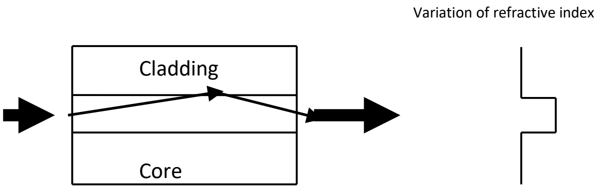
**Solutions to Applied Physics IAT-2**

1A

**Types:**

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

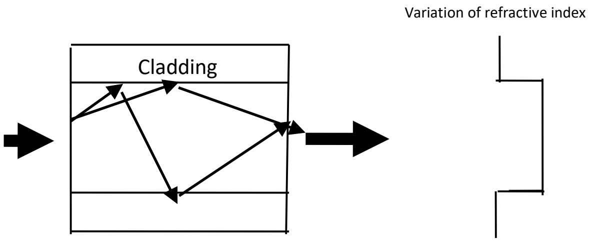
Core diameter is around 5-10 µm. The core is narrow and hence it can guide just a single mode.




- 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

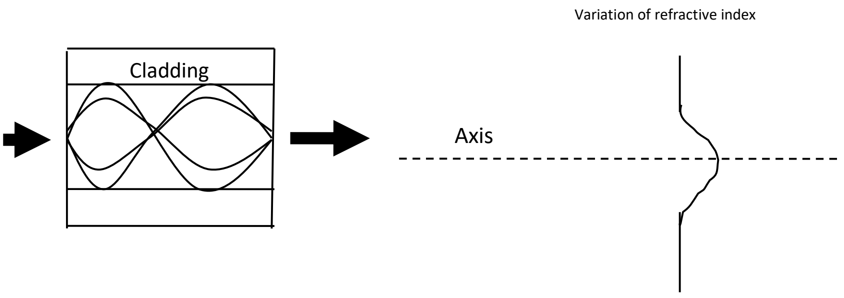
**Step index multimode fibre : (**2marks)

- 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:** (3marks)

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

1B ( Formula- 1mark, Substitution- 1 mark, Answer- 1 mark)

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

$$\frac{P_{IN}}{P_{OUT}} = 10^{\frac{\alpha L}{10}} = 2.75$$

$$P_{OUT} = 0.36 P_{IN}$$

2A

**Expression for condition for propagation :**

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 $n_0 \sin\theta_0 = n_1 \sin r = n_1\left(\sqrt{1-\cos^2 r}\right)$............ (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 - $\theta_1$) for which angle of refraction is $90^0$].

Substituting for cosr in equation (1) ( 3 marks)

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

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

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

Numerical aperture = $\sin\theta_0 = \sqrt{n_1^2 - n_2^2}$ ( 3 marks)

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

$$\therefore \sin\theta_i < \sin\theta_0$$ ( 1 mark)

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

This is the condition for propagation.

**2B** ( Formula- 1mark, Substitution- 1 mark, Answer- 1 mark)

Numerical Aperture =

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

$$n_2 = 1.54$$

Critical angle

$$SinC = \frac{n_2}{n_1}$$

$$C = 76.9^o$$

3A

**Failures of Classical free electron theory:** ( 4 marks)

1. Prediction of low specific heats for metals:

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:

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 τ 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:

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

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

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

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

**Assumptions of Quantum free electron theory** ( 3 marks)

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 attraction between the electrons and ions, the repulsion between electrons are ignored.

3B ( Formula- 1mark, Substitution- 1 mark, Answer- 1 mark)

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

$$e^{\frac{E-E_F}{kT}} = \frac{1}{f(E)} - 1 = 99$$

$$E - E_F = (\ln 99)kT$$

$$T = 504K$$

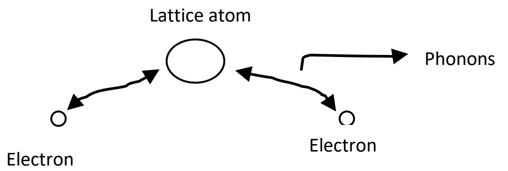
4A

It is a phenomenon in which some materials loose their resistance completely below certain temperature. ( 1 mark)

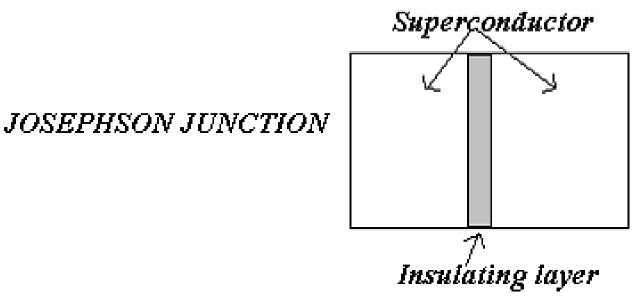
**BCS Theory :[Bardeen , Cooper, Schrieffer]** ( 6 marks)

According to this theory superconductivity occurs when an attractive interaction known as electron-lattice-electron interaction is established resulting in the formation of cooper pairs.

