M. Sc. Physics Examination, 2024

Semester - IV

Astrophysics

Paper: MPEC - 43 E-06

Answer any four

Full marks: 40 **Time:** 3Hrs

Symbols bear their usual meanings

1. (a) Explain the terms *apparent magnitude, absolute magnitude* and *bolometric magnitude*. Establish the relation between the absolute bolometric magnitude and the luminosity of a star.
   (b) Define right ascension (α) and declination (δ) of a star.
   (c) An interstellar hydrogen cloud contains 10 atoms per cm^3. How big (in pc) must the cloud be to collapse due to its own gravitation? The temperature of the cloud is 100 K. (3+2)+2+3

2. (a) Discuss the nuclear reactions in the CNO cycle. What is the role of carbon, nitrogen, and oxygen in this series of nuclear reactions? What is the triple alpha process of helium burning?
   (b) Derive the Lane-Emden equation. Solve the equation for $n = 1$ polytropes imposing the necessary boundary conditions. (2+1+2)+(3+2)

3. (a) From the basic stellar structure equations, show that $L \propto T_{eff}^6$.
   (b) Derive an expression for the radiative and convective temperature gradient inside the star.
   (c) Estimate the Eddington luminosity of a $0.072\ M_\odot$ star. Assume $\bar{k} = 0.001\ m^2\ kg^{-1}$. Is radiation pressure likely to be significant in the stability of a low-mass main-sequence star? 3+4+(2+1)

4. (a) What are thermal and nuclear time scale of a star? The mass of a star is $2M_\odot$, radius $3R_\odot$, and luminosity $60L_\odot$. Find its thermal and nuclear time scales (in years).
   (b) Assume that a star remains 10^9 years in the main sequence and burns 10% of its hydrogen. Then the star will expand into a red giant, and its luminosity will increase by a factor of 100. How long is the red giant stage, if we assume that the energy is produced only by burning the remaining hydrogen?
   (c) Show that in a gaseous configuration in equilibrium in which the radiation pressure is negligible

$$\bar{T} > \frac{1}{6}\frac{\mu m_p}{k_B}\frac{GM}{R}.$$

where the mean temperature $\overline{T}$ is defined by

$$\overline{T} = \frac{1}{M}\int_0^R T \mathrm{d}M(r)$$

(2+2)+3+3

5. (a) Consider a function I_ν defined by

$$I_\nu = \int_0^R G\frac{M(r)}{r^\nu}\,\mathrm{d}M(r)$$

Show that

$$I_\nu = 4\pi(4-\nu)\int_0^R Pr^{3-\nu}\,\mathrm{d}r$$

(b) Show that the theorem is restricted to the values $\nu < 4$.

(c) Interprete I_1 and I_4. (4+2+2+2)

6. (a) How important is electron degeneracy at the centres of the Sun and Sirius B? The central density and temperature of Sirius B is 3×10^9 kg m^{-3} and 7.6×10^7 K, respectively.

(b) Find an expression for the pressure due to a completely degenerate, relativistic electron gas. Hence, estimate the maximum mass of a white-dwarf.

(c) Discuss the process of *neutronization*. What is neutron drip?

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

7. (a) Define a perfect fluid.

(b) Consider an isoentropic equation of state. Consider a static perfect fluid in hydrostatic equilibrium. Show that the equation of hydrostatic equilibrium in Einstein's theory of gravity is

$$\frac{\mathrm{d}p}{\mathrm{d}r} = -(p+\rho)\frac{\mathrm{d}\Phi}{\mathrm{d}r}.$$

(2+8)

[$k_B = 1.380649 \times 10^{-23}$ m^2 kg s^{-2} K^{-1}, $G = 6.67 \times 10^{-11}$ m^3 kg^{-1} s^{-2}, $\sigma = 5.67 \times 10^{-8}$ W m^{-2} K^{-4}, $m_H = 1.67 \times 10^{-27}$ kg.]

M.Sc. Examination, 2024
(Semester - IV)
Physics
Paper: Particle Physics II
Paper Code: MPEC-43 (E-15)

Time : Three Hours | Full Marks : 40

Questions are of value as indicated in the margin.
Answer **question no. 1 and any three** from rest of the questions.

1. Answer any *five* questions. **2 × 5**

   (a) What are the number of generators for $SU(N)$ and $U(N)$ group?

   (b) What do you mean by colour confinement?

   (c) Construct two CP-eigenstates using K_0 and $\bar{K}_0$.

   (d) Why do photons have no mass?

   (e) Draw the Feynman diagram for the nuclear beta decay process.

   (f) Check if or not the following process are allowed:

   i. $\pi^- \rightarrow e^- + \nu_\mu$
   ii. $n \rightarrow p + e^- + \bar{\nu}_e$
   iii. $\mu^- \rightarrow e^- + \bar{\nu}_e$
   iv. $K^0 \rightarrow \pi^+ + \pi^- + +\pi^-$

2. (a) Describe Wu's experiment for the parity violation in weak interaction. 5

   (b) Why do we need the $V - A$ term in the Lagrangian of weak interaction? 3

   (c) What is the significance of Cronin-Fitch experiment? 2

3. (a) From Dirac equation find an expression for the parity operator and the charge conjugation operator. Hence, find the parities of a quark and antiquark? 3+3+1

   (b) How to obtain the parity of a composite object? Hence find the parity of a pi-meson and a proton in their ground states. 1+2

4. (a) Using the Young Tableaux method of group multiplication find the product $2 \otimes 2 \otimes 2$ for $SU(2)$ group. Draw the diagram for a decuplet state in quark model. What is the significance of the Ω state in the development of quark model? $3 + 2 + 1$

   (b) Use the isospin invaraince to find the ratio of two crosssections $\sigma(pp \rightarrow \pi^+ d)/\sigma(np \rightarrow \pi^0 d)$, where p and n are representing proton and neutron while d is the deuteron. d and π have isospin 0 and 1 respectively. 4

5. (a) Write down the Dirac Lagrangian for a free fermionic field. Check whether or not it is invariant under local gauge transformation. **4**

(b) Write down the gauge invaraint QCD Lagrangian. **2**

(c) Why can a Lagrangian have three gluons interaction term but not three photons interaction term? **2**

(d) What are Goldstone bosons? **2**

6. Discuss the phenomena of Higgs mechanism for a global and local $U(1)$ gauge symmetry. **10**

7. (a) Write down the $SU(2)_L \times U(1)_Y$ gauge invariant Lagrangian for a scalar field. **1**

(b) Considering the relevant term of the Lagrangian briefly discuss how do we obtain massive $W^{\pm}$ and Z gauge bosons and a massless photon. **6**

(c) Briefly explain the process by which a fermion can get mass. **3**

M.Sc. Examination – 2024
Semester – IV
Physics
Paper – MPEC-44
(Communications (E-22))

Time: Three Hours **Full Marks: 40**

Questions are of value as indicated in the margin
Answer question number 1 and any three.

1. Answer any *ten* of the following: 1 x 10
   (a) What do you mean by "natural sampling" in PCM?
   (b) What do you mean by "White noise"?
   (c) Mention the differences between step-index and graded-index of an optical fiber.
   (d) What is meant by "Noise figure"?
   (e) What do you mean by depth of modulation ?
   (f) Mention the different losses in optical fiber communication?
   (g) What is the main advantage of DPSK over BPSK in digital communication?
   (h) What is the use of V-number in optical communication?
   (i) Mention the natural noise sources that can affect communications over long distances.
   (j) What do you mean by "quantization error" in digital signaling?
   (k) Mention some major advantages of optical communication.
   (l) What is the use of a "Product modulator" in communication?

2.
   (a) State 'Sampling theorem' in the context of digital communication. Discuss the different sampling methods used in Pulse Code Modulation techniques.

   Let y(t) be a signal with Nyquist rate ω_s. Determine the Nyquist rate for each of the following signals.

   i. $y^6(t)$
   ii. $2y(t)\cos(\omega_s t)$ 1+3+2×2

   (b) Write the working principle of the "Frequency Shift Key" (FSK) considering the message signal bit pattern of '10011001'. 2

3.
   (a) What is the need for "multiplexing" in communication? What are the Time Division Multiplexing (TDM) and Frequency Division Multiplexing (FDM)? Explain the principle of TDM with the help of a schematic diagram. 2+2+4

   (b) What is "Delta Modulation" (DM) in digital communication? 2

4.
   (a) An FM signal with modulation index m_f accompanied by an additive noise with power spectral density of N/2 Watt/Hz is received at the input of an FM demodulator. The output baseband filter has a bandwidth of ω_m radian/s. Derive an expression for the output signal to noise power ratio $(SNR)_o$ in terms of input signal to noise power ratio $(SNR)_i$ of the FM receiver. 6

(b) What do you mean by "threshold" in FM receiver? Show that a threshold input SNR is required to extract the original signal from a frequency-modulated signal. 1+3

5.

(a) What do you mean by a DSB-SC signal? Why a DSB-SC signal cannot be detected by an envelope detector? What type of detector do you suggest is required to recover this type of signal? 2+2+2

(b) Show that for a DSB-SC signal the "noise figure" is independent of the modulation index. 4

6.

(a) What do you mean by modes of an optical fiber? Can any single-mode optical fiber be used as a multi-mode for other optical fibers? justify your answer. 2+2

(b) What type of materials are used for an optical fiber? Why are the refractive indices of the core and cladding of an optical fiber chosen very close? 2+2

(c) The percentage relative index difference for a step index single mode fiber is 0.3%. The fiber has a numerical aperture of 0.112. Calculate the relative refractive indices of the core and cladding. 2

M.Sc Examination, 2024

Semester-IV

Paper Name: Topics in Modern Quantum Mechanics

Paper Code: MPEC-44 (E-01)

Time : Three Hours **Full Marks : 40**

Answer any **four** questions

1. Consider a system of two particles (A and B) belonging from two dimensional Hilbert space. The basis set of each of the Hilbert space is given by: $\{|0\rangle_A, |1\rangle_A\}$ and $\{|0\rangle_B, |1\rangle_B\}$ respectively.

   (a) If the state of the system at some instant is : $|\psi\rangle = |0\rangle_A|0\rangle_B$, then determine the Entanglement entropy between the particles.

   (b) Do the same if the state of the system is given by : $|\psi\rangle = \frac{1}{\sqrt{2}}[|0\rangle_A|0\rangle_B + |1\rangle_A|1\rangle_B]$.

