2020

PHYSICS — HONOURS

Sixth Paper

Full Marks : 100

The figures in the margin indicate full marks.

Candidates are required to give their answers in their own words as far as practicable.

Answer ***question no.*** **1** and ***two*** each from ***Unit*** **- 11** and ***Unit*** **- 12**

1. Answer ***any five*** of the following : 4×5

(a) Obtain an expression for the Coulomb barrier when a nucleus of $_{92}U^{238}$ emits an α-particle.

(b) Why does U^{235} and not U^{238} undergo fission with thermal neutrons?

(c) Find out the ground state spin parity of $_{13}Al^{27}$ using single particle shell model.

(d) Define parity. For what types of interactions it is conserved?

(e) What is stripping reaction? Give an example of it.

(f) The maximum energy encountered in β-particle emission from radioactive nuclides is about 4 MeV. What is the shortest length of the waves associated with β-particles?

(g) Show that the density of states of free electrons in 3d at the Fermi energy E_F is given by $\frac{3}{2}\frac{n}{E_F}$, where n is the density of electrons at $T = 0$.

(h) Is Meissner effect consistent with the disappearance of resistivity in a superconductor? Explain.

(i) Estimate the electronic polarization of an atom of size $10^{-10}m$.

(j) Debye temperature of a solid is 1500 K. Compute the highest vibrational frequency of the solid at 30 K.

(k) An element whose atomic mass is 100 having a bcc structure. Its unit cell parameter is 4 Å. Calculate the number of unit cells in 10 gm of the element.

(l) What are the differences between semiconductor energy gap and the superconducting energy gap?

Unit - 11

(Nuclear and Particle Physics)

2. (a) In a mass spectrograph, singly ionised ^7Li ions are accelerated by a potential difference of 400 V and then passed through a uniform magnetic field of 0.08 T perpendicular to their direction of motion.

(i) Find the radius of the path of the ions.

(ii) The slit through which the ions enter the magnetic field is 1 mm wide. Estimate the broadening of the image due to diffraction.

(iii) Calculate the mass resolution m/dm of the system.

(b) A flux of 10^{12} neutrons/m^2 emerges each second from a port in a nuclear reactor. If these neutrons have a Maxwell-Boltzmann energy distribution corresponding to T = 300 K;

(i) Calculate the average velocity of a neutron.

(ii) Calculate the density of neutrons in the beam. (2+4+4)+(4+6)

3. (a) Use the semi empirical mass formula to construct the mass-parabola for isobars having same mass number A. Hence find an expression for the most stable isobar. Illustrate your answer by a suitable plot of M (A, Z) against Z.

(b) The range in standard air of α-particle from radium ((half-life = 1622 years) is 3.36 cm, while the range of α-particles from polonium (half-life = 138 days) is 3.85 cm. If radium, polonium and RaC are all members of the same radioactive series, calculate the half-life of RaC for which the α-particle range is 6.97 cm.

(c) Write down the nuclear 'magic numbers'. Why are they so called? (4+4+2)+6+(2+2)

4. (a) Why does the B.E. per nucleon for medium sized nuclei remain relatively constant? How do you explain the fall of the binding energy curve for lighter as well as heavier nuclei? Explain from the binding energy curve why energy is released in fission and fusion.

(b) Draw a typical β-spectrum. Explain how Pauli's hypothesis helped to explain its nature. What is the origin of some discontinuous peaks in the typical β-spectrum?

(c) ${}^{64}_{28}\mathrm{Ni}$ and ${}^{64}_{29}\mathrm{Cu}$ have atomic masses 63.9280u and 63.9298u respectively. Which of them show β-activity and of what type? (Given, $2m_e$ = 0.0011 u). (2+2+4)+(2+4+2)+4

5. (a) Outline the features of Liquid drop model proposed by Bohr and Wheeler.

(b) The change of the energy of the spherical nucleus distorted to an ellipsoid is given by

$$\Delta E = \frac{\epsilon^2}{5}\left[0.035A^{2/3} - \frac{7.73\times10^{-4}Z^2}{A^{1/3}}\right]$$

where ϵ is the eccentricity of the ellipsoid.

(i) Identify the origin of the above two terms.

(ii) Obtain the condition of spontaneous fission. Hence, discuss the nature (stable/unstable) of ${}_{92}\mathrm{U}^{238}$.

(c) What do you mean by thermal neutrons? Explain briefly why the capture cross-section of a nucleus for thermal neutrons is often very large. 6+(4+2+2)+(2+4)

6. (a) Explain the working principle of a fixed frequency cyclotron with a diagram. Show that for a fixed magnetic field, the kinetic energy of a particle in the cyclotron is proportional to the square of the orbit radius.

