

## PHYSICS IAT-2 SCHEME for CSE

# 1 A

### Failures of Classical free electron theory:

#### 1. Prediction of low specific heats for metals: (2 marks)

Classical free electron theory assumes that conduction electrons are classical particles similar to gas molecules. Hence, they are free to absorb energy in a continuous manner. Hence metals possessing more electrons must have higher heat content. This resulted in high specific heat given by the

expression  $C_V = 10^{-4} R$ .

This was contradicted by experimental results which showed low specific heat for metals.

#### 2. Temperature dependence of electrical conductivity: (2 marks)

From the assumption of kinetic theory of gases

$$\frac{3}{2}kT = \frac{1}{2}mv^2$$
$$\therefore v \propto \sqrt{T}$$

Also mean collision time  $\tau$  is inversely proportional to velocity,

$$\tau \propto \frac{1}{v}$$
$$\tau \propto \frac{1}{\sqrt{T}}$$
$$\therefore \sigma = \frac{ne^2\tau}{m} \Rightarrow \sigma \propto \frac{1}{\sqrt{T}}$$

However experimental studies show that  $\sigma \propto \frac{1}{T}$

#### 3. Dependence of electrical conductivity on electron concentration: (2 marks)

As per free electron theory,  $\sigma \propto n$

The electrical conductivity of Zinc and Cadmium are  $1.09 \times 10^7$  /ohm m and  $.15 \times 10^7$  /ohm m respectively which are very much less than that for Copper and Silver for which the values are  $5.88 \times 10^7$  /ohm m and  $6.2 \times 10^7$  /ohm m. On the contrary, the electron concentration for zinc and cadmium are  $13.1 \times 10^{28} /m^3$  and  $9.28 \times 10^{28} /m^3$  which are much higher than that for Copper and Silver which are  $8.45 \times 10^{28} /m^3$  and  $5.85 \times 10^{28} /m^3$ .

These examples indicate that  $\sigma \propto n$  does not hold good.

#### 4. Mean free path, mean collision time found from classical theory are incorrect.

# 1B. 4 properties (4X1) mark

## High temperature superconductivity:

These are generally alloy materials with critical temperature greater than 90K. They possess perovskite structure.

Ex:  $\text{Y Ba}_2 \text{Cu}_3 \text{O}_7$

However, the BCS theory can not explain the behaviour of high-temperature superconductors, discovered in 1986, which have transition temperatures as high as 138 K. These “cuprates” consist of parallel planes of copper oxide in which the copper atoms lie on a square lattice and where the charge is carried by “holes” sitting on oxygen sites. Each copper atom has an unpaired electron, and hence a magnetic moment or “spin”, and some researchers believe that it is the coupling between these spins that gives rise to superconductivity in these materials.

# 2A

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

$$f(E) = \frac{1}{e^{\left(\frac{E-E_F}{kT}\right)} + 1} \quad (2 \text{ marks})$$

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

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

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

**To show that energy levels above Fermi energy are empty:(3 marks)**

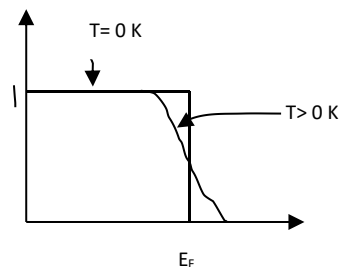
For  $E > E_F$ , at  $T=0$

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

**At ordinary temperatures, for  $E = E_F$ ,**

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

(Graph 1 mark)



# 2B

Formula 1 mark, Substitution 1 mark, Answers- 2marks

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

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

$$f(E) = 0.01$$

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

$$E = E_F + kT \cdot \ln \left[ \frac{1}{f(E)} - 1 \right]$$

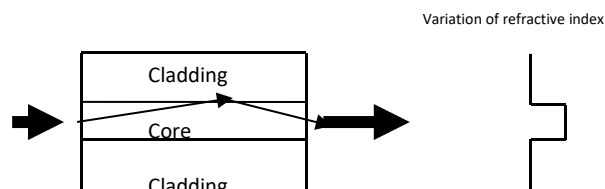
$$E = 9 \times 10^{-19} \text{ J} = 5.6 \text{ eV}$$

# 3A

## Types:

### 1. Single mode fiber: (2 marks)

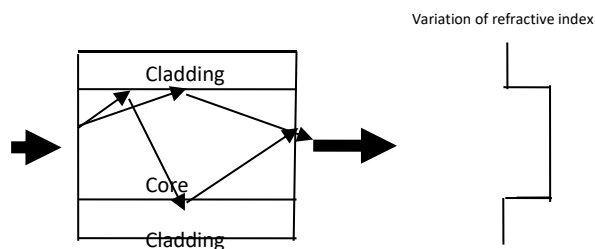
Core diameter is around 5-10  $\mu\text{m}$ . The core is narrow and hence it can guide just a single mode.



