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PES University, Bangalore

(Established Under Karnataka Act 16 of 2013) **UE18PH101**

August 2019: END SEMESTER ASSESSMENT (ESA) – Summer Term B.TECH. 1 / 2 Semester

UE18PH101: ENGINEERINGPHYSICS

Time: 3 Hrs **Answer All Questions** **Max Marks:100**

Useful constants:
| $m_e = 9.1x10^{-31}$ *kg* | $h = 6.63 \times 10^{-34} Js$ | $k_B = 1.38 \times 10^{-23} JK^{-1}$ |
| $c = 3 \times 10^8 ms^{-1}$ | $N_A = 6.02 \times 10^{23}$ *per mol* | $m_n = 1.67 \times 10^{-27}$ *kg* |

1.	**a)**	Starting from Maxwell's equations, derive the equations of wave propagation in free space.	**6**
	b)	Explain why electron cannot exist in the nucleus of radius 10^{-14} m.	**5**
	c)	Is an electron a particle or a wave? Explain your answer. Why is wave nature of matter not more apparent in our daily observation?	**5**
	d)	X-rays of wavelength 0.112 nm is scattered from a carbon target. Calculate the wavelength of X-rays scattered at an angle 90^o with respect to the original direction.	**4**
2.	**a)**	State the requirements of Schrodinger wave function and derive time independent Schrodinger equation for a particle.	**6**
	b)	How does a particle with energy lower than the barrier height, tunnel through it? Give one example	**6**
	c)	Discuss the probability densities and energy levels for particle in a one dimensional potential well of infinite height considering first two excited states.	**4**
	d)	Calculate the energy of the electron in the energy level immediately after the lowest energy level, confined in a cubical box of 0.1 nm side.	**4**
3.	**a)**	Define drift velocity, relaxation time and mobility for a free electron in a metal.	**6**
	b)	Describe how quantum free electron theory has been successful in overcoming the failures of Drude model.	**5**
	c)	The thermal and electrical conductivities of Cu at 20^oC are 390 $Wm^{-1}K^{-1}$ and $5.87x10^7\ \Omega^{-1}m^{-1}$, respectively. Calculate the Lorenz number.	**3**
	d)	Explain the Kronig-Penney model of solids and show that it leads to energy band structure of solids.	**6**
4.	**a)**	Explain with the help of an appropriate energy level diagram, how stimulated emission results from electron impact pumping in He-Ne laser.	**6**
	b)	Derive Einstein's relation for the stimulated emission of radiation and hence find the relation between stimulated emission and the spontaneous emission.	**5**
	c)	Why is optical resonator required in laser? What is the condition for threshold of laser oscillations?	**4**

	d)	What is the reason for monochromaticity of laser beam? For an ordinary source, the coherence time τ_c is 10^{-10}s. Calculate the degree of non-monochromaticity for wavelength of 5400 Å.	**5**
5.	**a)**	Explain briefly the electronic and ionic polarizations.	**4**
	b)	Compare and contrast ferromagnetism with ferrimagnetism.	**4**
	c)	Discuss Gaint Magneto Resistance and explain its application as a memory device.	**6**
	d)	Distinguish between ferroelectrics and piezoelectrics	**6**

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July 2019: END SEMESTER ASSESSMENT (ESA) – Summer Term B.TECH.

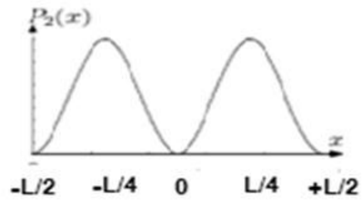
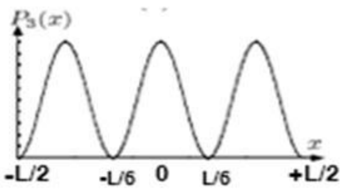
UE18PH101: ENGINEERING PHYSICS

