

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 stars with the Sun.
 - (ii) The red giants.
 - (iii) The white dwarfs.
 - (iv) The supergiants. 5

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- (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

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

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 $R_{\odot} = 6.9598 \times 10^8 \text{ m}$ and $L_{\odot} = 3.839 \times 10^{26} \text{ W}$.

(3)

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- (b) At stellar temperatures, the peak flux of a blackbody occurs at either ultraviolet, optical or at near-infrared wavelengths such that $hc/\lambda \gg kT$. 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 $I_\nu \rightarrow B_\nu$, when the optical depth $\tau_\nu \rightarrow \infty$. 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

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

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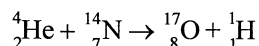
Paper : DSE-B-1.2
(Nuclear and Particle Physics)

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 :



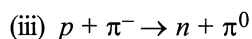
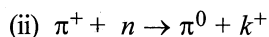
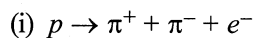
Given, atomic mass of ${}^4_2\text{He}$, ${}^{14}_7\text{N}$, ${}^{17}_8\text{O}$ and ${}^1_1\text{H}$ are $4.0038727u$, $14.003074u$, $16.999133u$ and $1.007825u$ respectively. Indicate also if the reaction is exoergic or endoergic.

- (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 ${}^{27}_{13}\text{Al}$. 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 positron 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 :



1+2+2

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

$$M(A, Z) = ZM_H + Nm_n - a_1A + a_2A^3 + a_3 \frac{Z^2}{A^{\frac{1}{3}}} + a_4 \frac{(A - 2Z)^2}{A}$$

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

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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
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