

2022

M.Sc.

4th Semester Examination

PHYSICS

PAPER—PHS-402

Full Marks : 40

Time : 2 Hours

The figures in the margin indicate full marks.

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

Illustrate the answers wherever necessary.

PHS-402.1 NUCLEAR PHYSICS II

[Marks : 20]

Group—A

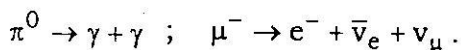
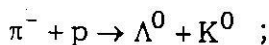
Answer any *two* questions.

2×2

1. Deduce $1/v$ law in nuclear reaction
2. Show that the light nuclei are more effective moderators than the heavy nuclei.

(Turn Over)

3. Discuss the ground state of deuteron wave function (ψ_0) with the mixture of 3S_1 and 3D_1 states wave functions.
4. Arrange the following decays in order of their increasing life times with proper explanation :



Group—B

Answer any *two* questions. 2×4

5. (a) Show that the scattering angles of neutron in the L-system and C-system are almost same if the collision is against a very heavy nucleus ($A \gg 1$).
- (b) Give the range of life-time and nucleon traverse-time on the formation and disintegration of the compound nucleus. 2+2
6. A 7.70 MeV alpha-particle interact with a target nucleus ${}^{14}_7\text{N}$ to produce a residual nucleus ${}^{17}_8\text{O}$ and a product particle ${}^1_1\text{H}$. The protons emitted at 90°

to the incident beam direction are found to have kinetic energy 4.44 MeV. Calculate the Q-value of the reaction and the atomic mass of the residual nucleus. Given the atomic masses :

$$M({}_2^4\text{He}) = 4.0026033 \text{ u and}$$

$$M({}_7^{14}\text{N}) = 14.0030742 \text{ u .}$$

7. (a) The neutrons that generated in ${}^9\text{Be}(\alpha, n){}^{12}\text{C}$ nuclear reaction are not mono-energetic. Why?
- (b) What do you understand by the level width (Γ) and level separation (D) between the levels of a continuum in nuclear reactions? 2+2
8. Show how far the liquid-drop model is successful in explaining why ${}^{235}\text{U}$ nuclide is fissile to slow neutrons but ${}^{238}\text{U}$ nuclide is not.

Group—C

Answer any one question.

1×8

9. (a) Show that the maximum loss of energy in a single collision between the neutron and moderator nucleus is proportional to the initial energy of the neutron.
- (b) Why the (d, p) reactions are more favourable than the (d, n) reactions at lower energy?

- (c) The compound nucleus can become de-excited either through γ -emission or by fission into larger nuclear fragments. The mean life time of the compound nucleus was found to be 4.7×10^{-15} sec and the partial width for γ -emission $\Gamma_\gamma = 3.4 \times 10^{-2}$ eV. Find the partial fission width Γ_f .
- (d) Why is the angular distribution of light product particles isotropic in C.M. system for the compound nucleus reaction whereas there is always a forward peaking for direct reactions?
- 2+3+2+3

10. (a) Deduce the Breit-Weigner resonance formula for nuclear reaction.

(b) What angular momentum and parity are predicted by the shell model for the ground state of ${}^{17}_8\text{O}$ nucleus?

(c) Assuming that the interaction potential in deuteron to be of rectangular well type with depth V_0 and range r_0 , show that the radius of the deuteron is given by $r_d = 2r_0 V_0^{1/2} / (\pi E_B^{1/2})$, where E_B is the binding energy of deuteron.

5+2+3

PHS-402.2 QUANTUM FIELD THEORY

[Marks : 20]

4. Answer any *two* questions : 2×2

(a) Show that the scalar particles obey Bose statistics and the Dirac particles obey Fermi-Dirac statistics.

(b) Chiral transformation is defined by $\psi \rightarrow e^{i\alpha\gamma^5} \psi$ where ψ is the Dirac field. Find the transformation of $\bar{\psi}\gamma^\mu\psi$ under this transformation. You may assume $\{\gamma^5, \gamma^\mu\} = 0$.

