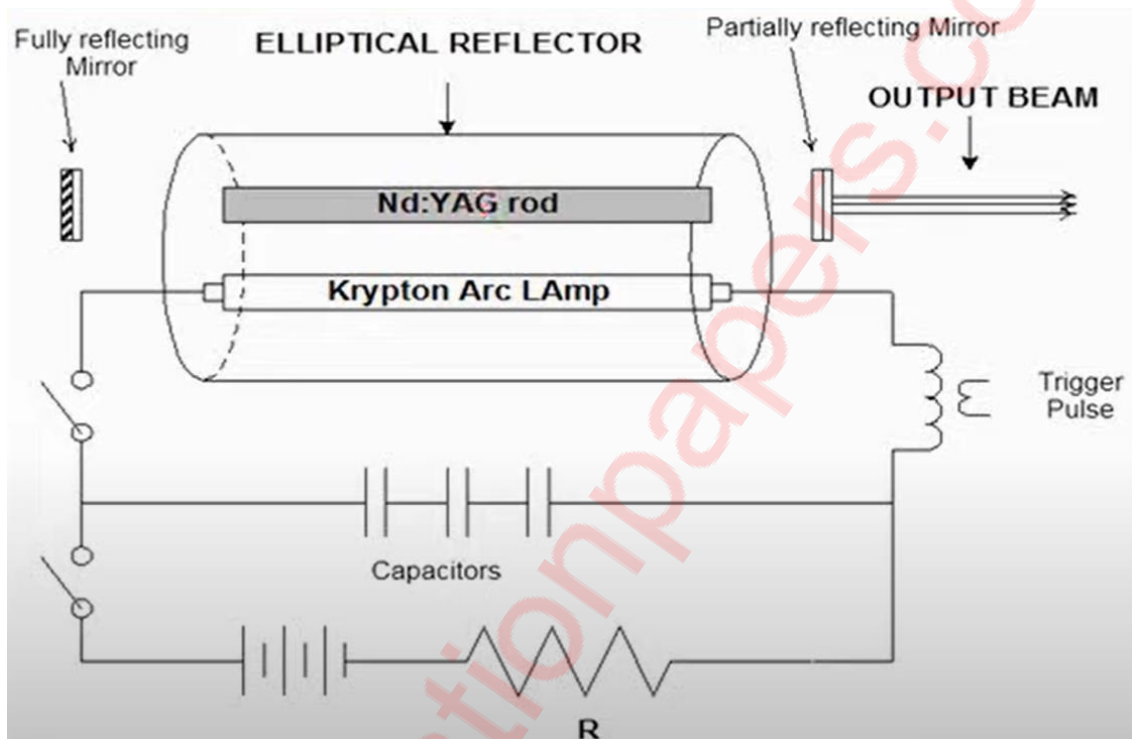
=0.7453 c =0.7453 x 3 x 10^8   -------- as (c = 3 x 10^8)

∴ V = 223590000 m/sec = 2.2359 x 10^8 m/sec

Q3] a) Explain with neat diagram construction of Nd-YAG laser.   (5)

ANS :

CONSTRUCTION:-

The neodymium (Nd) ion is a rare earth metallic ion. It produces emission, when doped into a solid state. When doped in YAG, Nd^{3+}\ ions take place of yttrium.

The Nd:YAG lasers are 4 level systems and therefore require lower pump energy.

Optical pumping is used for laser action

A linear flashtube and the lasing medium in the form of rod are placed inside a highly reflecting elliptical cavity.

If the flashtube is along one focal axis and the laser rod along the other, then the properties of ellipse ensure that most of radiations from flashtube pass through laser.

The flash tube is fired by power supply.

The optical cavity may be formed by grinding the ends of Nd:YAG laid flat and parallel and then silvering them. Two external mirrors are used. One mirror is made totally reflecting while the other is about 90% transmitting to give an output.

A large amount of heat is dissipated by flashtube and consequently the laser rod quickly become very hot. To avoid, the damage, system is cooled by circulating air.

