CBCS SCHEME

USN | | | | | | | | | | | **21PHY12**

First Semester B.E./B.Tech. Degree Examination, Feb./Mar. 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. *Physical constants : Speed of light "C" = 3×10^8 m/s^{-1} ;*
Planck's constant "h" = 6.625×10^{-34} JS ; Boltzmann constant "K" = 1.38×10^{-23} J/K^{-1}
Acceleration due to gravity "g" = 9.8 m/s^{-2} ;
Permittivity of Free space "$\in_0$" = 8.854×10^{-12} F/m^{-1}.

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-1

1 a. What is Free and Forced Oscillation? Obtain expression for Amplitude and phase of vibration in case of forced vibration. **(09 Marks)**

b. Describe the construction and working of the Reddy shock tube. **(06 Marks)**

c. Calculate the peak amplitude of vibration of a system whose natural frequency is 1000 Hz when it oscillates in a resistive medium of damping / unit mass of 0.008 rad/s under the action of an external periodic force / unit mass of 5N/m with tunable frequency. **(05 Marks)**

OR

2 a. What is Force Constant? Obtain expression for effective Spring constant and Time period for two springs connected in series. **(08 Marks)**

b. Define Simple Harmonic Motion and give two examples. Obtain the differential equation for Simple Harmonic Motion using Hooke's Law. **(08 Marks)**

c. In a Reddy shock tube experiment, the time taken to travel between the two sensors is 195 μs. If the distance between the two sensors is 100mm. Calculate the mach number. Assume speed of sound as 340 m/s. **(04 Marks)**

Module-2

3 a. Discuss the spectral distribution of energy in the black body radiation spectrum and hence explain Wein's Displacement Law. **(06 Marks)**

b. Using the Schrodinger Time Independent wave equation , obtain expression for Energy Eigen values and the Normalized wave function. **(09 Marks)**

c. The position and momentum of an electron with energy 0.5 Ke V is found with a minimum percentage uncertainty in momentum. Find its uncertainty if the measurement of position has a uncertainty of 0.5A°. **(05 Marks)**

OR

4 a. What is Wave function? Arrive at the Time Independent Schrodinger Wave equation. **(08 Marks)**

b. State and explain Heisenberg's Uncertainty principle and hence use it to show that electrons do not exist inside the nucleus. **(08 Marks)**

c. Evaluate the De – Broglie wavelength of Helium Nucleus accelerated through a potential difference of 500V. **(04 Marks)**

$M_n = M_p = 1.67 \times 10^{-27}$ Kg.

Module-3

5 a. Distinguish between the types of optical fibres based on Refractive Index profile and number of modes of propagation. (06 Marks)

b. Obtain the expression for Energy density using Einstein's A and B coefficients. Draw inference on the condition $B_{12} = B_{21}$. (10 Marks)

c. A pulse from laser with power 1mW lasts for 10nS, if the number of photons emitted per pulse is 3.491×10^7. Calculate the wavelength of laser. (04 Marks)

OR

6 a. Discuss the construction and working of the CO_2 laser. Explain the significance of Helium gas in the CO_2 laser system. (09 Marks)

b. Give the basics of point to point communication using optical fibres. (06 Marks)

c. Calculate the NA , Relative RI , V number and the number of modes in an optical fiber of core diameter 50 μm and the core and cladding R.I are 1.41 and 1.40 respectively. Given Wavelength of source 820nm. (05 Marks)

Module-4

7 a. What is Fermi Factor? Discuss the dependence of Fermi factor on temperature and energy. (08 Marks)

b. Mention the four assumptions of Quantum free Electron theory and hence discuss any two success of Quantum free Electron theory. (08 Marks)

c. The resistivity of intrinsic germanium at 27°C is equal to 0.47 ohm meter. Assuming electron and hole concentration to be 0.38 $m^2\ V^{-1}\ S^{-1}$ and $0.18m^2\ V^{-1}\ S^{-1}$. Calculate the Intrinsic carrier density. (04 Marks)

OR

8 a. What is Hall effect? Obtain expression for the Hall voltage in terms of charge density also state importance of Hall effect. (08 Marks)

b. Define Internal Field. Derive the Clausius – Mossotti equation. (07 Marks)

c. Find the temperature of which there is 1% probability that a state with an energy 0.2eV above Fermi level is occupied. (05 Marks)

Module-5

9 a. Explain the construction and working of X – Ray diffractometer. (07 Marks)

b. Describe in brief the construction and working, with Principle the Transmission Electron Microscope. (08 Marks)

c. Determine the crystal size when the peak width is 0.5° and peak position 30° for a cubic crystal. The wavelength of X rays used is 100A° and the Scherer's constant K = 0.92. (05 Marks)

OR

10 a. With a neat sketch, explain the principle , construction and working of Scanning Electron Microscope. (09 Marks)

b. Describe the construction, principle and working of X – ray Photoelectron Spectroscope. (08 Marks)

c. Mention applications of Atomic Force Microscope. (03 Marks)

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ODD 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