(b) What are the limitations of a fixed frequency cyclotron?

(c) A GM counter operates at 1 kV and has a wire of diameter 0.2 mm. The radius of the cathode is 20 mm and the tube has a guaranteed lifetime of 10^9 counts. What is the magnitude of the maximum radial field? If the counter is used on the average for 30 hours per week at 3000 counts per minute, then how long the counter will last? (6+4)+4+(4+2)

7. (a) Explain with reasons whether the following reactions are allowed or forbidden :

(i) $p \rightarrow \pi^+ + \pi^- + e^-$

(ii) $\pi^+ + n \rightarrow \pi^0 + k^+$

(iii) $p + \pi^- \rightarrow n + \pi^0$

(b) What are the end products in a *pp* chain reaction? Explain. How is the CNO cycle in stars different from the *pp* chain?

(c) What is charge conjugation? Neutron is electrically neutral but is not its own antiparticle — explain why. 6+(4+4)+(2+4)

Unit - 12

(Solid State Physics)

8. (a) Draw an FCC lattice structure. Show that it has a packing fraction of 0.74. Compare it with that of BCC lattice structure.

(b) Write down Bragg's law. How is this law modified due to refraction at crystal surface?

(c) A diffraction pattern of a cubic crystal of lattice parameter 3.16 Å is obtained with a monochromatic X-ray beam of wavelength 1.54 Å. The first four lines on this pattern were observed to have the following values :

Line (Numbers)	θ (in degrees)
1	20.3
2	29.2
3	36.7
4	43.6

Assign the Miller indices to these lines. (2+4+2)+(2+4)+6

9. (a) Derive Wiedemann-Franz law from free electron theory. What is the significant feature of this law?

(b) Aluminium metal crystalizes in FCC structure. If each atom contributes single electron as free electron and the lattice constant is 4 Å, calculate Fermi energy (E_f) and Fermi wave vector (k_f) treating conducting electrons as a free electron Fermi gas.

(c) Argue that the effective mass of the hole is opposite to that of an electron. (8+2)+6+4

10. (a) What are phonons? Distinguish between its optical and acoustic modes.

(b) The potential energy of a system of two atoms is given by

$$U(R) = -\frac{\alpha}{R^4} + \frac{\beta}{R^{12}}$$ (α, β are constants)

R = distance of separation between atoms

Calculate the amount of energy released when the atoms form a stable bond.

(c) Calculate the Hall coefficient in a solid where both electrons and holes contribute to the Hall effect. An electric field of 100V/m is applied to a sample of *n* type semiconductor whose Hall coefficient is – 0.0125 m^3/c. Determine the current density in the sample assuming the electron's mobility to be 0.36 $m^2V^{-1}s^{-1}$. (2+2)+6+(6+4)

11. (a) Calculate the density of atoms in (100), (110) and (111) planes of FCC aluminium whose lattice parameter is 4.05 Å .

(b) Consider the dispersion relation of tightly bound electrons in a linear lattice with atomic separation *a* as $E = E_0 - \alpha - 2\gamma \cos ka$ (α, E_0, γ are constants). Obtain an expression of the reciprocal of effective mass (m^*) as a function of *E*. Sketch (Y_{m^*}) as a function of *E*.

(c) What are the main assumptions in Debye model? Calculate the Debye cut-off frequency and write the physical significance of it. 6+(4+2)+(2+4+2)

12. (a) Sketch the inverse susceptibility function of paramagnetic and ferromagnetic materials as a function of temperature. Hence, distinguish between them.

(b) Consider a collection of *N* non-interacting spin ½ particles (with no orbital motion) in a uniform magnetic field B at a given temperature T. Compute the magnetization M (B, T) and susceptibility χ (B, T) of the system. Will the system show spontaneous magnetization? Explain.

(c) If the number of spins in a ferromagnetic material is $3\times10^{28}/m^3$ and its spin magnetic moment is $3\times10^{-23}\,Am^2$, find its saturation magnetization. (4+2)+(4+2+4)+4

13. (a) What is the physical implication of isotope effect in superconductivity? The critical temperature for mercury with isotope mass 202 is 4.159 K. Determine its critical temperature when its isotope mass is 200.7.

(b) Explain briefly the Meissner effect with suitable diagram. Show that the magnetic field decays inside the superconductor exponentially with a characteristic length scale.

(c) Derive Clausius-Mosotti relation for a dielectric. (4+2)+(2+6)+6