CBCS SCHEME

USN

21PHY12/22

First/Second Semester B.E. Degree Examination, July/August 2022
Engineering Physics

Time: 3 hrs. Max. Marks: 100

Note: 1. Answer any FIVE full questions, choosing ONE full question from each module.
2. Draw neat sketches wherever necessary.
3. Constants : Electron mass $M = 9.1\times10^{-31}$ kg, Electron charge $e = 1.6\times10^{-19}$ C,
Velocity of light $C = 3\times10^{8}$ m/s, Planck's constant $h = 6.626\times10^{-34}$ Js,
Avagadro number $N_A = 6.025\times10^{26}$/k mol,
Permitivity of free space $\epsilon_0 = 8.854\times10^{-12}$ F/m,
Acceleration due to gravity $g = 9.8$ m/s^2, Boltzman constant $K = 1.38\times10^{-23}$ J/K

Module-1

1 a. What are forced oscillations? Obtain expression for displacement of forced oscillations. **(08 Marks)**

b. With a neat diagram explain the construction and working of Reddy's shock tube. **(08 Marks)**

c. For a particle executing simple harmonic motion amplitude is 13m and period is 2π sec. Find its velocity when the displacement is 5m from the mean position. **(04 Marks)**

OR

2 a. Find the effective spring constant in case of spring connected in series and parallel combination. **(08 Marks)**

b. Define SHM and mention any two examples. Obtain differential equation of motion for SHM and its natural frequency of oscillation. **(08 Marks)**

c. A mass of 2 kg suspended by a spring of force constant 51.26 N/m is executing damped SHM with a damping 5 kg/s. Identify whether it is the case of underdamping or of overdamping. Also estimate the value of damping required for the oscillation to be critically damped (Ignore the mass of spring) **(04 Marks)**

Module-2

3 a. Using Schrodinger wave equation, obtain the eigen function and eigen value for a particle in a box. **(09 Marks)**

b. State Heisenberg Uncertainty Principle. Show that an electron does not exists inside the nucleus on the basis of Heisenberg Uncertainty Principle. **(07 Marks)**

c. Calculate the energy of the neutron in eV, if its deBroglie wavelength is $3\,\mathring{A}$ and $m_n = 1.67\times10^{-27}$ kg. **(04 Marks)**

OR

4 a. Discuss the spectral radiancy in Black body? Deduce Wein's law and Rayleigh-Jean's law from Planck's radiation law. **(09 Marks)**

b. Setup one-dimensional time-independent Schrodinger wave equation. **(07 Marks)**

c. An electron is bound in a 1-dimensional box of 0.1 nm length. Calculate the energy required to excite it from its ground state to third excited state. **(04 Marks)**

Important Note : 1. On completing your answers, compulsorily draw diagonal cross lines on the remaining blank pages.
2. Any revealing of identification, appeal to evaluator and /or equations written eg, 42+8 = 50, will be treated as malpractice.

Module-3

5 a. Explain the requisites for a laser action? Obtain the expression for energy density using Einstein's coefficients at thermal equilibrium condition. **(10 Marks)**

b. With neat diagram explain the principle, construction and working of phase modulated temperature sensor. **(06 Marks)**

c. How many photons of yellow light of wavelength 5500 Å constitutes 1.5 J of energy. **(04 Marks)**

OR

6 a. Explain the construction and working of carbon dioxide laser with the help of energy level diagram. **(09 Marks)**

b. What is numerical aperture? Derive the expression for acceptance angle of an optical fiber. **(07 Marks)**

c. Calculate the refractive indices of core and cladding of a given optical fiber with numerical aperture of 0.22 and fractional index change variation 0.012. **(04 Marks)**

Module-4

7 a. Mention any three assumptions of classical free electron theory? Discuss the success of Quantum free electron theory. **(09 Marks)**

b. Obtain expression for electrical conductivity in semiconductors. **(07 Marks)**

c. The dielectric constant of He gas at NTP is 1.0000684. Calculate the electronic polarisability of He atoms if the gas contains 2.7×10^{28} atom/m^3. **(04 Marks)**

OR

8 a. What is Hall Effect? Obtain expression for Hall voltage and express Hall voltage in terms of Hall coefficient. **(09 Marks)**

b. What is polarization? Explain different types of polarization. **(07 Marks)**

c. Find the temperature at which there is 1% probability that a state with an energy 0.5 eV above Fermi energy is occupied. **(04 Marks)**

Module-5

9 a. With a neat diagram, explain the principle, construction and working of Atomic Force Microscope. **(10 Marks)**

b. What are nano-materials and classify the nano materials based on the dimensional constraints. **(05 Marks)**

c. GaAs has its principle planes separated at 5.6534 Å. The first order Bragg reflection is located at 13° 40′. Calculate

(i) The wavelength of the x-ray

(ii) The angle for second order Bragg reflection. **(05 Marks)**

OR

10 a. Explain the construction and working of x-ray diffractometer. **(07 Marks)**

b. Describe the principle, construction and working of scanning electron microscope with the help of neat diagram. **(08 Marks)**

c. Determine the crystal size given the wavelength of x-ray 12 nm, the peak width 0.5° and peak position 23° for a cubic crystal. Given K = 0.94. **(05 Marks)**

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EVEN SEM 2021-22
VTU PHYSICS EXAM SCHEME

1.a) Forced oscillations are the Simple harmonic oscillations performed by an object under the influence of an external oscillating force.

EX:

- A child on a swing can be kept in motion by appropriately timed “pushes.” The amplitude of motion remains constant if the energy input per cycle of motion exactly equals the decrease in mechanical energy in each cycle that results from resistive forces.
- Vibrations of tuning fork placed on a resonating box make the walls of the box and the air inside oscillate.
- Oscillations of Electrons in LCR circuit

Let F = F_o Sin$\omega_f t$ be the oscillating applied force

The equation of motion is given by

$$F = ma = -kx - bv + F_o \sin \omega_f t$$

$$m\frac{d^2x}{dt^2} + b.\frac{dx}{dt} + kx = F_o \sin \omega_f t$$

$$\frac{d^2x}{dt^2} + \frac{b}{m}\frac{dx}{dt} + \frac{k}{m}x = \frac{F_o}{m}\sin \omega_f t$$

$$Let\ \ \frac{b}{m} = 2R; \frac{k}{m} = \omega^2; \frac{F_o}{m} = F$$

$$\frac{d^2x}{dt^2} + 2R\frac{dx}{dt} + \omega_o{}^2 x = F \sin \omega_f t \text{.....(1)}$$

Let one particular solution be $x = A.\sin(\omega_f t - \phi)$

$$\frac{dx}{dt} = \omega_f A.\cos(\omega_f t - \phi)$$

$$\frac{d^2x}{dt^2} = -\omega_f^2 A.\sin(\omega_f t - \phi)$$

Also

$$F \sin \omega_f t = F.\sin(\omega_f t - \phi + \phi)$$

$$= F \sin(\omega_f t - \phi)\cos\phi + F \cos(\omega_f t - \phi)\sin\phi$$

Substituting in (1)

$$-\omega_f^2 A.\sin(\omega_f t - \phi) + 2RA\omega_f \cos(\omega_f t - \phi) + \omega_o^2 A\sin(\omega_f t - \phi) = F \sin(\omega_f t - \phi)\cos\phi + F \cos(\omega_f t - \phi)\sin\phi$$

Comparing coefficients of $\sin(\omega_f t - \phi)$ *and* $\cos(\omega_f t - \phi)$ on both sides

$$A(.\omega_o^2 - \omega_f^2) = F\cos\phi$$

$$2RA\omega_f = F\sin\phi$$

$$\therefore F^2 = A^2(\omega_o^2 - \omega_f^2)^2 + 4R^2A^2\omega_f^2$$

$$A = \frac{F}{\sqrt{(\omega_o^2 - \omega_f^2)^2 + 4R^2\omega_f^2}}$$

$$\tan\phi = \frac{2R\omega_f}{\omega_o^2 - \omega_f^2}$$

Case 1: amplitude is infinity when at $\omega_0 = \omega_f$, damping is zero

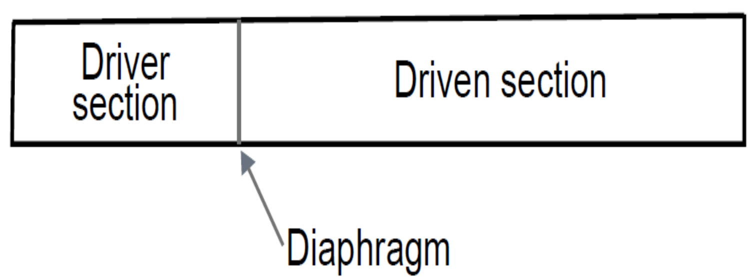
Case 2: Amplitude is less when $\omega_0 \neq \omega_f$