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

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

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

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

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

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

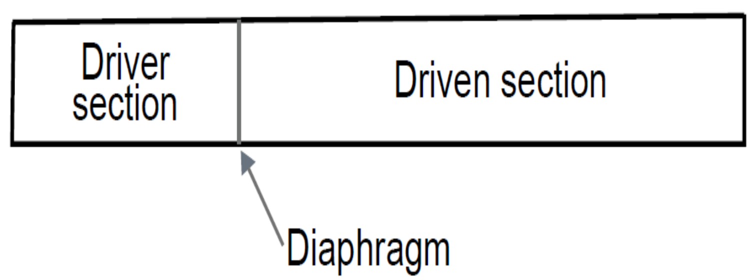
Case 2: Amplitude is less when $\omega_0 \neq \omega_f$

1 B

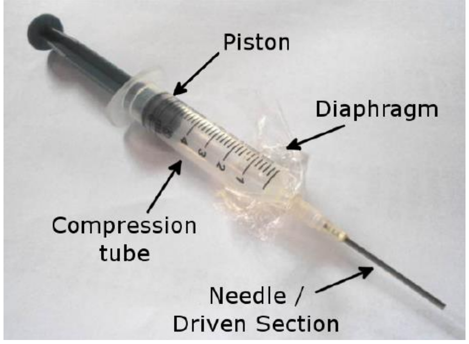
Reddy shock tube:

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.

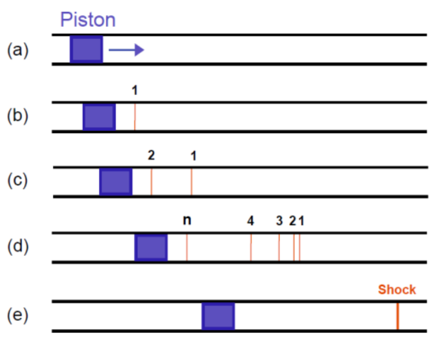


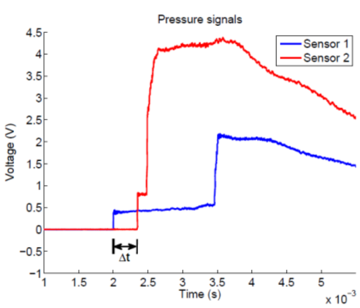
Working:

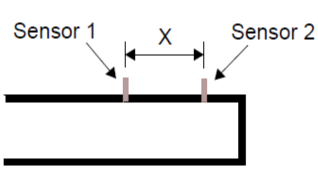
- The piston is initially at rest and accelerated to final velocity V in a short time t.
- The piston compresses the air in the compression tube. At high pressure, the diaphragm ruptures and the shock wave is set up. For a shock wave to form, $V_{piston} > V_{sound}$.

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 $M = \dfrac{V_{Shock}}{V_{Sound}}$

1C

$$A = \frac{\frac{F_o}{m}}{\sqrt{\left(\omega_o^2 - \omega_f^2\right)^2 + \frac{b^2}{m^2}\omega_f^2}}$$

Here b is in kg/s

b/m is damping per unit mass = 0.008 rad/s

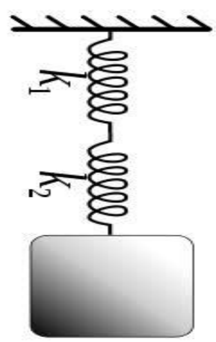
F_o is external periodic force = 1000 Hz

F_o/m is Force per unit mass = 5 rad/s

At resonance $\omega_o = \omega_f$

$$A = \frac{\frac{F_o}{m}}{\sqrt{\left(\omega_o^2 - \omega_f^2\right)^2 + \frac{b^2}{m^2}\omega_f^2}} = 0.03m$$

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

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

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

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

$$Timeperiod = \frac{2\pi}{\omega} = \frac{2\pi}{\sqrt{\frac{k}{m}}} = \frac{2\pi}{\sqrt{\frac{1}{m}\left(\frac{k_1 k_2}{k_1 + k_2}\right)}}$$

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 (described in APPENDIX)

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.

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

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 cosω_ot + B sinω_ot.

This can also be expressed as x(t) = C cos(ω_ot-ɵ) where

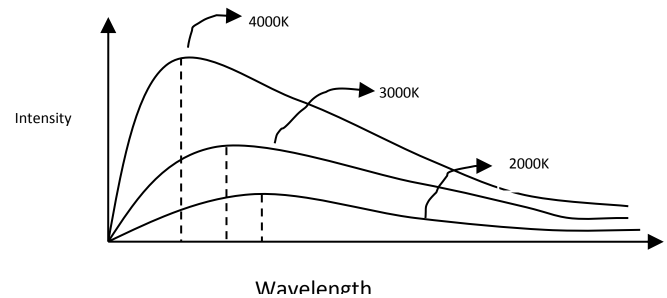
$C = \sqrt{A^2 + B^2}$ tanɵ = B/A

2C

$$V_{shock} = \frac{dx}{dt} = \frac{100x10^{-3}}{195x10^{-6}} = 510m/s$$
$$M = \frac{V_{Shock}}{V_{sound}} = \frac{510}{340} = 1.5$$

3A

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.