- 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

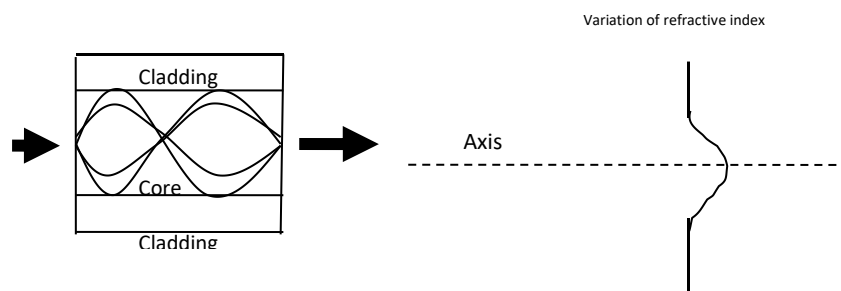
### Step index multimode fibre :(2 marks)

- Here the diameter of core is larger so that large number of rays can propagate. Core diameter is around 50.  $\mu\text{m}$ .
- 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:(2 marks)**

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 whereas 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

## 3B Formula 1 mark, Substitution 1 mark, Answers- 2marks

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

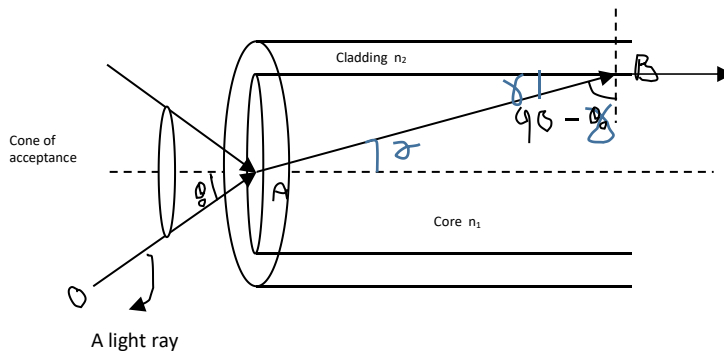
$$n_1 = 1.56$$

$$\Delta = \frac{n_1 - n_2}{n_1}$$

$$\Delta = 0.019$$

$$\theta_A = \sin^{-1}(0.3) = 17.45^\circ$$

## 4A



### Expression for condition for propagation : (2 marks)

Consider a light ray falling in to the optical fibre at an angle of incidence  $\theta_0$  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  $n_0 \sin \theta_0 = n_1 \sin r = n_1 \left( \sqrt{1 - \cos^2 r} \right) \dots \dots \dots (1)$

$$n_1 \sin(90 - r) = n_2 \sin 90$$

For the ray AB  $n_1 \cos r = n_2$

$$\cos r = \frac{n_2}{n_1}$$

[ here the angle of incidence is  $(90 - \theta_1)$  for which angle of refraction is  $90^\circ$ ].

Substituting for  $\cos r$  in equation (1)

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

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

If the medium surrounding the fiber is air then  $n_0 = 1$ , (3 marks)

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

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. (1 mark)

## 4B

### Different loss mechanisms:

#### 1. Absorption losses: (2 marks)

In this case, the loss of signal power occurs due to absorption of photons by the impurities and defects present in glass. Impurities such as Ge-O, B-O, absorb in the range of 1-2  $\mu\text{m}$ , chromium and copper ions absorb at 0.6  $\mu\text{m}$ , Fe ions absorb at 1.1  $\mu\text{m}$ . Hydroxy ions absorb at 1.38  $\mu\text{m}$ . Better techniques of making glass with reduced water content can minimize these losses. To minimize the absorption loss, impurity content has to be less than 1 part in  $10^9$ .