Q3] b) Explain the relativistic phenomenon of Time dilation with

appropriate mathematical derivation. (5)

ANS :
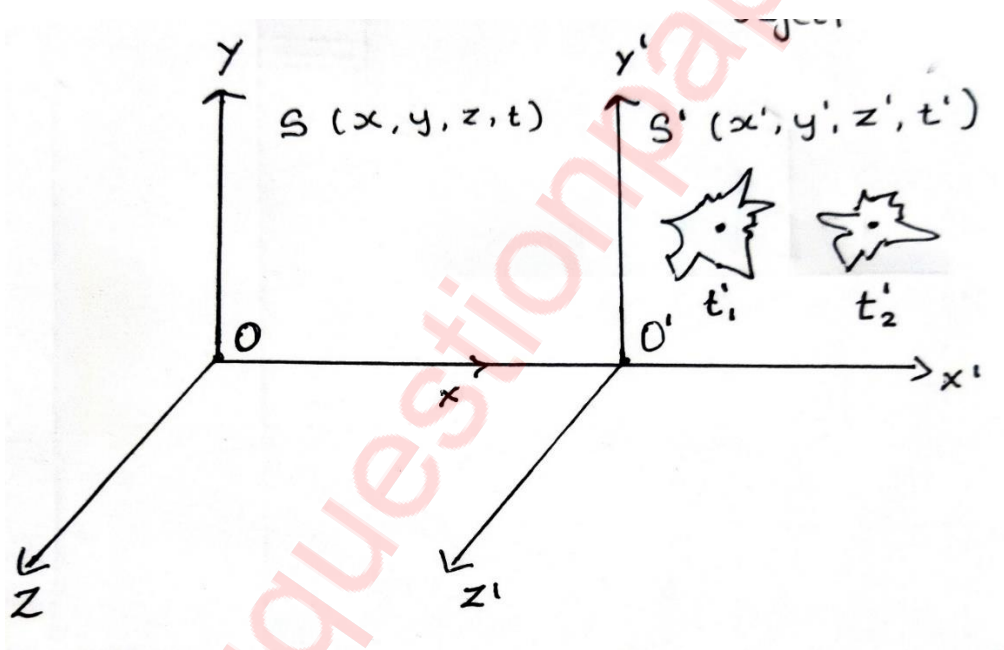
- Let us assume show shots were shot at t'_1 and t'_2 in S' frame of reference.

- The time interval ($t'_2 - t'_1$) of the shots measured by O' at rest in the moving frame S' is called the proper time interval and is given by :-

$$T_0 = t'_2 - t'_1 \qquad \text{-------(i)}$$

As the motion between the two frames is relative, we may assume that the frame S is moving with velocity -V along negative X direction relative to frame S'. The observer O who is at the origin of S frame hears two shots at different times t_1 and t_2. The time interval observed by O in S frame is given by :-

$$T = t_2 - t_1 \qquad \text{-------(ii)}$$

- From Inverse Lorentz Transformation equation we get :-

$$t_1 = \frac{t_1' - (V_{x'}/ c^2)}{\sqrt{1-(V^2/c^2)}} \quad \text{------(iii)}$$

$$t_2 = \frac{t_2' - (V_{x'}/ c^2)}{\sqrt{1-(V^2/c^2)}} \quad \text{------(iv)}$$

Substituting equation (iii) and (iv) in equation (ii) we get :-

$$T = \frac{t_2' - t_1'}{\sqrt{1 - (V^2/c^2)}}$$

Using equation (i) in equation in the above equation we get the following equation :-