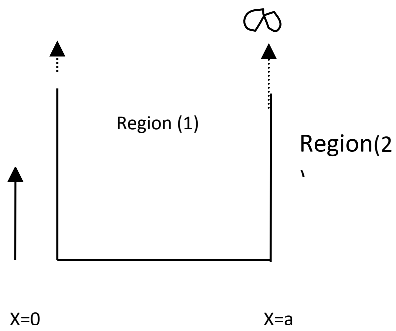
Weins displacement law: The product of the wavelength at which maximum energy is radiated and the temperature is a constant.

$$\lambda_{max}.T = 2.898 \times 10^{-3}\,mk$$

3B

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

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

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

Roots are D = +ik and D = -ik

The general solution is

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

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 = $\dfrac{n^2h^2}{8ma^2}$

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 = $\sqrt{\dfrac{2}{a}}$

$$\therefore \Psi_n=\sqrt{\frac{2}{a}}$$

$$\sin\left(n\frac{\Pi}{a}\right)x$$

For n = 1, First state

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

3C

percentage uncertainty in momentum = $\frac{\Delta p}{p} = \frac{\frac{h}{4\pi.\Delta x}}{\sqrt{2mE}}$

$$= \frac{\frac{6.62x10^{-34}}{4x3.14x0.5x10^{-10}}}{\sqrt{2x9.1x10^{-31}x0.5x1000x1.6x10^{-19}}} = 0.08$$

4A

Eigen function: It is the physically acceptable solution to Schrodinger's equation. It represents the matter wave corresponding to a quantum particle in a specific state.

Ex: For a particle in an infinite potential well, the eigen function is $\Psi_n = \sqrt{\frac{2}{a}}\sin\left(n\frac{\Pi}{a}\right)x$

4B

Time independent Schrödinger equation

A matter wave can be represented in complex form as

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

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

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)

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

4C

$$\lambda = h/\sqrt{2meV}$$

$$m = 2proton + 2neutron = 4x1.67x10^{-27}kg$$

$$V = 500V$$

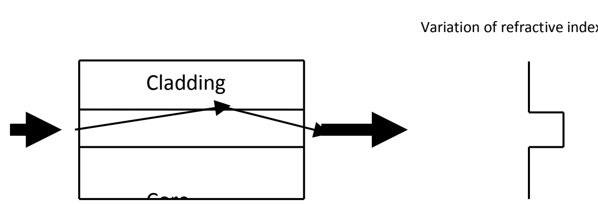
$$\lambda = 6.4x10^{-13}m$$

5A

Types:

1. Single mode fiber:

Core diameter is around 5-10 µm. The core is narrow and hence it can guide just a single mode.

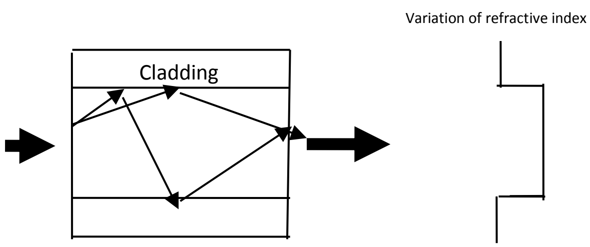


- No modal dispersion
- Difference between n_1& n_2 is less.Critical angle is high. Low numerical aperture.

- Low Attenuation -0.35db/km
- Bandwidth -100GHz
- Preferred for short range

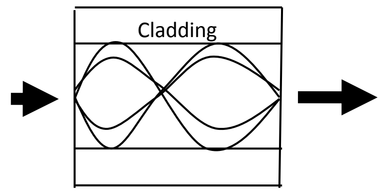
Step index multimode fibre :

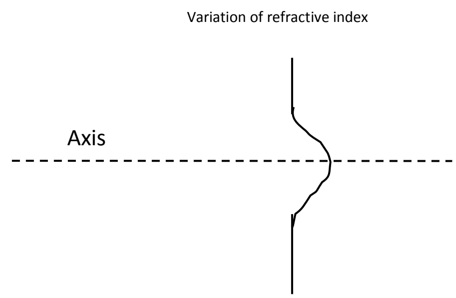
- Here the diameter of core is larger so that large number of rays can propagate. Core diameter is around 50. µm.
- High modal dispersion
- Difference between n_1& n_2 is high. Low Critical angle. Large numerical aperture.
- Losses high
- Bandwidth -500MHz
- Allows several modes to propagate
- Preferred for Long range



Graded index multimode fiber:

In this type, the refractive index decreases in the radially outward direction from the axis and becomes equal to that of the cladding at the interface. Modes travelling close to the axis move slower where as the modes close to the cladding move faster.As a result the delay between the modes is reduced. This reduces modal dispersion.





- Low modal dispersion
- High data carrying capacity.
- High cost
- Many modes propagate
- Bandwidth -10GHz

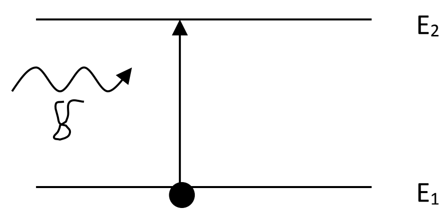
5B

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 = $B_{12}\ N_1\ U_\gamma$

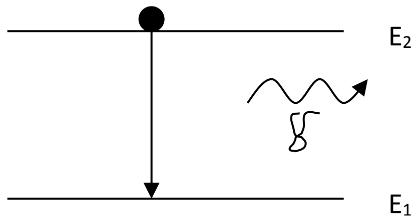
Here B_{12} is a constant known as Einsteins coefficient of spontaneous absorption.