1 B

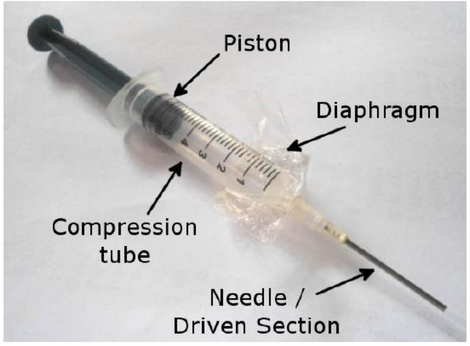
Reddy shock tube:

A shock tube is a device used to study the changes in pressure & temperature which occur due to the propagation of a shock wave. A shock wave may be generated by an explosion caused by the buildup of high pressure which causes diaphragm to burst.

It is a hand driven open ended shock tube. It was conceived with a medical syringe. A plastic sheet placed between the plastic syringe part and the needle part constitutes the diaphragm.



- A high pressure (driver) and a low pressure (driven) side separated by a diaphragm.
- When diaphragm ruptures, a shock wave is formed that propagates along the driven section.
- Shock strength is decided by driver to driven pressure ratio, and type of gases used.

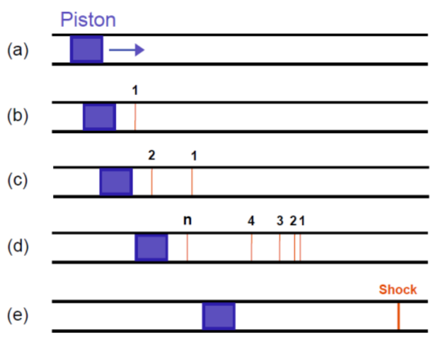


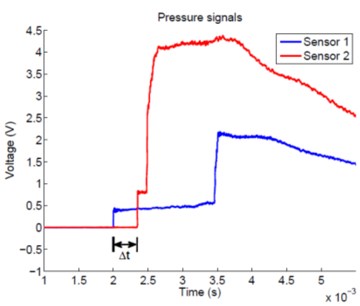
Working:

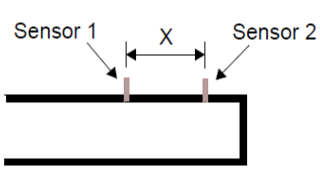
- The piston is initially at rest and accelerated to final velocity V in a short time t.
- The piston compresses the air in the compression tube. At high pressure, the diaphragm ruptures and the shock wave is set up. For a shock wave to form, $V_{piston} > V_{sound}$.

Formation of shock wave:

As the piston gains speed, compression waves are set up. Such compression waves increase in number. As the piston travels a distance, all the compression waves coalesce and a single shock wave is formed. This wave ruptures the diaphragm.







$$U_S = \frac{X}{\Delta t}$$

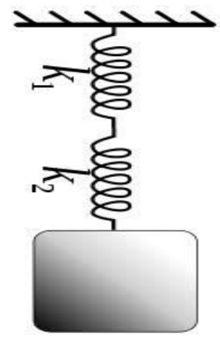
Mach number $M = \frac{V_{Shock}}{V_{Sound}}$

1C

$$V = \omega\sqrt{A^2 - x^2}$$

$$= \frac{2\pi}{T}\sqrt{13^2 - 5^2} = 12 m/s$$

2A Force constant represents the amount of restoring force produced per unit elongation and is a relative measure of stiffness of the material.



Consider a load suspended through two springs with spring constants k_1 and k_2 in series combination. Both the springs experience same stretching force. Let Δx_1 and Δx_2 be their elongation.

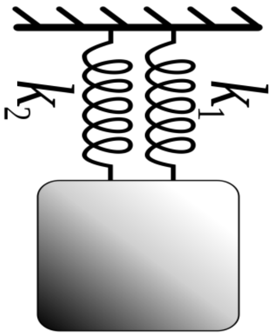
Total elongation is given by

$$\Delta X = \Delta X_1 + \Delta X_2 = \frac{F}{k_1} + \frac{F}{k_2}$$

$$\frac{F}{k_{eqv}} = \frac{F}{k_1} + \frac{F}{k_2}$$

$$\frac{1}{k_{eqv}} = \frac{1}{k_1} + \frac{1}{k_2}$$

Expression for Spring Constant forParallel Combination



Consider a load suspended through two springs with spring constants k_1 and k_2 in parallel combination. The two individual springs both elongate by x but experience the load non uniformly.

Total load across the two springs is given by

$$F = F_1 + F_2$$
$$k_{eqv}.\Delta X = k_1.\Delta X + k_2.\Delta X$$
$$k_{eqv} = k_1 + k_2$$

2B

SIMPLE HARMONIC MOTION

It is the periodic oscillations of an object caused when the restoring force on the object is proportional to the displacement. The restoring force is directed opposite to displacement.

Ex: 1. Oscillation of mass connected to spring

2. Oscilations of prongs of Tuning fork

3. Simple pendulum

Restoring force α – displacement

F = -k x

Here k is the proportionality constant known as spring constant. It represents the amount of restoring force produced per unit elongation and is a relative measure of stiffness of the material.

$$F_{\text{Re}\,storing} = -kx$$
$$m\frac{d^2x}{dt^2} = -kx$$
$$Let\ \omega_o^{\,2} = \frac{k}{m}$$
$$\frac{d^2x}{dt^2} + \omega_o^{\,2}x = 0$$

Here ω_o is angular velocity = 2.π.f

f is the natural frequency $f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$

The Solution is of the form $x(t) = A\cos\omega_o t + B\sin\omega_o t$.

This can also be expressed as $x(t) = C\cos(\omega_o t - \theta)$ where

$C = \sqrt{A^2 + B^2}$ $\tan\theta = B/A$

2C

$$b^2 = 25$$
$$4mk = 4x2x51.26 = 410$$
$$b^2 < 4mk$$
$$underdamping$$

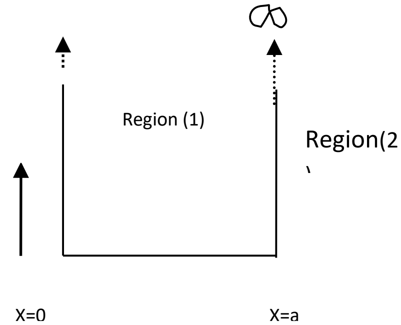
For critical damping

$$b^2 = 4mk = 4x2x51.26 = 410$$
$$b = 20.25kg/s$$

3A

Particle in an infinite potential well problem:

Consider a particle of mass m moving along X-axis in the region from X=0 to X=a in a one dimensional potential well as shown in the diagram. The potential energy is assumed to be zero inside the region and infinite outside the region.



