RAMAKRISHNA MISSION VIDYAMANDIRA

(Residential Autonomous College affiliated to University of Calcutta)

B.A./B.Sc. SIXTH SEMESTER EXAMINATION, JULY 2021

THIRD YEAR [BATCH 2018-21]

PHYSICS (HONOURS)

Paper : IX

Date : 13/07/2021

Time : 11.00 am - 3.00 pm

Full Marks : 100

Group - A

Answer **any five** questions of the following : [5×10]

1) a) Estimate the thickness of lead (density 11.3 g cm^{-3}) required to absorb 90% of gamma rays of energy 1MeV. The absorption cross-section of gamma rays of energy 1MeV in lead (A = 207) is 20 barns/atom.

b) Show that if the two decay fragments are of equal size, (i.e. X=A/2, Y=Z/2), then

$$Z^2/A > a_s(2-2^{2/3}) / a_c(2^{2/3}-1) > 18$$

c) Use the above equation to estimate the energy given out in the fission of U-235 to two equal sized fragments. (3+5+2)

2) a) Show that the maximum velocity that can be imparted to a proton at rest by non-relativistic alpha particle is 1.6 times the velocity of the incident alpha particle.

b) The α-particle from *ThC'* have an initial energy of 8.8 MeV and a range in standard air of 8.6 cm. Find their energy loss per cm in standard air at a point 4 cm distance from a thin source.

c) A collimated beam of 1.5MeV gamma rays strikes a thin tantalum foil. Electrons of 0.7 MeV energy are observed to emerge from the foil. Are these due to the photoelectric effect, Compton scattering or pair production? Assume that any electrons produced in the initial interaction with the material of the tantalum foil do not undergo a second interaction. (2+4+4)

3) a) Radium being a member of the uranium series occurs in uranium ores. If the half lives of uranium and radium are respectively 4.5×10^9 and 1620 years, calculate the relative proportions of these elements in a uranium ore, which has attained equilibrium and from which none of the radioactive products have escaped.

b) Using liquid drop model, Prove that to dissociate a proton from a heavy nucleus needs more energy than to dissociate a neutron (assuming that the specific nuclear forces are exactly equal between all pairs of nucleons).

c) Explain qualitatively how the neutrino hypothesis solves the apparent breakdown of conservation of angular momentum and energy in Beta-decay? (4+5+1)

4) a) Calculate the energy to be imparted to an α-particle to force it into the nucleus of U-238 (r_0 = 1.2 fm). Assume only Coulomb barrier.

b) Radium, Polonium and RaC are all members of the same radioactive series. Given that the range in air at S.T.P of the α-particles from Radium (half-life time 1622 Year) the range is 3.36 cm where as from polonium (half life time 138 D) the range is 3.85 cm. Calculate the half-life of *RaC'* for which the α-particle range at S.T.P is 6.97 cm.

c) Explain the role of spin-orbit coupling to explain the magic numbers in the shell model of nucleus. (4+5+1)

5) a) From the shell model predictions find the ground state spin and parity of the following nuclides: ${}_2He^3$; ${}_{13}Al^{27}$; ${}_{21}Sc^{41}$.

b) A nucleus has the following sequence of states beginning with the ground state: $3/2^-$, $7/2^-$, $5/2^+$, $1/2^-$, $3/2^-$. Draw a level scheme showing the intense *gamma* transitions likely to be emitted and indicate their multipole assignment. Which of the transitions would you expect to be have the smallest chance to happen? [3+(5+2)]

6) a) Calculate the energy of protons detected at 90^o when 2.1 MeV deutrons are incident on ^{27}Al to produce ^{28}Al with an energy difference $Q = 5.5$ MeV.

b) Calculate the thickness of Indium foil which will absorb 1% of neutrons incident at the resonance energy for Indium (1.44 eV) where $\sigma = 28000$ barns. At. Wt. of Indium = 114.7 amu, density of Indium = 7.3g/cm^3.

c) By considering the general conditions of nucleus stability show that the nucleus $_{90}Th^{229}$ will decay and decide whether the decay will take place by α or β emission.

The atomic mass excesses of the relevant nuclei are:

$_2He^4 = 2603$ amu $\times 10^{-6}$

$_{88}Ra^{225} = 23528$ amu $\times 10^{-6}$

$_{89}Ac^{229} = 32800$ amu $\times 10^{-6}$

$_{90}Th^{229} = 31652$ amu $\times 10^{-6}$

$_{91}Pa^{229} = 32022$ amu $\times 10^{-6}$ (3+3+4)

7) a) Calculate the maximum wavelength of γ-rays which in passing through matter, can lead to the creation of electrons.

b) Calculate the thickness of aluminum in g cm^{-2} that is equivalent in stopping power of 2 cm of air. Given the relative stopping power for aluminum $S = 1700$ and its density = 2.7 g cm^{-3}.