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 = $A_{21}\ N_2$

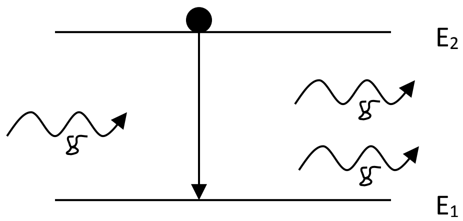
Here B_{12} is a constant known as Einsteins coefficient of spontaneous emission.



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

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.

5C

$$\lambda = \frac{nhc}{Pt} = \frac{3.491x10^{7}\, x6.62x10^{-34}\, x3x10^{8}}{1x10^{-3}\, x10x10^{-9}}$$

$$= 6933x10^{-10}\, m$$

6A

Carbon dioxide laser

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

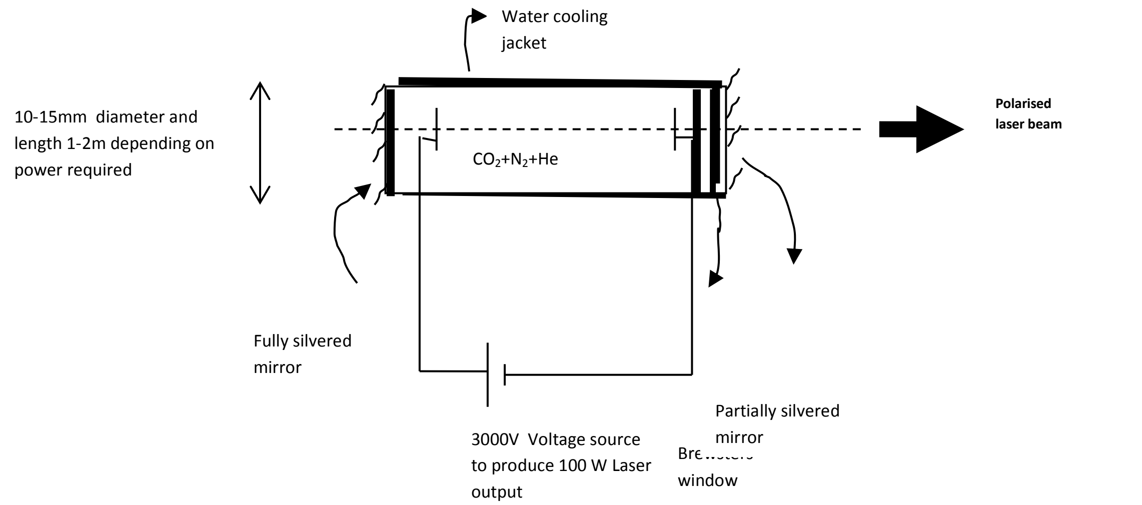
Construction

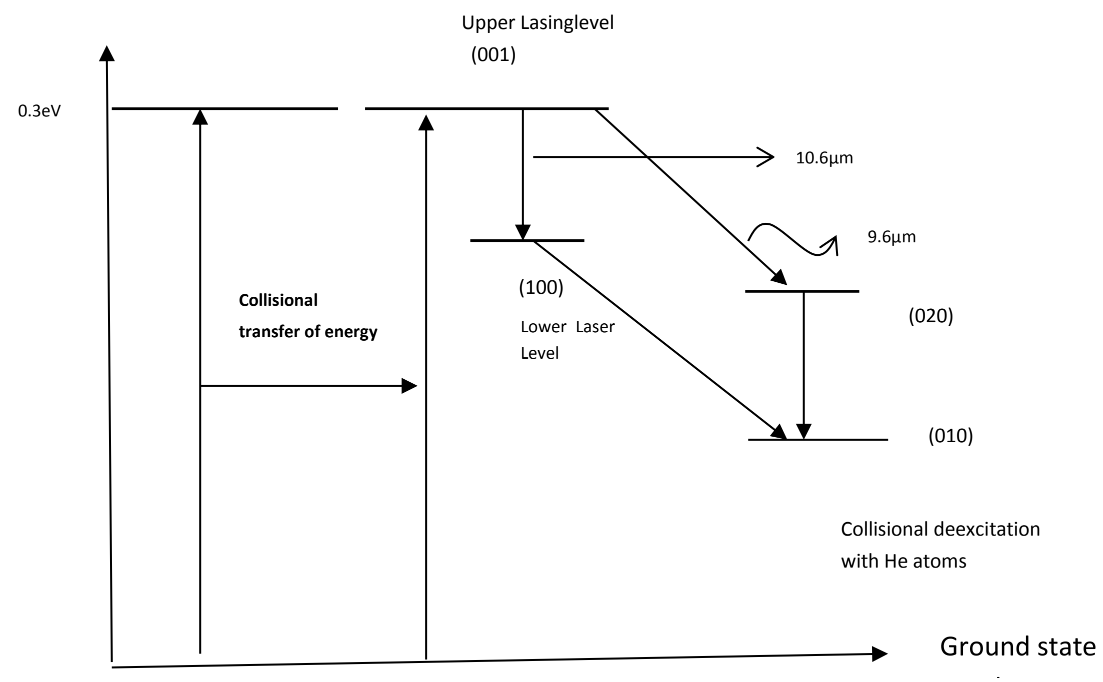
1.Active medium – Mixture of CO_2, N_2 and He in the ratio 1:2:8. Nitrogen absorbs energy from the pumping source efficiently.Helium gas conducts away the heat and also catalyses collisional deexcitation of CO_2 molecules.