Applying, Schrodingers equation for region (1) as particle is supposed to be present in region (1)

$$\frac{d^2\Psi}{dx^2} + \frac{8\Pi^2 mE\psi}{h^2} = 0$$

$$\because V = 0$$

But $k^2 = \frac{8\Pi^2 mE}{h^2}$

$$\therefore \frac{d^2\Psi}{dx^2} + k^2\Psi = 0$$

Auxiliary equation is $\left(D^2 + k^2\right)x = 0$

Roots are D = +ik and D = -ik

The general solution is

$$x = Ae^{ikx} + Be^{-ikx}$$
$$= A(\cos kx + i\sin kx) + B(\cos kx - i\sin kx)$$
$$= (A+B)\cos kx + i(A-B)\sin kx$$
$$= C\cos kx + D\sin kx$$

The boundary conditions are

1. At x=0, $\Psi = 0 \therefore C = 0$
2. At x=a, $\Psi = 0$

D sin ka = 0 $\Rightarrow$ ka = n Π ………(2)

where n = 1, 2 3…

$$\therefore \Psi = D\sin\left(n\frac{\Pi}{a}\right)x$$

From (1) and (2) E = $\frac{n^2h^2}{8ma^2}$

To evaluate the constant D:

Normalisation: For one dimension

$$\int_0^a \Psi^2 dx = 1$$

$$\int_0^a D^2 \sin^2(\frac{n\Pi}{a})xdx = 1$$

But $\cos 2\theta = 1 - 2\sin^2\theta$

$$\int_0^a D^2 \frac{1}{2}(1-\cos 2(\frac{n\Pi}{a})x)dx = 1$$

$$\int_0^a \frac{D^2}{2}dx - \int_0^a \frac{1}{2}\cos 2(\frac{n\Pi}{a})x)dx = 1$$

$$\frac{D^2a}{2} - \quad [\sin 2\left(\frac{n\Pi}{a}\right)\frac{x}{2}]_0^a = 1$$

$$D^2\frac{a}{2} - 0 = 1$$

D = $\sqrt{\frac{2}{a}}$

$$\therefore \Psi_n = \sqrt{\frac{2}{a}}\sin\left(n\frac{\Pi}{a}\right)x$$

For n = 1, First state

$$\therefore \Psi_1 = \sqrt{\frac{2}{a}}\sin\left(1.\frac{\Pi}{a}\right)x$$

3B

The position and momentum of a particle cannot be determined accurately and simultaneously.The product of uncertainty in the measurement of position (Δx) and momentum (Δp) is always greater than or equal to $\frac{h}{2\Pi}$.

$$\boxed{(\Delta x).(\Delta p) \geq \frac{h}{4\Pi}}$$

TO SHOW THAT ELECTRON DOES NOT EXIST INSIDE THE NUCLEUS:

We know that the diameter of the nucleus is of the order of 10^{-14}m.If the electron is to exist inside the nucleus, then the uncertainty in its position Δx cannot exceed the size of the nucleus

$$\Delta x = 5x10^{-15}m$$

Now the uncertainty in momentum is

$$\Delta x = 5x10^{-15}m$$
$$\Delta P = \frac{h}{4\pi x\Delta x} = 0.1x10^{-19}kg.m/s$$

Then the momentum of the electron can atleast be equal to the uncertainty in momentum.

$$P \approx \Delta P = 0.1x10^{-19}\, kg.m/s$$

Now the energy of the electron with this momentum supposed to be present in the nucleus is given by (for small velocities -non-relativistic-case)

$$E = \sqrt{p^2c^2 + m_o^2c^4} = 1.56x10^{-17}\, J = 98MeV$$

The beta decay experiments have shown that the kinetic energy of the beta particles (electrons) is only a fraction of this energy. This indicates that electrons do not exist within the nucleus. They are produced at the instant of decay of nucleus ($n \rightarrow p + e + \bar{\nu}$ / $p \rightarrow n + \overset{+}{e} + \nu$).

3C

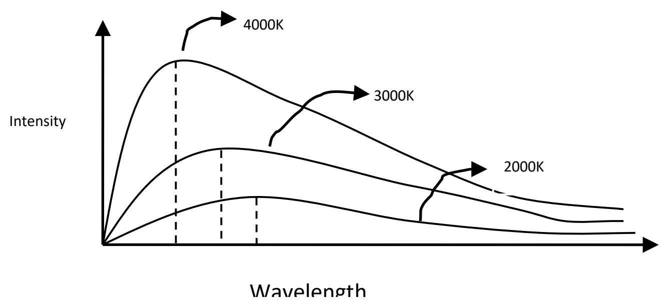
$$\lambda = \frac{h}{\sqrt{2mE}}$$

$$E = 2.67x10^{-17}\, J$$

$$E = 16.72eV$$

4A

Features of Black body spectrum:



Interpretation of the graph:

1. A black body emits over wide range of wavelengths at different temperatures.
2. At each temperature, there exists a wavelength at which maximum energy is radiated.
3. As the temperature increases, the amount of energy radiated (the area under the curve) increases and the peak shifts towards shorter wavelengths.
4. As temperature increases, energy emitted also increases.

Deduction of Weins law:

It is applicable at smaller wavelengths.

For smaller wavelengths $e^{\frac{h\gamma}{kT}} >> 1$

$$\therefore e^{\frac{h\gamma}{kT}} >> 1 = e^{\frac{h\gamma}{kT}}$$

So Planck's radiation law becomes

$$E_\lambda d\lambda = \frac{8\pi hc}{\lambda^5}\left[\frac{1}{e^{\left[\frac{h\gamma}{kT}\right]}}\right]$$

Deduction of Rayleigh Jeans Law:

It is applicable at longer wavelengths.

For longer wavelengths $\frac{h\gamma}{kT} << 1$

$$\therefore e^{\frac{h\gamma}{kT}} = 1 + \frac{h\gamma}{kT} + \left(\frac{h\gamma}{kT}\right)^2 \frac{1}{2|} + ... = 1 + \frac{h\gamma}{kT}$$

$$E_\lambda d\lambda = \frac{8\pi hc}{\lambda^5}.\frac{1}{1 + \frac{h\gamma}{kT} - 1} d\lambda = \frac{8\pi kT}{\lambda^4} d\lambda$$

4B

<u>**Time independent Schrödinger equation**</u>

A matter wave can be represented in complex form as

$$\Psi = A \sin kx(\cos wt + i \sin wt)$$

$$\boxed{\frac{d^2\Psi}{dx^2} + \frac{8\Pi^2 m(E-V)\Psi}{h^2} = 0}$$

$$\Psi = A\sin kxe^{iwt}$$

Differentiating wrt x

$$\frac{d\Psi}{dx} = kA\cos kxe^{iwt}$$

$$\frac{d^2\Psi}{dx^2} = -k^2 A\sin kxe^{iwt} = -k^2\Psi \text{ ……………………..}$$

(1)

From debroglie's relation

$$\frac{1}{\lambda} = \frac{h}{mv} = \frac{h}{p}$$

$$k = \frac{2\pi}{\lambda} = \frac{2\Pi p}{h}$$

$$k^2 = 4\Pi^2 \frac{p^2}{h^2} \text{ ………………………. (2)}$$

Total energy of a particle E = Kinetic energy + Potential Energy

$$E = \frac{1}{2} m v^2 + V$$

$$E = \frac{p^2}{2m} + V$$

$$p^2 = (E-V)2m$$

Substituting in (2)

$$k^2 = \frac{4\Pi^2(E-V)2m}{h^2}$$

$\therefore$ From (1)

4C

$$E = \frac{n^2h^2}{8mL^2}$$

$$n = 4$$

$$E = 9.6x10^{-17}\,J = 602eV$$

5A

Requisites of Laser :

1.Active medium: A suitable material possessing meta stable states is required. These atoms readily absorb energy through optical/thermal/chemical sources.

Ex: Ruby, He-Ne

2.**Optical pumping:**

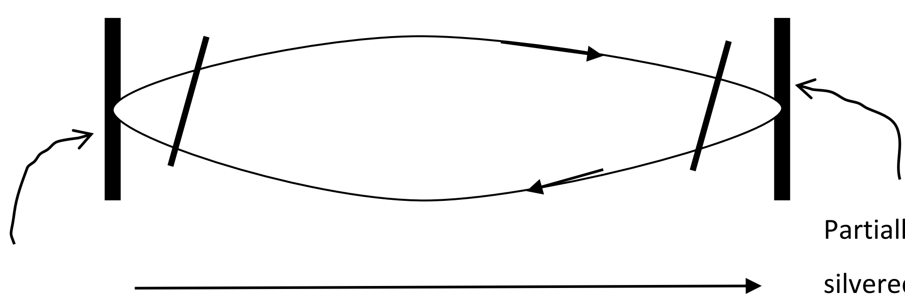
The population inversion is achieved by the method of optical pumping. In this process the active medium is excited by the irradiation with light or through electrical discharge .The atoms of the active medium absorb energy and rise to higher energy state. As a result the number of atoms in the higher energy states increases and the population inversion is said to be achieved.

