BIRLA INSTITUTE OF TECHNOLOGY AND SCIENCE, PILANI
SECOND SEMESTER 2022-2023

Comprehensive Exam 2023 (Closed Book)

Part-I

Course Title: **Introduction to Astronomy & Astrophysics (PHY F215)** Date: 06.05.2023

Max. Time: 90 min. Total Marks: 60

NAME______________________________ **ID. No.**_________________________________ **MARKS** ☐

Instructions:

- ✓ ***All questions are compulsory and of 2 marks. Write ONLY the answers in the box provided below each question.***
- ✓ **$k = 1.38 \times 10^{-23}$ JK^{-1}, $c = 3\times10^{8}$ m s^{-1}, $M_\odot = 2 \times 10^{30}$ kg, $L_\odot = 3.8 \times 10^{26}$ J s^{-1}, 1 AU = 1.49×10^{11} m, 1 pc = 3.08×10^{16} m**

Q1. How does a 1 $M_\odot$ star move on an H-R diagram immediately after turning off from the main-sequence? How does a 5 $M_\odot$ star move? If there is a difference in this stage of these two stars, what is/are the reasons behind it?

Q2. Which physical parameter becomes constant inside the cores of stars after the core H fusion is over? Why?

Q3. Does the luminosity of the Sun increase, decrease, or remain constant when the Sun is on the main-sequence? Explain why.

Q4. What is the source function? What is its relation with specific intensity?

Q5. What was the Solar neutrino problem? What was its resolution?

Q6. When a low- or intermediate-mass star is in the red giant branch phase, it does not produce any nuclear energy in its core. Explain why its luminosity still steeply rises in this phase.

Q7. In stellar evolution, we come across these timescales: Dynamic, Kelvin-Helmholtz, and Nuclear. Arrange them from shortest to longest.

Q8. Sketch the butterfly diagram of sunspots. Label the graph as accurately as possible.

Q9. What are coronal holes? Are they related to any observed phenomena?

Q10. Define mean molecular weight. Why do we need to know its value inside stars? (No need to derive the numerical value.)

Q11. Explain the meaning of $\frac{dlnP}{dlnT} < 2.5$. Where is this condition found to be true? Write all the examples that were discussed in the course.

Q12. Can we observationally confirm that Sun has a convective envelope? If yes, write how? Mention only the **direct** evidence.

Q13. If we could cut it open, which kind of stars (in which stage) would have an Onion shell structure? Why?

Q14. What is Schonberg-Chandrasekhar limit? Is there any observational verification of it? What is it?

Q15. What constitutes the confirmation of convection in evolved low and intermediate-mass stars?

Q16. What would it imply for the star to have Eddington luminosity?

Q17. If massive stars are unable to fuse elements heavier than Iron inside their cores, how do we explain the existence of heavier elements such as Uranium or Radium on Earth?

Q18. During the RGB stage, the core of a 1 $M_\odot$ star has heated up to a temperature of about 2.0 x 10^7 K, and at the same time, it has become dense with a density of 1.0 x 10^8 kg m^{-3}, whereas the core of a 5 $M_\odot$ star has heated up to a temperature of about 2.2 x 10^8 K, and at the same time it has become dense with a density of 1.0 x 10^9 kg m^{-3}. Check the condition of degeneracy for both these cores. Which of these cores are degenerate?

Q19. A main-sequence star at a distance of 50 pc is barely visible using a certain telescope. However, when in its giant branch, its temperature would drop by a factor of three and its radius would increase by a factor of 100, what is the new maximum distance at which the star would then be visible using the same telescope?

Q20. Sun is losing ~ 2 million tons of its mass every second in the form of solar wind. How long will the Sun take to lose all its mass through the solar wind? (1 ton = 1000 kg)

Q21. In the pp-chain mechanism in the Sun, two neutrinos are produced per every He nucleus produced. Using the knowledge that 0.7% of the mass is converted into energy in the fusion of H to He, and the other details related to the Sun, estimate how many neutrinos are passing through your fingernails every second. Take the area of your fingernail to be 3 cm^2.

Q22. In which kinds of stars do the models predict a He core flash? Why should it occur only in these kinds of stars?

Q23. Write down any four stellar structure equations.