Time: 3 Hrs **Answer All Questions** **Max Marks: 100**

Useful constants:
| $m_e = 9.1x10^{-31}$ kg | $h = 6.63 \times 10^{-34}$ Js | $k_B = 1.38 \times 10^{-23}$ JK^{-1} |
| $c = 3 \times 10^{8}$ ms^{-1} | $N_A = 6.02 \times 10^{23}$ per mol | $m_n = 1.67 \times 10^{-27}$ kg |

1.	**a)**	**Starting from Maxwell's equations, derive the equations of wave propagation in free space.**	**6**
		To derive wave equations, consider the four Maxwell's equations, $\nabla.E = 0$ (1); $\nabla.B = 0$ (2); $\nabla\times E = -(\partial B/\partial t)$ (3); $\nabla \times B = (\boldsymbol{\mu_o \varepsilon_o}\, \partial E/\partial t)$ (4)	
		Taking the curl of curl of the electric field the equation,	**2**
		$\vec{\nabla} \times (\vec{\nabla} \times \vec{E}) = \vec{\nabla} \times \left(-\frac{\partial \vec{B}}{\partial t}\right)$ this reduces to	**1**
		$\vec{\nabla}(\vec{\nabla}.\vec{E}) - \nabla^2\vec{E} = \left(-\frac{\partial \vec{\nabla}\times\vec{B}}{\partial t}\right)$	**1**
		Since $\vec{\nabla}.\vec{E} = 0$, this reduces to $-\nabla^2\vec{E} = \left(-\frac{\partial \vec{\nabla}\times\vec{B}}{\partial t}\right)$	
		Substituting for curl of B from equation (4), the above equation simplifies to $\nabla^2\vec{E} = \left(\mu_o\varepsilon_o \frac{\partial^2 E^2}{\partial t^2}\right)$.	**1**
		But we know that $\mu_o\varepsilon_o = \frac{1}{c^2}$ and the equation reduces to	
		$\nabla^2\vec{E} = \left(\frac{1}{c^2}\frac{\partial^2\vec{E}}{\partial t^2}\right)$ which is the general form of a wave equation.	
		In a very similar way we could starting from the curl of the curl of the magnetic field show that	**1**
		$\nabla^2\vec{B} = \left(\frac{1}{c^2}\frac{\partial^2\vec{B}}{\partial t^2}\right)$.	
		These equations represent the wave equations in E and B.	
	b)	**Explain why electron cannot exist in the nucleus of radius 10^{-14} m.**	**5**
		According to the uncertainty principle	
		$\Delta x.\ \Delta p \geq \hbar/2$;	
		Where Δx = uncertainty in the position of a particle Δp = uncertainty in its momentum	**1**
		Considering the electron inside the nucleus, the uncertainty Δx in the position of an electron is roughly the same as the diameter of the nucleus which is of the order of $\Delta x \approx 10^{-14}$ m,	**1**
		then $\Delta p \approx \hbar/2.\Delta x = 5.28 \times 10^{-21}$ kgms^{-1}.	**1**
		Hence the minimum momentum of the electron 'p' has to be at least the uncertainty Δp and a rough estimate of energy of the electron in the nucleus gives, $E = p^2/2m \approx 96$ MeV.	**1**
		Thus according to the result an electron confined inside the nucleus would have very high kinetic energy. But experimentally the electrons emitted by radioactive nuclei are very less than the calculated value and proves that electron cannot stay in nucleus.	**1**