Population inversion is achieved in certain systems which possess **metastable states.** The life time of the excited atoms in these energy levels is higher(10^{-3} s).Hence atoms stay for a longer time .

Note: Metastable states are identified lesser width. $life\ time \alpha \frac{1}{\Delta\lambda}$ *where* $\Delta\lambda$ *is the spectral width of the state. For Ground state* $\Delta\lambda = 0$ *and hence said to be stable (life time is infinity).*

3.Resonant cavity:

It consists of quartz tube with fully silvered mirror and a partially silvered mirror at the ends. The length of the cavity is such that rays undergo constructive interference after multiple reflections and an intense Laser beam emerges out. Polarising plates are used to produce polarized light.

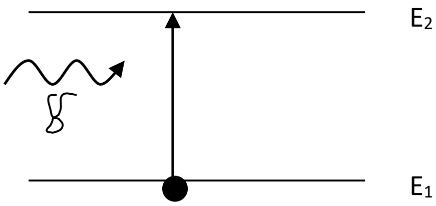


The resonant cavity allows selected modes to sustain.

Expression for energy density:

Induced absorption:

It is a process in which an atom at a lower level absorbs a photon to get excited to the higher level.
Let E_1 and E_2 be the energy levels in an atom and N1 and N_2 be the number density in these levels respectively. Let U_γ be the energy density of the radiation incident..



$$\gamma = \frac{E_2 - E_1}{h}$$

Rate of absorption is proportional to the number of atoms in lower state and also on the energy density U_γ.

Rate of absorption = $B_{12}\ N_1\ U_\gamma$

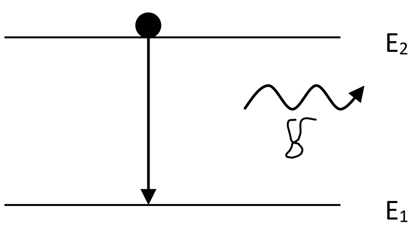
Here B_{12} is a constant known as Einsteins coefficient of spontaneous absorption.

Spontaneous emission:

It is a process in which ,atoms at the higher level voluntarily get excited emitting a photon. The rate of spontaneous emission representing the number of such deexcitations is proportional to number of atoms in the excited state.

Rate of spontaneous absorption = $A_{21}\ N_2$

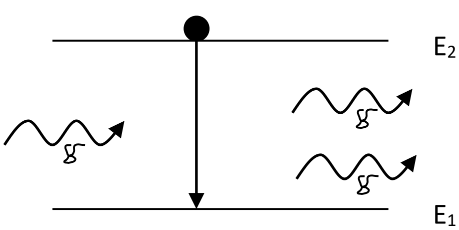
Here B_{12} is a constant known as Einsteins coefficient of spontaneous emission.



$$\gamma = \frac{E_2 - E_1}{h}$$

Stimulated emission:

In this process, an atom at the excited state gets deexcited in the presence of a photon of same energy as that of difference between the two states.



$$\gamma = \frac{E_2 - E_1}{h}$$

The number of stimulated emissions is proportional to the number of atoms in higher state and also on the energy density U_γ.

Rate of stimulated emission = $B_{21}\ N_2\ U_\gamma$

Here B_{21} is the constant known as Einsteins coefficient of stimulated emission.

At thermal equilibrium,

Rate of absorption = Rate of spontaneous emission + Rate of stimulated emission

$$B_{12}\ N_1\ U_\gamma \;=\; A_{21}\ N_2 \;+\; B_{21}\ N_2\ U_\gamma$$

$$U_\gamma = \frac{A_{21} N_2}{B_{12} N_1 - B_{21} N_2}$$

Rearranging this, we get

$$U_\gamma = \frac{A_{21}}{B_{21}} \left[\frac{1}{\frac{B_{12} N_1}{B_{21} N_2} - 1} \right]$$

From Boltzmans law , $\frac{N_1}{N_2} = e^{\frac{h\gamma}{kT}}$

Hence

$$U_\gamma = \frac{A_{21}}{B_{21}} \left[\frac{1}{\frac{B_{12}}{B_{21}} e^{\frac{h\gamma}{kT}} - 1} \right]$$

From Planck's radiation law,

$$U_\gamma = \frac{8\pi h \gamma^3}{c^3} \left[\frac{1}{e^{\left[\frac{h\gamma}{kT}\right]} - 1} \right]$$

Comparing these expressions, we get

$$\frac{A_{21}}{B_{21}} = \frac{8\pi h \gamma^3}{c^3} \quad \text{and} \quad \frac{B_{12}}{B_{21}} = 1$$

Conclusion

1. In thermal equilibrium , rate of induced absorption is equal to rate of stimulated emission.

5B

Temperature sensor Based on Phase Modulation

Temperature measurement plays a decisive role in areas of meteorology, biology, environmental monitoring and manufacturing.

Construction:

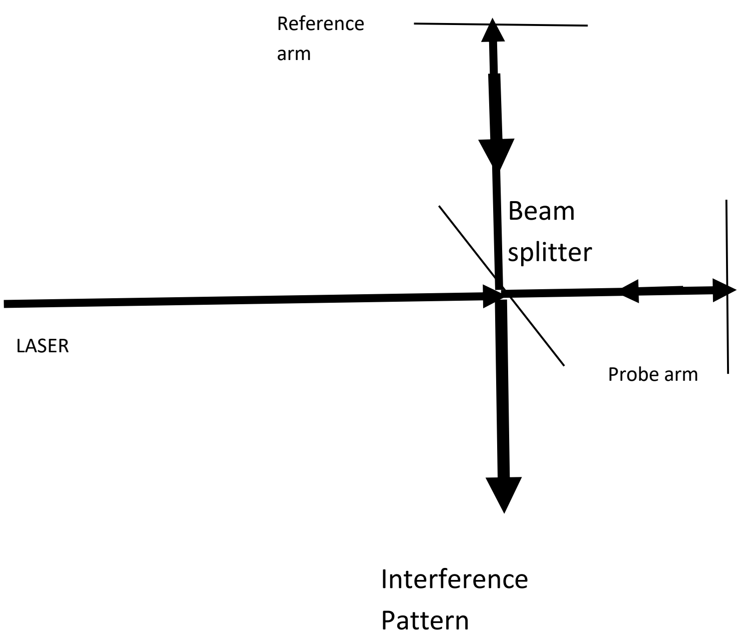
The apparatus comprises of

1. Interferometer consisting of Laser source, beam splitter, Probe arm and reference arm having optical fibers of equal length.
2. The Interference pattern produced is observed through a spectrometer.
3. The probe arm is kept in external environment where temperature is to be measured.

Principle: Under normal temperature, the interference pattern formed is recorded. When the temperature changes, the optical fiber in the probe arm is deformed and causes path difference. Hence the interference pattern will be shifted.

Working

The probe arm will be placed in external environment to be measured in the experiment, the light propagating within the arm will be influenced by the external parameters. Thus, the phase difference of the light in two arms will be changed and the interference fringe will be shifted with it, and the wavelength shift is the final parameter we use mostly for probing the external environment change. Change in length due to mechanical or thermal strain will cause a phase change.



5C

$$\lambda = \frac{nhc}{pt}$$

$$n = 4.15x10^{18}$$

6A

Carbon dioxide laser

It one of the high efficient laser with power output in the range of few 100W to Kilowatt.