#### 2. Scattering losses: (2 marks)

This occurs due to the Rayleigh scattering of the signal caused by variations in refractive index of the glass due to changes in composition, defects, presence

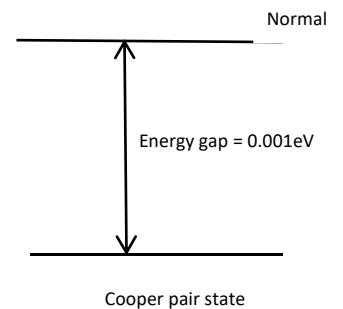
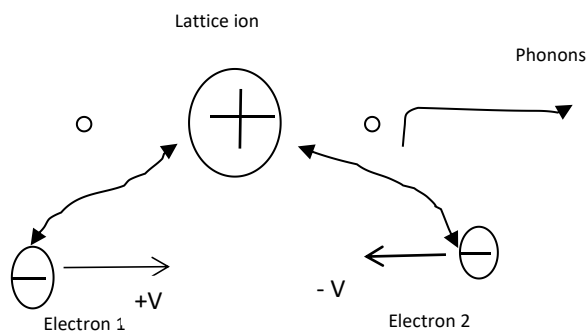
of air bubbles, strains etc. The scattered light moves in random direction and escapes from the fiber reducing the intensity. These losses decrease at higher wavelengths. Hence, this loss is minimized by operating at high wavelengths.

$$\text{Scattered Intensity} \propto \frac{1}{\lambda^4}$$

## 5A

### BCS Theory : [Bardeen, Cooper, Schrieffer]

1. When the temperature of the material is reduced below critical temperature, electrons attain lower energy state than the normal energy creating an energy gap of few milli electron volt.
2. Positively charged lattice ion attracts a pair of electrons with equal and opposite spin and momentum through a feeble attractive interaction known as electron-lattice-electron interaction constituting cooper pairs. (2 marks)
3. Cooper pairs interact through exchanging Phonons.
4. All the cooper pairs are in same energy state and possess common wavefunction and Energy.
5. When a potential difference applied, the current is constituted by flow of cooper pairs and are not scattered as the energy required to break it up is large enough. This reduces the resistance. (2 marks)



6. When the temperature / magnetic field is increased beyond critical limit, cooper pairs breakup and normal state is restored. (2 marks)

## 5B Formula 1 mark, Substitution 1 mark, Answers- 2marks

$$H_c = H_o \left( 1 - \left( \frac{T}{T_c} \right)^2 \right)$$

$$2.7 \times 10^4 = H_o \left( 1 - \frac{9^2}{T_c^2} \right) \dots\dots(1)$$

$$5.3 \times 10^4 = H_o \left( 1 - \frac{6^2}{T_c^2} \right) \dots\dots(2)$$

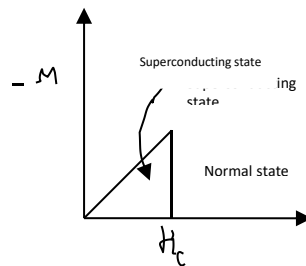
From (1) and (2)

$$T_c = 11.3 \text{ K}$$

$$H_o = 7.3 \times 10^4 \text{ A/m}$$

# 6A

## Type 1 Superconductors: (3 marks)



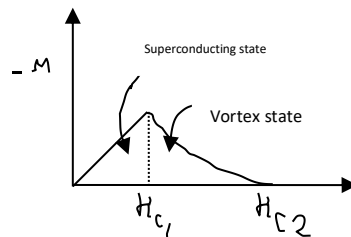
These are pure superconductors.

When kept in magnetic field, initially they continue to exhibit superconductivity and the negative magnetic moment increases. At critical magnetic field there is a sharp transition to normal state due to the penetration of magnetic flux lines. The transition is sharp.

These possess low critical magnetic fields. Their critical temperatures also low. They are generally pure metals.

Ex: Al, Pb

## Type 2 superconductor: (3 marks)



These are generally alloys.

When kept in magnetic field, initially they continue to exhibit superconductivity and the negative magnetic moment increases. At lower critical magnetic field  $H_{c1}$ , the flux lines start penetrating. As the magnetic field is increased, the super conductivity coexists with magnetic field and this phase is known as mixed state (vortex state). At higher critical magnetic field  $H_{c2}$ , the penetration is complete and the material transforms to normal state. They possess higher critical magnetic fields. Their critical temperatures are high.