In a lattice, an electron passing close to a lattice atom is attracted towards it and displaces it. This lattice atom will interact with another electron and in turn forms an **electron – lattice –interaction.** This system of two electrons of equal and opposite momentum attached to a lattice atom is known as a **cooper pair**. Cooper pair electrons possess lesser energy than unpaired electrons. A common wave function represents all the cooper pairs. Collective motion of cooper pairs constitutes current .The electrons are bound to the lattice atom through the exchange of phonons (Lattice vibrations).When electrons flow in the form of cooper pairs they do not get scattered as the energy required to break it up is large enough. This reduces the resistance.

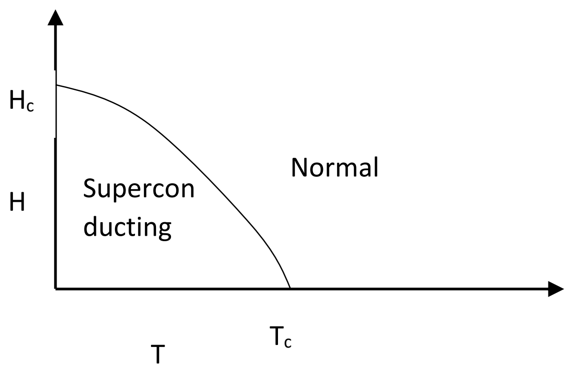



4B **Josephson Junction**: When 2 superconductors are separated by a thin insulating film of thickness 10A°, it forms a junction called **Josephson junction** which facilitates tunneling of cooper pairs. ( 1 mark)

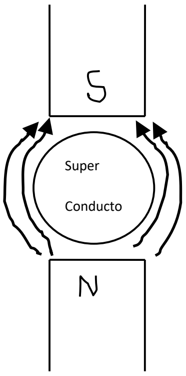



**Critical magnetic field:** It is the maximum magnetic field a superconductor can withstand beyond which it attains normal state. ( 1 mark)

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



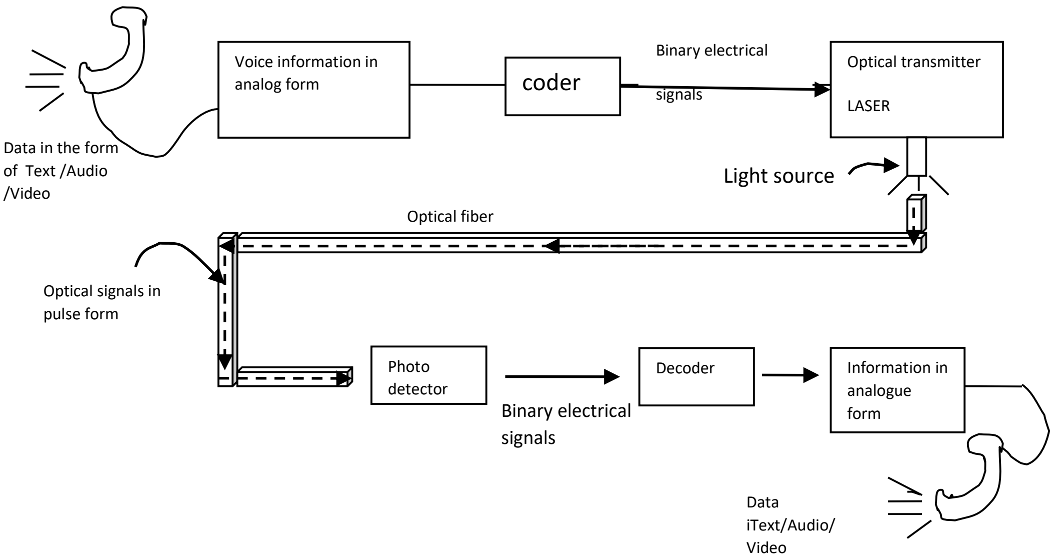
When a superconductor is placed in a magnetic field, it expels the magnetic flux out of its body and behaves like a diamagnet.This effect is known as **Meisseners effect.** ( 1 mark)