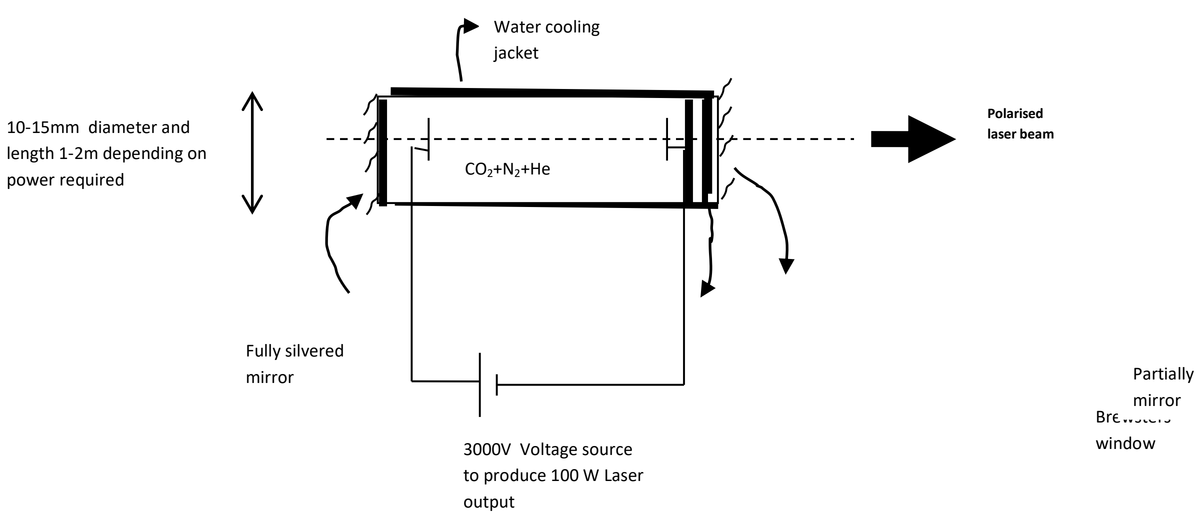
Construction

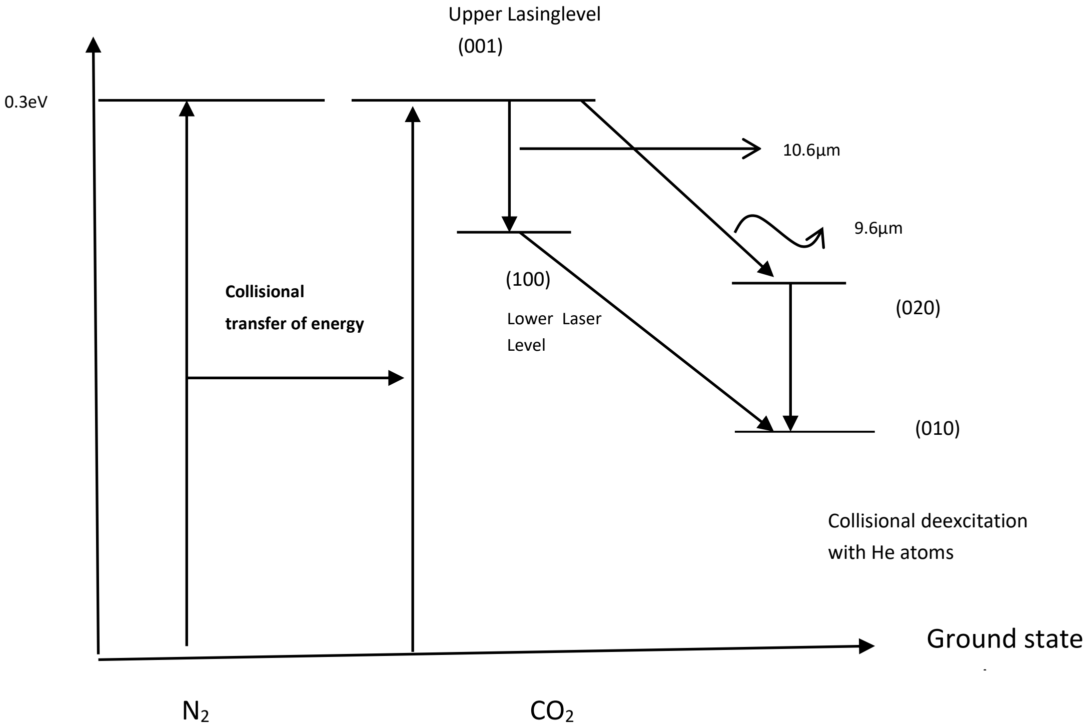
1.Active medium – Mixture of CO_2, N_2 and He in the ratio 1:2:8. Nitrogen absorbs energy from the pumping source efficiently.Helium gas conducts away the heat and also catalyses collisional deexcitation of CO_2 molecules.

2.The discharge tube consists of a glass tube of 10-15mm diameter with a coaxial water cooling jacket.

3.Partially reflecting and fully reflecting mirrors are mounted at the ends of the tube.

4.Optical pumping is achieved by electric discharge caused by applying potential difference of over 1000V.





Working:

1.CO_2 is a linear molecule and has three modes of vibration – Symmetric stretching (100), Asymmetric stretching (001) and bending (010).

2. Asymmetric stretching (001) is the upper laser level which is a metastable state. (100) and (020) are the lower lasing states

3.During electric discharge, the electrons released due to ionisation excite N_2 molecules to its first vibrational level which is close to upper lasing level of CO_2.

4.N_2 molecules undergo collisions with CO_2 molecules and excite them to (001). This results in population inversion.

5.Lasing transition occurs between (001) and (100) emitting at 10.6µm and (001) to (020) emitting at 9.6µm

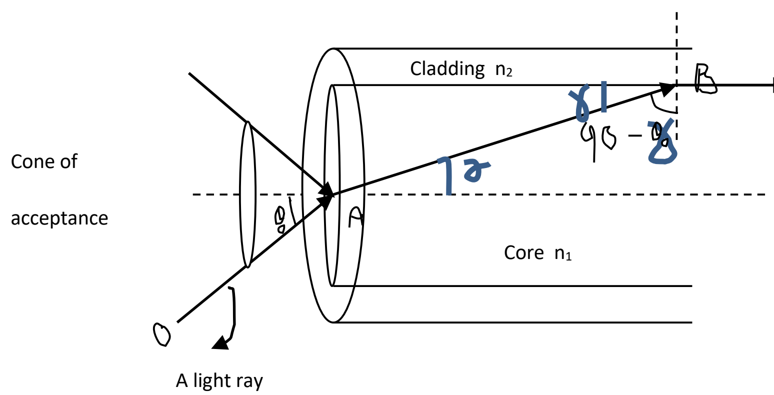
6. CO_2 molecules deexcite to ground state through collisions with Helium atom.

7.SIGNIFICANCE OF HELIUM GAS:

Helium gas conducts away the heat and also catalyses collisional deexcitation of CO_2 molecules.

6B
Numerical aperture:

It represents the light carrying capacity of an optical fiber.



Expression for condition for propagation :

Consider a light ray falling in to the optical fibre at an angle of incidence θ_0 equal to acceptance angle. Let n_0 be the refractive index of the surrounding medium .

Let n_1 be the refractive index of the core.

Let n_2 be the refractive index of the cladding.

From Snell's Law:

For the ray OA $n_0 \sin\theta_0 = n_1 \sin r = n_1\left(\sqrt{1-\cos^2 r}\right)$

………… (1)

For the ray AB

$$n_1 \sin(90-r) = n_2 \sin 90$$
$$n_1 \cos r = n_2$$
$$\cos r = \frac{n_2}{n_1}$$

[here the angle of incidence is (90 - θ_1) for which angle of refraction is 90^0].

Substituting for cosr in equation (1)

$$n_0 \sin\theta_0 = n_1 \sqrt{1-\frac{n_2^2}{n_1^2}}$$

$$\sin\theta_0 = \frac{\sqrt{n_1^2 - n_2^2}}{n_0}$$

If the medium surrounding the fiber is air then $n_0 = 1$,

Numerical aperture = $\sin\theta_0 = \sqrt{n_1^2 - n_2^2}$

The total internal reflection will take place only if the angle of incidence $\theta_i < \theta_0$

$\therefore \sin\theta_i < \sin\theta_0$

$\sin\theta_i <$ $\sqrt{n_1^2 - n_2^2}$

This is the condition for propagation.