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.

SIGNIFICANCE OF HELIUM GAS:

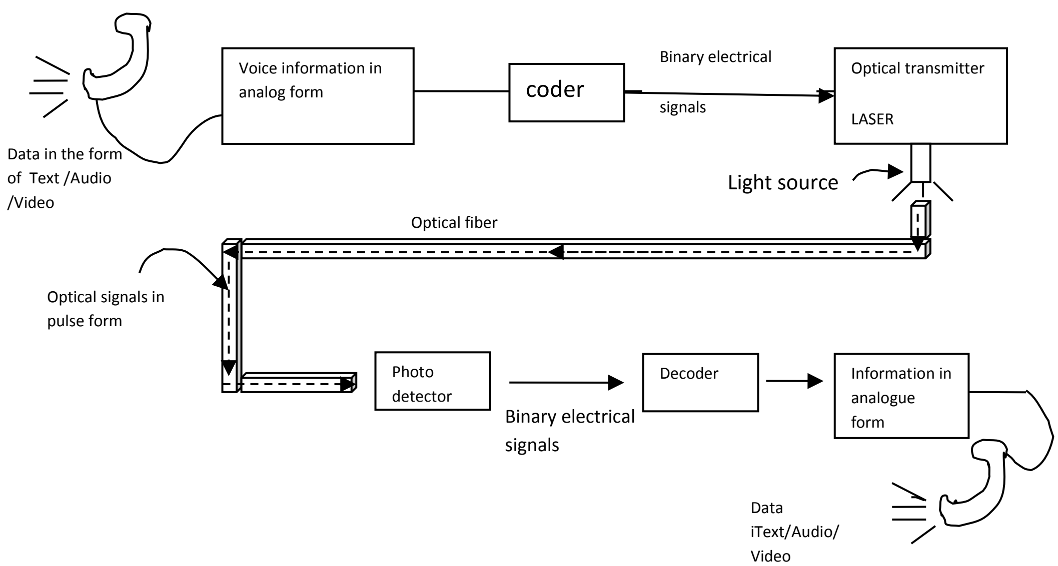
Helium gas conducts away the heat and also catalyses collisional deexcitation of CO_2 molecules.

6B

<u>Point to point communication system using optical fibers</u>

This system is represented through a block diagram as follows.

The information in the form of voice/ picture/text is converted to electrical signals through the transducers such as microphone/video camera. The analog signal is converted in to binary data with the help of coder. The binary data in the form of electrical pulses are converted in to pulses of optical power using Semiconductor Laser. This optical power is fed to the optical fiber. Only those modes within the angle of acceptance cone will be sustained for propagation by means of total internal reflection. At the receiving end of the fiber, the optical signal is fed in to a photo detector where the signal is converted to pulses of current by a photo diode. Decoder converts the sequence of binary data stream in to an analog signal . Loudspeaker/CRT screen provide information such as voice/ picture.



6C

$$V_{number} = \frac{2\pi R(NA)}{\lambda} = 27$$

$$NA = \sqrt{n_1^2 - n_2^2} = \sqrt{1.41^2 - 1.4^2}$$

$$No.of.modes = \frac{V^2}{2} = 365$$

7A

Fermi probability factor: It represents the probability of occupation of an energy level.

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

To show that energy levels below Fermi energy are completely occupied:

For E **<** E_F, at T = 0,

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

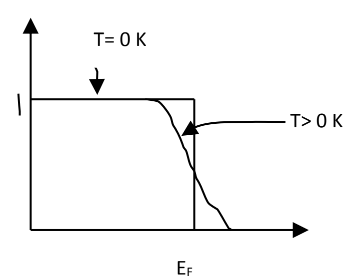
To show that energy levels above Fermi energy are empty:

For E > E_F , at T=0

f (E) = $\frac{1}{e^{(\frac{E-E_F}{kT})} + 1}$ = 0

At ordinary temperatures, for E = E_F,

f(E) = $\frac{1}{2}$



7B

Quantum free electron theory:

Assumptions:

1. The energy of conduction electrons in a metal is quantized.
2. The distribution of electrons amongst various energy levels is according to Pauli's exclusion principle and Fermi – Dirac statistical theory.
3. The average kinetic energy of an electron is equal to $\frac{3}{5}E_F$
4. The interaction between the electrons and ions, the repulsion between electrons are ignored.The electrons travel in a constant potential inside the metal but stay confined within its boundaries.

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.

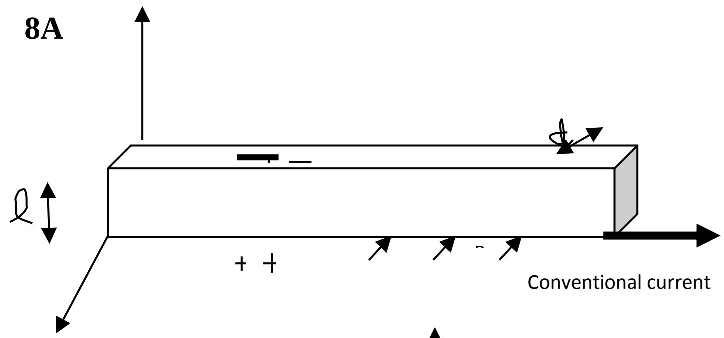
Metal	n	σ
Cu	$8.45x10^{28}/m^3$	$6x10^7(\Omega m)^{-1}$
Zn	$13x10^{28}/m^3$	$1x10^7(\Omega m)^{-1}$

7C

$$\rho = \frac{1}{\sigma} = \frac{1}{ne(\mu_e + \mu_h)}$$

$$n = 1.56x10^{19}/m^3$$

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

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

Applications:1. To identify P and N type semiconductor

For P type semiconductor, the bottom surface will be at positive potential.