Ex:  $Nb_3Ge$ ,  $YBa_2Cu_3O_7$



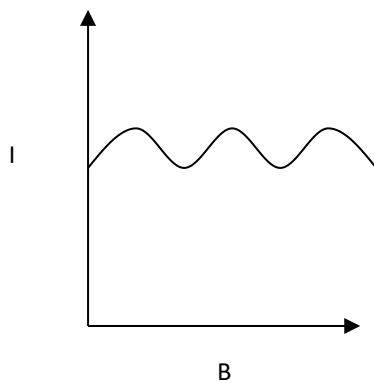
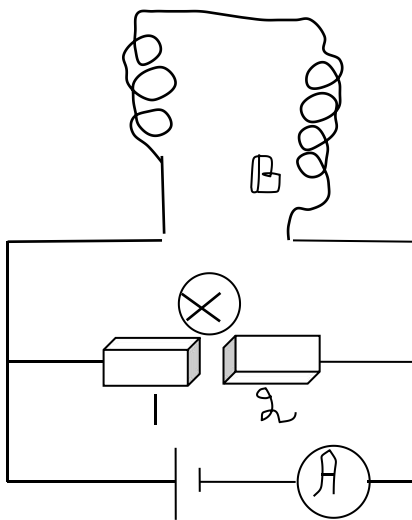
TYPE I	TYPE II
Pb $40 \times 10^3 \text{A/m}$	Pb – Bi $100 \times 10^3 \text{A/m}$

## 6B

### SQUIDS :( Superconducting quantum interference devices)

SQUID is a bi junction quantum interferometer formed from two Josephson's junctions. SQUID is a bi junction quantum interferometer formed from two Josephson's junctions. Principle of working is FLUX quantization. (1mark)

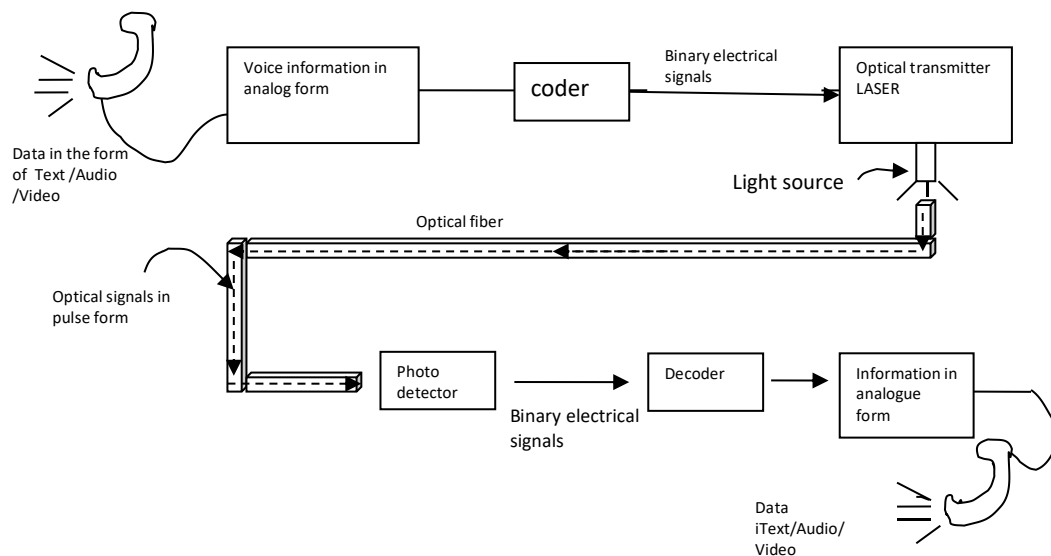
**RADIO FREQUENCY (RF) SQUID** : It uses a Josephson junction connected to a DC voltage source. A transverse magnetic field is applied across the junction. A inductive circuit amplifies the radio frequency signal produced in the junction. Alternating current is induced whose magnitude periodically varies with Magnetic flux due to flux quantization. This is used as precise magnetometer, standard voltage measurement. (3 marks)



7A Block diagram: 1 mark

## Point to point communication system using optical fibers

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. (3 marks)

### **Merits and Demerits of optical fiber communication**

#### **Merits – (2 marks)**

- Large bandwidth (1000GHz)
- Data security
- No Electrical Interference (No cross talk)
- Low loss (0.01dB/km)
- Portable
- Cheaper

#### **Demerits**

- Repair costs high

Light emitting sources are limited to low power  
The distance between the transmitter and receiver should keep short or repeaters are needed to boost the signal.

**7B** Formula 1 mark, Substitution 1 mark, Answers- 2marks

$$\alpha = \frac{10}{L} \log \left( \frac{P_{IN}}{P_{OUT}} \right)$$

$$\log \frac{P_{IN}}{P_{OUT}} = \frac{\alpha L}{10}$$

$$\frac{P_{in}}{P_{out}} = 10^{\frac{\alpha L}{10}} = 1.05$$

$$P_{out} = \frac{P_{in}}{1.05} = 0.95 P_{in}$$