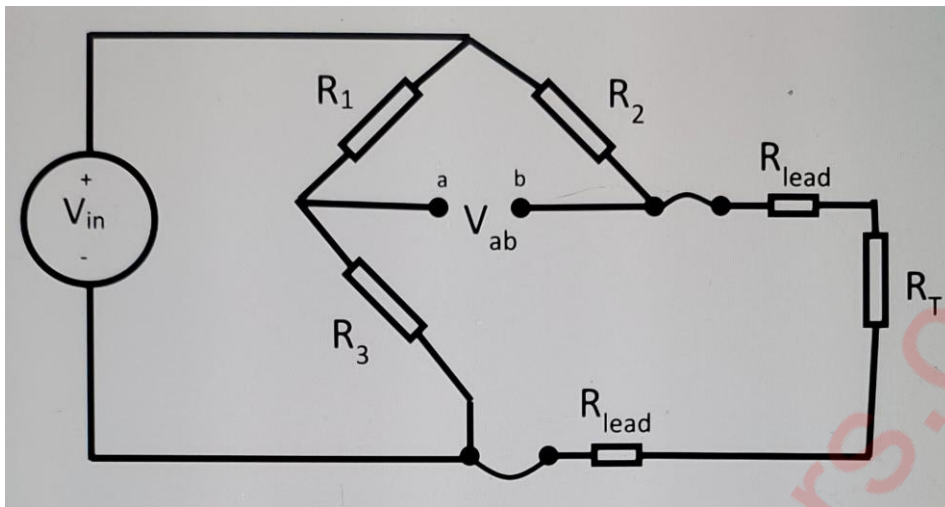$$T = \frac{T_o}{\sqrt{1 - (V^2/c^2)}}$$

Which shows that $T > T_o$

- Here T_o is called the proper time which is defined as the time measured in the time of reference in which the object is at rest

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Q3] c) Explain the use of PT100 as an industrial thermometer. (5)

ANS :

Circuit Diagram :-

- PT 100 temperature sensors are the most common type of platinum resistance thermometer refers to that the sensor is made from Platinum (Pt).
- 100 refers to that at 0°C the sensor has a resistance of 100 ohms (Ω).They are a popular choice due to their stability, accuracy and repeatability.
- A pt100 resistance thermometer is used to measure the temperature of a medium. It doesn't have a readable scale, and that makes that it differs from a regular thermometer.
- Also, a pt100 doesn't contain moving parts and can be read from a distance. This allows you to place the pt100 in a place that's hard to reach and maybe even unreachable for the engineers.
- The signal the pt100 sends can be used for many different measuring purposes.

Q4] a) A glass clad fibre is made with core glass of refractive index 1.5 and

The cladding is doped to give a fractional index difference of 0.0005

Find: -

    (i)   **Cladding Index**

    (ii)   **The critical internal reflection angle**

    (iii)   **The external critical reflection angle**

    (iv)   **The numerical aperture**   **(5)**

ANS :

Given : - $n_1 = 1.5$, $\Delta = 0.0005$

To find : -

- Cladding Index (n_2)
- The critical internal reflection angle (θ_c)
- The external critical reflection angle (i_a)
- The numerical aperture (N.A)

Formulae : -

(I) $N.A = \sqrt{n_2^1 - n_2^2}$ (II) $i_a = sin^{-1}(N.A)$

(III) $\Delta = \frac{n_1 - n_2}{n_1}$ (IV) $\theta_c = sin^{-1}\left(\frac{n_2}{n_1}\right)$

Solutions: -

(1) $\Delta = \frac{n_1 - n_2}{n_1}$ ⟹ $0.0005 = \frac{1.5 - n_2}{1.5}$

$n_2 = 1.5 - 1.5 \times 0.0005$ ⟹ $n_2 = 1.4925$

(2) $\theta_c = sin^{-1}\left(\frac{n_2}{n_1}\right) = sin^{-1}\left(\frac{1.4925}{1.5}\right)$