: For n type semiconductor, the bottom surface will be at positive potential

2. To find electron density

8B **INTERNAL FIELDS IN A DIELECTRIC:**

It is the resultant of the applied field and the field produced due to all the dipoles.

CLAUSIUS – MOSOTTI RELATION:

This expression relates dielectric constant of an insulator (ε) to the polarization of individual atoms(α) comprising it.

$$\frac{\varepsilon_r - 1}{\varepsilon_r + 2} = \frac{N\alpha}{3\varepsilon_0}$$

where N is the number of atoms per unit volume

α is the polrisability of the atom

ε_r is the relative permittivity of the medium

ε_o is the permittivity of free space.

Proof:

If there are N atoms per unit volume,the electric dipole moment per unit volume –known as polarization is given by

$$P = N\alpha E_i$$

By the definition of polarization P, it can be shown that

P =

$$\varepsilon_0 E_a(\varepsilon_r - 1) = N\alpha E_i$$

$$\varepsilon_0\varepsilon_r E_a - \varepsilon_0 E_a = N\alpha E_i$$

$$\varepsilon_r = 1 + \frac{N\alpha E_i}{\varepsilon_0 E_a}$$

…………………..(1)

The internal field at an atom in a cubic structure(γ =1/3) is of the form

$$E_i = E_a + \frac{p}{3\varepsilon_0} = E_a + \frac{N\alpha E_i}{3\varepsilon_0}$$

$$\frac{E_i}{E_a} = \frac{1}{\left[1 - \left(\frac{N\alpha}{3\varepsilon_0}\right)\right]}$$

Substituting for $\frac{E_i}{E_a}$ in equation (1)

$$\varepsilon_r = 1 + \frac{N\alpha}{\varepsilon_0}\left[\frac{1}{\left(1 - \frac{N\alpha}{3\varepsilon_0}\right)}\right] = \frac{\varepsilon_0\left[1 - \frac{N\alpha}{3\varepsilon_0}\right] + \frac{N\alpha\varepsilon_0}{\varepsilon_0}}{\varepsilon_0\left[1 - \frac{N\alpha}{3\varepsilon_0}\right]} = \frac{1 + \frac{2}{3}\left(\frac{N\alpha}{\varepsilon_0}\right)}{1 - \frac{1}{3}\left[\frac{N\alpha}{\varepsilon_0}\right]}$$

$$\left[\frac{\varepsilon_r - 1}{\varepsilon_r + 2}\right] = \frac{\dfrac{1 + (2/3)\frac{N\varepsilon}{\varepsilon_0}}{1 - (1/3)\frac{N\alpha}{\varepsilon_0}} - 1}{\dfrac{1 - (2/3)\frac{N\alpha}{\varepsilon_0}}{1 - (1/3)\frac{N\alpha}{\varepsilon_0}} + 2} = \frac{N\alpha}{3\varepsilon_0}$$

8C

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

$$E - E_F = +0.2eV = 0.2x1.6x10^{-19}\,J$$

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

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

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

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

T =503 K

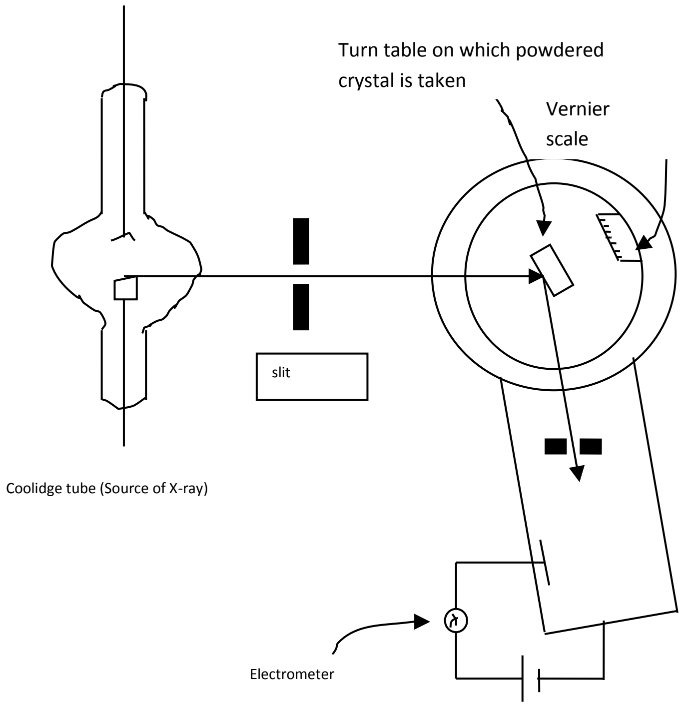
9A

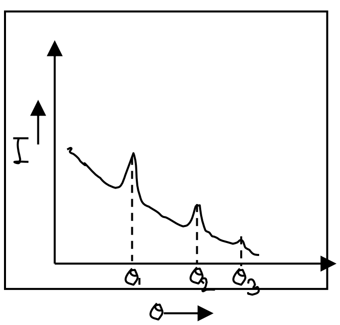
X-ray diffraction spectrometer:

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.