   (c) What is the property of density operator of a system to have a non-zero Entanglement entropy ? **[3+6+1]=10**

2. (a) Define pure and mixed states in terms of density operator.

   (b) State the physical significance of diagonal and off-diagonal elements of density operator.

   (c) Write the density operator for a mixed state corresponding to a system of particles having temperature T (with proper normalization condition).

   (d) Find the mixed density operator of a system containing N distinguishable harmonic oscillators of temperature T. **[2+1+2+5]=10**

3. (a) Based on the path integral formalism, determine the transition probability of a particle (having zero potential) from $|\Psi(t=0)\rangle = |q_i\rangle$ to $|\Psi(t=T)\rangle = |q_f\rangle$ (where $|q_{i,f}\rangle$ are the eigenstates of position operator).

   (b) Thereafter generalize the result for a non-zero potential. **[6+4=10]**

4. (a) Show that at the limit of $\hbar \to 0$, the path integral transition probability leads to the

classical path (Use the "Saddle Point approximation"). How do you physically reconcile this result with the commutation of $\hat{X}$ and $\hat{P}$?

(b) Given a forced Hamiltonian,

$$\hat{H} = \frac{\hat{P}^2}{2m} + V_1(\hat{Q}) - f(t)\hat{Q} - h(t)\hat{P} \ ,$$

how do you determine the expectation of $\hat{Q}$ by using the path integral formalism ? **[5+5]=10**

5. (a) Given a Hamiltonian,

$$\hat{H}_1 = \frac{\hat{P}^2}{2m} + V_1(\hat{X}) \ ,$$

find the superpartner Hamiltonian, in particular, find the superpartner potential $V_2(\hat{X})$ (consider that the ground level energy of $\hat{H}_1$ is zero).

(b) Show that the spectrums of $\hat{H}_1$ and $\hat{H}_2$ are identical, except the fact that number of eigenstates of one of the Hamiltonians is one less than that of the other Hamiltonian. **[5+5]=10**

6. Based on the formalism of the previous question:

(a) Find the superpartner potential for 1-D infinite potential well.

(b) Find the superpartner potential for 3-D Hydrogen atom. **[4+6]=10**

M.Sc.(Physics) Semester-IV Examination 2024
[MPEC-44] - Biophysics II (E34)

Time: Three Hours **Full Marks: 40**

- Answer **any four** of the following questions. Questions are of value as indicated in the margin.
- Symbols have their usual meanings unless specified otherwise. Symbols used in a question can not be changed while writing the answer for the same.

1. Consider a single species delay population model described by the equation,

$$\frac{dN}{dt} = rN(t)\left[1 - \frac{N(t-T)}{K}\right],$$

where r, K, T are positive constants.

   (a) Can the above system admit periodic solutions? Give qualitative discussions. 2

   (b) Find the equilibrium points and examine their linear stability. 4

   (c) Consider a time-delay equation of the form: $\frac{dy}{dt} = ay(t) + by(t-\tau), t > 0$, where τ is the delay and a, b are constants. Find the condition for Lyapunov stability of the system. 3

   (d) Show that a population model of the form $\frac{dN}{dt} = f(N)$ without any time delay can not admit periodic solution. 1

2. Consider the logistic population model in which the mortality rate is enhanced, as a result of harvesting:

$$\frac{dN}{dt} = rN\left(1 - \frac{N}{K}\right) - EN$$

where r, K are the natural carrying capacity and the linear per capita growth rate respectively. The quantity EN is the harvesting yield per unit with E a measure of the effort expended.

   (a) Discuss the nature of yield with varying efforts. 2

   (b) Discuss the growth rate as a function of N for various efforts with the help of a plot. 2

   (c) Discuss the ratio of the recovery times as a function of the yield. 4

(d) Use graphical method for determining the steady state yield. 2

3. Consider the 2-species predator-prey model,

$$\frac{dN}{dt} = N\left[r\left(1 - \frac{N}{K_1}\right) - \frac{K_2 P}{N + D}\right]$$
$$\frac{dP}{dt} = P\left[s\left(1 - \frac{hP}{N}\right)\right]$$

where r, K_1, K_2, D, s, h are constants.

(a) Express the equations in non-dimensional form in terms of three dimensionless parameters. 2

(b) Find the equilibrium points and determine the linear stability of the positive solutions. 6

(c) Comment on the existence of limit cycle in the system. 2

4. (a) Represent the dynamics of a criss-cross venereal disease SI model in terms of a flow diagram. Discuss the assumptions of the model and formulate the dynamics of a disease in terms of a set of coupled differential equations. 4

(b) Show that the zero steady state is unstable. 2

(c) Find the threshold condition for a nonzero steady state infected population and interpret the result. 4

5. (a) Discuss the assumptions of the basic epidemic model for HIV infection in a homosexual population with the help of a flow diagram, and write down the equations governing the model. 4

(b) Derive the condition for an epidemic to start by assuming that an infected individual is introduced at $t = 0$ in an otherwise infection-free population of susceptible. 2

(c) Find an expression for the time at which the number of infected people becomes twice at initial value. 2

(d) Find an expression for AIDS patients at time t assuming that there is no such patient at $t = 0$. 2

6. Write notes on any two of the following topics: 5+5

(a) Fibonacci sequence and its occurrence in nature

(b) Fishery Management Model with harvest taken from population

(c) Turing instability & the Brusselator Model

M.Sc Sem-IV Examination - 2024

Paper: Thin Film Deposition and Vacuum Techniques

Paper Code: MPEC 44; E-29

(Elective Paper)

Full Marks: 40 Time: 3 hours

Answer any four (4) questions. Marks are shown in the margin.

1. (a) From the energy minimization model find the critical radius (r^*) and change in critical energy (ΔG^*) for the nucleation. Plot the ΔG^* vs r^*curve to show the critical radius. 3

(b) What are the two broad type surface binding processes? Mention their respective strength in energy. 2

(c) Write down the series of step in film formation. 2

(d) From the capillary model find the nucleation rate ($\dot{N}$) on substrate surface. 3

2. (a) What do you mean by 'Thin film'? What are different categories of processes of fabricating thin film? Write down their names. 3
(b) Write down the typical steps in fabricating thin film by physical vapour deposition process (PVD) with suitable schematic diagram. 3
(c) What is the need of 'mechanical shutter' in vapour deposition technique? 1
(d) Write down the process flow in 'thermal vapour deposition'. 2
(e) For powder sample vapour deposition what type of crucible will you use? 1

3. (a) What do you mean by 'Surface'? Describe the 'relaxation' and 'reconstruction' of surface atoms through sketch. 2
(b) Establish the relation between surface tension and surface energy for addition of atom to the surface from thermodynamics consideration. 2
(c) From the surface geometry consideration of the thin film deposition technique, find out the film thickness and show that film is lees thicker than the point geometry. 4
(d) Write down the names of three fundamental type of growth modes thin film on the substrate surface and describe the growth modes with schematic diagram. 2

4 (a) Why silicon (Si) cannot be deposited by thermal deposition method? 1
(b) Write down the relative advantages of physical vapour deposition (PVD) process over chemical vapour deposition (CVD) process. 2
(c) Why the melting point of refractory materials decreases inside the vacuum? Can you give some suitable example of such material? 1.5
(d) What is the use of liquid nitrogen trap in connection with the diffusion pump? 2
(e) What is meant by pumping speed (S) and throughput (Q) of vacuum pump? 2
(f) If a mechanical vacuum pump obtains a base pressure of 15 mTorr, what is compression ratio (K) of the vacuum pump? 1.5

5. (a) What is the roll of 'gasket' in vacuum chamber? What are different type of gaskets and which range of chamber pressure they are used? 1.5
(b) What are the different type of 'Gauges' used to measure the chamber pressure and mention their respective range of use? 1

(c) Draw the schematic diagram of 'Ionization Gauge' and describe the working principles. 3.5

(d) Sketch and describe the Low Pressure CVD (LPCVD) technique. 3

(e) What do you mean by coalescence of islands and write the name of the type of coalescences? 1

6. (a) Fill in the blanks. 1 torr = ____ bar = ____ atoms pressure = ___ Pascal? 2

   (b) Describe with proper detailing the structure and working principle of oil sealed rotary vane pump with appropriate schematic diagram. 4

   (c) Write down short notes on Turbo-molecular pump. 4

7. Write short notes on:

   (i) Scanning electron microscopy

   (ii)Scanning tunnelling microscopy 5+5

MSc in Physics Examination, 2024
Semester - IV
Paper: Nuclear Astrophysics
Paper Code: MPEC-44 (E-32)

Time: 3 hours **F.M.: 40**

Answer any four questions

1. (a) Draw a schematic plot to show the abundances of nuclides in the solar system at its birth. 3

(b) What are the essential features that you would like to draw from the plot. 3

(c) What is the basic difference between the abundances of even-A and odd-A nuclides? What inference you would like to draw from it? 1+1

(d) Distinguish between s-process and r-process of nucleosynthesis. 2

2. (a) Illustrate Hoyle state. 2

(b) Draw the necessary diagram to explain the resonance phenomena. 2

(c) Write down Breit-Wigner formula for single isolated level for l=0 neutrons. Explain the significance of the various terms those are present in the formula. 1+1

(d) Suppose that the excited levels of ^{32}S are populated via resonances in the ^{31}P + p reaction. Make a table to enlist the possible values of l_p , by taking into consideration of the conservation of angular momentum and parity, so that the ground 0^+ level and the excited 0^-, 1^+, 1^-, 2^+, 2^- levels of ^{32}S are formed. [**Hint**: *you have to use the concept of single-particle shell model in order to determine the ground state spin-parity of the target nucleus, ^{31}P*] (The symbols have their usual significance). 4

3. (a) Illustrate the significance of Gamow peak in the field of nuclear astrophysics. 2

(b) Do the necessary calculations to find out the standard expression for the position of Gamow peak of a particular reaction in terms of the parameter, T_9. (The symbols have their usual significance) 4

(c) Consider the reaction, $^{12}C(\alpha,\gamma)^{16}O$ at a temperature of T = 0.2 GK. Calculate the approximate position of Gamow peak for the reaction. Compare the calculated value with the Coulomb barrier of the system. Comment on your results. 2+1+1

4. (a) Considering the same thermo-nuclear temperature, give your comments on the nature of Gamow widths for the reactions, $^{12}C + ^{12}C$ and $^{16}O + ^{16}O$. 2