$\theta_c = 84.268^o$
$= 84^o \ 16' \ 5''$

(3) $N.A = \sqrt{n_2^1 - n_2^2} = \sqrt{(1.5)^2 - (1.4925)^2}$

$= \sqrt{2.25 - 2.2275} = \sqrt{0.02244} = 0.1498$

$N.A = 0.15$

(4) Acceptance angle $i_a = sin^{-1}(N.A)$
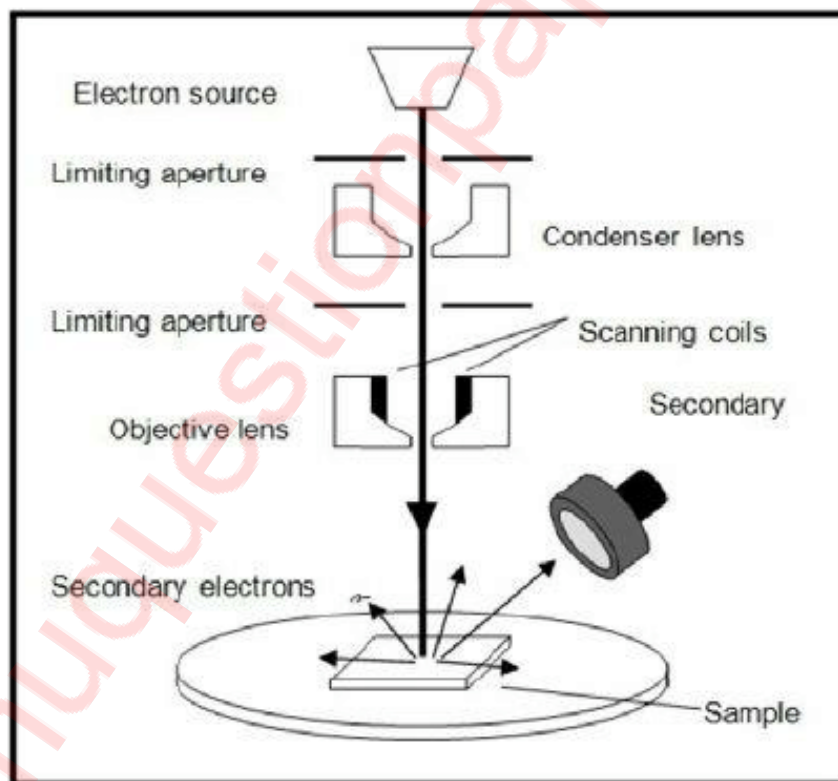
$i_a = sin^{-1}(0.15)$

$$= 8.6269^o$$

$$i_a = \mathbf{8.6269^o}$$

$$= \mathbf{8^o \ 37' \ 36''}$$

Q4] b) Draw the Schematic diagram of Scanning Electron Microscope (SEM)

   and explain it's working.   **(5)**

ANS :

Diagram : -

Working of Scanning Electron Microscope (SEM): -

- In SEM, an electron beam is thermionically emitted from an electron gun fitted with the tungsten filament cathode.

- The electron beam is focused by one or two condenser lenses to a spot about 0.4 nm to 5 nm diameter.
- The beam passes through a pair of scanning coil, which deflect the beam in X and Y - axis so that it can scan in a raster fashion over a rectangular area of the sample surface.
- When the beam of electron incident on the specimen, the primary electron beam interact with the sample, electron loss their energy by scattering and absorption within a small volume of specimen known as interaction volume.
- Emission of secondary electrons and emission of electromagnetic radiation detected by detector.
- The electrons interact with electrons in the sample, producing various signals that can be detected and contain information about the sample's surface topography and composition.
- Electronic amplifiers of various types are used to amplify the signal which are displayed as a variation in the brightness of CRT.
- The resulting image therefore a distribution map of intensity of the signal being emitted from the scanned area of the specimen.

Q4] c) Derive Maxwell's First equation and state it's significance. **(5)**

ANS :

As per Gauss' Law, the electric flux density passing through any closed surface is equal to the total charge enclosed by that surface.

i.e. $\phi = \oint_S \vec{D} \cdot d\vec{s} = Q_{enclosed}$ ---------(i)

Expressing charge enclosed by the surface in terms of surface charge density

$Q_{enclosed} = \int_v \rho_v \, . \, dv$ -----------(ii)

$\therefore \quad \oint_S \vec{D} \cdot d\vec{s} = \int_V \rho_v \, . \, dv$ -----(iii) from (i) and (ii)

(Integral Form of Maxwell's first equation)