Q24. Is our assumption of adiabatic expansion of the blob justified while deriving the condition for stability against convection? Give reasons.

Q25. Explain the term limb darkening. Why does it occur? For which kinds of celestial objects we observe this effect?

Q26. What is the most technical definition of Photosphere? What does it imply about the physical layer from which radiation emanates?

Q27. Draw a rough sketch showing all the evolutionary stages of a 5 $M_{\odot}$ star. Label all the stages.

Q28. How can we claim that White Dwarves cannot have Hydrogen in their cores?

Q29. Explain why more massive white dwarves are smaller in sizes.

Q30. Estimate the Kelvin-Helmholtz time scale of the Sun.

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Part II

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Max. Time: 90 min. Total Marks: 60

- ✓ ***This paper is printed double-side; question paper on the one side, and some data and physcal constants on the other side.***
- ✓ ***All the five questions are compulsory.***

Q1 Helium-burning

(a) Calculate the energy released in each triple-alpha reaction. [5]
(b) Assuming that at any stage approximately 10% of the mass is in the core, calculate how much total energy Sun can produce if it is hot enough to fuse Helium by the above reaction. (Take Y=0.28) [6]
(c) When the Sun reaches the Horizontal branch star, it would have its luminosity equal to 100 $L_\odot$, estimate the time-scale of the Horizontal branch stage using the numbers you calculated. [3]

Q2. Sun

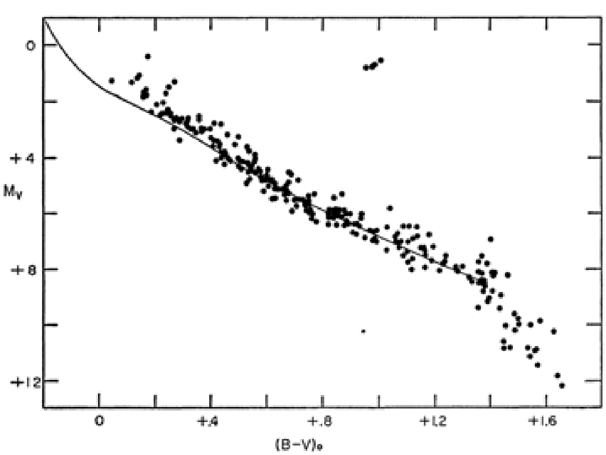
(a) If the Sun was producing its energy by slow contraction as suggested by Helmholtz and Kelvin, estimate the amount by which the radius of the Sun has to decrease every year to produce the observed luminosity. [10]
(b) If there were no outward force holding the Sun against gravity, how long would it take to collapse? [4]

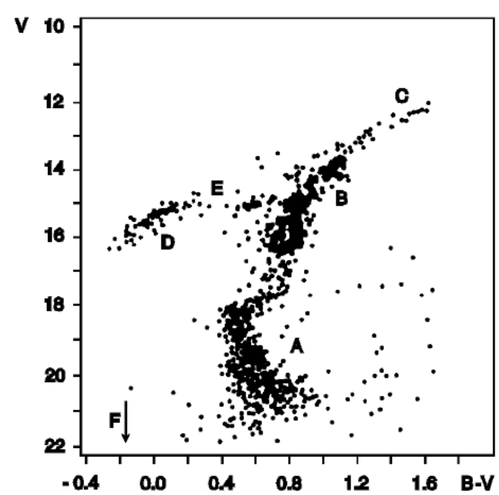
Q3. Radiative Transfer

Suppose you are observing the Sun using two wavelengths say, 5000 Å and 16000 Å. The density and the temperature of the gas in the photosphere is 2.2 X 10^{-4} kg m^{-3}, and 5777 K, respectively. The opacity of the gas at 5000 Å is 0.026 m^2 kg^{-1} and for 16000 Å is 0.070 m^2 kg^{-1}. At which wavelength would you see deeper (farther) into the Sun? How much deeper? [8]

Q4. Star Clusters

(a) Estimate the ages (or age range) of the two clusters. [6]
(b) Estimate the distances (or distance range) of the two clusters. [6]





