B.Sc

2024

PHYSICS — HONOURS

Paper : DSE-B-1.1 and DSE-B-1.2

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-1.1

(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) What is cosmological red shift? How is it different from Doppler shift?

(b) Why does helium fusion require much higher temperatures than hydrogen fusion?

(c) Define parsec. How is it related to astronomical unit (a.u.)?

(d) The apparent magnitude of a star is observed to be +3.3 and its parallax is $0.025''$. Find the absolute magnitude of the star.

(e) The surface temperatures of Sirius A and Sirius B are found to be equal. The absolute magnitude of Sirius B is larger than that of Sirius A by 10. Compare their radii.

(f) What is meant by Chandrasekhar limit?

(g) What is Hubble's law?

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

(a) Calculate the non-relativistic escape velocity v of a particle from the surface of a sphere of radius r and uniform mass density ρ. Show that if one assumes Hubble's law $v = Hr$, the particle will escape provided $\rho < 3H^2/8\pi G$. 3+2

(b) Draw a neat sketch of the Hertzsprung-Russell (H-R) diagram labelling the axes carefully and locate the position of

(i) The main sequence starts with the Sun.

(ii) The red giants.

(iii) The white dwarfs.

(iv) The supergiants. 5

(c) (i) Using laws of thermodynamics, derive the fluid equation

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

(ii) A yellow supergiant star X has the same colour as the sun and it has 10000 times larger luminosity compared to the sun. Find the ratio of radii of the star X and the sun. 3+2

(d) What are apparent and absolute magnitudes of a star? Show that

$$m-M=5\log_{10}\left(\frac{d}{10\text{ pc}}\right),$$

where m and M are the apparent and the absolute magnitudes of a star respectively and d is the distance to the star in parsec (pc). 2+3

(e) What is the Big Bang theory? Explain how Hubble's law and discovery of cosmic microwave background radiation support the Big Bang theory. 1+4

3. (a) Derive the Friedmann equation

$$H^2=\frac{8\pi G}{3}\rho+\frac{\kappa}{a^2}$$

from Newtonian gravity, where κ is the curvature parameter.

(b) Hence, derive the acceleration equation

$$\frac{\ddot{a}}{a}=\frac{4\pi G}{3}\left(\rho+\frac{3p}{c^2}\right).$$ 5+5

4. (a) Starting from First law of thermodynamics, derive the Stefan-Boltzmann law.

(b) For a non-relativistic degenerate electron gas, $p \propto \rho^{5/3}$ (p is the pressure and ρ is the mass density). Using scaling arguments show that radius of a non-relativistic white dwarf which is supported by electron degeneracy scales with its mass as $R \propto M^{-1/3}$.

(c) Compare the resolving power of an optical telescope operating at 457 nm and a radio telescope operating at 1 cm, both having the same diameter of 200 cm. 4+3+3

5. (a) What is the origin of the 21 cm line of hydrogen? Explain the importance of this line in astronomy.

(b) Derive the expression of Jeans mass (M_J) for a spherical cloud of hydrogen of radius R. Using this, obtain a relation between the Jeans mass and the density of a star assuming that the collapse process is adiabatic. (2+2)+(4+2)

6. (a) Suppose a star has a radius 1.67 $R_\odot$ and a luminosity 25 $L_\odot$. Use this information to calculate the energy flux at the surface of that star. Then calculate its surface temperature.
Take $R_\odot = 6.9598\times10^8$ m and $L_\odot = 3.839\times10^{26}$ W.

(b) At stellar temperatures, the peak flux of a blackbody occurs at either ultraviolet, optical or at near-infrared wavelengths such that $hc/\lambda >> kT$. Use this approximation to derive Wien's Displacement law from Planck's law. (2+3)+5

7. (a) Suppose $B_\nu(T)$ represents the specific intensity of blackbody radiation at temperature T. Show that when radiation of frequency ν passes through matter with absorption coefficient α_ν, the change in the specific intensity I_ν as it moves an infinitesimal distance ds is given by,

$$\frac{dI_\nu}{ds} = \alpha_\nu[B_\nu(T(s)) - I_\nu(s)].$$

Assume that the matter is locally in thermal equilibrium.

(b) Find a formal solution to the above radiative transfer equation and prove that $I_\nu \to B_\nu$ when the optical depth $\tau_\nu \to \infty$. 5+5

8. (a) For a spherically symmetric star with total mass M, radius R, density $\rho(r)$ and pressure $P(r)$ in hydrostatic equilibrium, show that

$$\int_0^R \frac{GM(r)}{r^3} dM(r) = 4\pi \int_0^R P(r)dr,$$

where $M(r)$ is the mass enclosed within the radius r.