To convert surface integral to volume integral using divergence theorem in the RHS of eq (iii)

$$\oint_S \vec{D} \cdot d\vec{s} = \int_V (\vec{\nabla} \cdot \vec{D})\, dV \qquad \text{-------------(iv)}$$

From eq (iii) and eq (iv)

$$\int_V (\vec{\nabla} \cdot \vec{D})\, dV = \int_V \rho_v \cdot dv$$

$$\therefore \vec{\nabla} \cdot \vec{D} = \rho_v$$

$$\therefore \vec{\nabla} \cdot \vec{E}\varepsilon_0 = \rho_v \qquad \text{--------}(\because \vec{D} = \vec{E}\varepsilon_0)$$

$$\therefore \boldsymbol{\vec{\nabla} \cdot \vec{E}} = \frac{\rho_v}{\varepsilon_0}$$

(Differential form or point form of maxwell's first equation)

Physical significance :-

The total electric displacement through the surface enclosing a volume is equal to the total charge within the Volume

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Q5] a) Plane waves of wavelength 600nm fall normally on single slit of width 0.2mm. Calculate the total angular width of the central maximum and also the linear width as observed on screen placed 2 cm away.   (5)

ANS :-

Given :-

$$\lambda = 600nm = 6\ x\ 10^{-7}\ m$$

$$b = 0.2\ mm = 0.2\ x\ 10^{-3}\ m$$

Solution :-

(I)   Angular width of first minima from central maxima in diffraction pattern –

$\theta = \frac{\lambda}{d}$, $Where\ d\ is\ slit\ width$

$\therefore$ Angular width of central maxima

$$\theta_c = 2\theta = \frac{2\lambda}{d}$$

$$\theta_c = \frac{2 \ x \ 6 \ x \ 10^{-7}}{0.2 \ x 10^{-3}} = 6 \ x \ 10^{-3} \ rad$$

(II) Linear width of central maxima is given as –

$$x = \frac{f\lambda}{d}$$

X = width on either side

f = distance between slit and screen

d = slit width

λ = wave length of source

f = 2 cm = 2 x 10^{-2} -----given

$$X = \frac{2 \ x \ 10^{-2} \ x \ 6 \ x \ 10^{-7}}{0.2 \ x \ 10^{-3}} = 6 \ x \ 10^{-5} \ m$$

Total angular width of central maxima = 6 x $\boxed{10^{-3}}$ rad

Linear width of the central maximum kept at 2 cm away

$$= 6 \ x \ 10^{-5} \ m$$

Q5] b) What is difference between Bottom up and Top down approach of

synthesis of nanoparticles.   **(5)**

ANS :

Bottom up Technique	Top Down Technique
It is mostly a chemical process	It is mostly a physical process
It start by collection and combination of atoms and molecules to build complex structure	It start from macroscopic (bulk) material and progressively reduces to smaller dimension
It consists of chemical synthesis such as soft chemical method and self-assembly of molecular structure	It consists of ultrafine micromachining of materials using lithography, epitaxy and etching
This technique is relatively cheaper	This technique is relatively costly

Chemical purification of nanoparticles is required	Chemical purification is not required
Large scale production is difficult	Large scale production : deposition over a large substrate is possible
Examples of bottom up techniques are :- Sol-gel Process Electrochemical Deposition Aerosol Process	Examples of top down techniques are :- Chemical etching Mechanical Alloying /Ball milling Explosion Process

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Q5] c) What is resolving power of the grating ? Discuss the factors on which

It is dependent ? What is significance of resolving power of grating?

(5)

Ans :

- when two objects or their images are very closed to each other, they appear as a one and it may not be possible for eye to see them as separate.

- If objects are not seen separately then we say that the details are not resolved by eyes.

- The method adapted to seeing the close object as a separate image is called as 'Resolution'.

- An ability of an optical instrument to produce distinctly separate images of two object located very close to each other is called as resolving power.