6C

$$NA = n_1\sqrt{2\Delta}$$
$$0.22 = n_1\sqrt{2x0.012}$$
$$n_1 = 1.42$$
$$\Delta = \frac{n_1 - n_2}{n_1}$$
$$0.012 = \frac{1.42 - n_2}{1.42}$$
$$n_2 = 1.40$$

7A

Classical free electron theory

Postulates:

1. A metal is assumed to possess a three dimensional array of positive ions with randomly moving free electron gas confined to metallic boundary.
2. These free electron gas is treated as equivalent to gas molecules and they are assumed to obey the laws of kinetic energy of gases. In the absence of any electric field the energy associated with electrons is equal to

Kinetic energy = $\frac{3}{2}kT$

3. The electric current in a metal is due to the drift of electrons in a direction opposite to applied Electric field.

4. The electric field due to all the ions is assumed to be constant.

Success of Quantum free electron theory

1. Specific heat:

Classical theory predicted high values of specific heat for metals on the basis of the assumption that all the conduction electrons are capable of absorbing the heat energy as per Maxwell - Boltzmann distribution i.e., $C_V = \frac{3}{2}R$

But according to the quantum theory, only those electrons occupying energy levels close to Fermi energy (E_F) are capable of absorbing heat energy to get excited to higher energy levels. Thus only a small percentage of electrons are capable of receiving the thermal energy and specific heat value becomes small.

It can be shown that $C_V = 10^{-4}R$.

This is in conformity with the experimental values.

2. **Temperature dependence of electrical conductivity.**

According to classical free electron theory,

Electrical conductivity $\propto \frac{1}{\sqrt{Temperature}}$

Where as from quantum theory

Electrical conductivity

$\propto \frac{1}{\text{collisional area of crosssection of lattice atoms}} \alpha \frac{1}{\text{vibrational energy}} \alpha \frac{1}{\text{Temperature}}$

This is in agreement with experimental values.

3. **Dependence of electrical conductivity on electron concentration:**

According to classical theory,

$$\sigma = \frac{ne^2\tau}{m} \Rightarrow \sigma \propto n$$

But it has been experimentally found that Zinc which is having higher electron concentration than copper has lower Electrical conductivity.

According to quantum free electron theory, Electrical conductivity $\sigma = \frac{ne^2}{m}\left(\frac{\lambda}{V_F}\right)$ where V_F is the Fermi velocity.

Zinc possesses lesser conductivity because it has higher Fermi velocity.

Metal	n	σ
Cu	$8.45x10^{28}/m^3$	$6x10^7(\Omega m)^{-1}$
Zn	$13x10^{28}/m^3$	$1x10^7(\Omega m)^{-1}$

7B

Expression for Electrical conductivity:

Imagine a conductor across which an electric field E is applied. Let the wave number change from k_1 to k_2 in time interval τ_F in the presence of electric field.

The force on the free electron is

F= dp/dt = eE

$$k = \frac{2\pi}{\lambda} = \frac{2\pi}{h/p} = \frac{2\pi p}{h}$$

$$p = \frac{hk}{2\pi}$$

$$\frac{dp}{dt} = \frac{h}{2\pi}\left(\frac{dk}{dt}\right)$$

$$dk = \frac{2\pi}{h}eEdt$$

On integration $k_2 - k_1 = \Delta k = \frac{2\pi.eE.\tau_F}{h}$ ....(1)

From quantum theory, conductivity $J = \Delta k.ne.\frac{h}{2\pi.m^*}$ ....(2)

Substituting (1) in (2)

We get $J = \frac{ne^2\tau_F}{m^*}E$ ...(3)

Since from Ohm's, J = σE, conductivity σ can be written as

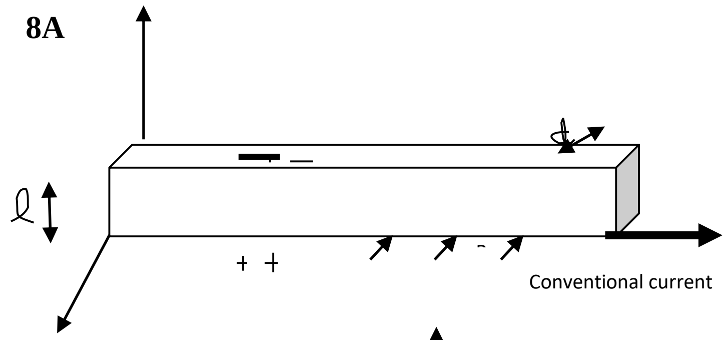
$$\sigma = \frac{ne^2\tau_F}{m^*} = \frac{ne^2}{m^*}\frac{\lambda}{v_F}$$

7C

$$\alpha_e = \frac{\varepsilon_o(\varepsilon_r - 1)}{N} = 2.24x10^{44} \text{ cm}^2/\text{V}$$

8A

8A



Here B is along –X , V is along –Y axis

Lorentz force= = e (VXB)

$$-e\left(-\hat{j}\ X - \hat{i}\right) = +\hat{k}$$

So the electron is deflected along + Z axis

Hall effect: When a conductor carrying current is placed in transverse magnetic field, an electric field is produced inside the conductor in a direction normal to both current and the magnetic field.

Consider a rectangular slab of an n type semiconductor carrying a current I along + X axis. Magnetic field B is applied along –Z direction. Now according to Fleming's left hand rule, the Lorentz force on the electrons is along +Y axis. As a result the density of electrons increases on the upper side of the material and the lower side becomes relatively positive. This develops a potential V_H-Hall voltage between the two surfaces. Ultimately, a stationary state is obtained in which the current along the X axis vanishes and a field E_Y is set up.

Expression for Hall Coefficient:

At equilibrium, Lorentz force is equal to force due to applied electric field

$$Bev_d = eE_H$$

Hall Field $E_H = BV_d$

$$Current\ \ density\ \ J = n_e e v_d$$

$$v_d = \frac{J}{n_e e}$$

$$E_H = B\frac{J}{n_e e}$$

Hence $\frac{E_H}{JB} = \frac{1}{n_e e} = R_H$

Hall voltage $V_H = E_H.d = JBR_H d$

8B

<u>**Polarisation :**</u>The separation of effective centre of positive and negative charges in a substance by the application of electric field is known as polarization

<u>**Different polarization mechanisms:**</u>

There are 4 mechanisms.

1. Electronic polarization
2. Ionic polarization
3. Orientation polarization
4. Space charge polarization

Electronic polarization: These are generally seen in the case of covalent compounds.

When a covalent compound is placed in electric field, displacement of electron cloud takes place relative to the nucleus. This displacement creates a dipole which develops dipole moment.

Electronic polarisability α_e =

$$\frac{\varepsilon_o(\varepsilon_r - 1)}{N}$$

N is number of dipoles per unit volume

It is independent of temperature.

Ionic polarization:

This is exhibited by ionic compounds.

When ionic compounds are kept in an electric field, displacement of positive and negative ions occurs developing a dipole moment.

Ionic polarisability α_{i}=

$$\frac{\varepsilon_o(\varepsilon_r - 1)}{N_i} \approx 0.1\alpha_e$$

Orientation polarization:

Polar molecules exhibit this mechanism.

When polar molecules are kept in an electric field, already existing dipoles tend to align in the direction of applied electric field .This increases the dipole moment.

Orientation polarization α_o =

$$\frac{\mu^2}{kT}$$

Space charge polarization:

This polarization exists in materials possessing different phases due to difference in temperatures. In such materials charge carriers drift and accommodate in certain regions of higher conductivity (electrodes) causing dipole moment. It occurs in ferrites and semiconductors.Its magnitude is very small compared to other mechanisms.