(b) Write down the different sequences for CNO1 and CNO2 cycles. 2+2

(c) Draw the necessary curves to show the fraction of ^4He nuclei produced by the pp1, pp2 and pp3 chains with varying temperatures. 2

(d) The reaction $^{113}Cd(n,\gamma)^{114}Cd$ has a resonance at 0.176 eV whose width is 0.115 eV. Calculate the mean lifetime of the resonance state. Given: value of reduced Planck constant = 1.054×10^{-34} Joule-sec 2

5. (a) Deduce the following relation:

$$\Gamma_{\lambda c} \simeq 2\frac{\hbar^2}{mR^2}P_c C^2 S\,\theta^2_{pc}$$

where the symbols have their usual significance. 5

(b) Write down the reactions that occur during Neon burning process. 2

(c) Illustrate the reciprocity theorem. 3

6. (a) Define the terms: (i) Stellar enhancement factor (SEF) (ii) Stellar rate ground state fraction (GSF)

1+1

(b) Deduce Saha statistical equation [*you have to consider a forward and reverse reaction involving four particles; you have to carry out all the necessary steps*]. 5

(c) Consider the $^{32}S(p,\gamma)^{33}Cl$ reaction at a stellar temperature of $T_9 = 10$. For the laboratory reaction rate (assuming that the ^{32}S target nuclei are in the ground state), consider a value of $N_A\langle\sigma v\rangle_{32S+p} = 1.23 \times 10^3\ cm^3mol^{-1}s^{-1}$. Calculate the stellar rate for the forward reaction and the stellar decay constant for the reverse reaction. [Given: SEF = 0.83; $Q_{32S+p} = 2.2765$ MeV; $G_{32S}^{norm} = 1.6$; $G_p^{norm} = 1$; $G_{33Cl}^{norm} = 1.9$; **<u>Hint</u>**: *you have to use the concept of single-particle shell model in order to determine the ground state spins of the required nuclides*; the symbols have their usual significance.] 1+2

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M. Sc. Examination, 2024

Semester – IV

Physics

Elective Course: MPEC-44

(E-17, Laser Physics)

Time: Three Hours **Full Marks: 40**

Questions are of value as indicated in the margin

Answer ***any four*** of the following questions

1. (a) Following Einstein's idea of spontaneous and stimulated emission, find out a relation between A and B coefficients. (b) Hence determine the stimulated transition rate in terms of the spontaneous life time (t_{sp}), line shape function (g) and transition frequency for the situation when the prevailing radiation field is monochromatic in nature. 5 + 5
2. (a) Derive the Beer-Lambert law associated with the propagation of electromagnetic radiation through a medium.
   (b) When can a medium provide gain to the electromagnetic radiation passing through it? 8 + 2
3. Derive the Gaussian line shape function associated with the Doppler broadening of a transition. Hence find out an expression for the full width at half maximum intensity of this line shape function and show its dependence with absolute temperature of the ensemble. 7 + 3
4. (a) The electric field associated with a classical radiating electron is given by

$$E(t) = E_0 e^{-\frac{\gamma_0 t}{2}} e^{-i\omega_0 t} \; for \; t \geq 0$$
$$= 0 \text{ for } t < 0$$

   The symbols used here have usual meaning. Find out the corresponding intensity distribution of the radiated energy as a function of frequency. (b) Determine an analytic expression for the width of this intensity distribution. (c) Suppose the life time of an excited state of electron in an atom is 1×10^{-8} sec. What will be the classical linewidth of the corresponding emission line profile? 6 + 2 + 2
5. (a) By neglecting the losses within a cavity, find out the cavity modes (only electric field) present within an optical resonator of length 'L'. (b) Now introduce the finite conductivity (σ) of the active medium and hence show that the conductivity is responsible for the decay of cavity modes with time. (c) If the polarization of the medium is also taken into consideration, what will be the form of the Maxwell's equations? (d) What will be your trial solution in that case? 4 + 4 + 1 + 1
6. (a) Consider an optical resonator of dimension 2a × 2b × d. Derive an expression for the frequency of an oscillating mode within this cavity. (b) Find out the frequency separation between two longitudinally oscillating modes. 8 + 2
7. Write short notes on any two of the following: 5 + 5
   (a) Ruby laser (b) He-Ne laser (c) Carbon di-oxide laser (d) Dye laser

M.Sc. (Physics) Semester-IV Examination, 2024
Particle Physics I
(MPEC-42 E-14)

Time : 3 Hours | Full Marks: 40

Question 1 is compulsory. Answer any four questions from the rest. Questions are of value as indicated in the margin.

Unless otherwise specified symbols carry their usual meanings and the Standard Model (SM) of Particle Physics is assumed.

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1. Answer all the questions. 8×2

   (a) Write the the possible final state(s) for the interaction $\nu_\mu + e^- \rightarrow$. Draw the corresponding lowest order Feynman diagram(s).

   (b) In the decay $A \rightarrow B + C$, energy of B in the rest frame of A is

   $$E_B = \frac{m_A^2 + m_B^2 - m_C^2}{2M_A}.$$

   Use qualitative arguments to find the maximum energy $E_{B,max}$ and minimum energy $E_{B,min}$ of B for the decay, $A \rightarrow B + C + D$.

   (c) Calculate $\sqrt{s}$ for the following colliding beam experiments.
   LEP: electron 45.6 GeV, positron 45.6 GeV;
   KEKB: electron 7 GeV, positron 4 GeV;
   PEPII: electron 9 GeV, positron 3.1 GeV

   (d) Explain whether the decay $p^+ \rightarrow e^+ + \pi^0$ is allowed in the Standard Model.

   (e) Use the commutation properties of the Pauli spin matrices σ_i to prove $(\vec{\sigma} \cdot \hat{p})^2 = 1$.

   (f) Calculate the minimum energy $E_{\nu,min}$ required for the interaction $\nu_\mu + n \rightarrow \mu^- + p^+$ when the neutron is at rest.

   (g) Use the commutation properties of the Dirac γ matrices to evaluate $\bar{\psi}\gamma^\mu \frac{1}{2}(1 - \gamma^5)\psi$ in terms of ψ_L, ψ_R, etc.

   (h) Use the commutation properties of the Dirac γ matrices to evaluate $Tr\left(\gamma^\mu\gamma^\nu\gamma^\lambda\gamma^\sigma\right)$.

2. (a) Consider three reference frames – S_0, S_1 and S_2. S_1 is moving with a velocity β_1 w.r.t. S_0 and S_2 is moving with a velocity β_2 w.r.t. S_1. Show, using L.T., that the velocity of S_2 w.r.t. S_0 is

   $$\beta = \frac{\beta_1 + \beta_2}{1 + \beta_1\beta_2}$$

   (b) Consider the decay $A \rightarrow B + C$. Evaluate the energy of C in the rest frame of A. Explain how this result led to the idea of neutrino in nuclear β decay.

   2+4

3. (a) Briefly describe with a schematic diagram the major components of a modern collider detector.

(b) Briefly discuss how the following particles produced in collisions will ~~be~~ interact with the electromagnetic calorimeter.
i) a photon; ii) an electron; iii) a proton.

3+3

4. (a) Use the example of Δ^{++} to explain the idea of *color* of quarks.
(b) Calculate the ratio $\sigma(e^+e^- \to q\bar{q}) : \sigma(e^+e^- \to \mu^+\mu^-)$ for different $\sqrt{s} < 12$ GeV, where q refers to all possible quarks allowed at that $\sqrt{s}$. Explain how this may be used to confirm the idea of color.

2+4

5. Consider a particle with momentum $\vec{p} = (0, 0, p_z)$.

(a) Obtain the spinors for this particle that satisfy the Dirac equation: $(\gamma^\mu p_\mu - m)\, u = 0$
(b) Evaluate the helicity of the spinors obtained above.

4+2

6. For a generic V-A interaction, with arbitrary strengths of the vector (C_V) and axial-vector (C_A) parts, evaluate the following using the properties of Dirac γ matrices.

$$Tr\left[\gamma^\mu(c_V - c_A\gamma^5)(\not{p}_1 + m_1)\gamma^\nu(c_V - c_A\gamma^5)(\not{p}_2 + m_2)\right]$$

Simplify the result when the particles involved are e^- and ν_e. 6

7. Explain the idea of Lepton Universality. Discuss how different experimental results may be used to verify it.
6

M.Sc. Examination, 2024

Semester-IV

Physics

Course: MPEC-42 (Quantum Electronics II, E-20)

Time: Three Hours **Full Marks:40**

Questions are of value as indicated in the margin.

Answer *any four* questions

1. Establish that the parametric interaction can be used for frequency up conversion. Mention the useful applications of the frequency up conversion. (8+2)

2. (a) What you mean by internal second harmonic generation? Obtain the expression for the optimum coupling during an internal second harmonic generation.
(b) In an internal second harmonic generation of $Nd^{3+} : YAG$ laser of $\lambda = 1.06 \times 10^{-6} m$ with internal loss $L_i = 2 \times 10^{-2}$, saturation power $2W$, and $n = 1.5$. Assuming the beam diameter as $70\,\mu m$, and phase matching condition, calculate the optimum length of the crystal. $d = 1.1 \times 10^{-22}$ MKS (1+6+3)

3. Establish that the squeezed vacuum state can be expressed in terms of the even photon number state. Calculate the projection of vacuum state on the squeezed coherent state $< 0|\alpha, \xi >$. (5+5)

4. What are the possible uses of squeezed states? Give a brief sketch of detecting the squeezed state by using Balanced Homodyne technique. (2+8)

5. Solve the nonlinear Schrodinger equation $-\frac{1}{2}\sigma\mu\frac{\partial^2 E_\omega}{\partial\tau^2} - \lambda|E_\omega|^2 E_\omega = i\frac{\partial E_\omega}{\partial\xi}$ (Symbols are of usual meaning). Put your comments on the nature of the solution. (8+2)

6. (a)What is LIGO? What changes are being made in the usual Michelson Interferometer to invent the most sensitive instrument LIGO? Discuss briefly the working principle of a LIGO. (1+1+3)
(b) The input Nd laser of wavelength $1064\,nm$ and power output $5\,Watt$ is used in a LIGO of $4\,kilometers$ arm lengths. The recycling mirrors enhances the power by a factor of 60 and the cavity mirrors enhances the length by 50 times. Estimate the detectable strain with the said LIGO. (5)