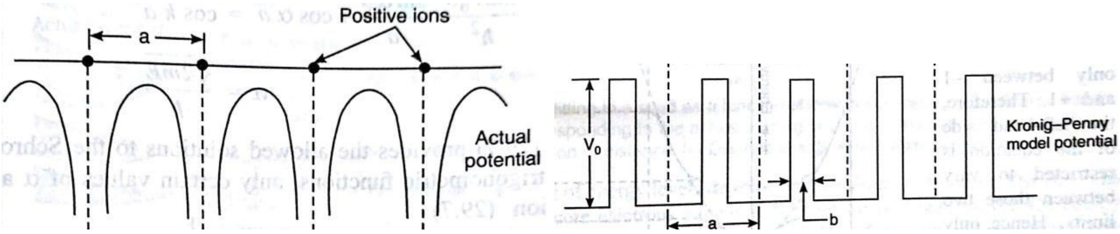
	c)	**Is an electron a particle or a wave? Explain your answer. Why is wave nature of matter not more apparent in our daily observation?** Since nature is symmetric, matter and waves must be symmetric. Thus matter can display particle as well as wave properties. Wavelength of the wave associated with particle of mass 'm' moving with velocity 'v' (momentum p= mv) as, λ = h/p. As the properties of matter waves differ from the usual waves, larger the mass of the matter particle, shorter the wavelength associated with it. In our daily observation mass of the particle is very large; de-Broglie's wavelength will be less than atomic size and is beyond our perception.	**5** **3** **2**
	d)	**X-rays of wavelength 0.112 nm is scattered from a carbon target. Calculate the wavelength of X-rays scattered at an angle 90^o with respect to the original direction.** Compton shift is given by, $\lambda' - \lambda = (h/m_0c)\,(1 - \cos\theta)$ $= (6.626 \times 10^{-34}/ 9.1 \times 10^{-31} \times 3 \times 10^{8})\,(1 - \cos 90^o)$ $= 0.024$ Å Thus, $\lambda' = 1.12 + 0.024 = 1.144$ Å	**4** **1** **2** **1**
2.	a)	**State the requirements of Schrodinger wave function and derive time independent Schrodinger equation for a particle.** For all physically acceptable problems the wave function ψ(r,t) should be well behaved by following the below conditions. (i) The wave function ψ(r,t) must be finite, single valued and continuous (ii) Derivatives of wave function must be finite, single valued and continuous (iii) Wave function must satisfy normalization condition The general form of the wave function is given by $\Psi(x,t) = Ae^{\frac{i}{\hbar}(px-Et)}$ The total energy of the system = kinetic energy + potential energy Ie E= KE + V Multiplying throughout with ψ *we get* $E\Psi = KE\Psi + V\Psi$ ……… (1) The total energy operator is $\left\{i\hbar\frac{d}{dt}\right\}$, the kinetic energy operator is $\{-\frac{\hbar^2}{2m}\frac{d^2}{dx^2}\}$. replacing the terms with the respective operators we can rewrite the expression (1) as $$i\hbar\frac{d\Psi}{dt} = -\frac{\hbar^2}{2m}\frac{d^2\Psi}{dx^2} + V\Psi$$ or $\frac{\hbar^2}{2m}\frac{d^2\Psi}{dx^2} + i\hbar\frac{d\Psi}{dt} - V\Psi = 0$ ….(2) which is the Schrödinger's time dependent wave function since Ψ is a function of both position and time. For steady state systems the wave function could be independent of time. In such a case we can write the wave function as $\Psi(x,t) = Ae^{\frac{i}{\hbar}(px)}Ae^{-\frac{i}{\hbar}(Et)} = \psi(x)\,.\,\phi(t)$ Substituting in equation (2) we get, $\frac{\hbar^2}{2m}\frac{\partial^2\psi(x).\phi(t)}{\partial x^2} + i\hbar\frac{\partial\psi(x).\phi(t)}{\partial t} - V\psi(x).\phi(t) = 0$ The total energy E of the system being a constant, the total energy operator can be replaced by the value E with no loss of sense.	**6** **2** **1** **1** **1**