(b) From the stellar structure equation related to hydrostatic equilibrium show that the pressure profile $P(r)$ of a model star of radius R and constant density ρ is given by

$$P(r) = \frac{2}{3}\pi G\rho^2\left(R^2 - r^2\right).$$ 5+5

Please Turn Over

Paper : DSE-B-1.2
(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) What do you mean by saturation of nuclear force?

(b) Write down the nuclear magic numbers. Why are they so called?

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

(d) What is the role of neutrinos in the process of beta decay?

(e) Find the Q value of the following nuclear reaction :

$$^{4}_{2}\text{He} + {}^{14}_{7}\text{N} \rightarrow {}^{17}_{8}\text{O} + {}^{1}_{1}\text{H}$$

Given, atomic mass of $^{4}_{2}$He, $^{14}_{7}$N, $^{17}_{8}$O and $^{1}_{1}$H are $4.0038727u$, $14.003074u$, $16.999133u$ and $1.007825u$ respectively. Indicate also if the reaction is exoergic on endoergic.

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

(g) What are the basic differences between baryons and mesons?

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

(a) (i) Assuming that nuclear matter is incompressible justify that the radius (R) of a nucleus of mass number A, can be written as $R \propto A^{\frac{1}{3}}$.

(ii) Using the single particle shell model, calculate the ground state spin and parity of $^{27}_{13}$Al. Draw the necessary energy level diagram. 2+3

(b) Explain the pair production process and identify the conditions required for it to occur. Find the wavelength of photon of minimum energy that can produce an electron position pair. 3+2

(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 n-th tube of a LINAC is proportional to $\sqrt{n}$. 2+3

(e) Explain with reasons whether the following reactions are allowed or forbidden :

(i) $p \rightarrow \pi^+ + \pi^- + e^-$

(ii) $\pi^+ + n \rightarrow \pi^0 + k^+$

(iii) $p + \pi^- \rightarrow n + \pi^0$ 1+2+2

3. The semi-empirical mass formula, neglecting the pairing energy term, is given by :

$$M(A,Z) = ZM_H + Nm_n - a_1 A + a_2 A^{\frac{2}{3}} + a_3 \frac{Z^2}{A^{\frac{1}{3}}} + a_4 \frac{(A-2Z)^2}{A}$$

where $a_1 = 0.016919u$, $a_2 = 0.019114u$, $a_3 = 0.000763u$, $a_4 = 0.02544u$, $M_H = 1.00784u$ and $m_n = 1.00864u$.

Symbols have their conventional significance.

(a) Using this formula, show that $M(A, Z)$ follows a parabolic variation with Z for a group of isobars.

(b) Find out an expression for the atomic number for the most stable isobar and hence identify the most stable isobar corresponding to mass number $A = 109$.

(c) What are mirror nuclei? Find out the mass difference between two mirror nuclei in terms of their mass number by using the semi-empirical mass formula. 3+(2+1)+(1+3)

4. (a) What is Compton effect? Derive an expression for the change in wavelength of the scattered light.

(b) A photon with an initial energy of 0.5 MeV undergoes Compton scattering of an electron at rest. If the photon is scattered at an angle of 60°, calculate the energy of the scattered photon.

(c) Define nuclear reaction cross-section. On what factors does the nuclear reaction cross-section depend? (1+4)+2+(1+2)

5. (a) Why the compound nucleus theory became necessary in nuclear reaction? Write down the typical time-scale of compound nucleus formation.

(b) What is Cherenkov radiation? Show that the necessary condition for Cherenkov radiation is $v > \frac{c}{n}$, 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.

(c) A beam of neutrons is incident on a thick layer of Cd. Find the absorption length. Given : density of Cd = 8650 kg/m^3 and neutron absorption cross-section = 24,500 barn. (2+1)+(1+3)+3

6. (a) Explain the basic principles of photomultiplier tube (PMT).

(b) What is scintillation process? Why is photomultiplier tube used in a scintillation detector?

(c) The average energy deposited per fission of ^{235}U with slow neutron in a neutron-fission counter is 200 MeV. Find the pulse height produced by a capacitor of 40 pF connected to the collecting electrode. Assume that an average energy of 35 eV is needed to produce an ion pair. 3+(1+2)+4

Please Turn Over

7. (a) Describe the basic working principle of a van-de Graaff generator and its application in accelerating charged particles.

(b) Explain how a synchrotron accelerates particles and discuss one major advantage it has over a cyclotron.

(c) A cyclotron is used to accelerate protons. Given a magnetic field strength of 1.2 T and a final radius of 0.3 m, calculate the velocity and the corresponding momentum of proton in non-relativistic approximation. 4+3+3

8. (a) Draw the meson octet diagram labelling each meson with its quark content.

(b) Write the Gellmann-Nishijima formula explaining each term. A neutral baryon has isospin $I = \frac{1}{2}$. Calculate its strangeness number. Identify the particle.

(c) Why we do not observe protons to decay? 5+(2+1+1)+1
