2022

PHYSICS — HONOURS

Paper : DSE-B-1(a) and DSE B-1(b)

The figures in the margin indicate full marks.

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

Paper : DSE-B-1(a)

(Astronomy and Astrophysics)

Full Marks : 65

Answer ***question nos.*** 1 and 2 and ***any four*** questions from the rest.

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

(a) The luminosity of a star is 40 times that of the Sun and its temperature is twice as much. Determine the radius of the star in terms of solar radius.

(b) If the apparent magnitudes of the components of a binary star are 1 and 2, what will be the total apparent magnitude of the system? (*hint* : it's not 3, unlike the flux we cannot simply add magnitudes.)

(c) Show that the specific intensity along the ray in free space is constant.

(d) For the same diameter, compare the resolving power of an optical telescope operating at $\lambda = 457$ nm (nanometer) and a radio telescope operating at $\lambda = 1$ cm.

(e) What is meant by Local Thermodynamic Equilibrium?

(f) Argue that the p-p chain reaction is somewhat capable to explain the fact that the sun is still shining beyond the Kelvin-Helmholtz time scale.

(g) Consider a carbon white dwarf of mass 1.4 M_{sun}, the Chandrasekhar mass. How many ^{12}C nuclei are there?

2. Answer ***any three*** questions :

(a) At one stage during its birth, the protosun had a luminosity of 1000 $L_{\odot}$ and a surface temperature of about 1000 K. At this time, what was its radius? Express your answer in three ways : as a multiple of the Sun's present-day radius, in kilometers, and in astronomical units (AU). 5

(b) Briefly discuss the different stages of stellar evolution, starting from the main sequence to creation of white dwarfs, neutron stars and black holes along with their observational evidences. 5

(c) Explain briefly the possibility of nuclear fusion inside the core of stars irrespective of the fact that two nuclei of same charge repel each other due to Coulomb interaction. 5

(d) Consider the value of solar luminosity to be 3.9×10^{26} W, and four protons are required to produce a helium 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 earth due to nuclear reactions inside the sun. (Neglect pp2 and pp3 branches, and use 1 AU $=1.5\times10^{11}$ m.). 3+2

(e) Use the Friedmann equation and the fluid equation to derive the acceleration equation for an expanding universe. 5

3. (a) The mass of star Sirius is thrice that of the Sun. Find the ratio of their luminosities and the difference in their absolute magnitudes. Taking the absolute magnitude of the Sun as 5, find the absolute magnitude of Sirius. (Use the scaling relation $L \sim M^{3.5}$, Sirius is 47 times more luminous than Sun; $M_{\text{Sirius}} = 0.83$)

(b) Calculate the diffraction limit of resolution of Mount Palomar telescope of 200 inch diameter for $\lambda = 457$ nm. Compare its light gathering power with a telescope of 200 mm diameter.

(c) Show that pressure due to isotropic radiation field is given as $p_\nu = \dfrac{4\pi I_\nu}{3c}$. 3+3+4

(Symbols have their usual meanings)

4. (a) From the first principles of statistical mechanics, obtain the scaling relationship between pressure and density of a degenerate fermi gas in non-relativistic limit.

(b) What are the limitations of Chandrasekhar's theory?

(c) What are brown dwarfs? 5+2+3

5. (a) Suppose a star has a density profile $\rho(r) = \dfrac{A}{r(r_s + r)^2}$. Find out the mass contained within a radius r. (A and r_s are constants.)

(b) Find out the speed of rotation $v(r)$ and plot it as a function of r.

(c) Show that for $r << r_s$, $v \sim \sqrt{r}$. 3+(2+2)+3

6. (a) Derive the hydrostatic equilibrium equation of stellar structure for spherically symmetric objects under the assumption that accelerations are negligible.

(b) Consider a sun-like star with mass $M = 1.99\times10^{30}$kg and radius $R = 6.96\times10^{8}$ m.

(i) From the hydrostatic equilibrium equation for star, calculate the pressure at radius $r = R_\odot/2$.