Q5. Telescopes

SIM PlanetQuest mission can resolve two point sources with an accuracy of better than 0.000004" for objects as faint as 20th magnitude in visible light.
(a) Assuming that grass grows at the rate of 2 cm per week, and assuming that SIM could observe a blade of grass from a distance of 10 km, how long would it take for SIM to detect a measurable change in the length of the blade of grass? [3]
(b) Using a baseline of the diameter of Earth's orbit, how far away will SIM be able to determine distances using trigonometric parallax, assuming the source is bright enough? [3]
(c) From your answer to part (b), what would the apparent magnitude of the Sun be from that distance? [3]
(d) The star Betelgeuse has an absolute magnitude of 5.14. How far could Betelgeuse be from SIM and still be detected? [3]

Bohr radius (a_0)	5.29×10^{-11}	m
Solar mass ($M_\odot$)	1.99×10^{30}	kg
Solar luminosity ($L_\odot$)	3.84×10^{26}	W
Solar radius ($R_\odot$)	6.96×10^{8}	m
Solar effective temperature	5800	K
Solar abs. bolometric magnitude	4.74	

Gravitational constant (G)	6.67×10^{-11}	N m^2 kg^{-2}
Coloumb's constant (k_e)	8.99×10^{9}	N m^2 C^{-2}
Speed of light (c)	3.00×10^{8}	m s^{-1}
Electric charge (e)	1.60×10^{-19}	C
Planck's constant (h)	6.63×10^{-34}	J s
hc	1.24	eV µm
Boltzmann's constant (k)	1.38×10^{-23}	J K^{-1}
	8.62×10^{-5}	ev K^{-1}
Stefan-Boltzmann constant (σ)	5.67×10^{-8}	W m^{-2} K^{-4}
Radiation constant (a)	7.57×10^{-16}	J m^{-3} K^{-4}
Electron mass (m_e)	9.11×10^{-31}	kg
	0.511	MeV
Proton mass (m_p)	1.6726×10^{-27}	kg
	938.27	MeV
Neutron mass (m_n)	1.6749×10^{-27}	kg
	938.57	MeV
Atomic mass unit (u)	1.66×10^{-27}	kg

Mass of Helium – 4.002602 u
Mass of Carbon – 12 u

Sp. Type	M_V	B-V
O5	-5.7	-0.33
O9	-4.5	-0.31
B2	-2.45	-0.84
B5	-1.2	-0.17
B8	-0.25	-0.11
A0	0.65	-0.02
A2	1.3	0.05
A5	1.95	0.15
F0	2.7	0.30
F2	3.6	0.35
F5	3.5	0.44
F8	4.0	0.52
G0	4.4	0.58
G2	4.7	0.63
G5	5.1	0.68
G8	5.5	0.74
K0	5.9	0.81
K2	6.4	0.91
K5	7.35	1.15
M0	8.8	1.40

Spectral Class	Mass [$M_\odot$]	U-B color index	B-V color index [mag]	V-I color index [mag]	bolometric correction B.C. [mag]
O5	32	- 1.19	- 0.35		- 4.0
B0	16	- 1.08	- 0.31		- 2.8
B5	6.5	- 0.58	- 0.16		- 1.5
A0	3.2	- 0.02	0.00		- 0.4
A5	2.1	+0.10	+0.13		- 0.12
F0	1.75	+0.03	+0.27		- 0.06
F5	1.25	- 0.02	+0.42		0.00
G0	1.06	+0.06	+0.58		- 0.03
G5	0.92	+0.20	+0.70		- 0.07
K0	0.80	+0.45	+0.89		- 0.19
K5	0.69	+0.98	+1.18	+1.25	- 0.60
M0	0.48	+1.22	+1.45	+1.69	- 1.19
M5	0.20	+1.24	+1.63		- 2.3

Evolution of Main-Sequence Star

Spectral Class	Mass [$M_\odot$]	time to form [million years]	MS lifetime [million years]
O5	32	0.01	1
B0	16	0.1	10
B5	6		100
A0	3	1	500
A5	2		1,000
F0	1.75		2,000
F5	1.25		4,000
G0	1.06	10	10,000
G5	0.92		15,000
K0	0.80		*20,000
K5	0.69		30,000
M0	0.48	10	75,000
M5	0.20	100	200,000