8C

$$f(E) = \frac{1}{e^{\frac{E-E_F}{kT}} + 1}$$

$$E - E_F = +0.5eV = 0.5x1.6x10^{-19}\,J$$

$$e^{\frac{E-E_F}{kT}} + 1 = \frac{1}{f(E)}$$

$$e^{\frac{E-E_f}{kT}} = \frac{1}{f(E)} - 1$$

$$\frac{E - E_F}{kT}\ln_e e = \ln\left(\frac{1}{f(E)}\right) - \ln_e 1$$

$$T = \frac{E - E_F}{k.\ln\left(\frac{1}{f(E)}\right)} \quad \because \ln_e 1 = 0$$

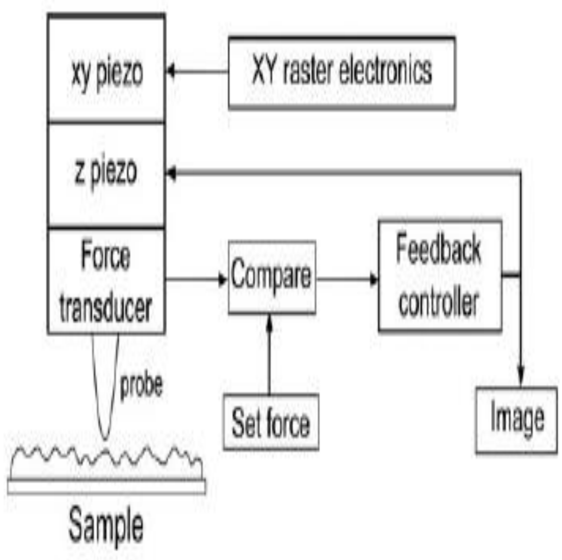
T =1258 K

9A

ATOMIC FORCE MICROSCOPY

PRINCIPLE: In AFM, a sharp tip is mounted on a very flexible cantilever. As in the STM, it is rastered over the surface by means of piezoelectric transducers. Tip-surface interaction forces are sensed in AFM by the deflection of the lever. AFM is therefore ideal for studies of insulating materials that are not directly accessible to STM imaging. The resolution of AFM is not truly atomic, as is the case with STM. The forces of interaction produce a contact spot that is several tens of angstroms in diameter, depending on the applied load. Thus atomic-size point defects are not observed in AFM.

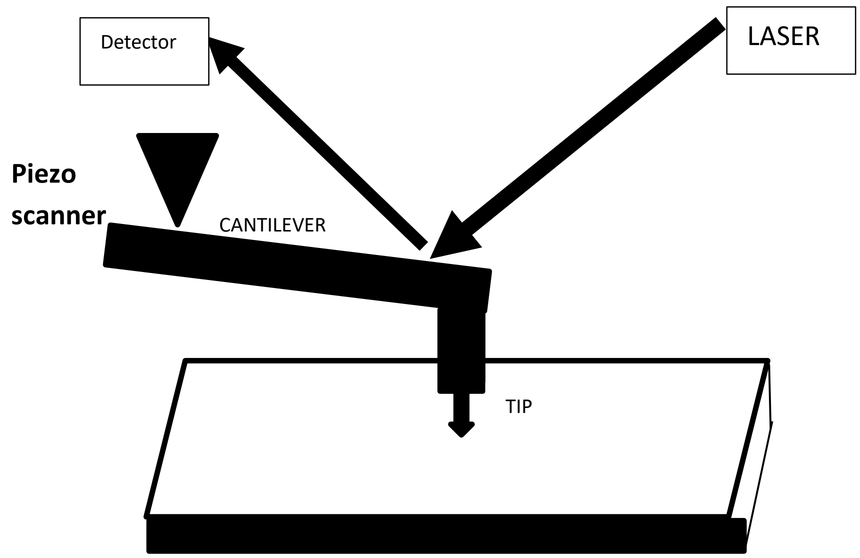
SPECIMEN: Metal –Cells – DNA
VACUUM: Not required
INSTRUMENTATION: Sharp tip attached to scanner, sample holder, force sensor, Display



Force sensor: When a potential is applied across Piezoelectric sensor, it changes geometry. Expansion coefficient of the sensor is 0.1nm/V. It controls the motion of the Force sensor (cantilever) across the sample surface.

Atomic force between the sample – Tip is a measure of separation distance. A Laser beam is reflected by the backside of cantilever onto a photodetector. When the tip experiences a force, it bends and the reflected path will change whose magnitude is related to surface structure.

Working: When the tip encounters an increase in force, the force sensor delivers feedback to Piezo scanner to move away from the surface. The amount scanner moves up / down to maintain the force constant gives surface topography.

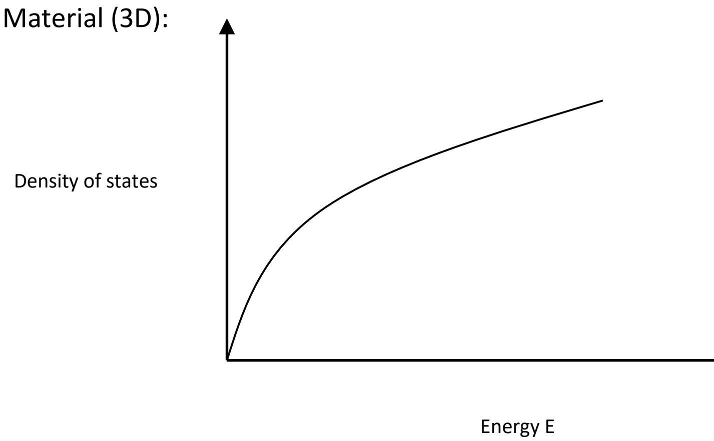


9B

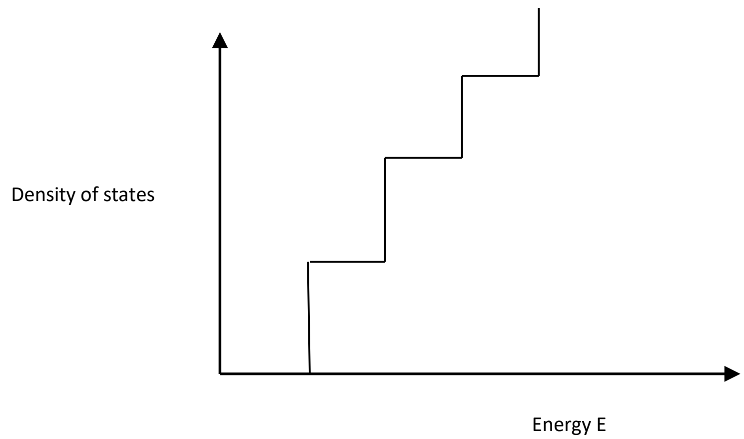
Nano materials:

Nano materials possess dimensions of 0.1 to 100nm.Their properties are dependent on their dimensions. Many parameters such as density of states, energy gap, electrical &, thermal conductivity etc, are different from that from their bulk counterparts.

Bulk Material (3D):

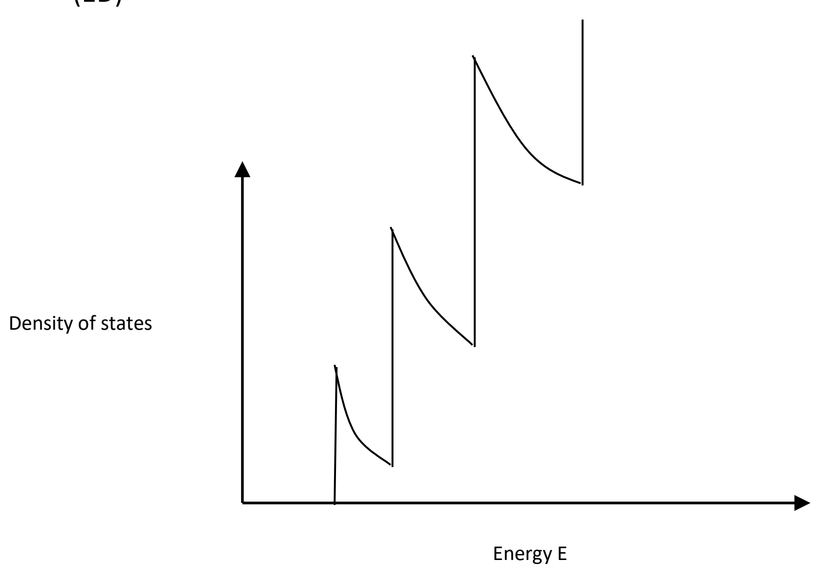


(2D)



g(E)(dE) = $\dfrac{m^*}{\pi\left(\dfrac{h}{2\pi}\right)^2}\left(E-E_i\right)$ dE

(1D)



g(E)(dE) = $\dfrac{1}{\left(\dfrac{h}{2\pi}\right)}\sqrt{\dfrac{m*}{2(E-E_i)}}$ dE