(ii) Estimate its temperature at $r = R_\odot/2$ (take the mean molecular weight of the star $\mu = 0.61$).

(iii) Calculate the radiation pressure in the star at $r = R_\odot/2$.

(take the radiation constant $a = 7.57\times10^{-16}$ J/m^{3}K^4)

4+(3+2+1)

7. (a) The two Friedmann equations for a simple flat universe are given as

$$\left(\frac{\dot{R}}{R}\right)^2 = \frac{8\pi G}{3}\rho$$

$$\frac{\ddot{R}}{R} = -\frac{4\pi G}{3}\left(\rho + \frac{3P}{c^2}\right)$$

where R is the scale factor, ρ is the mean mass density and P is the pressure of the Universe.

(i) From the above equations derive the *fluid equation* as

$$\dot{\rho} + 3\frac{\dot{R}}{R}\left(\rho + \frac{P}{c^2}\right) = 0.$$

(ii) Now consider only radiation with pressure $P = \frac{1}{3}\rho c^2$ and show that $\rho \propto R^{-4}$. What is the physical explanation for density falling as the fourth power of scale factor?

(iii) Using Friedmann equation, show that the Hubble parameter for this universe will be

$$H(t) = \frac{1}{2t}.$$

(b) What is *Einstein-de Sitter* Universe? Considering a small expanding spherical region in this universe, show that mean density of the universe (known as the *critical density* ρ_c) is $\rho_c = \frac{3H^2}{8\pi G}$.

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

8. Consider a spherical region of the universe having total mass $M = \frac{4\pi r^3}{3}\rho$, with density ρ, centred on a given point of radius r at a time t. Take a test galaxy of mass m at the edge of that massive sphere. It will be affected by a central force due to gravity and the cosmological force as :

$$m\ddot{r} = -\frac{4\pi G}{3}\frac{r^3\rho m}{r^2} + \frac{1}{3}m\Lambda r$$

Note that, both r and ρ are changing with time and can be expressed in terms of scale factor R as $r = (R/R_0)r_0$ and $\rho = (R_0/R)^3\rho_0$.

(a) Show that,

$$d\left(\dot{R}^2\right) = -\frac{2a}{R^2}dR + \frac{2}{3}\Lambda R dR$$

where $a = 4\pi G R_0^3 \rho_0 / 3$.

(b) From there arrive at the basic differential equation governing $R(t)$:

$$\frac{\dot{R}^2}{H_0^2 R_0^2} = \Omega_0 \frac{R_0}{R} + \Omega_\Lambda \left(\frac{R}{R_0}\right)^2 + 1 - \Omega_0 - \Omega_\Lambda$$

where $\Omega_0 = \rho_0/\rho_c$ and $\Omega_\Lambda = \Lambda/(3H_0^2)$. The critical density $\rho_c = 3H_0^2/8\pi G$.

(c) Now take a simple Universe with $\Omega_\Lambda = 0$ and $\Omega_0 = 1$. By solving the equation for $R(t)$, show that the age of this Universe is $t_0 = \frac{2}{3}\frac{1}{H_0}$. 3+4+3

Paper : DSE-B-1(b)

(Nuclear and Particle Physics)

Full Marks : 65

Answer ***question nos.*** **1**, and **2** and ***any four*** questions from the rest.

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

(a) Which of the nuclei between $^{54}_{27}$Co and $^{55}_{27}$Co do you expect to have higher neutron capture cross-section and why?

(b) Justify that the time scale of direct nuclear reactions is of the order of 10^{-22} s.

(c) Compare the stopping power of a proton and an alpha-particle of same energy in a particular medium.

(d) Why is the scintillation detector more efficient than the GM counter for the detection of γ-ray?

(e) Give an experimental evidence of short range nature of nuclear force.

(f) Neutron is electrically neutral, but has a magnetic moment $-1.91\ \mu_N$. Explain the reason.

(g) Find the distance of closest approach of 1 MeV proton incident on gold nucleus ($Z = 79$) with zero impact parameter.

