# 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 ($\psi_0$) 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 :

$$\pi^- + p \rightarrow \Lambda^0 + K^0 \;;$$

$$\pi^0 \rightarrow \gamma + \gamma \;; \quad \mu^- \rightarrow e^- + \bar{\nu}_e + \nu_\mu .$$

## 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 >> 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 $^{14}_{7}N$ to produce a residual nucleus $^{17}_{8}O$ and a product particle $^{1}_{1}H$. 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 :

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

$$M\left({}^{14}_{7}\text{N}\right) = 14.0030742\,\text{u}\,.$$

**7.** (a) The neutrons that generated in ${}^9$Be(a, n)${}^{12}$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 ${}^{235}$U nuclide is fissile to slow neutrons but ${}^{238}$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 $\gamma$-emission or by fission into larger nuclear fragments. The mean life time of the compound nucleus was found to be $4.7 \times 10^{-15}$ sec and the partial width for $\gamma$-emission $\Gamma\gamma = 3.4 \times 10^{-2}$ eV. Find the partial fission width $\Gamma\gamma$.

(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 $^{17}_{8}O$ 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 $r_d = 2r_0V_0^{\frac{1}{2}} / \left(\pi E_B^{1/2}\right)$, 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 $\psi$ 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 $\left[H, a_k^\dagger\right] = E_k a_k^\dagger$. Show that the n-particle state, $|k_1 k_2 ... k_n\rangle$ 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 $\psi \to \Lambda_{\frac{1}{2}}\psi$, where $\Lambda_{\frac{1}{2}} = \exp\left[-\frac{1}{2}S^{\rho\sigma}\omega_{\rho\sigma}\right]$. 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, $2\pi$.

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

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

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

(c) The action for a Dirac field $\psi$ coupled to the electromagnetic field $A_\mu$ is given by,

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

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

(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 $\phi$ 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

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

(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 $\lambda$.

(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 $\lambda^2$. is the ground state in the interacting theory. Draw the corresponding Feynman diagrams. Leave your answer in terms of the Feynman propagator $D_F(x - y)$.

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