		Thus, $\{\frac{\hbar^2}{2m}\frac{d^2\psi(x).}{dx^2}+E\psi(x)\ -V\psi(x)\}.\phi(t)=0$ We recognize that $\phi(t)\neq 0$ and hence $\frac{\hbar^2}{2m}\frac{d^2\psi(x).}{dx^2}+E\psi(x)\ -V\psi(x)=0$ ………………….(3) This is the Schrödinger's time independent one dimensional wave equation.	1
	b)	**How does a particle with energy lower than the barrier height, tunnel through it? Give one example** Classically a particle approaching a potential barrier with energy E< barrier height V_0, the particle cannot be transmitted to the region II, but quantum mechanical analysis provides a finite probability of finding the particle in region II (an exponentially damped wave $\psi = Ce^{-\alpha x}$). Although damped but penetrated into classically forbidden region II. The value of transmission coefficient (T) is very sensitive to the thickness, height of the barrier and wave number. $T=\frac{transmitted\ flux}{incident\ flux}=\cong\ e^{-2k_{II}a}$ Thus the probability of transmission is more if either $\boldsymbol{k_{II}}$ or $\boldsymbol{a}$ is small. Smaller $\boldsymbol{k_{II}}$ implies smaller (V_o-E). Thus particles with higher energy have higher transmission probability through the barrier. If the width of the barrier 'a' is less than the 'penetration depth' then there is a finite probability that the particle is transmitted across the barrier, known as barrier tunnelling. Emission of α particles (helium nucleii) in the decay of radioactive elements can be example of tunnelling.	6 2 1 2 1
	c)	**Discuss the probability densities and energy levels for particle in a one dimensional potential well of infinite height considering first two excited states.**  Probability density when n = 2 (First excited state) Probability density when n = 3 (Second excited state) $E_2=\frac{2^2h^2}{8mL^2}$ $E_3=\frac{3^2h^2}{8mL^2}$	4 2 2
	d)	**Calculate the energy of the electron in the energy level immediately after the lowest energy level, confined in a cubical box of 0.1 nm side.** For the energy level immediately after the lowest energy level, $n_x = n_y = 1$ and $n_z = 2$ The energy of the electron in (112) state is, $E_{112} = (h^2/8mL^2)\ (1^2 + 1^2 + 2^2)$ $= 6h^2/8mL^2$ $= 36.12 \times 10^{-18}$ J	4 1 2 1
3.	a)	**Define drift velocity, relaxation time and mobility for a free electron in a metal.** **Drift velocity:** In the presence of an electric field, the free electrons show a net drift across the metal in a direction opposite to that of the electric field. This velocity is known as the drift velocity v_d. **Relaxation time:** The time between successive collisions or the time for the drift velocity to fall to 1/e times its steady value in the presence of an electric field.	6 2 2

		Mobility: Mobility is drift velocity per unit electric field, $\boldsymbol{\mu} = \frac{e\tau}{m} = \frac{v_d}{E}$.	2
	b)	**Describe how quantum free electron theory has been successful in overcoming the failures of Drude model.** The specific heats, electrical conductivity and electron concentration of metals unexplained by classical theory was explained very well by quantum free electron theory. **a) Heat capacity due to free electrons*** The electronic specific heat can be evaluated in the light of the fact that only electrons close to the Fermi level participate in the conduction. Hence the heat absorption happens due to that fraction of electrons. This number can be estimated as the effective number of electrons (in one mole of the metal for a monovalent metal) in the conduction process as $n_{eff} = \frac{N_a}{E_f}.k_B T$. Thus the electronic specific heat is temperature dependent and is a fraction of the value predicted by the CFET. This analysis gives the correct correlation with the experimental results. **b) Temperature dependence of the resistivity*** The quantum free electron theory takes into account the thermal vibrations of the ionic array which accounts for the scattering of electrons. The amplitude of the random vibrations of the lattice ions increase with increasing temperature and hence increase the probability of electron scattering. This reduces the mean free path of the electrons. When the ions vibrate the lattice presents an effective cross sectional area for scattering of $\boldsymbol{\pi r^2}$ where $\boldsymbol{r}$ is the amplitude of vibration. The electron mean free path λ is inversely proportional to the scattering cross section and hence $\lambda \propto 1/T$ The expression for conductivity $\boldsymbol{\sigma} = \frac{ne^2\tau}{m} = \frac{ne^2\lambda}{mv_f}$ shows that the conductivity is proportional to the mean free path. Hence the conductivity will be inversely proportional to temperature or resistivity $\rho \propto T$ as is found experimentally. **c) Relation between electrical conductivity and thermal conductivity (Wiedemann-Franz law)*** The ratio of the thermal conductivity to electrical conductivity can also be calculated correctly as per quantum free electron theory as $$\frac{\boldsymbol{K}}{\boldsymbol{\sigma}} = \frac{\boldsymbol{\pi^2}}{\boldsymbol{3e^2}} \boldsymbol{k_B}^2\boldsymbol{T}.$$ This is the Wiedemann-Franz law. *Any two explanations are expected.	5 1 2 2 or 2
	c)	**The thermal and electrical conductivities of Cu at 20°C are 390 $Wm^{-1}K^{-1}$ and 5.87×10^7 $\Omega^{-1}m^{-1}$, respectively. Calculate the Lorenz number.** Lorenz number, L = K/σT = 390 / 5.87×10^7 x 293 = 2.2676×10^{-8} $W\Omega K^{-2}$	3 1 2