5A

## Point to point communication system using optical fibers

This system is represented through a block diagram as follows. ( 2 marks)




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)

**Advantages of optical networks** ( 2 marks)

High speed capability (theoretically possible to send 50 Terabits per second using a single fiber)

- Low losses
- Data Security
- No Electromagnetic interference
- Low cost

5B ( Formula- 1mark, Substitution- 1 mark, Answer- 1 mark)

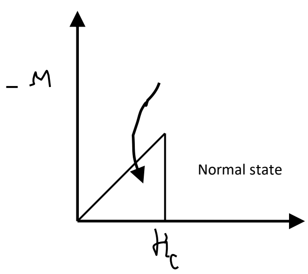
$$H_c = H_o\left(1-\left(\frac{T}{T_c}\right)^2\right)$$

$$T_C = 11.31K$$

6A

**Types of superconductors**

**Type 1 Superconductors:** ( 3 marks)



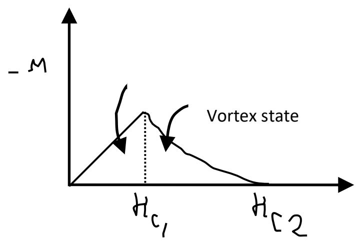
These are pure superconductors.

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: $Nb_3Ge$, $YBa_2Cu_3O_7$

6B

## Different loss mechanisms: ( 2 marks + 2 marks)

## 1. Absorption losses:

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- 0 , B-O, absorb in the range of 1-2 μm, chromium and copper ions absorb at 0.6μm.,Fe ions absorb at 1.1μm. Hydoxy ions absorb at 1.38μm. Better techniques of making glass with reduced water content can minimize these losses.Tominimise the absorption loss, impurity content has to be less than 1 part in $10^9$.

**2. Scattering losses:**

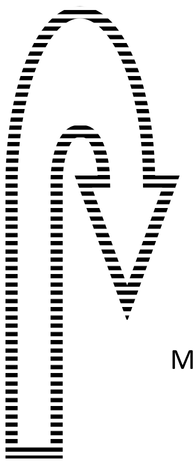
This occurs due to the Rayleigh scattering of the signal caused by variations in refractive index of the glass due to  changes in composition, defects, presence of air bubbles, strains etc. The scattered light moves in random direction and escapes from the fiber reducing the intensity. These losses decrease at higher wavelengths.Hence, this loss is minimized by operating at high wavelengths.

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

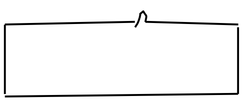
**3. Radiation losses:**

Radiative losses occur due to bending of fiber.

**Macroscopic Bends**:This refers to the bends having radii that are large compared to the fibre diameter.These losses are reduced by using lower wavelength and lower numerical aperture. This loss is high at 1550nm.



Macro bend



Micro bend

**Microscopic bends:**

These are repetitive small scale fluctuations in the linearity of the fibre axis.

7A

**Fermi probability factor**: It represents the probability of occupation of an energy level. ( 1 mark)

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

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

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

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

**Variation of Fermi Probability factor with temperature and Energy**

For E > $E_F$ , at T=0

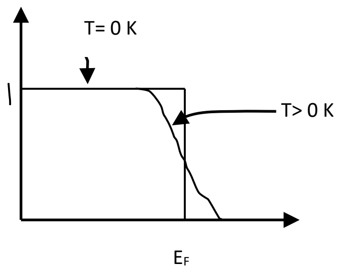
$$f(E) = \frac{1}{e^{\left(\frac{E-E_F}{kT}\right)}+1} = 0$$

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

$$f(E) = \frac{1}{2}$$ ( 3 marks)

**Fermi energy for T > 0k,** $E_f = E_{f0}\left[1-\frac{\Pi^2}{12}\left(\frac{kT}{E_F}\right)^2\right]$

**Graph:** ( 1 mark)




8A ( Fig: 1 mark, Graph: 1 mark, Working: 3 marks)

**DC SQUID:**

When magnetic field is applied, current is induced in the SQUID which opposes the external magnetic field. Magnetic Flux through the SQUID is quantized .The current through the SQUID varies periodically with the external magnetic field.