9C

$$2d\sin\theta = n\lambda$$
$$\lambda = 2.67x10^{-10}\,m$$

$$2d\sin\theta = n\lambda$$
$$n = 2$$
$$\sin\theta = \frac{2\lambda}{2d}$$
$$\theta = 28.2^0$$

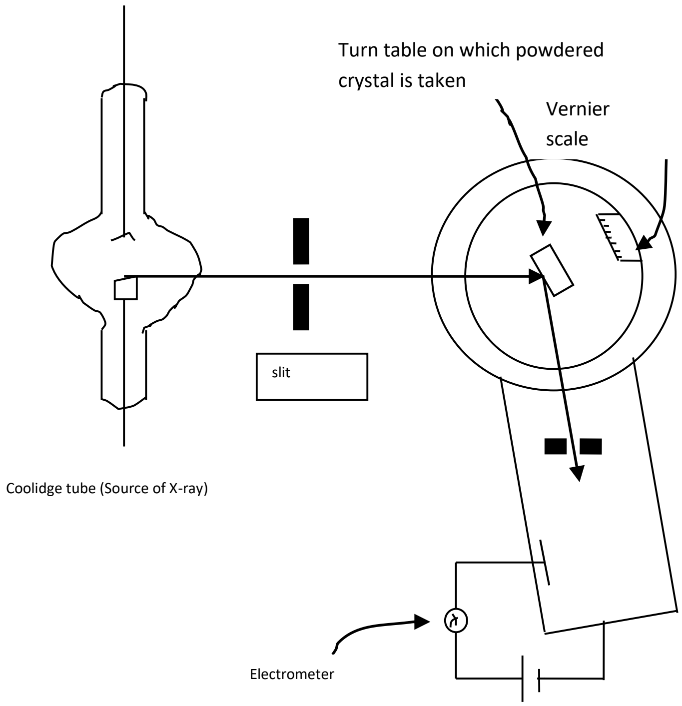
10A

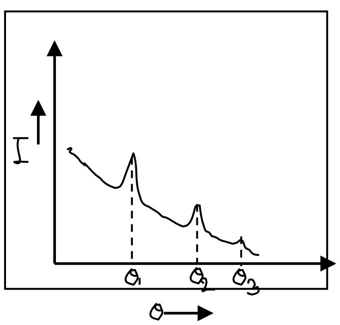
X-ray diffraction spectrometer:

Construction: X –ray beam after reflection from the crystal enters the ionization chamber mounted on a mechanical arm which can turn co axially with the turn table .This ionization chamber is coupled with the turn table so that if the turn table rotates through an angle ‘θ’, the ionization chamber rotates through ‘2θ’.The ionization current produced by X-rays is recorded by the electrometer.

Working: The ionization current is measured for different values of glancing angle ‘θ’. A plot is then obtained between ‘θ’ and ionization current .For certain values of ‘θ’, the intensity of Ionization current increases abruptly.

Whenever the crystal receives X-rays at an angle of incidence satisfying Bragg’s law 2d sinθ = nλ ,constructive interference takes place and maximum intensity occurs .The rise in current occurs more than once as ‘θ’ is varied because the law is satisfied for various values of ‘n’ i.e., 2d sin θ = 1λ ,2λ,3λ etc.





10B

SCANNING ELECTRON MICROSCOPE

Scanning electron microscopy is central to microstructural analysis and therefore important to any investigation relating to the processing, properties, and behavior of materials that involves their microstructure. The SEM provides information relating to topographical features, morphology, phase distribution, compositional differences, crystal structure, crystal orientation, and the presence and location of electrical defects. The strength of the SEM lies in its inherent versatility due to the multiple signals generated, simple image formation process, wide magnification range, and excellent depth of field.

Scanning electron microscopy (SEM) is based on the measurement of the secondary electron yield of conductive Substrates. This yield changes both as a function of composition and local surface slope. The spatial resolution of SEM is determined by the spot size of the electron beam (≈ 20A °) and by the diffusion of the secondary electrons before exiting the sample. The SEM operates in vacuum and the best results are obtained with conductive substrates.

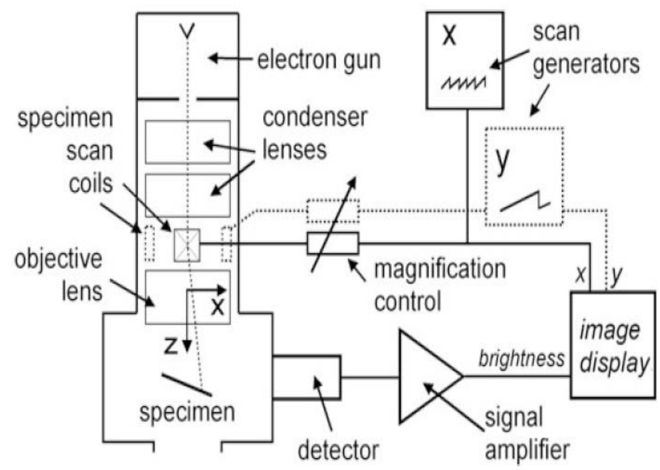
Resolution of 1 nm is now achievable from an SEM with a field emission (FE) electron gun. Magnification is a function of the scanning system rather than the lenses, and therefore a surface in focus can be imaged at a wide range of magnifications from 3 up to 150,000.

PRINCIPLE: The electron beam is a focused probe of electrons accelerated to moderately high energy and positioned onto the sample by electromagnetic fields. These beam electrons interact with atoms in the specimen by a variety of mechanisms when they impinge on a point on the surface of the specimen. The secondary electrons emitted are received by the detector to form the image.

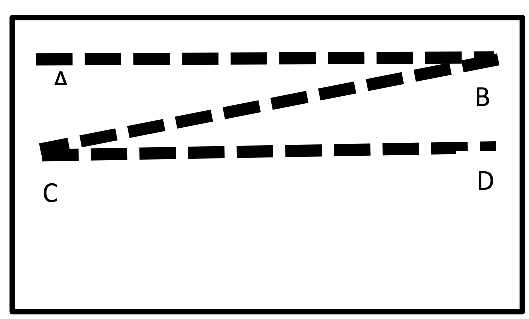
Illumination: Electron source is Tungsten filament. Operating voltage is 30KV.

Focussing by Magnetic scan coils. In TEM electron beam is stationary. In SEM, the electron probe is scanned horizontally across the specimen in X-Y directions.

Working: Scan Generators supply current to scan coils located on either side of the Electron probe. For X-scan, these coils generate magnetic field in the Y direction creating force on an electron travelling in Z direction that deflects in X direction.



SCANNING:



During Z deflection, the electron probe moves in a line from A to B. After reaching B, the beam is deflected back to C along BC. This process is repeated n times to scan the sample. Output of the scan generators are also supplied to display device on which image appears. The digital image in terms of position and Intensity is recorded.

Interaction with Specimen: A small fraction of Primary electrons are elastically back scattered (BS) by atomic nuclei . Inelastic scattering with atomic electrons reduces kinetic energy and are absorbed by the specimen releasing secondary electrons (SE). Since electrons normally undergo multiple interactions, the inelastic and elastic interactions result in the beam electrons spreading out into the material and losing energy. The depth at which this occurs is called penetration depth. Volume of sample containing scattered electrons is called Interaction volume.The intensity of the BSE signal is a function of the average atomic number (Z) of the specimen, with heavier elements (higher Z samples) producing more BSEs. It is thus a useful signal for generating compositional images, in which higher Z phases appear brighter than lower Z phases. The topography, or physical features of the surface, is then imaged by using these properties of the BSE signal. The SE is emitted from an outer shell of a specimen atom upon impact of the incident electron beam. The term ‘‘secondary’’ thus refers to the fact that this signal is not a scattered portion of the probe, but a signal generated within the specimen due to the transfer of energy from the beam to the specimen. The depth from which SEs escape the specimen is generally between 5 and 50 nm due to their low energy.

10C

$$peakwidth = \frac{k\lambda}{d\cos\theta}$$

$$d = 1.4x10^{-6}m$$