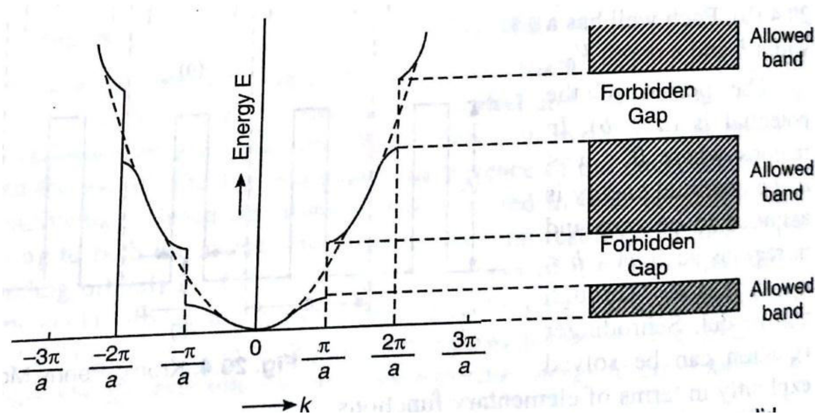
	d)	**Explain the Kronig-Penney model of solids and show that it leads to energy band structure of solids.**	**6**

In the Kronig-Penney model the periodic potential is approximated as a long chain of coupled finite square wells, of barrier height V_0, with a period '***a***', and barrier thickness '***b***'. **2**



The wave function of the electron is a modulated wave of the form $\boldsymbol{\psi(x) = e^{ikx}.V_k(x)}$. **2**

The solutions to Schrödinger's equation exist only for those allowed range of $\boldsymbol{K = n\frac{\pi}{a}}$. Thus there exists a range of allowed energy states and forbidden energy states.

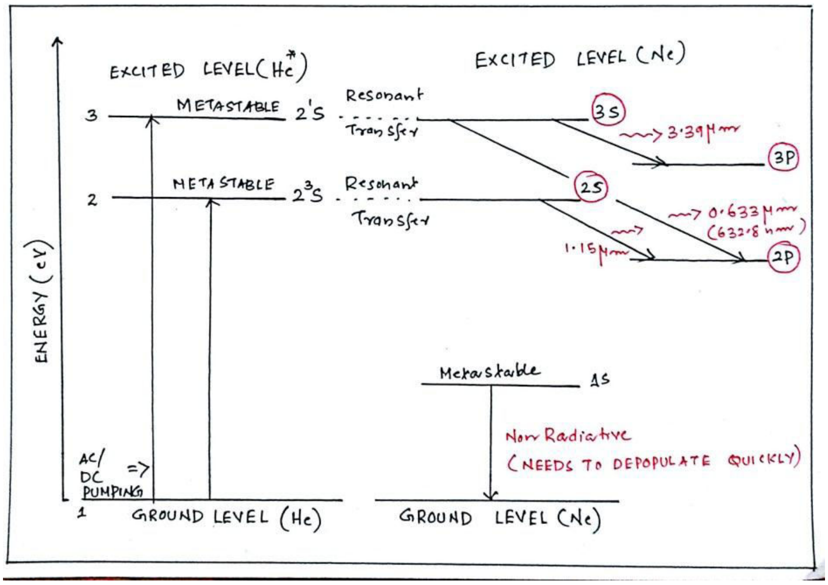


From the plot of energy 'E' as a function of the wave number, 'k' the parabolic relation between E and k obtained in case of free electron is interrupted with allowed energy bands and forbidden gaps. **2**

