2018

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 ***four*** each from **Unit – 11** and **Unit – 12**

1. Answer ***any ten*** of the following : 2×10

(a) A nucleus with mass number A = 235 splits into two spherical fragments whose mass numbers are in the ratio 3 : 2. Find the separation between the centres of the fragments at the time of splitting. Given : nuclear radius parameter R_0 = 1.3 fm.

(b) Determine the ground state spin parity of $_9F^{19}$ in the context of single particle shell model.

(c) The decay $\Xi^- \rightarrow \Lambda^0 + \pi^-$ is observed in nature, whereas the apparently similar decay $\Xi^- \rightarrow n^0 + \pi^-$ is never observed. Why?

(d) Explain why a Geiger counter cannot measure the energy of a moving charged particle.

(e) A 0.01 mm thick ^7_3Li target is bombarded with 10^{13} protons per second. As a result, 10^6 neutrons per second are produced. What would be the cross-section for this reaction? (The density of Li = 500 kg/m^3).

(f) In a mass spectrometer study of an ion, the following values of $\left(\frac{q}{m}\right)$ are observed : 4.81×10^6 C Kg^{-1}, 9.62×10^6 C Kg^{-1}, 4.56×10^6 C Kg^{-1} and 4.35×10^6 C Kg^{-1}. Explain the observation.

(g) What is the basic physical principle responsible for the origin of energy bands rather than specific energy levels in a crystalline solid?

(h) What are the differences of energy gap seen in superconductor and semiconductor?

(i) Sketch the spontaneous magnetization as a function of temperature. Indicate the universal feature associated with the graph.

(j) In a drop of water of radius 10^{-3} m, the molecular dipoles are pointed in the same direction. If the dipole moment of the water molecule is 6×10^{-30} c-m, calculate the polarization.

(k) Estimate the molecular field for a ferromagnetic material having Curie temperature 500 K.

(l) Obtain an expression for bulk modulus of a free electron gas.

Unit – 11

(Nuclear and Particle Physics)

2. (a) Derive an expression for the 'surface energy' of a uniformly charged liquid drop and hence write down the corresponding term in the semi-empirical mass formula. Clearly mention the assumptions. 4

(b) Write down the nuclear 'magic numbers'. Why are they so called? 2+1

(c) Show that $\gamma \rightarrow e^+ + e^-$ process cannot take place in vacuum. 3

3. (a) $^{212}_{84}Po$ emits alpha-particles of energy 10.54 MeV. Give an estimate of the barrier height faced by the alpha-particle in order to come out of the nucleus. Hence, comment on the relatively long lifetime of lower energy alpha-emitters. 4+2

(b) Discuss the significance of the end-point energy in the β-decay spectrum using a proper sketch. 2

(c) When a nucleus exists in an excited state of spin-parity $5/2^+$ and subsequently decays by a transition having multipolarity M2, what will be the spin-parity of the final state? Justify your answer. 2

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

$$\Delta E = \frac{\epsilon^2}{5}\left(0.035\, A^{2/3} - \frac{7.73\times10^{-4} z^2}{A^{1/3}}\right)$$

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 $_{92}U^{238}$. 2+1+1

(b) Outline the similarities between a nucleus and a liquid drop. Why the Weizsacker mass formula is called the semi-empirical mass formula? 3+1

(c) Estimate the critical mass of a sphere of $_{92}U^{235}$, assuming that the fission and radiative capture cross-sections are equal. The absorption cross-section for fission neutrons is 5 barns. The density of uranium is 18×10^3 kg m^{-3}. 2

5. (a) Calculate the minimum energy required to be given to the neutron in order that the following nuclear reaction may occur :

$$^1_0n + ^{31}_{15}P \rightarrow ^{31}_{14}Si + ^1_1H$$

Given the masses (in *amu*) :

$$M\left({}_{0}^{1}n\right)=1.008665,\ M\left({}_{15}^{31}P\right)=30.973766,\ M\left({}_{14}^{31}Si\right)=30.975349$$

and $M\left({}_{1}^{1}H\right)=1.007825$. 3

(b) Which compound system was produced in Ghosal's Experiments and in how many ways? How did the results corroborate with the Bohr's hypothesis of compound nucleus? 1+2

(c) Discuss the validity and limitations of compound nucleus hypothesis. 2+2

6. (a) What is the role of resonance in the operation of a cyclotron? Derive the expression for energy of the emitted particle from a cyclotron and hence define *K*-factor of the machine. 1+2+1

(b) What do you mean by plateau region of a GM counter? A GM counter has dead time of 200 μs. What are the true counting rates when the observed rates are 1000 per minute? 2+2

(c) What are the end products in a P-P chain reaction? Explain. 2

7. (a) What is Lepton Family (LF) number? Check whether LF number is violated in the decay $\mu^- \rightarrow e^- \overline{\nu}_e \nu_\mu$. 1+2

(b) What is strangeness? Name a particle with non-zero strangeness. Is it a good quantum number under all fundamental interactions? 1+1+1

(c) Explain why the following processes are not allowed.