c) Since $_{14}Si^{27}$ and $_{13}Al^{27}$ are "mirror nuclei", their ground states are identical except for charge. If their mass difference is 6 MeV, estimate their radius (neglecting the proton-neutron mass difference). (3+3+4)

8) a) The masses of the mirror nuclei $_{13}Al^{27}$ and $_{14}Si^{27}$ are 26.981539 (amu) and 26.986704 (amu) respectively. Determine the Coulomb's coefficient in the semi empirical mass formula.

b) Assuming that the energy released per fission of U-235 is 200MeV, calculate the number of fission processes that should occur per second in a nuclear reactor to operate at a power level of 20000 kW. What is the corresponding rate of consumption of U-235.

c) Determine the range of neutrino energies in the solar fusion reaction, $p + p \rightarrow d + e^+ + \nu$. Assume the initial protons have negligible kinetic energy and that the binding energy of the deuteron is 2.22MeV, $m_p = 938.3$MeV/c^2 and $m_d = 1875.7$MeV/c^2 and $m_e = 0.51$MeV/c^2.

d) Classify the following transitions (the spin parity, J^P, of the nuclear states are given.):-

$^{14}O \rightarrow {}^{14}N* + e^+ + \nu \; (0^+ \rightarrow 0^+)$

$^6He \rightarrow {}^6Li + e^- + \nu \; (0^+ \rightarrow 1^+)$. (3+2+3+2)

Group - B

Unit - I

Answer **any two** questions of the following : [2×10]

9) a) Calculate the De Broglie wavelength of an electron accelerated to energy 30 GeV. How will you consider whether a particle is relativistic or not?

b) If the strong binding force between nucleons in a nucleus follows from the Yukawa potential given by $V(r) = -g\frac{e^{-\mu r}}{r}$ where g is a constant, what should be the mass of the exchanged particle? What would be the value for μ ? Take the strong interaction range as 10 fm.

Take $\hbar c = 197 MeV\ fm$; Compton wave length of a particle of mass m is $\lambda_c = \frac{h}{mc}$.

c) What should be the threshold energy of a photon for the production of an e^+e^- pair? (2+6+2)

10) a) In strong interactions we often see processes $\pi^- + p \to K^0 + \Lambda^0$ but never see process like $\pi^- + p \to \pi^0 + \Lambda^0$. However, Λ^0 decays weakly by $\Lambda^0 \to \pi^- + p$. How do you explain these processes?

b) State with reasons which of the following interactions are allowed and which are forbidden.

i) $\pi^- + p \to p + \bar{p} + \pi^+ + \pi^-$. Assume that the incident π^- has sufficient kinetic energy.

ii) $\mu^- \to e^- + \nu_\mu + \bar{\nu}_e$

iii) $e^- + p \to \nu_e + n$

iv) $p \to \pi^+ + n$

v) $K^- + p \to \Omega^- + K^+ + K^0$

vi) $\Sigma^+ \to n + e^+ + \nu_\mu$

c) In a process going via strong interaction $K^- + p \to \Xi^- + K^+$, what should be the strangeness of Ξ^-? (2+6+2)

11) a) What do you mean by the Isospin symmetry for strong interactions? What is the Gell-Menn-Nishijima (G-N) scheme? What would be the 3rd component of Isospin for $\bar{K}^0$ and K^- according to the G-N scheme?

b) What is a Pseudo vector? How does the magnetic field transform under parity? Explain. What should be the parity of hydrogen atom energy eigen-states? Explain.

c) Show the quark structure of Λ^0 and π^+. (2+6+2)

Unit - II

Answer **any three** questions of the following : [3×10]

12) a) In 1838, after four years of observing 61 Cygni, Bessel announced his measurement of a parallax angle of $0.316''$ for that star. How far the star is from us?

b) Proxima Centauri (α Centauri C) is the closest star to the Sun and is a part of triple star system. It has the epoch J2000 coordinates $(RA, dec) = (14^h 29^m 42.95^s, -62^o 40' 46.1'')$. The brightest member of the system, Alpha Centauri (α Centauri A) has J2000 coordinates of $(RA, dec) = (14^h 39^m 36.50^s, -60^o 50' 02.3'')$.

i) What is the angular separation of Proxima Centauri and Alpha Centauri?

ii) If the distance to Proxima Centauri is 4.0×10^{16} m, how far is the star from alpha Centauri?

c) A star at a distance of 4 pc has an apparent magnitude 2. What is its absolute magnitude? Given the fact that the Sun has a luminosity 3.9×10^{26} W and has an absolute magnitude of about 5, find the luminosity of the star.

d) The Hubble Space Telescope has a primary mirror diameter 2.4 m. Determine its angular resolution at a visible wavelength of 500 nm.