4.	**a)**	**Explain with the help of an appropriate energy level diagram, how stimulated emission results from electron impact pumping in He-Ne laser.**	**6**

HeNe gas mixture contained in a quartz tube of narrow diameter and maintained at a low pressure which forms the active medium. The energy pump is enabled by maintaining an electrical discharge across the length of the Quartz tube by either a high voltage DC source or a RF source. **1**

He and Ne mixed in the ratio of 10:1, where the absorption levels are in the He atoms and the lasing levels are in the Ne atomic transitions. The He atoms are excited with an electrical discharge and the two excited states of helium atom, the 2 ^{3}S and 2 ^{1}S which are Meta stable. These excited He atoms transfer (resonant transfer) their energy to Ne atoms by collisions and the excites the Neon atoms to the $2s_2$ and $3s_2$ levels as the energy levels of these states are close to the He excited states. **2**

		 A large number of Ne atoms due to collision with He atoms get to the excited state create a population inversion with the ground state. The excited states of Ne are not meta stable and hence de-excites to the ground states through the intermediate states of 3p and 2p. The transition between the 3s to the 2p intermediate states gives the characteristic red laser of Ne with a wavelength of 632.8 nm. The transitions from the 3s to 3p and 2s to 2p lines give rise to radiations with wavelengths in the Infra-red of 3.39 micrometers and 1.152 micrometers.	**3**
	b)	**Derive Einstein's relation for the stimulated emission of radiation and hence find the relation between stimulated emission and the spontaneous emission.** An atom in the excited meta stable have to be stimulated to return to the lower energy state with an external intervention in the form of a photon whose energy is equal to E_2-E_1. In this process the energy of the excited atom is released as a photon whose characteristics remain the same as that of the stimulating photon. The rate of stimulated emission is then dependent on the population of atoms in the excited state and the energy density of radiation is given by $\boldsymbol{R_{st\,em} = B_{21} * N_2 * \rho(\nu)}$ The rate of spontaneous emission is dependent on the population of atoms in the excited state N_2 only, $\boldsymbol{R_{sp\,em} = A_{21} * N_2}$ The ratio of the rate of stimulated emission to the rate of spontaneous emission, $= \frac{B*N_2*\rho(\nu)}{AN_2} = \frac{\rho(\nu)}{\frac{A}{B}} \approx \frac{N_2}{N_1}$.	**5** **2** **1** **2**
	c)	**Why is optical resonator required in laser? What is the condition for threshold of laser oscillations?** Once the lasing action is initiated it is essential that the stimulated emission in the desired wavelength is amplified to get a sustainable laser action of sufficient intensity. Also, helps in eliminating undesired wavelengths which may be present in the lasing process and increase the monochromaticity of the system. If I_0 is the starting intensity of photons, then the intensity after one round trip gain is given by $\boldsymbol{I = I_0 R_1 R_2 e^{2(g_o - \alpha)L}}$ The threshold of laser oscillations is defined by $\boldsymbol{R_1 R_2 e^{2(g_o - \alpha)L} = 1}$	**4** **2** **2**

d) **What is the reason for monochromaticity of laser beam? For an ordinary source, the coherence time τ_c is 10^{-10} s. Calculate the degree of non-monochromaticity for wavelength of 5400 Å.** **5**

Light from a laser comes from atomic transition with a single precise wavelength and therefore, laser light has a single spectral color. **2**

$\tau_{c\,=\,1} / \Delta\nu$, $\Delta\nu = \Delta(c / \lambda)$ **1**

$\Delta\lambda = \Delta\nu \times \lambda^2 / c = 9.7 \times 10^{-12}$ m **2**

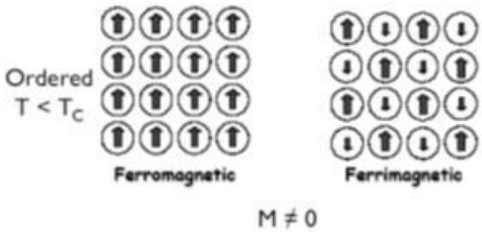
5.

