2021

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.

1. Answer ***any ten*** questions : 2×10

(a) Two deuteron nuclei undergo nuclear fusion to produce a helium nucleus. Calculate the energy released in MeV. Given mass of ${}_1^2\mathrm{H} = 2\cdot014102u$, mass of ${}_2^4\mathrm{He} = 4\cdot002604u$, $[1u = 931.5$ MeV]

(b) Explain whether the following reaction can occur or not :

$$e^+ + e^- \rightarrow \mu^+ + \pi^-$$

(c) A GM counter has a dead time of 400 μs. What is the counting rate when the observed rate is 1000/minute?

(d) What is the significance of the pairing term in the semi-empirical mass formula.

(e) Explain why $n \rightarrow p + e^-$ decay is not valid.

(f) Which quantum numbers are violated in the weak interactions?

(g) What is the origin of non-zero value of average energy of degenerate electron gas at T = 0K?

(h) What is isotope effect in superconductivity?

(i) What is the dimension of Hall coefficient? Can it be zero for a given material?

(j) Consider two ferromagnets : one having a hysteresis curve with a broad area and another with a narrow area. Which one can be used as an electromagnet and why?

(k) The powder diffraction pattern of a BCC crystal is recorded by Cu - K_α radiation of wavelength $1.54\,\mathring{A}$. What is the lattice constant?

(l) Consider two-dimensional identical circular atoms of maximum possible radii with their centres attached to the four corners of a square lattice. Calculate the packing fraction.

Unit - 11

(Nuclear and Particle Physics)

Answer ***any four*** questions.

2. (a) What do you mean by the saturation of nuclear force? What do you mean by mirror nuclei? Give one example of it.

(b) Explain the phenomenon of pair production.

(c) The energy liberated in the alpha decay of $_{88}Ra^{226}$ is 4.87 MeV. Identify the daughter nuclide. Find the energy of the alpha particle and recoil energy of the daughter atom. 3+3+(1+3)

3. (a) Define threshold energy and derive an expression for the threshold energy Q of an endoergic reaction.

(b) Find out the ground state spin-parity of $_{13}Mg^{25}$ using extreme single particle shell model.

(c) Discuss with suitable example the role of a moderator in a nuclear reactor. (1+4)+2+3

4. (a) According to Bohr–Wheeler's theory of nuclear fission, the critical energy required for neutrons in fission is given by $E_C = 0.89A^{2/3} - 0.02\ \dfrac{Z(Z-1)}{A^{1/3}}$ MeV. Based on the above equation, explain clearly why U-235 is fissile with slow neutrons while U-238 is not.

(b) Electron-positron pair creation cannot take place in vacuum while the reverse process, i.e., pair annihilation can. Explain the reason with necessary mathematical logic.

(c) Polonium-212 emits alpha particles of K.E. 10.54 MeV. Determine the alpha disintegration energy. 4+3+3

5. (a) The density of iron is 8×10^3 kg m^{-3}. The neutron capture cross-section of iron is 2.5 barns. What fraction of the normally incident neutron beam is absorbed by an iron sheet of 0.01 mm thickness?

(b) Draw the characteristic curve of a GM counter. Why can't a GM counter measure the energy of the incident particle?

(c) A GM tube operates at 1000V and has a wire having a diameter 0.2 mm. The radius of the cathode is 2 cm. What is the maximum radial field? 4+(1+2)+3

6. (a) State Bohr's independence hypothesis about a compound nucleus. Briefly explain how it was verified experimentally.

(b) What is the main advantage of synchrocyclotron over cyclotron? What are the design parameters for a cyclotron that would accelerate α-particles to a maximum energy of 20 MeV? The dees are to have diameters of 1m.

(c) Mention main aspects of p-p chain and CNO cycle in reference to primordial nucleosynthesis. (2+3)+(1+2)+2

7. (a) What is hypercharge? Show the multiplet of spin-$\frac{1}{2}$ baryons on a plot of hypercharge versus isospin projection.

(b) Explain with reasons whether the following processes are allowed or not.