- One of the most important property of a diffraction grating id its ability to resolve spectral lines, which have nearly same wavelength.
  Resolving power of grating is defined in terms of the smallest wavelength (dλ) that can be detected by it. It is given by : -

$$\frac{\lambda}{d\lambda}$$

  Where, λ - average of two wavelength

  dλ - wavelength difference
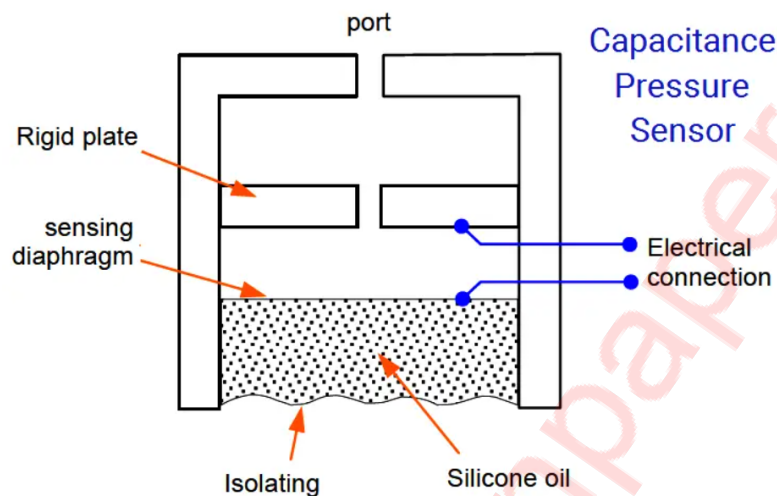
  Therefore Resolving Power $= \frac{\lambda}{d\lambda}$

- The wavelength of light, refractive index, and angular aperture are the significant factors that affect the resolving power

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Q6] a) With appropriate diagram explain concept of Pressure sensing by Capacitive method. **(5)**

ANS :

Capacitive Pressure Sensor

The Capacitive pressure sensor operates on the principle that, if the sensing diaphragm between two capacitor plates is deformed by a differential pressure, an imbalance of capacitance will occur between itself and the two plates.

A capacitor consists of two parallel conducting plates separated by a small gap. The capacitance is defined by:

$$C = \varepsilon_r \varepsilon_0 \frac{A}{d}$$

- ε_r is the dielectric constant of the material between the plates (this is 1 for a vacuum)
- ε_0 is the electric constant (equal to 8.854x1012 F/m),
- A is the area of the plates
- d is the distance between the plates

This imbalance is detected in a capacitance bridge circuit and converted to a D.C. output current of 4 to 20 mA.

Another type of capacitor uses concentric hollow metal cylinders. The capacitance of this type just like the flat-plate type is proportional to the area.

This principle can be applied to differential pressure measurement, as shown in Figure. The pressure acting on the isolating diaphragms set up similar pressures in the silicone oil filling the space between them.

This is shown in Figure, where the movement of a flexible diaphragm relative to a fixed plate is sensed by the capacitance change. A secondary isolating diaphragm is used to protect the sensing diaphragm.

A net force proportional to the difference between the two pressures acts upon the metal sensing diaphragm and deflects it to one side or the other, depending on which input pressure is the greater.

Each plate forms a capacitor with the sensing diaphragm, which is connected electrically to the metallic body transducer.
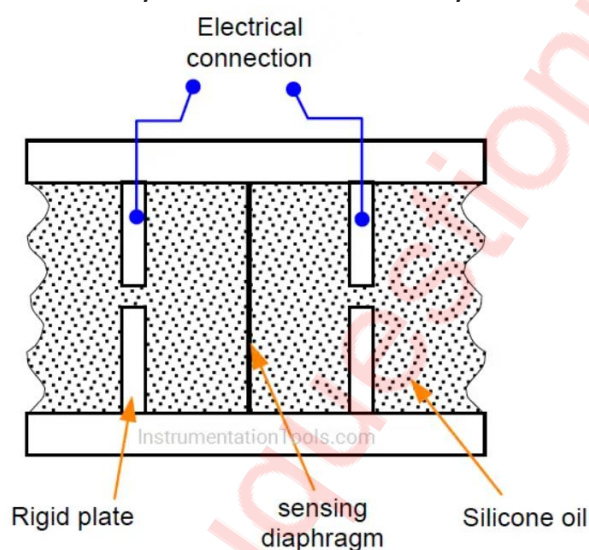
The sensing diaphragm and capacitor thus form a differential variable separation capacitor. When the two input pressure are equal, the diaphragm is positioned centrally and the capacitances are equal.