a) **Explain briefly the electronic and ionic polarizations.** **4**

When an atom is subjected to an electric field E, the nucleus and the electron cloud will try to move in opposite directions and results in an induced dipole. The polarization produced due to this induced dipole is called “electronic polarization”. **2**

In dielectric materials with ionic bonding, presence of an external electric field results in the elongation of bond and results in a net induced dipole moment. The polarization produced due to this induced dipole is called “ionic polarization”. **2**

b) **Compare and contrast ferromagnetism with ferrimagnetism.** **4**

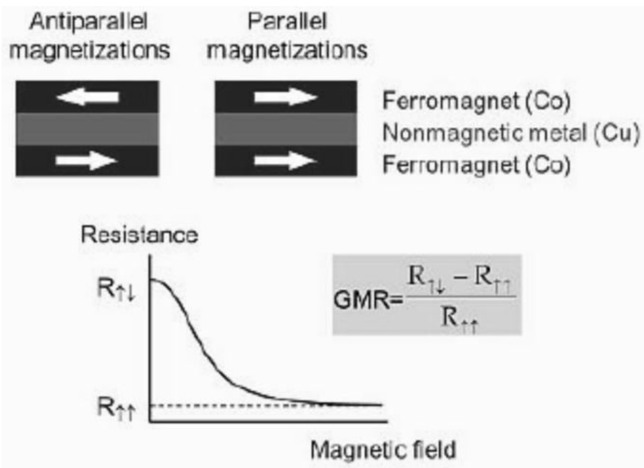


1

Ferromagnetic	Ferrimagnetic
High susceptibilities	Susceptibility variation similar to ferromagnetic
High ordering of spins (parallel with each other)	Magnetic moments are anti-parallel and unequal.
Sharp hysteresis	Above Tc- materials display paramagnetic behaviour.

3

c) **Discuss Gaint Magneto Resistance and explain its application as a memory device.** **6**



2

Magneto resistance is observed in layered magnetic materials where the resistance across the thickness of two magnetic layers (generally Cobalt) separated by a non-magnetic layer (generally Copper) shows a dependence on the magnetisation states of the individual layers. The effect has been attributed to the spin scattering of the electrons when they flow through the material. The scattering of electron is reduced when the magnetisation of the two layers is parallel. When the spin state of the two layers are anti-parallel the scattering and hence the resistance increases. **2**

		The GMR finds application in the read head of magnetic memories. One of the layers ferromagnetic (soft magnetic material) layer is pinned (magnetization of that layer is fixed) and the other (soft magnetic material) free layer’s spin orientation is flipped by the magnetisation of the domain (hard magnetic material) on the recording media.	**2**
	d)	**Distinguish between ferroelectrics and piezoelectrics**	**6**
		Non centro symmetric crystals can respond to an external stimulus producing polarization which shows up as a potential across the element. Piezoelectric behavior is the response of these crystals to external mechanical pressures and ferroelectric behavior is a response of the material to external electric fields.	**2**
		Ferroelectrics display a nonlinear response of polarization to changing electric fields and display a hysteresis in the P versus E variations. The hysteresis loop is caused by the existence of permanent electric dipoles in classes of materials, which develop spontaneously below the Curie temperature. The polarisation state of the ferroelectric material has a memory effect and hence is used extensively in DRAMs and SRAMS.	**2**
		The piezoelectric effect is used to convert electrical energy into mechanical energy, and vice versa; i.e., the substance is used as a transducer. The microscopic origin of piezoelectricity lies in the displacement of ionic charges within the crystal. In the absence of strain, the distribution of the charges at their lattice sites is symmetric, so the internal electric field is zero. But when the crystal is strained, the charges are displaced.	**2**

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