Ref. No. Ex/SC/PHY/UG/DSE/TH/01/3B/2022

B. Sc. Physics Examination, 2022

(3rd Year, 2nd Semester)

Subject : Astrophysics

(Subject Code : UG/SC/DSE/PHY/TH/01/3B)

Time : Three hours | Full Marks : 80

Use separate Answer Script for both Groups A and B

Some useful constants: Solar mass ($M_\odot$) $= 1.98 \times 10^{30}$ Kg; Solar luminosity ($L_\odot$) $= 3.83 \times 10^{26}$ W; Solar radius ($R_\odot$) $= 6.98 \times 10^8$ m; AU$= 1.49 \times 10^{11}$ m; Persec $= 3.08 \times 10^{16}$ m; G$= 6.67 \times 10^{-11}$ N m^2 kg^{-2}; $m_e = 9.109 \times 10^{-31}$ Kg; $m_p = 1.672 \times 10^{-27}$ Kg; $m_n = 1.674 \times 10^{-27}$ Kg; $m_H = 1.673 \times 10^{-27}$ Kg; Stefan-Boltzmann constant (σ) $= 5.67 \times 10^{-8}$ Wm^{-2} K^{-4}, $e = 1.6 \times 10^{-19}$ C, $h = 6.62 \times 10^{-34}$ J-sec.

Group: A

Answer any ***Four*** questions

1. (a) What is virial theorem ? Calculate the self gravitational potential energy of a spherical star of mass M and radius R with an average density ρ. Find the thermal energy and total energy of the star using virial theorem.
(b) Find the thermal (Kelvin-Helmholtz) time scale of a hypothetical white dwarf star of mass 1.0 $M_\odot$ and radius 10^{-2} $R_\odot$. It has a thin, high-opacity, nondegenerate shell at effective (surface) temperature 33,000 K as compared with the solar effective temperature of 5800 K. The luminosity is $L = 4\pi R^2 \sigma T_{eff}^4$.
[(1+3+1)+5]

2. A star is a sphere of gas that is held together by its self gravity, and is balanced against collapse by pressure gradients through hydrostatic equilibrium. Using the hydrostatic equilibrium condition, estimate the temperature from the pressure assuming that the interior of the **sun** corresponds to an ideal gas of ionized hydrogen and having constant mass density? What is the central temperature of the sun? Is this also a lower limit on the true temperature? What is the estimated central pressure of the Sun? [7+1+1+1]

3. (a) A ray of frequency ν passes through medium of optical depth τ, energy may be added or subtracted from it by emission or absorption. Define emission coefficient and absorption coefficient.
(b) Derive the formal solution $I_\nu(\tau)$ of the radiative transfer equation where both the mechanism (absorption and emission) are present. In this derivation you assume that the source function is constant.
(c) Find out the solution $I_\nu(\tau)$ for following cases (i) medium is optically thick i.e. $\tau \to \infty$ and (ii) optically thin i.e. $\tau << 1$. Make comments on the specific intensity along the ray propagation when source function $S_\nu > I_\nu$. [2+5+(1+1+1)]

4. (a) What is the Solar Corona ? Give some properties of the Solar Corona.
(b) Derive the model-pressure created by Solar Corona at a distance r ($r > R_\odot$, surface distance from the center of the Sun) from the center of the Sun using hydrostatic equilibrium concept i.e. the corona is hydrostatic equilibrium with the hot gas surrounding the Sun. Further, you assume that the Corona is not isothermal envelope of hot gas surrounding the Sun. Why does this pressure model fail to explain the pressure in the Interstellar Medium (ISM) ?. [(2+2)+(5+1)]

5. Short note on (a) Limb darkening, (b) Solar neutrino and (c) Solar seismology. [4+3+3]

Group: B

Answer any ***Four*** questions

6. (a) Assume that, in our galaxy, all stars have same intrinsic luminosity L. Further assume that, stars are uniformly distributed in 3D with number density n. Show that the total number of stars having flux greater than f_0 follows the scaling relation $N(f > f_0) \propto f_0^{-3/2}$. What could be possible explanation if the observed N increases slowly with decreasing f compared to the above relation?
(b) Assume that a Cepheid variable has a mean apparent magnitude of 18 and period of 10 days. Calculate its distance. The absolute magnitude (M) varies with the period P as $M = -2.78log_{10}(P) - 1.35$. [(3+2)+5]

7. (a) The rotational velocity of a star, which is 20 Kpc from the centre of a spiral galaxy, is 300 km/s. The total amount of luminous matter (baryonic matter) inside the radius 20 Kpc is measured to be $1.046 \times 10^{11} M_\odot$. Calculate the fraction of the dark matter the galaxy has inside the above radius.
(b) What is the Tully-Fisher relation and how this relation can be used to estimate distances to distant spiral galaxies? [6+4]

8. (a) How do the star formation rate and fraction of gas change from Sa-Sc galaxies?
(b) Our galaxy hosts a supermassive black of mass $\sim 4 \times 10^6 M_\odot$ in its centre. Estimate the size of the Schwarzschild radius corresponding to the blackhole and its angular size observed from the earth. Will a telescope similar in size to the diameter of the earth be able to resolve the angular size at wavelength 1.3 m? [(2.5)+(2.5+2.5+2.5)]

9. (a) Discuss, briefly, the major stages that a star with initial mass $M < 8M_\odot$ go through and corresponding physical processes occur during those major stages.
(b) Show that the electron degeneracy pressure inside a white dwarf scales as $P_e \propto \rho^{4/3}$ in the relativistic case, where ρ is the matter density inside the white dwarf. [5+5]

10. (a) Show that the age of a pulsar can be written as $t_{\text{pulsar}} = \frac{\omega_0^3}{2\dot{\omega}_0}\left(\frac{1}{\omega_0^2} - \frac{1}{\omega_i^2}\right)$, where ω_0 and ω_i are the present and initial angular (during formation) frequencies of the pulsar respectively. $\dot{\omega}_0$ is the present value of $d\omega/dt$.
(b) The supernovae associated with the Crab pulsar occurred in the year 1054. The present angular frequency and the rate of change of the angular frequency are found to be $190\,\text{s}^{-1}$ and $-2.4 \times 10^{-9}\, s^2$. Calculate the time period of the Crab pulsar during the time it was formed. [5+5]