A difference in the two input pressures causes displacement of the sensing diaphragm and is sensed as a difference between the two capacitances.

This change in capacitance is measured using a bridge circuit to measure the equivalent pressure signal.

Q6] b) Find maximum value of resolving power of a diffraction grating 3 cm wide having 5000 lines per cm, if the wavelength of light used is 589 nm. **(5)**

ANS : -

Given : -

Width W = 3 cm

N = 5000 lines/cm

λ = 589 nm

= 5890 $\dot{A}$

= 5890 x 10^{-8} cm

To find : - Maximum value of resolving power

Formulae: -

$(a + b) = \frac{1}{N}$

$(a + b) \sin\theta = n\lambda$

R.P = nN

Solution : -

(I)   Grating elemnt (a+b) = (1/N) = (1/5000)

R.P is maximum when N is maximum.

N is maximum when $\sin\theta$ =1

$\sin\theta = 1$

(a+b) $\sin\theta = n\lambda$

$$n_{max} = \frac{1}{N\lambda}$$

$$n_{max} = \frac{1}{5000 \ x \ 5890 \ x \ 10^{-8}} = 3.39$$

N cannot be 4 as $sin \ \theta$ exceeds one

$$n_{max} = 3$$

(II)   R.P = n N = 3 x 5000

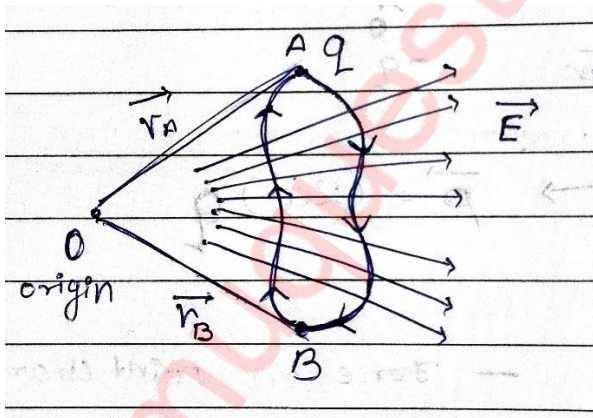----------(as grating is 3 cm wide)

R.P = 45000

Maximum value of Resolving Power is 45000

Q6] c) How will you state Faraday's law in differential (in point) form explain with appropriate derivation.   (5)

ANS :

We have calculated potential difference by

$$V_{AB} = - \int_{A}^{B} \vec{E} \cdot d\vec{l} \qquad \text{--------(i)}$$

Potential difference for a closed path in a static electric field is given as

$$\Delta v = - \oint \vec{E} \cdot d\vec{l}$$

$$= - \int_{A}^{B} \vec{E} \cdot d\vec{l} \ + (- \int_{B}^{A} \vec{E} \cdot d\vec{l} \ )$$

$$= V_{AB} + V_{BA}$$

$$= (V_B - V_A) + (V_A - V_B)$$

$$= 0$$

$$\therefore \oint \vec{E} \cdot \vec{dl} = 0 \quad \text{--------(Integral form)}$$

Applying Stoke's Theorem to the RHS in the above eq

$$\therefore \oint \vec{E} \cdot \vec{dl} = \int_S (\vec{\nabla} \times \vec{E}) \, d\vec{s}$$

$$\therefore \int_S (\vec{\nabla} \times \vec{E}) \, d\vec{s} = 0$$

$$\therefore \vec{\nabla} \times \vec{E} = 0 \quad \text{---------(Differential form or point form)}$$

It explains work done to move a charge in closed path under external field is zero. This equation signifies and explains how electric generators work and how electrical energy can be converted from one from to another