7. (a) Alice sends the message 001011001011 according to the BB84 protocol with the following sequence of basis ⊕⊕⊗⊕⊗⊗⊗⊕⊕⊗⊕⊗.If Bob using the following sequence of detection basis ⊗⊕⊕⊗⊗⊕⊕⊕⊗⊕⊗⊗, find the sifted data set. (5)
(b) A laser operating at 800nm emits pulses at a rate of 4 MHz. The laser is attenuated so that the average power is 0.1 pW. Calculate
(i) the average number of photons per pulse;
(ii)the fraction of the pulses that contain no photons;
(iii)the fraction of the pulses that contain one photon;
(iv)the fraction of the pulses that contain more than one photon;
(v)the ratio of the number of pulses containing more than one photon to the number with just one. (5)

M. Sc. Examination, 2024
Semester-IV
Physics (Core)
Course: MPEC-42 (E-09)
Condensed Matter Physics-II

Time: Three Hours **Full Marks: 40**

(Questions are of value as indicated in the margin)
*Answer any **four** of the following*

1. Considering the exchange interaction between two spin *1/2* particles, show that the effective Hamiltonian can be written as $\hat{H} = -2J S_1 . S_2$ and hence obtain its value for singlet and triplet states. 6+4=10

2. Briefly discuss a) spin chains, b) spin ladders and c) superparamagnetism. 3+3+4=10

3. What are crystal fields? Discuss the effect of crystal field on a magnetic ion for octahedral and tetrahedral crystal environments. Hence define the high spin and low spin state for a $3d^6$ ion. 2+6+2=10

4. Obtain an expression for the dielectric function $\varepsilon(\omega, K)$ of an electron gas in terms of plasma frequency (ω_p) and hence discuss the dispersion of an electromagnetic wave when $\omega < \omega_p$ and $\omega > \omega_p$. 6+(2+2)=10

5. a) Show that the thermal expansion of a solid can be explained only if lattice potential be anharmonic.
   b) What are umklapp processes? Explain how does it explain the thermal conductivity in solids. 4+(2+4)=10

6. a) What is recoilless absorption of γ-ray by nucleus? How is this useful in Mossbauer spectroscopy?
   b) What are electric quadrupole and hyperfine magnetic field splitting in Mossbauer spectrum? Discuss with an energy level diagram for ^{57}Fe nucleus. (2+2)+(3+3)=10

7. Describe the objective, functionality and application of the following two spectroscopic techniques:
   a) muon spin resonance and b) nuclear magnetic resonance. 5+5=10

(Symbols have their usual meanings)

MSc in Physics Examination, 2024
Semester - IV
Paper: Nuclear Physics – II
Paper Code: MPEC-42 (E-12)

Time: 3 hours **F.M.: 40**

Answer any four questions

1. (a) What are the common features of the n-p scattering that are analogous to optical diffraction phenomenon? 2

(b) Solve the Schrodinger equation of a two-nucleon scattering in centre of mass frame to arrive at a term δ, the phase shift. Show that the scattering potential shifts the phase of the scattered wave at points beyond the scattering region. Draw a diagram showing the phase shifts for both attractive and repulsive potentials. 6

(c) Plot the diagram of a typical n-p scattering cross section as a function of neutron energy, and explain its features. 2

2. (a) Establish the relation that the transition probability per unit time for an incident electron scattered by a nucleus is inversely proportional to the fourth power of momentum transferred to the interacting nucleus. 6

(b) Show that the quadrupole moment of deuteron is

$$Q = \frac{1}{\sqrt{50}}\int_0^\infty dr\, r^2\, u\, w - \frac{1}{20}\int_0^\infty dr\, r^2 w^2$$

where, u(r) and w(r) are the radial wave functions in the S and D states. [For deuteron, J=S=1ħ]. 4

3. (a) What are the important differences between scattering of identical nucleons and that of different nucleons ? 2

(b) Show, with a schematic diagram, that the scattering at angle θ and π-θ in the centre-of-mass frame for the case of scattering of identical particles will lead to identical results. 3

(c) How will you define polarization of nucleons in a beam? With the help of a schematic diagram show that spin-orbit interaction comes from the concept of polarization of scattered nucleons in a nucleon-nucleon scattering experiment. 1+4

4. (a) Consider the following even-even isotopes of Nd (Z = 60):

^{148}Nd, ^{142}Nd, ^{150}Nd, ^{144}Nd, ^{146}Nd

Arrange these isotopes in terms of their increasing value of quadrupole deformation parameter (β_2). You have to justify your answer. 1+1

(b) Write down the two basic assumptions for Deformed Shell model (Nilsson model). 2

(c) On the basis of statistical theory of nuclear reaction, deduce the following expression:

$$\rho(E_x) = \rho_0 \exp(2\sqrt{aE_x})$$

where the symbols have their usual significance. 3

(d) Assume that the nucleons inside a nucleus constitute Fermi gas. Estimate the depth of the nuclear potential. Given: $R_0 = 1.2 \times 10^{-15}$ metre; $h = 6.6 \times 10^{-34}$ J-sec; mass of one nucleon $= 1.6 \times 10^{-27}$ Kg. 3

5. (a) Draw the typical fission yield curve for the thermal neutron induced fission of ^{235}U. Identify the symmetric and asymmetric components in the curve. 2+1

Draw the typical energy distribution profile of the fission fragments following the aforesaid fission reaction. 2

(b) Show that the condition for a system (with atomic number Z and mass number A) to undergo spontaneous symmetric fission is $Z^2/A > 17.6$ [Given: $a_s = 0.019114$ u and $a_c = 0.0007626$ u which represent respectively the coefficients of surface energy and Coulomb energy term of the semi-empirical mass formula] 5

6. (a) By tabulating the possible m-states of two quadrupole ($l = 2$) phonons, and their symmetrized combinations, obtain the possible 2-phonon states. Draw the level scheme of the nucleus undergoing two-phonon quadrupole modes of vibrations. Draw the possible γ-transitions between the states by applying the phonon selection rule. 2+2+1

(b) Consider the case of ^{92}Mo, which has the 6^+ isomeric state of mean-lifetime 2.22 ± 0.07 nsec. The isomeric state decays with the γ transition of energy 350 keV, and subsequently feeds the low-lying 4^+ state. Consider the branching of the transition to be 85% and ICC = 0.017. Calculate the experimental B(E2) value (in e^2b^2 unit) for the transition. 3

(c) The energy of the first excited state of an even-even nucleus is 400 keV. Draw the level scheme of the nucleus (due to collective rotational motion) up to 8^+ states. Assume that the nucleus behaves like a rigid rotor. 2

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M.Sc.(Physics) Semester-IV Examination 2024
[MPEC-42] - Nonlinear Dynamics II (E26)

Time: Three Hours | Full Marks: 40

- Answer **any four** of the following questions. Questions are of value as indicated in the margin.
- Symbols have their usual meanings unless specified otherwise. Symbols used in a question can not be changed while writing the answer for the same.

1. Consider the Hamiltonian $H(I, \theta)$,

$$H(I, \theta) = H_0(I) + \epsilon H_1(I, \theta)$$

where I, θ are the action-angle variables.

(a) Find first order corrections to I, θ and $\omega_0 = \frac{\partial H_0}{\partial I}$ within the framework of canonical perturbation theory by treating $H_1(I, \theta)$ as a perturbation to $H_0(I)$ for $\epsilon \ll 1$. 6

(b) Consider the Hamiltonian,

$$H(p.q) = \frac{1}{2}\left(p^2 + \omega^2 q^2\right) + \epsilon q^3$$

with $\epsilon \ll 1$. Express $H(p, q)$ in terms action-angle variables and show that the first order correction to the energy is zero. 4

2. (a) Obtain exact solution of the damped harmonic oscillator and express it in powers of the coefficient b of the damping term, up to the order of $O(b^2)$, when $b \ll 1$. 3

(b) Describe the Poincaré-Lindsteadt perturbation theory for a damped harmonic oscillator by treating the damping term as perturbation, and obtain up to second order corrections to the unperturbed solution. 5

(c) Compare the exact solution in the limit $b \ll 1$ with the perturbed solution and discuss your observations by explicitly mentioning the validity of the perturbed solution. 2

3. (a) State and discuss Liouville criteria of integrability. 3

(b) Verify the truth in the following statement: "A Hamiltonian system in one space dimension may or may not be integrable". 2

(c) Show that the following system

$$H = p_x^2 + p_y^2 + x^2 + y^2 + \alpha xy$$

is integrable for any values of α by constructing the required number of integrals of motion. 5

4. (a) Show that the standard map,

$$\begin{aligned} x_{n+1} &= x_n + K \sin y_n \; (\text{mod} 2\pi), \\ y_{n+1} &= y_n + x_{n+1} \; (\text{mod} 2\pi) \end{aligned}$$

is conservative. 1

(b) Show that the system is exactly solvable for $K = 0$ and plot its various orbits. 2

(c) Show that the criteria for linear stability of period-1 fixed point of a conservative two dimensional map is $\mid Tr(J) \mid < 2$, where $Tr(J)$ denotes the trace of the Jacobian matrix evaluated at the fixed point. 3

(d) Find the period-1 equilibrium points of the Standard Map and discuss their stability. 2

(e) Discuss chaos in the Standard Map. 2

5. (a) Define Autocorrelation function and power-spectra of a time series. State and prove Wiener-Khintchin theorem. 3

(b) Consider a signal of the form,

$$x_j = exp\left(i\frac{2\pi j \bigtriangleup t}{T}\right), \; j = 0, 1, \ldots, n.$$

Find an analytic expression for the k-th component of the power-spectra in the limit $\frac{n\Delta t}{T} - k \ll n$ for $\frac{n\Delta t}{T} \neq$ integer. 4

(c) Discuss the nature of power-spectra for a quasi-periodic signal. 3

6. Write notes on any two of the following topics: 5+5

(a) Hamilton-Jacobi theory

(b) Multiple time-scale analysis

(c) Poincaré Section

M.Sc. in Physics Semester-IV Examination, 2024
Paper Code: [MPEC-42]: E-05
Paper Name: Cosmology

Full Marks: 40 Time: 3 Hours

Questions are of value as indicated in the margin.

Answer **any four** questions

Symbols bear their usual meanings

1. (a) Solve the Einstein's field equations for a radiation dominated FRW universe to obtain the evolution dynamics of the universe.
(b) Show that $Tt^{1/2}$ = constant for a radiation dominated universe.
(c) Find out the luminosity distance and the angular diameter distance for a flat FRW universe with $k = 0$ when the universe is dominated by radiation ($\Omega_{r0} = 1$).
(d) Calculate the redshift of matter-radiation equality given the present value of matter density parameter $\Omega_{m0} = 0.3$ and radiation density parameter $\Omega_{r0} = 8.4 \times 10^{-5}$.