(i) $\mu^- \rightarrow e^- + \bar{\nu}_e + \nu_\mu$

(ii) $\pi^+ + p \rightarrow \pi^+ + p + \pi^- + \pi^0$

(iii) $\Lambda^0 \rightarrow \pi^+ + \pi^-$

(c) All resonance particles have very short lifetimes. Why does this suggest they must be hadrons?

(d) Name a reaction in which parity is not conserved. Which class of interaction does this reaction belong to?

(1+2)+3+2+2

Unit - 12

(Solid State Physics)

Answer ***any four*** questions.

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

(b) Draw a BCC lattice structure. Show that it has a packing fraction of 0.68.

(c) Using Bragg's equation, argue that greater is the angle of diffraction, greater is the accuracy in determining the lattice parameter.

(d) A metallic element exists in the form of a cubic lattice. Each edge of the unit cell is 2.88 Å. The density of the metal is 7.2×10^3 kg/m^3. How many unit cells are there in 100 gm of the metal?

2+(1+2)+2+3

9. (a) Show that the Madelung constant for an infinite linear chain of ions of alternating charge at an equilibrium separation R is 2 ln 2.

(b) The primitive translation vectors of the hexagonal space lattice are given as

$$\vec{a}_1 = \frac{a}{2}\left(\hat{i} + \sqrt{3}\hat{j}\right);\ \vec{a}_2 = \frac{a}{2}\left(-\hat{i} + \sqrt{3}\hat{j}\right);\ \vec{a}_3 = c\hat{k}$$

Show that the lattice is its own reciprocal but with a rotation of axes. What is the volume of the unit cell in reciprocal cell?

(c) Obtain the dispersion relation for one-dimensional monatomic lattice. Sketch the dispersion relation as a function ka, a being the lattice constant.

3+(2+1)+(3+1)

10. (a) Show that if the total energy of an ionic crystal can be expressed as $U = \frac{-Ae^2}{r} + \frac{B}{r^n}$, where A and B are constants, then the equilibrium energy is $U_0 = \frac{-Ae^2}{r_0}\left(1 - \frac{1}{n}\right)$, where r_0 is the equilibrium separation.

(b) What is the reduced zone scheme?

(c) From the dispersion relation of lattice waves in a linear monatomic lattice, obtain, with physical explanation, the dispersive behaviours at low and high frequency limits. 4+2+4

11. (a) The Hall coefficient of a metal is $-2.36 \times 10^{-10} \mathrm{m^3/C}$. In an experimental set-up using a thin foil of thickness 1mm made of this metal, a current of 10A is seen to flow across it when a magnetic field of 1.5T is applied normal to it. Find the Hall voltage developed across the width of the foil.

(b) The energy bands of an electron in a 1D periodic potential are given by $E_1(ka) = A(1 - \cos ka)$ and $E_2\,(ka) = B$; A and B being constants of appropriate dimensions. Find the effective mass of electron in each band. Mention which one would contribute to electrical conduction.

(c) Quantum theory of paramagnetism yields $M = \frac{NJ(J+1)\,g_j^{\,2}\,\mu_B^2\,B}{3K_BT}$, with symbols having their usual meaning. Obtain Curie's law from it. 3+(2+1)+4

12. (a) Obtain the specific heat of solid according to Einstein's theory at high temperature and low temperature limits.

(b) In a two-dimensional crystals with 2-atom basis, how many acoustical and optical branches are there?

(c) What do you mean by electrical polarizability? If the dielectric constant of NaCl crystal is 5.6 and its optical refractive index is 1.5, find the ratio of its electrical polarizability to its total polarizability.

4+2+(1+3)

13. (a) From which experiment, one can get the idea of the energy gap in superconductivity? How does the energy gap depend on temperature?

(b) What are Cooper pairs? What can you say about its spin state?

(c) Write down two important differences between normal superconductors and high T_c superconductors.

(d) The electron energy near the top of the valence band in a semiconductor is given by $E = -10^{-37}\,k^2\,J$, where $\vec{k}$ is the wave vector. An electron is removed from the state $\vec{k} = 10^9\,\hat{x}m^{-1}$. Compute the effective mass, energy, momentum and velocity of the resulting hole. The sign or direction of each quantity must be given. 2+2+2+4