(c) For a real scalar field theory show that the commutator $[\phi(x), \phi(y)]$ vanishes for spacelike separation i.e. for $(x - y)^2 < 0$.

(d) Given that for a real scalar field theory

$$[H, a_k^\dagger] = E_k a_k^\dagger. \text{ Show that the } n\text{-particle state,}$$

$|k_1 k_2 \dots k_n\rangle$ is an eigenstate of the Hamiltonian.

What is the eigenvalue ?

5. Answer any two questions : 2×4

(a) Given that the Dirac field transforms as

$$\psi \rightarrow \Lambda_{\frac{1}{2}} \psi, \text{ where } \Lambda_{\frac{1}{2}} = \exp\left[-\frac{1}{2} S^{\rho\sigma} \omega_{\rho\sigma}\right]. \text{ Evaluate}$$

the transformation matrix $\Lambda_{\frac{1}{2}}$ for rotations about the z-axis. Hence show that the Dirac field changes sign upon rotation by an angle, 2π .

(b) The normal ordered conserved charge corresponding to the global transformation $\phi(x) \rightarrow e^{i\alpha} \phi(x)$ for the free complex scalar theory is given by

$$Q = \int \frac{d^3 p}{(2\pi)^3} [a_p^\dagger a_p - b_p^\dagger b_p].$$

Compute $[\phi(x), Q]$ and show that $e^{-i\alpha Q} \phi(x) e^{i\alpha Q} = e^{i\alpha} \phi(x)$, where α is a constant.

(c) The action for a Dirac field ψ coupled to the electromagnetic field A_μ is given by,

$$S = \int d^4 x \left[\bar{\psi} (i\gamma^\mu D_\mu - m) \psi - \frac{1}{4} F^{\mu\nu} F_{\mu\nu} \right];$$

$$D_\mu = \partial_\mu + iA_\mu.$$

- (i) Show that the action is invariant under the transformations :

$$\psi \rightarrow e^{i\alpha(x)}\psi, \quad A_\mu \rightarrow A_\mu - \partial_\mu\alpha(x).$$

- (ii) Derive the equations of motion for the Dirac field and the electromagnetic field.
- (d) Use Wick's theorem to evaluate the correlation function :

$$\frac{\lambda}{4} \int d^4x \langle 0 | T \{ \phi(x_1) \phi^*(x_2) \phi(x_3) \phi^*(x_4) \phi(x)^4 \} | 0 \rangle$$

where ϕ is a complex scalar field and $|0\rangle$ is the non-interacting vacuum state. Leave your answer in terms of the scalar Feynman propagator, $D_F(x - y)$. Draw the corresponding Feynman diagrams.

6. Answer any one question : 1×8

- (a) Consider the free Dirac theory

$$S = \int d^4x \bar{\psi} (i\gamma^\mu \partial_\mu - m) \psi.$$

- (i) Compute the Hamiltonian density and evaluate the normal ordered Hamiltonian, H for the free Dirac theory in terms of the creation and annihilation operators.
- (ii) Show that $[H, a_p^{\dagger s}] = E_p a_p^{\dagger s}$.

- (b) Consider the theory of self-interacting scalars in 3+1 space time dimensions given by the following :

$$L = \frac{1}{2} (\partial_\mu \phi)^2 - \frac{1}{2} m^2 \phi^2 - \frac{\lambda}{4!} \phi^4 .$$

- (i) In units of find the dimension of the coupling constant λ .
- (ii) Write down the position-space Feynman rules for computing correlation functions in this theory.
- (iii) Giving symmetry arguments explain which correlation functions vanish to all orders in perturbation theory.
- (iv) Compute the two point function $|\Omega\rangle T\{\phi(x)\phi(y)\}|\Omega\rangle$ upto order λ^2 . is the ground state in the interacting theory. Draw the corresponding Feynman diagrams. Leave your answer in terms of the Feynman propagator $D_F(x - y)$.