3+2+3+2=10

2. (a) What is recombination?
(b) Given that recombination happened at $z = 1100$, calculate the age of the Universe at the time of recombination assuming a spatially flat Universe with $\Omega_{m0} = 1$ and $H = 70$ km/s/Mpc.
(c) Calculate the Hubble radius at recombination for the same model.
(d) What angle would it subtend at the present observer? Assume the same cosmological parameters.
(e) What is last scattering surface?

2+2+2+2+2=10

3. (a) Calculate the neutron to proton ratio at neutrino freeze out. Given $kT_F = 0.8\,\text{MeV}$.
(b) What is the deuterium bottleneck and why was it important during the formation of nuclei in the early universe?
(c) Show that for scalar field models of dark energy, in order to drive the present observed acceleration of the universe, the potential term should dominate over the kinetic term.
(d) What is a rotation curve? Explain how rotation curve of spiral galaxies accounts for the existence of dark matter in our universe.

2+3+2+3=10

4.(a) Calculate how the density perturbations evolve in an Einstein de-Sitter cosmological model. You can use the equation governing the growth of density perturbations in an expanding universe without a derivation.
(b) Compare a density contrast at $z = 99$ and $z = 0$ in the Einstein-de Sitter model by calculating the ratio.
(c) Draw Hubble's tuning fork diagram and hence describe Hubble's morphological classification of galaxies. How are SBa type galaxies different from Sc type galaxies?
(d) Show that for a FRW universe, event horizon does not exist.

4+1+(2+1)+2=10

5. (a) Consider the Lagrangian for a scalar field ϕ as

$$L_\phi = \frac{1}{2} g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi - V(\phi)$$

and the corresponding energy momentum tensor as

$$T_{\mu\nu} = -\frac{1}{2} g_{\mu\nu} g^{\alpha\beta} \partial_\alpha \phi \partial_\beta \phi + V(\phi) g_{\mu\nu} + \partial_\mu \phi \partial_\nu \phi.$$

i) Calculate the components of the energy momentum tensor for the scalar field.
ii) From the Einstein's field equations for a scalar field, obtain the Klein-Gordon equation.
(b) Show that the entropy of the relativistic particles do not change during the expansion of the universe. (2+3)+5=10

6.(a) Using entropy conservation for the relativistics particles, show that we expect a cosmological neutrino background with present temperature $T_{\nu 0} = (\frac{4}{11})^{\frac{1}{3}} T_{CMB0}$ and number density $n_{\nu 0} = (\frac{3}{11}) n_{CMB0}$ where T_{CMB0} and n_{CMB0} are the present temperature and number density of CMB photons respectively. You can use the expressions for the energy density of the particles without a derivation.
(b) Briefly describe the horizon problem of standard Big Bang Cosmology. How does inflation solve this problem?
(c) Show that a cosmological constant model happens to be a very good candidate for inflation. 5+(2+1)+2=10

7. (a) Consider the Einstein's equations for a FRW universe.

(i) Show that these equations can be recast in the form

$$\frac{d}{dt}\left(\rho a^3\right) = -p \frac{d}{dt}\left(a^3\right)$$

(ii) From this show that

$$\frac{d}{da}\left(\rho a^3\right) = -3a^2 p$$

(b) Under what conditions a scalar field can serve as an effective candidate for Dark Energy?
(c) Explain the origin of the dipole anisotropy observed in the Cosmic Microwave Background Radiation(CMBR)?
(d) What are primary and secondary anisotropies in CMBR? (2+2)+1+3+2=10

M.Sc. in Physics Examination, 2023
Semester - IV
Paper: E05
Subject: Cosmology

Time: 3 Hours

Full Marks: 40

Questions are of value as indicated in the margin.

Answer any **four** questions.
Symbols in the questions bear their usual meanings

1. (a) Write down the Einstein's equations for homogeneous and isotropic Friedmann-Robertson-Walker (FRW) universe obeying a perfect fluid distribution. Using these equations, obtain the conservation equation for the system.
(b) Show that in a flat FRW universe with $k = 0$, the luminosity distance to a galaxy for a matter dominated universe (Ω_{m0}) is given by $d_L(z) = \frac{2}{H_0}\left[(1+z) - \sqrt{1+z}\right]$.
(c) Assuming an adiabatic expansion of the universe and a general equation of state $p = \omega\, \rho c^2$ show that $\rho \propto a^{-3(1+\omega)}$ where a is the scale factor.

(1+2)+3+4

2. (a) Solve the Einstein's field equations for a FRW universe with $k = +1$ to obtain the expression for the age of the universe in terms of observational parameters. Justify why a $k = +1$ model is also called a closed universe model.
(b) Obtain the general expression for the entropy density of the relativistic particles in the early universe.

5+5

3. (a) (i) Show that a particle species decouples from thermal equilibrium with the photon bath when its interaction rate Γ satisfies the condition $\frac{\Gamma}{H} < 1$. (ii) What are hot relics and cold relics?
(b) Obtain the non-zero Christoffel symbols for the FRW metric corresponding to t co-ordinate.
(c) Explain how cepheid variables are used to determine the distance of a galaxy.

(3+2)+3+2

4. (a) Calculate the growing mode of density perturbations in a (i) matter dominated and (ii) Lambda dominated flat universe.
(b) Draw Hubble's tuning fork diagram and explain how SBa type galaxies are different from Sb type galaxies.
(c) Find the age of a spatially flat matter dominated universe. Given $H_0 = 70\ km/s/Mpc$.

(3+2)+3+2

5. (a) Calculate the ratio of the number density of CMB photons at $z = 1100$ and $z = 0$.
(b) Briefly explain how the position of the first peak in the CMBR angular power spectrum determines the geometry of the universe.
(c) Consider the motion of a light wave crest travelling towards an observer located at the origin. Show that the redshift parameter z, which relates the frequency of absorption and emission, is given by $1 + z = \frac{a_0}{a}$ where symbols have their usual meaning.

2+4+4

6. (a) Applying the spherical collapse approximation in an Einstein-deSitter universe obtain the parametric solutions $R(t) = A\,(1 - \cos\theta)$, $t = B\,(\theta - \sin\theta)$.
(b) Show that the density contrast of a spherically symmetric overdense region in such an universe is $\delta_{NL} = 4.55$ at the time of turn-around and $\delta_{NL} = 177$ at the time of virialization.

4+(3+3)

7.(a) Consider the Lagrangian for a scalar field ϕ as

$$L_\phi = \frac{1}{2} g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi - V(\phi)$$

and the corresponding energy momentum tensor as

$$T_{\mu\nu} = -\frac{1}{2} g_{\mu\nu} g^{\alpha\beta} \partial_\alpha \phi \partial_\beta \phi + V(\phi) g_{\mu\nu} + \partial_\mu \phi \partial_\nu \phi.$$

(i) Calculate the components of the energy momentum tensor for the scalar field.
(ii) Starting from the Einstein's equations for a scalar field cosmological model, show that in order to obtain an accelerated expansion phase of the universe, the potential term of the scalar field must dominate over the kinetic term.
(b) What is 'graceful exit problem' in inflationary physics? How does slow-roll inflation provide a possible solution to this problem?
(c) Establish the relation $\frac{dz}{dt} = -H_0\,(1+z)^2\,(1 + 2zq_0)^{1/2}$ for a matter dominated universe

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

M. Sc. Physics
Semester - IV, 2023
Elective paper E-06

Answer any four

Full marks: 40 **Time:** 3Hrs

Symbols bear their usual meanings

1. Describe the
   (a) Celestial equator.
   (b) Celestial Poles.
   (c) Ecliptic.
   (d) Declination.
   (e) Right Ascention. 2 × 5

2. (a) Write down the TOV equation.
   (b) Find the limiting relation of mass and radius of a star of uniform density. (2+8)

3. (a) Define a polytrope. Write down the equation of state of a polytrope.
   (b) Establish the Lane-Emden equation for a configuration consisting of polytropic matter in equilibrium.
   (c) Solve the Lane-Embden equation for polytropic index $n = 1$ to find the radius and mass of the configuration. (1+1+4+4)

4. (a) Explain the homogeneous model of star stating clearly the assumptions.
   (b) Show that for such a model
      i. $T \propto \frac{M}{R}$
      ii. $L \propto M^3$
   (c) Is this model realistic? Justify your answer. 3+4+3

5. (a) What is a white dwarf? Why is it called *white*? What is electron degeneracy pressure?
   (b) Find out the equation of state for fully relativistic fermionic gas. ((2+2+2)+4)

6. (a) What is Penrose process? Explain how energy can be extracted from a black hole through Penrose process.
   (b) Establish the relation

$$\delta M = \frac{\kappa}{8\pi}\delta A + \Omega_H \delta J$$

(2 +4+4)

7. (a) What is the expression of surface gravity for Kerr metric?
   (b) Write down the four laws of Black hole thermodynamics. (2+ 2×4)

M. Sc. Examination, 2023

Semester IV

Subject: Physics

Paper: [MPEC 44] - Laser Physics (E-17)

Time: 3:00 Hours **Full Marks: 40**

Questions are of value as indicated in the margin

Answer ***any four*** of the following questions:

1. Consider a rectangular cavity of dimensions 2a × 2b × d. Derive an expression for the frequency of the oscillating modes inside the cavity. What will be the longitudinal mode spacing for a laser resonator with d = 100 cm (here the symbols have their usual meaning)? 8 + 2
2. Derive the Gaussian line shape function originating due to the Doppler shifting of radiation frequency with respect to moving atoms and plot it. What is the full width at half maximum of the Gaussian line shape? 7 + 1 + 2
3. What is quality factor (Q-factor) of a mode oscillating within an optical resonator? Find out a relation between the passive cavity life time and Q-factor of a mode. Assuming the following expression for the electric field associated with the cavity mode:

$$E(t) = E_0 \exp\left(-{\omega_0 t}/{2Q}\right) e^{2\pi i \nu_0 t}$$

determine the relationship between the width of the intensity distribution of the cavity mode and the corresponding Q factor. Here the symbols have their usual meaning. 1 + 2 + 7

4. What is mode locking? Derive an expression for the intensity of mode locked pulse. Why the bandwidth of a gain medium plays important role in determining the peak pulse power of a mode locked laser? 2 + 7 + 1
5. Give a brief description of reciprocal lattice model. Establish that the optically induced band to band transition in a semiconductor is most favoured for direct band gap materials. 3 + 7
6. Suppose, for a two-level system the atom-field interaction Hamiltonian is given by $-e\vec{E}.\vec{r}$, where the symbols have their usual meaning. Determine the time evolution of the system in terms of the time-dependent coefficients. What is the main problem in interpreting the result? How do we remove this problem? Define the associated density matrix elements for this problem and evaluate the average dipole moment of the atom in terms of the density matrix elements. 3 + 1 + 1 + 1 + 4
7. The electric field associated with a classical radiating electron is described by:

$E(t) = E_0 \exp(-\gamma_o t/2) \exp(-i\omega_o t)$ for $t \geq 0$

$E(t) = 0$ for $t < 0$.