e) Why radio waves with wavelengths larger than 10 m cannot reach Earth's surface? Determine the resolution of the Very Large Array (VLA) at a wavelength of 2 cm, assuming a baseline of 35 km. [2+2+1+(1+1)+1+(1+1)]

13) a) If we neglect intergalactic extinction, why galaxies which has been resolved by a telescope would appear equally bright irrespective of how far they are? Then why to distant star look dimmer?

b) Consider a model of star Dschubba (δ Sco), the center star in the head of the constellation Scorpius. Assume that Dschubba is a spherical blackbody with a surface temperature of 28000 K and radius of 5.16×10^{9} m. Let this model star be located at a distance of 123 pc from Earth. Determine the following of the star: (i) Luminosity, (ii) Absolute magnitude, (iii) Apparent magnitude, (iv) Radiant flux at star's surface, (v) Radiant flux at Earth's surface, (vi) Peak wavelength λ_{max}.

c) Consider a large hollow spherical shell of hot gas surrounding a star. Under what circumstances would you see the shell as a glowing ring around the star? What can you say about the optical thickness of the shell? [(1+1)+(1+1+1+1+1+1)+(1+1)]

14) a) A stellar atmosphere composed of pure helium. The ionization energies of neutral helium and singly ionized helium are $\chi_I = 24.6$ eV and $\chi_{II} = 54.4$ eV respectively. The partition functions are $Z_I = 1, Z_{II} = 2$ and $Z_{III} = 1$. Use $P_e = 20$ Nm-2 for the electron pressure. Find N_{II}/N_I and N_{III}/N_{II} for temperatures of 5000 K, $15{,}000$ K and $25{,}000$ K. How do they compare? Show that $N_{II}/N_{total} = N_{II}/(N_I + N_{II} + N_{III})$ can be expressed in terms of the ratios N_{II}/N_I and N_{III}/N_{II}.

b) Suppose a star of total mass M and radius R has a density profile $\rho = \rho_c(1 - r/R)$, where ρ_c is the central density. (i) Find $M(r)$, (ii) Express the total mass M in terms of R and ρ_c, (iii) Solve for the pressure profile, $P(r)$, with the boundary condition $P(R) = 0$. [(3+1+1)+(1+1+3)]

15) a) Consider that the solar luminosity 3.9×10^{26} W, and 4 protons are required to produce a He nucleus releasing about 26 MeV of energy. Estimate the number of protons used per second to account for the observed luminosity. Also, estimate the flux of neutrinos on the Earth due to the nuclear reactions in the interior of the Sun (Neglect pp2 and pp3 branch).

b) Calculate the ratio of the energy generation rate for the pp chain to the energy generation rate for the CNO cycle given conditions characteristic of the center of the present-day (evolved) Sun, namely $T = 1.5696 \times 10^{7}$ K, $\rho = 1.527 \times 10^{5}$ kgm^{-3}, $X = 0.3397$ and $X_{CNO} = 0.0141$.

c) Near the orbit of the Earth, the solar wind has a velocity of about 400 kms^{-1} and contains about 10 protons per cm^3. Assuming that the solar wind always had these characteristics during the Sun's lifetime of 4.5×10^9 year, estimate the fraction of mass the Sun have lost in the solar wind during its lifetime.

d) The rotational period of the Sun near the equator is about 25 days and about 36 days near the poles. Determine the time taken by a point at the equator to complete one more revolution compared to a point near the pole.

e) Differential rotation can give rise to toroidal field lines from poloidal field lines, how this toroidal field lines produces toroidal field lines? [(1+1)+2+2+2+2]

16) a) Under what conditions star formation takes place inside dark molecular cloud? Let's say the Jeans mass for a cloud at a temperature of 10 K is $5M_\odot$. By what approximate factor would the Jeans mass change if the temperature increases to 100 K, with other physical properties remaining the same?

b) Why type Ia supernovae are almost identical while type II supernovae are different from each other?

c) In a fully degenerate gas, all the particles have energies lower than the Fermi energy. For such a gas we found the relation between the density n_e and the Fermi momentum p_F: $n_e = \frac{8\pi}{3h^3} p_F^3$.

i) For a nonrelativistic electron gas, use the relation $p_F = \sqrt{2m_e E_F}$ between the Fermi momentum, the electron mass m_e and the Fermi energy E_F. Express E_F in terms of n_e and m_e.

ii) Estimate a characteristic n_e under typical conditions inside a white dwarf. Using the result of (i), and assuming a temperature $T = 10^7$ K, evaluate the ratio E_{th}/E_f, where E_{th} is the characteristic thermal energy of an electron in a gas of temperature T, to see that the electrons inside a white dwarf are indeed degenerate.

d) The Crab pulsar has period $P = 0.033$ s and characteristic slowing time $\dot{P}/P = 2.5 \times 10^3$ year. Estimate the energy loss rate and the magnetic field. [(2+1)+2+1+2+2]

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