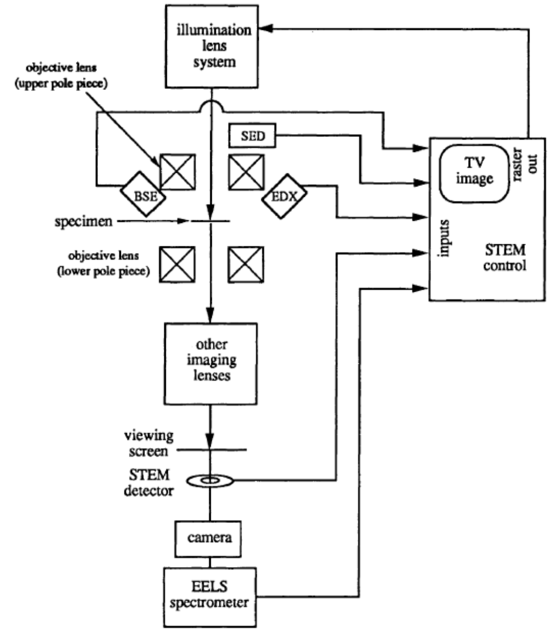


9B

TRANSMISSION ELECTRON MICROSCOPE

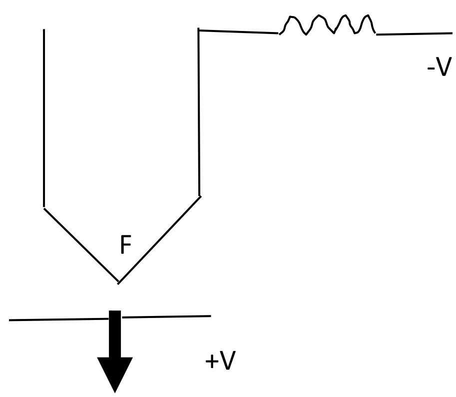
Transmission electron microscopy (TEM) is the premier tool for understanding the internal microstructure of materials at the nanometer level. Although x-ray diffraction techniques generally provide better quantitative information than electron diffraction techniques, electrons have an important advantage over x rays in that they can be focused using electromagnetic lenses. In scanning transmission electron microscopy (STEM), a focused beam of electrons (typically <1 nm in diameter) is the probe to interact with the sample. Electrons that pass through the specimen can be detected to form images. Transmission electron microscope has the capability to record the variations in image intensity across the specimen.

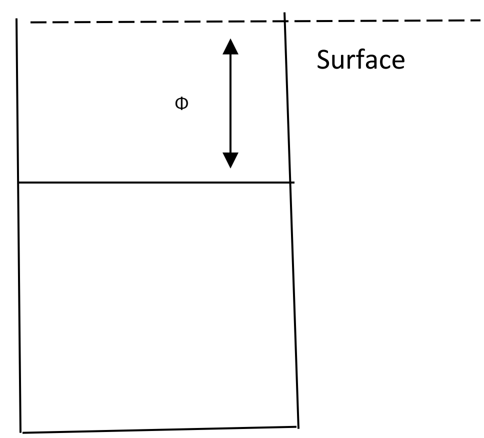
A block diagram of such a transmission electron microscope is shown in Figure.



Illumination system: Electron gun together with condenser lenses that focus the electrons onto the specimen.

Electron gun: Produces beam of electrons by thermionic emission whose kinetic energy is high enough to allow them to pass through the thin area of the specimen. It consists of electron source cathode at negative potential and an electron acceleration region.





A dc current heats the filament to 2700K at which Tungsten emits electrons into the surrounding medium. Electrons close to Fermi level are likely to be if a minimum energy Φ (work function) is supplied.

Current density $J = AT^2 e^{-\frac{\phi}{KT}}$

A – Richardson constant

T - Absolute temperature of Cathode

Vaccum system : 0.1 Pa

Condenser lens: Electromagnetic lens focusses the electron beam on to the sample.

Specimen stage: The interaction between the electron beam and the nucleus in specimen gives rise to elastic scattering where no energy is transferred. They are back scattered (BS). Interaction between incident electrons and electrons in specimen results in inelastic scattering. They loose energy to release secondary electrons (SE) from specimen.

Image Display: The secondary electrons released are collected by the detector. They provide information about surface structure. Scintillating screen produces visible light when bombarded with electrons. This light reaches photodiodes which produce electrical signal and image is generated by CRT.

9C

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

$$D = \frac{k\lambda}{peakwidthx\cos\theta} = \frac{0.92x100x10^{-10}}{\frac{0.5x\pi}{180}.\cos 30} = 7.5x10^{-3}m$$

10A

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.