Deduce the corresponding intensity distribution. Suppose the life time associated with the transition of electron in an atom from an upper state to the ground state is 2×10^{-7} sec. Determine the corresponding classical emission linewidth. Here the symbols have their usual meaning. 8 + 2

M.Sc. Examination, 2023
(Semester - IV)
Physics
Course Code: E-15
Particle Physics II

Time : Three Hours   Full Marks : 40

Questions are of value as indicated in the margin.
Answer **question no. 1 and any three** from rest of the questions.

1. Answer any *five* questions. 2×5

   (a) Can we observe a spin-1 baryon in the quark model?
   (b) Why cannot right-handed particles participate in the weak interaction?
   (c) What is $\tau - \theta$ puzzle?
   (d) What is the necessity of colour quantum number?
   (e) In the Standard Model why $SU(3)_c$ symmetry is not broken?
   (f) Check if the process $n \to p + e^- + \nu_e$ is allowed.
   (g) How to distinguish a neutrino from antineutrino?

2. (a) Briefly describe the Wu's experiment for the parity violation in weak interaction. 3
   (b) From Dirac equation find an expression for the parity operator. 3
   (c) Hence, find the parities of a quark and an antiquark? 2
   (d) Find the parity of a pi-meson and neutron in the ground states. 2

3. (a) Using the Young Tableaux method of group multiplication find the product $3 \otimes 3$ for $SU(3)$ group and $2 \otimes 2 \otimes 2$ for $SU(2)$ group. $2 + 3$
   (b) Draw the weight diagram $(I_3 - Y)$ for the Baryon decuplet with various particle contents. What can you comment about the spin of this multiplet? $3 + 1$
   (c) What is the importance of the state $\Omega^-(sss)$ in the quark model? 1

4. (a) Show that neither K^0 nor $\bar{K}^0$ are the eigenstate of the CP-operator. 2
   (b) Construct CP-eigenstates from the K^0 and $\bar{K}^0$ states. 2
   (c) Briefly describe the Cronin and Fitch experiment to show that CP is not a good symmetry. 3
   (d) Draw the Feynman diagram to show that K^0 can turn into its antiparticle $\bar{K}^0$ and vice-versa. 3

5. (a) What are the generators of the $SU(2)$ groups? 2
   (b) Show that these generators must be traceless and hermitian? 3
   (c) Express the pi-messon (spin-0) and K^*-messon (spin-1) masses in terms of its constituent quark and anti-quark masses. 5

6. (a) Show that the QED Lagrangian for a free electron is not invariant under a local gauge transformation. 4

(b) How to obtain a QED invariant Lagrangian. 4

(c) Why can't we have mass term for the gauge boson in this Lagrangian? Why do we need to generate mass for the gauge bosons? $1+1$

7. Discuss the phenomena of Higgs mechanism for a local $U(1)$ gauge symmetry in detail to generate the mass for the corresponding gauge boson. 10

M.Sc. Examination, 2023

Semester-IV

Physics

Course: [MPEC-42]-Quantum Electronics II (Elective Paper, E-20)

Time: Three Hours Full Marks:40

Questions are of value as indicated in the margin.

Answer ***any four*** questions

1. Discuss how the second harmonic generation is obtained in a laboratory? Obtain an expression for the conversion efficiency in a second harmonic generation. (4+6)

2. How the parametric interaction and hence the parametric amplifier is taken care quantum mechanically? What you mean by noise terms? (8+2)

3. Explain what you mean by Raman scattering? Establish the classical Hamiltonian for Raman Scattering. Obtain an expression for the rate of change of Stokes photon number. What is the basic difference between Stimulated and spontaneous Raman scattering. (1+2+6+1)

4. Assuming the undpleted pump condition, obtain the conversion efficiency of second harmonic generation of input Gaussian beam. What you mean by confocal focussing? The second harmonic generation under confocal focussing condition is achieved by using $\lambda = 1\mu m$ in KH_2PO_4 of length $1\,cm$, $d = 3.6\times 10^{-24}\ MKS$ and $n = 1.5$. Obtain the conversion efficiency. (5+1+4)

5. Define Squeezing operator $S(\zeta)$. Establish the following relations

$$\begin{aligned} S^\dagger(\zeta) a S(\zeta) &= a\cosh r - a^\dagger \exp(i\theta)\sinh r \\ S^\dagger(\zeta) a^\dagger S(\zeta) &= a^\dagger \cosh r - a\exp(-i\theta)\sinh r \end{aligned}$$

where $\zeta = r\exp(i\theta)$. Why the eigenstate of the squeezing operator is termed as two-photon coherent state? Assuming $\theta = 0$ and the initial squeezed vacuum state $|\zeta >= S(\zeta)|0>$, show that

$$\begin{aligned} (\Delta X_1)^2 &= \tfrac{1}{4}\exp(-2r) \\ (\Delta X_2)^2 &= \tfrac{1}{4}\exp(2r) \end{aligned}$$

where X_1 and X_2 are the usual dimensionless quadrature operators. (1+5+1+3)

6. Give two examples where the squeezed states could be used. Show that the two-photon annihilation operator (b) due to Yuen operating on the squeezed vacuum state gives rise to zero ($i.e$ $b|\xi >= 0$). Establish that Yuen operator b is also an eigenoperator of squeezed coherent state with eigenvalue $\alpha\cosh r + \alpha^* e^{i\theta}\sinh r$, where the symbols are of usual meanigs. (2+4+4)

7. The nonlinear Schrodinger equation is $-\frac{1}{2}\sigma\mu\frac{\partial^2 E_\omega}{\partial\tau^2} - \lambda|E_\omega|^2 E_\omega = i\frac{\partial E_\omega}{\partial\xi}$ (Symbols are of usual meaning). Interpret the equation physically? In absence of nonlinearity, solve the NLS equation in the integral form. (2+8)

Examination: MSc in Physics, 2023
Semester: Sem-IV
Subject: [E-12] – Nuclear Physics – II

Time: 3 hours **F.M.: 40**

Answer any four questions

1. (a) The first excited state of ^{69}Zn (Z = 30) decays with the half-life of 13.8 hour. Deduce the spin-parity for the ground state and excited state on the basis of spherical shell model. Hence explain the origin of the long-lived excited state. 1+1+2

(b) "Internal conversion is not a two step process" – Explain the statement with simple argument. 1

(c) The nucleus, ^{168}Er (Z = 68) has the first, second, third, and fourth excited states at the excitation energies of 80 keV, 264 keV, 549 keV, and 928 keV, respectively. The J^{π} values of the four excited states are 2^+, 4^+, 6^+, and 8^+, respectively. Draw the necessary level scheme (following approximate scale limit) and show the most dominant decay paths (along with their multipolarities) of the gamma transitions. Calculate the B(E2) values (in Wu) for the most probable γ-decay transitions.

Given: half-lives of the first, second, third, and fourth excited states are 1.853 ns, 114 ps, 12 ps and 3.56 ps, respectively.

[*No need to take into account the effect of internal conversion*] 2+3

2. (a) Deduce the standard expression for the dependence of nuclear level density on the excitation energy of a nucleus. [*You have to deduce the expression following the assumptions of Statistical Theory of Nuclear Reaction*]. 5

(b) Draw a suitable figure illustrating the effect of shell-closure on level-density parameter. 2

(c) Draw the necessary curve to show the presence of resonance in a particular nuclear reaction. 2

(d) On the basis of partial wave analysis of nuclear reaction, what should be the maximum percentage component of nuclear reaction in the presence of all the accompanying possible events? 1

3. (a) Write down two limitations of Spherical Shell model. 2

(b) Write down the two basic assumptions for Deformed Shell model (Nilsson model). 2

(c) Draw the single particle levels following spherical shell model in order to accommodate fifty numbers of neutrons (you have to include the spin-orbit coupling effect). 4

(d) "Woods-Saxon potential is considered to be the best mean filed potential for spherical shell model" 2

4. (a) Draw the necessary curves to represent the dependency of internal conversion co-efficient on gamma transition energy fort the elements, Zr (Z=40), Nd(Z=60) and Hg(Z=80). Consider the concerned gamma transitions are of electric dipole nature. 2

(b) "Shell prediction for the ground state spin-parity of ^{75}As (Z = 33) is $5/2^-$; whereas the experimentally observed value for the same is $3/2^-$" – State your views on the issue incorporating the necessary justification. 3

(c) Distinguish between "Spin isomer" and "Shape isomer"? 2

(d) Write down the possible Nilsson quantum numbers for the lowest N = 5, $h_{11/2}$ based Nilsson orbits. Arrange the Nilsson orbits according to their increasing values of energies for a given deformation. 2+1

5. (a) Identify the degenerated excited states originating from the two-phonon octupole excitation mode by making the necessary m-scheme table. Hence, draw the low-lying levels starting from zero octupole phonon ground state, one octupole phonon excited state, and two octupole phonon excited states. 4

(b) What is Harris parametrization? 2

(c) Illustrate the backbending phenomena with a suitable diagram. 2

(d) On the basis of what parameters, you would distinguish a vibrating nucleus from a rotating one. 2

M. Sc. Examination, 2023
Semester-IV
Physics (Core)
Course: MPEC-42 (E-09)
Condensed Matter Physics-II

Time: Three Hours **Full Marks: 40**

(Questions are of value as indicated in the margin)
*Answer any **four** of the following*

1. Explain (a) direct exchange, (b) superexchange and (c) RKKY interaction in solids. 3+4+3

2. What are spin waves and magnons? Obtain the magnon dispersion relation and hence Bloch's $T^{3/2}$ law. 2+5+3

3. Write down the Frohlich Hamiltonian and hence obtain the BCS ground state energy for a superconductor using Bogoliubov transformation. 10