2. Answer ***any three*** questions :

(a) What are mirror nuclei? Give an example. Find out the mass difference between two mirror nuclei in terms of their mass number by using the semi-empirical mass formula. 2+3

(b) What do you mean by stripping nuclear reaction? Give an example. Define the Q value of nuclear reaction in terms of the nuclear binding energy and thereby calculate the Q value of the $^{27}Al(n,p)^{27}Mg$ reaction. Given, the binding energies of ^{27}Al and ^{27}Mg are 224.95 MeV and 223.76 MeV respectively. 2+3

(c) Using a schematic circuit diagram, explain the working principle of a semiconductor detector for detecting nuclear radiation. What are the main advantages of semiconductor detectors amongst all types of radiation detectors? 3+2

(d) Why is it necessary to increase the length of the successive tubes in a linear accelerator (LINAC)? Show that the length of the nth tube of a LINAC is proportional to $\sqrt{n}$. 2+3

(e) Mention the distinct characteristics of the weak interaction. Are the parity and strangeness conserved in weak interaction? Give an example of a phenomenon involving the weak interaction. 3+1+1

3. (a) Calculate the nuclear surface area and estimate the Coulomb repulsion energy of ^{17}O nucleus. Determine its spin and parity in the ground state.

(b) $^{64}_{28}Ni$ and $^{64}_{29}Cu$ have atomic masses 63.9280 u and 63.9298 u respectively. Which of these nuclei exhibits β disintegration and of what type? Justify your answer. Given, the mass of electron is 0.0005 u. (2+2+2)+4

4. (a) Consider the following reaction where X is the target nucleus at rest, a is the projectile, Y is the residual nucleus and b is the outgoing particle.

$$a + X \rightarrow Y + b$$

Draw the appropriate vector diagram of the above reaction in the centre of mass frame.

(b) Suppose you would like to produce $^{92}_{40}Zr$ as compound nucleus using $^{76}_{32}Ge$ as target and $^{16}_{8}O$ as projectile. What should be the minimum beam energy (kinetic energy) of $^{16}_{8}O$?

(c) A nucleus (X) undergoes α decay by emitting two groups of α-particles of different energies accompanying by γ-radiation. Represent this process in the energy level diagram. 3+4+3

5. (a) What is Cherenkov radiation? Show that the necessary condition for Cherenkov radiation is $v > c/n$, where v is the velocity of the particle, c is the velocity of light in free space and n is the refractive index of the medium.

(b) What is the typical energy of the electron emitted in the β disintegration? How such an electron loses energy while passing through a medium?

(c) The absorption cross-section of 1 MeV gamma rays in lead (mass number 208, density 11.25 g/cc) is 20 barns/atom. Check whether a lead block of thickness 7 cm will act as shield for 1 MeV gamma rays. (1+3)+(1+2)+3

Please Turn Over

6. (a) Derive an expression for the maximum energy of acceleration attainable in a fixed frequency cyclotron. Is it possible to use the same cyclotron for accelerating deuterons and α-particles? Explain. In which case do you expect higher energy of acceleration?

(b) Why is it not possible to accelerate the ions to their relativistic energies with fixed frequency cyclotron? How is this limitation circumvented with a synchro-cyclotron? (3+2+1)+(2+2)

7. (a) Describe the working principle of a GM counter for the detection of nuclear radiation. Why is it not possible to detect the type and measure the energy of the incident radiation by using GM counter?

(b) Why a meson with charge +1 and strangeness –1 is not possible?

(c) What is strange about strange particles? (4+2)+2+2

8. (a) Using the conservation of lepton number, find out the missing particles in the following muon decay :

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

(b) Explain the eightfold way in reference to the meson octet.

(c) An isospin singlet baryon has strangeness of –3. Determine the hypercharge and electric charge of the baryon. Do you identify the baryon?

(d) Are the following reactions allowed or forbidden? Justify your answer.

(i) $\Xi^- \rightarrow n + \pi^-$

(ii) $\pi^- + n \rightarrow \Sigma^- + K^0$. 2+3+2+3