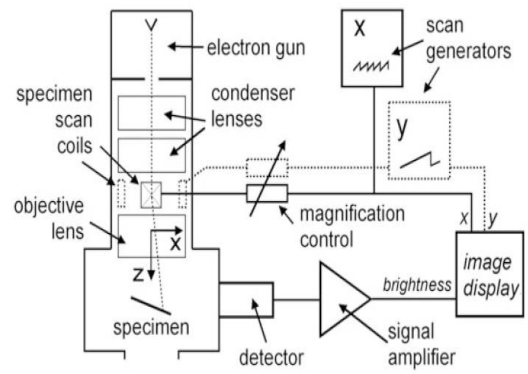
Resolution of 1 nm is now achievable from an SEM with a field emission (FE) electron gun. Magnification is a function of the scanning system rather than the lenses, and therefore a surface in focus can be imaged at a wide range of magnifications from 3 up to 150,000.

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.

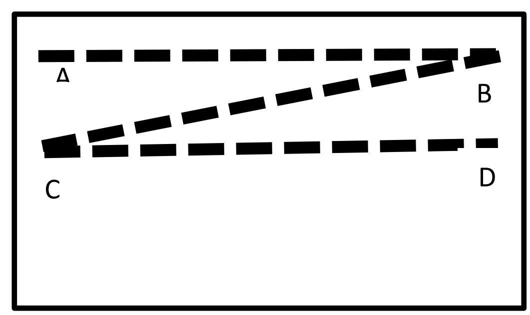
Illumination: Electron source is Tungsten filament. Operating voltage is 30KV.

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.

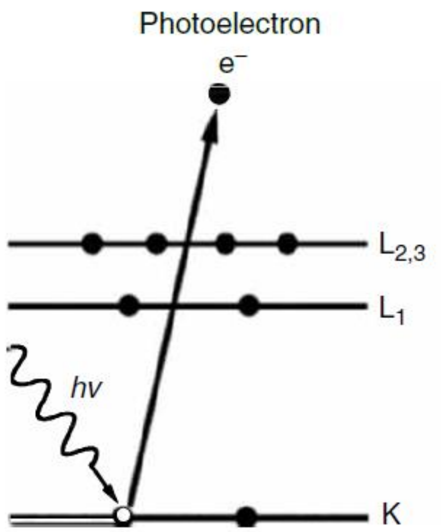
Interaction with Specimen: A small fraction of Primary electrons are elastically back scattered (BS) by atomic nuclei . Inelastic scattering with atomic electrons reduces kinetic energy and are absorbed by the specimen releasing secondary electrons (SE). Since electrons normally undergo multiple interactions, 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.

10B

X RAY PHOTOELECTRON MICROSCOPY

X-ray photoelectron spectroscopy is widely applied to all types of solids, including metals, ceramics, semiconductors, and polymers, in many forms, including foils, fibers, and powders. It has also been used to obtain spectra of gas phase compounds. When applied to solids, XPS is a surface sensitive technique. The nominal analysis depth is on the order of 1 to 10 nm (10 to 100 monolayers). Surface sensitivity can be increased by collecting the emitted photoelectrons at to glancing angles to the surface. The primary limitation of XPS is the need for ultrahigh vacuum conditions during analysis. This generally limits the type of material to those with a low vapor pressure (<108 mbar) at room temperature and limits the sample size to that which will fit through the introduction ports on the vacuum chamber.

X-ray photoelectron spectroscopy (XPS) uses x rays of a characteristic energy (wavelength) to excite electrons from orbitals in atoms. The photoelectrons emitted from the material are collected as a function of their kinetic energy, and the number of photoelectrons collected in a defined time interval is plotted versus kinetic energy to obtain XPS spectrum.Peaks appear in the spectrum at discrete energies due to emission of electrons from states of specific binding energies (orbitals) in the material. An incident X-ray photon can have sufficient energy to knock out an inner-shell electron, for example, from the atom's K shell. In such a case, the K-shell electron would be ejected from the surface as a photoelectron with kinetic energy E_K. Knowing the kinetic energy E_K, we can calculate the binding energy of the atom's photoelectron (EB) based on the following relationship
$EB = h\nu - E_K - \Phi$
ϕ is the parameter representing the energy required for an electron to escape from a material's surface, h is Planck's constant and ν is the frequency. The binding energies of atomic electrons have characteristic values required to identify elements,
The positions and shapes of the peaks in an XPS spectrum can also be analyzed in greater detail to determine the chemical state of the constituent elements in the material, including oxidation state, partial charge, and hybridization.



10C

Applications of Atomic force microscopy (AFM)

It is a powerful technique that enables the imaging of almost any type of surface, including polymers, ceramics, composites, glass and biological samples. AFM is used to measure and localize many different forces, including adhesion strength, magnetic forces and mechanical properties. The AFM has been applied to problems in a wide range of disciplines of the natural sciences, including solid-state physics, semiconductor science and technology, molecular engineering, polymer chemistry and physics, surface chemistry, molecular biology, cell biology, and medicine.

Applications in the field of solid state physics include (a) the identification of atoms at a surface, (b) the evaluation of interactions between a specific atom and its neighbouring atoms, and (c) the study of changes in physical properties arising from changes in an atomic arrangement through atomic manipulation.

In molecular biology, AFM can be used to study the structure and mechanical properties of protein complexes and assemblies. For example, AFM has been used to image microtubules and measure their stiffness.

In cellular biology, AFM can be used to attempt to distinguish cancer cells and normal cells based on a hardness of cells, and to evaluate interactions between a specific cell and its neighbouring cells in a competitive culture system. AFM can also be used to indent cells, to study how they regulate the stiffness or shape of the cell membrane or wall.