4. (a) Derive the expression for Lagrangian strain tensor, η_{ij}, of rank two and define Brugger's 2nd and 3rd order elastic constants. What is Voigt abbreviation? How many independent 2nd order elastic constants survive for cubic crystals?
(b) Discuss Fuch's elastic constants in terms of deformation parameters for a cubic crystal. 6+1+1+2

5. (a) Show that for a crystal lattice with r atoms / unit cell, the vibration frequencies for a wave vector k are obtained from the solution of a 3r - degree secular equation built from the elements of the dynamical matrix.
(b) Discuss the conditions satisfied by the dynamical matrix. 8+2

6. (a) Define Frenkel defects and Schottky defects. Deduce the expressions for the equilibrium concentration of Frenkel and Schottky defects.
(b) Calculate the concentration of Schottky vacancies at 300 K if the energy required to remove a Na atom from the inside of a Na crystal to the boundary is 1eV. 8+2

7. Answer any two of the following:
(a) What are Cooper pairs? How do they lead to superconducting state?
(b) What is superparamagnetism? Briefly discuss.
(c) Discuss 'Diffusion' and obtain the expression for 'Diffusion coefficient' or 'Diffusivity'. Mention its unit.
(d) What do you mean by acoustic and optical modes of vibration? In optical mode of vibration show that the two ions in a unit cell in an ionic crystal moves in opposite directions (oscillations are out of phase by π) while the mass centre of the cell remains fixed, discuss its optical significance. 5+5

(Symbols have their usual meanings)

M.Sc. Examination, 2023
(Semester-IV)
Physics
Course: MPEC-44(E-01)
(Topics in Modern Quantum Mechanics)

Time: Three Hours **Full Marks: 40**

- Questions are of value as indicated in the margin.
- Symbols have their usual meanings unless specified otherwise.
- **Symbols used in a question can not be changed while writing answer for the same.**
- Answer **any four** of the following questions.

1. Consider the zero-energy ground-state wave-function ψ_0 of a Hamiltonian H,

$$\psi_0(x) = (\text{sech}(\alpha x))^{\frac{A}{\alpha}}$$

   (a) Find condition(s) for normalizability of ψ_0 on the whole line. 2

   (b) Find the Hamiltonian H. 2

   (c) State the shape-invariance condition for a generic suspersymmetric Hamiltonian. 2

   (d) Solve the eigenvalue problem of H by using the techniques of supersymmetric quantum mechanics. 4

2. (a) Establish the following relations involving the eigenvalues $E_n^{(\pm)}$ and eigen functions $\psi_n^{(\pm)}$ of the the supersymmetric partner Hamiltonians $H^{(+)} = AA^\dagger$ and $H^{(-)} = A^\dagger A$ in the supersymmetric phase: 3

$$E_n^{(+)} = E_{n+1}^{(-)}, \; E_0^{(-)} = 0, \; n = 0, 1, 2, 3, \ldots$$

$$\psi_n^{(+)} = \left(E_{n+1}^{(-)}\right)^{-\frac{1}{2}} A\psi_{n+1}^{(-)}, \; \psi_{n+1}^{(-)} = \left(E_n^{(+)}\right)^{-\frac{1}{2}} A^\dagger \psi_n^{(+)}$$

   (b) Explain the degeneracy in the eigen spectra of $H^{(-)}$ and $H^{(+)}$ with the help of supersymmetry algebra. 3

   (c) The eigenvalues and the eigenfunctions of the Hamiltonian $H_1 = A_1^\dagger A_1 + E_0^{(1)}$ are denoted as $E_n^{(1)}$ and $\psi_n^{(1)}$, respectively. Construct a Hamiltonian $H_p = A_p^\dagger A_p + E_{p-1}^{(1)}$ that is isospectral with H_1 except for the first $p-1$ eigenvalues of H_1, i.e. $E_n^{(p)} = E_{n+1}^{(p-1)} = E_{n+2}^{(p-2)} \cdots = E_{n+p-1}^{(1)}$, $p \geq n+1$, n=0, 1, ..., p-1. 4

3. (a) Find the density matrix for a partially polarized beam with 50% of $|S_z;-\rangle$, 30% of $|S_x;+\rangle$ and remaining 20% of $|S_y;+\rangle$. 2

(b) Consider $\tilde{\rho} = \lambda\rho_1 + (1-\lambda)\rho_2,\ 0 < \lambda < 1$, where $\rho_{1,2}$ correspond to density matrices of two distinct pure ensembles. Show that $\tilde{\rho}$ corresponds to a mixed ensemble, i.e. $Tr(\tilde{\rho}^2) < 1$. 2

(c) Show that the density matrix in the Schrödinger picture satisfies the relation:

$$\frac{\partial \rho}{\partial t} = \frac{1}{i\hbar}[H, \rho]$$

where H is the Hamiltonian governing the system. 2

(d) Consider a composite system consisting of two spin-$\frac{1}{2}$ particles with the sub-systems denoted as $A\&B$. Ignore the spatial degrees of freedom. Denote the eigenstates of $S_z^{(a)}, a = A, B$ of the two sub-systems as $|s, m_s\rangle_a$. Determine whether the state

$$|\psi\rangle_{AB} = \frac{1}{\sqrt{2}}\left[|\frac{1}{2},\frac{1}{2}\rangle_A\,|\frac{1}{2},\frac{1}{2}\rangle_B + |\frac{1}{2},-\frac{1}{2}\rangle_A\,|\frac{1}{2},-\frac{1}{2}\rangle_B\right]$$

is an entangled state or not by calculating its Schmidt number. 4

4. (a) Write a short note on Bell's inequality. 5

(b) Consider the spin-singlet state $|0,0\rangle$ of two spin-$\frac{1}{2}$ operators $\vec{S}_{(A)}$ and $\vec{S}_{(B)}$, the 2×2 identity matrix I and two linearly independent unit vectors $\hat{a}, \hat{b}$. Prove the following identity: 5

$$\left\langle 0,0\middle|\left(\frac{1}{2}I + \vec{S}_{(A)}\cdot\hat{a}\right)\left(\frac{1}{2}I + \vec{S}_{(B)}\cdot\hat{b}\right)\middle|0,0\right\rangle = \frac{1}{4}\left(1 - \hat{a}\cdot\hat{b}\right)$$

5. (a) Evaluate the propagator $K(x_f, t_f; x_i, t_i)$ of a free particle of mass m in the momentum basis and show that, 3

$$K(x_f, t_f; x_i, t_i) = \sqrt{\frac{m}{2\pi i\hbar(t_f - t_i)}}\, e^{\frac{i}{\hbar}S_0[x_c]},\ S_0[x_c(t)] \equiv \frac{m}{2}\frac{(x_f - x_i)^2}{t_f - t_i}.$$

(b) Verify that the propagator $K(x_f, t_f; x_i, t_i)$ satisfies the free particle Schrödinger equation in terms of the variables x_f and t_f. 2

(c) Evaluate $K(x_f, t_f; x_i, t_i) = \mathcal{N}\int_{x(t_i)=x_i}^{x(t_f)=x_f} \mathcal{D}[x(t)]e^{\frac{i}{\hbar}S_0[x(t)]}$ by using path-integral technique and compare it with the result obtained for the same in the momentum basis to fix the constant $\mathcal{N}$. 5

6. (a) Prove the convolution property of the propagator $K(x_f, t_f; x_i, t_i) \equiv \langle x_f | e^{-\frac{i}{\hbar}(t_f - t_i)H} | x_i \rangle$, where $|x_i\rangle$ and $|x_f\rangle$ denote the position eigenkets at the initial time t_i and the final time t_f, respectively. 2

(b) Show that $\tilde{K}(x_f, t_f; x_i, t_i) \equiv \theta(t_f - t_i) K(x_f, t_f; x_i, t_i)$ is the retarded Green's function for the Schrödinger equation, where $\theta(t_f - t_i)$ is the Heaviside step function. 2

(c) Show that the functional determinant of the operator $\hat{O} := -\partial_t^2$ is infinite, 6

$$Det[-\partial_t^2] = \prod_{n=1}^{\infty} \frac{n^2 \pi^2}{(t_f - t_i)^2}$$

M.Sc. Examination – 2023
Semester – IV
Physics
Paper – MPEC-44
(Communications (E-22))

Time: Three Hours **Full Marks: 40**

Questions are of value as indicated in the margin
Answer question number 1 and any three.

1. Answer any *ten* of the following: 1 x 10
   (a) What do you mean by "Flicker noise"?
   (b) What is meant by "Noise figure"?
   (c) What is the need for modulation in communication?
   (d) What do you mean by "Ideal sampling" in PCM?
   (e) What do you mean by "DPCM" in digital modulation?
   (f) What do you mean by "Numerical Aperture" for an optical fiber?
   (g) What type of materials are used in fiber optic cable?
   (h) What does the term "OOK" mean in the context of digital modulation?
   (i) Is it possible to design a fiber optic cable using air as the cladding?
   (j) What do you mean by "modulation index"?
   (k) What do you mean by "laser chirping"?
   (l) What is the use of a "Product modulator" in communication?

2.
   (a) Mention the different modulation techniques used in digital communication. Explain the working principle of Binary Phase Shift Key (BPSK), a modulation scheme used in digital modulation. 2+3
   (b) State the sampling theorem used in Pulse Code Modulation (PCM). What do you mean by "Quantization error"? Show that the RMS of the quantization error is inversely proportional to the number of quantization levels. 2+1+2

3.
   (a) What do you mean by a "DSB-SC" signal? Can you detect a "DSB-SC" signal by an envelope detector? Give reasons for your answer. 2+2
   (b) What do you mean by "Synchronous detector"? A DSB+C signal is accompanied by a band-limited white noise. Calculate the "Noise figure" using a synchronous detection method at the receiver. 2+4

4.
   (a) Explain the working principle of a simple slope discriminator with the help of a circuit diagram. 4

(b) What do you mean by Pre-emphasis and De-emphasis in an FM broadcasting system? Draw a simple Pre-emphasis circuit and explain the working principle. 2+2

(c) A sinusoidal modulating waveform of amplitude 5 V and a frequency of 2 KHz is applied to the FM generator, which has a frequency sensitivity of 40 Hz/volt. Calculate the frequency deviation and modulation index. 2

5.