(i) $p \rightarrow \pi^0 + e^+$

(ii) $p + \pi^0 \rightarrow \overline{p} + \pi^+ + \pi^+$

(iii) $n \rightarrow p + e^-$

(iv) $e^- \rightarrow \nu_e + \gamma$ (photon). 1+1+1+1

Unit – 12

(Solid State Physics)

8. (a) Draw an FCC lattice structure. Show that it has packing fraction of 0.74. Compare it with that of a simple cubic lattice structure. 1+2+1

(b) Find the Miller indices of a plane that makes an intercept of 3Å, 4Å and 5Å on the coordinate axes of an orthorhombic crystal with a : b : c = 1 : 2 : 5. 2

(c) A beam of thermal neutrons emitted from the opening of the reactor is diffracted by the (111) planes of nickel crystal at an angle of 28°30′. Calculate the effective temperature of the neutrons. Nickel has FCC structure and its lattice parameter is 3.52Å. 4

9. (a) Distinguish between density of states, g(E) and density of occupied electron states, N(E) of non-relativistic free electron in 3d at T = 0 with suitable diagrams. 2+1

(b) What is meant by relaxation time of free electrons? Hence, derive Wiedemann-Franz law from free electron theory. 1+4

(c) The Fermi energy of silver is 5.5 eV. Calculate the fraction of free electrons at room temperature (300K) located within a width of K_BT on either side of the Fermi energy. 2

10. (a) What do you mean by "effective mass" of an electron in a solid? Under what condition, the effective mass of electron is equal to its free electron mass? 2+1

(b) Consider the dispersion relation of tightly bound electrons in a two-dimensional square lattice of lattice constant **a** as: $E = E_0 - \alpha - 2\beta(\cos k_x a + \cos k_y a)$; E_0, α, β are constants.

(i) Find the energy bandwidth.

(ii) Obtain an expression of effective m* for small values of K. 2+2

(c) Calculate the Hall coefficient in a solid where both electrons and holes contribute to the Hall effect. 3

11. (a) Clearly explaining the basic assumptions, derive Clausius-Mosotti relation for a dielectric. Explain how it modifies when more than one dielectric is present. 4+2

(b) Find the magnetic field B_0 which has to be applied to paramagnetic salt containing ions with $\mu_{m_j} = \pm\mu_B$ so that x percent of these ions is in the lowest energy state. 4

12. (a) The Curie temperature of iron is 1043K. Assume that iron atoms, when in metallic form, have moments of $2\mu_B$ per atom. Iron is BCC with lattice parameter a = 0.286 *nm*. Given $\mu_B = 5.7884\times10^{-5}\ eV.T^{-1}$. Calculate (i) the saturation magnetization, (ii) the Curie constant. 4

(b) In an assembly of 10^{23} harmonic oscillators, each has a frequency of 10^{13} Hz. Calculate (ignoring the zero point energy) the mean thermal energy of the system at 20K. What is the value of Einstein temperature of such a system? Explain significance of the relations used. 4+2

13. (a) Explain "isotope effect" in superconductivity. Briefly discuss its significance. 2+1

(b) Derive the behaviour of magnetic field inside the superconductor. Hence, define the characteristic length scale. 2+1

(c) The phonon dispersion relation for a vibrating diatomic chain in which alternate atoms are M_1 and M_2 is given by

$$\omega^2 = K_1\left(\frac{1}{M_1}+\frac{1}{M_2}\right) \pm K_1\left[\left(\frac{1}{M_1}+\frac{1}{M_2}\right)^2 - \frac{4\sin^2 ka}{M_1M_2}\right]^{1/2}$$

$$\left(K_1 = \text{force constant};\ k = \frac{2\pi}{\lambda}\right)$$

Identify and obtain the minimum and maximum angular frequencies of the acoustical and optical branch. 2+2