(a) What do you mean by the angle of acceptance for an optical fiber? Establish a relationship between the acceptance angle and the relative refractive index of an optical fiber. Do all the angles within the acceptance angle allow light propagation through an optical fiber? Justify your answer. 1+2+2

(b) What do you mean by the V-number of an optical fiber? What is the significance of this number? 1+2

(c) A step-index fiber has the following parameters: Core radius = 6.7 μm, Core refractive index, n1 = 1.447, cladding refractive index, n2 = 1.445. Calculate the cut-off wavelength for the single-mode operation of this fiber. Determine whether this fiber will act as a single-mode fiber for a light of 1.3 μm. 2

6.

(a) Mention some advantages and disadvantages of optical communications. 2

(b) What do you mean by electro-optic material? What is the use of electro-optic material in optical communication? Explain the working principle of the IM-DD indirect method with the help of a neat sketch. 1+2+3

(c) What do you mean by WDM in the context of optical communication? 2

M.Sc. (Physics) Semester-IV Examination, 2023
Particle Physics I
(E 14)

Time : 3 Hours | Full Marks: 40

Question 1 is compulsory. Answer any four questions from the rest. Questions are of value as indicated in the margin.

Unless otherwise specified symbols carry their usual meanings and the Standard Model (SM) of Particle Physics is assumed.

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1. Answer each question. 8×2

   (a) Explain briefly how a nuclear emulsion plate acts as target, detector and data storage.

   (b) A proton with four-momentum $(E,\ \vec{P})$ is incident on a proton at rest: $p+p \to p+p+p+\bar{p}$. What is the minimum energy (E_{min}) required for this process? Assume $M_p = 1\ GeV/c^2$.

   (c) Write down the values of the quantum numbers associated with a u quark.

   (d) Explain whether the decay $p^+ \to e^+ + \pi^0$ is allowed in the Standard Model.

   (e) Use the commutation properties of the Pauli spin matrices σ_i to prove $(\vec{\sigma}\cdot\vec{p})^2 = |\vec{p}|^2$.

   (f) Show that the adjoint spinor $\bar{u}$ satisfies the equation $\bar{u}\,(\gamma^\mu p_\mu - m) = 0$.

   (g) Parity operation for a Dirac spinor is given by $P(\psi) \to \psi' = \gamma^0\psi$. Calculate $P(\overline{\psi})$ and $P(\overline{\psi}\gamma^\mu\psi)$.

   (h) Write the the possible final state(s) for the interaction $\nu_\mu + e^- \to$. Draw the corresponding lowest order Feynman diagram(s).

2. (a) Briefly describe with a schematic diagram the major components of a modern collider detector.

   (b) Describe how the following particles produced in collisions will be detected in such a detector: i) a photon; ii) an electron; iii) a muon. $3+3$

3. (a) For photon mediated interactions, estimate without detailed calculations the ratio

$$\frac{\sigma\,(e^+e^- \to u\bar{u})}{\sigma\,(e^+e^- \to \mu^+\mu^-)}$$

   (b) Estimate the following ratio at different centre-of-mass energies ($\sqrt{s}$) where q denotes all quarks that are kinematically allowed.

$$\frac{\sigma\,(e^+e^- \to q\bar{q})}{\sigma\,(e^+e^- \to \mu^+\mu^-)}$$

   Explain how these results can prove that quarks have 3 colors. 2+4

4. Prove the following using the properties of Dirac γ matrices: 1+2+3

   (a) $\overline{\psi}_L = \overline{\psi} P_R$

   (b) $\overline{\psi}\gamma^\mu (1-\gamma^5)\psi = \overline{\psi}_L\gamma^\mu (1-\gamma^5)\psi_L$

(c) $Tr\,(\gamma^\mu \not{a} \gamma^\nu \not{b}) = 4\,(a^\mu b^\nu + a^\nu b^\mu - (a.b) g^{\mu\nu})$

5. Quark compositions for D^0, K^+, K^-, π^+ and π^+ respectively are $c\bar{u}$, $\bar{s}u$, $s\bar{u}$, $u\bar{d}$ and $\bar{u}d$.

   (a) Draw the Feynman diagrams for the decays $D^0 \to \pi^+ K^-$, $D^0 \to \pi^+\pi^-$ and $D^0 \to \pi^- K^+$.

   (b) In the spectator quark approximation, estimate in terms of the Cabibbo angle $\Gamma\,(D^0 \to \pi^+ K^-) : \Gamma\,(D^0 \to \pi^+\pi^-) : \Gamma\,(D^0 \to \pi^- K^+)$ 2+4

6. (a) The charge raising current is defined as $J^\mu = \bar{u}_\nu \gamma^\mu \frac{1}{2}(1-\gamma^5) u_e$. Show that the charge lowering current is the hermitian conjugate of J^μ: $J^\dagger_\mu = \bar{u}_e \gamma^\mu \frac{1}{2}(1-\gamma^5) u_\nu$

   (b) Define helicity.

   (c) The experimental value of

$$\frac{\Gamma\,(\pi^+ \to e^+ \nu_e)}{\Gamma\,(\pi^+ \to \mu^+ \nu_\mu)} \sim 1.2 \times 10^{-4}$$

   although phase space considerations favor decays for which the mass decrease is larger. Explain with appropriate diagram(s). 2+1+3

7. (a) Briefly describe neutrino detection using chemical and water Cerenkov techniques. Name one experiment for each technique.

   (b) What are the advantages and disadvantages of the two techniques? 3+3

Examination: MSc in Physics, 2023
Semester: Sem-IV
Subject: [E-32] – Nuclear Astrophysics

Time: 3 hours **F.M.: 40**

Answer any four questions

1. (a) Draw a representative curve showing the abundances of nuclides in the solar system at its birth. 2
(b) What is the specialty of ^{56}Fe peak in the curve? 2
(c) Illustrate the p-process of nucleosynthesis. 2
(d) What is Hertzsprung – Russel diagram? 2
(e) What are brown dwarfs? 2

2. (a) Illustrate the reciprocity theorem. 4
(b) In the laboratory, β^+-decays of the nuclide ^{26}Al have been observed both from the ground state ($J^\pi = 5^+$) and from the first excited (isomeric) state ($J^\pi = 0^+$) located at an excitation energy of $E_x = 228$ keV. The ground state decays via positron emission to the excited levels in the daughter nucleus ^{26}Mg with a half-life of $T_{1/2}(gs) = 7.17 \times 10^5$ y, while the first excited state decays to the ^{26}Mg ground state with a half-life of $T_{1/2}(ms) = 6.345$ s. Above a temperature of T = 0.4 GK, both of these ^{26}Al levels are in thermal equilibrium. Calculate the stellar half-life of ^{26}Al when the plasma temperature amounts to T = 2 GK. [Consider $kT = 0.0862\ T_9$ MeV] 4
(c) What do you mean by the term "spectroscopic factor"? Mention its usefulness. 1+1

3. (a) Mention the importance of "Gamow peak" in stellar nucleosyntehsis. 2
(b) Do the necessary mathematical steps to find out the general expression for the width of the Gamow peak. 6
(c) What is the specialty of mass number A = 5 and A = 8 in the nuclear chart? 1
(d) What is Hoyle state? 1

4. (a) Write down the three different sequences of pp-chains. 2
(b) Draw the necessary curves to show the fraction of ^{4}He nuclei produced by the pp1, pp2 and pp3 chains with varying temperatures. 2
(c) The reaction $^{A}X(n,\gamma)^{A+1}X$ has a resonance at 0.256 eV whose width is 0.105 eV. Calculate the mean lifetime of the resonance state. Given: value of reduced Planck constant = 1.054×10^{-34} Joule-sec. 2
(d) Deduce the standard expression for photodisintegration decay constant for a typical photo disintegration reaction. 4

5. (a) Write down the four different sequences of CNO-cycles. 4

(b) Write down the set of coupled differential equations for a closed CNO1 cycle. 2

(c) Draw the necessary curve to show the variation of power generation per unit mass of fuels with temperature for proton-proton and CNO processes. 2

(d) Write down the most likely primary reactions for Carbon burning process. 2

M.Sc Sem-IV Examination (Elective Paper)---2023

MPEC-44: E-29

Thin Film Deposition and Vacuum Techniques

Full Marks: 40 Time: 3 hours

Answer any four (4) questions. Marks are shown in the margin.

1. (a) What do you mean by 'Thin film'? What are different categories of processes of fabricating thin film? Write down their names. 3
(b) Write down the typical steps in fabricating thin film by physical vapour deposition process (PVD) with suitable schematic diagram. 3
(c) What is the need of 'mechanical shutter' in vapour deposition technique? 1
(d) Write down the process flow in 'thermal vapour deposition'. 2
(e) For powder sample vapour deposition what type of crucible will you use? 1

2. (a) Why silicon (Si) cannot be deposited by thermal deposition method? 1
(b) Write down the relative advantages of physical vapour deposition (PVD) process over chemical vapour deposition (CVD) process. 2
(c) Why the melting point of refractory materials decreases inside the vacuum? Can you give some suitable example of such material? 1.5
(d) What are the two different main method to vacuum a chamber? On that basis draw a chat for different type vacuum pumps and write down their names. 2.5
(e) What is meant by pumping speed (S) and throughput (Q) of vacuum pump? 2
(f) If a mechanical vacuum pump obtains a base pressure of 15 mTorr, what is compression ratio (K) of the vacuum pump? 1

3. (a) What is the roll of 'gasket' in vacuum chamber? What are different type of gaskets and which range of chamber pressure they are used? 1.5

(b) What are the different type of 'Gauges' used to measure the chamber pressure and mention their respective range of use? 1

(c) Draw the schematic diagram of 'Ionization Gauge' and describe the working principles. 3.5

(d) What do you mean by nucleation and growth of thin film? Draw schematic diagram and show the different processes for the formation of thin film on the substrate. 3

(e) What do you mean by coalescence of islands and write the name of the type of coalescences? 1

4. (a) Write down the names of three fundamental type of growth modes and describe the growth modes with schematic diagram. 2

(b) Describe with proper detailing the structure and working principle of oil sealed rotary vane pump with appropriate schematic diagram. 4

(c) Write down short notes on oil diffusion pump (DP). 3

(d) What is the use of liquid nitrogen trap in connection with the diffusion pump? 1

5. (a) Describe the grazing angle incidence x-ray reflection phenomenon on a surface with suitable diagram. 5

(b) Show how the thickness of a thin film can be measured using x-ray reflectivity measurements. 5

6. (a) Write short notes on:

(i)Scanning electron microscopy

(ii)Transmission electron microscopy 5+5