UNIVERSITY COLLEGE LONDON

University of London

EXAMINATION FOR INTERNAL STUDENTS

For The Following Qualifications:-

B.Sc. *M.Sci.*

Astronomy 2B12: Astrophysical Processes: Nebulae to Stars

COURSE CODE	:	**ASTR2B12**
UNIT VALUE	:	**0.50**
DATE	:	**21-MAY-03**
TIME	:	**14.30**
TIME ALLOWED	:	**2 Hours 30 Minutes**

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TURN OVER

Answer ALL questions from Section A and THREE questions from Section B.

The numbers in square brackets in the right-hand margin indicate the provisional allocation of maximum marks per sub-section of a question.

Solar luminosity	$L_\odot = 3.83\times10^{26}$ W
Solar radius	$R_\odot = 6.96\times10^{8}$ m
Solar mass	$M_\odot = 1.99\times10^{30}$ kg
Parsec	pc $= 3.09\times10^{16}$ m
Gravitational constant	$G = 6.67\times10^{-11}$ N m^2 kg^{-2}
Boltzmann constant	$k = 1.38\times10^{-23}$ J deg^{-1}
Hydrogen atom mass	$m_H = 1.67\times10^{-27}$ kg
Planck's constant	$h = 6.63\times10^{-34}$ J s
Velocity of light	$c = 3.00\times10^{8}$ m s^{-1}

$$\int_{-\infty}^{+\infty} \frac{dx}{x^2 + a^2} = \frac{\pi}{a}$$

$$\int_0^\infty x^2 e^{-a^2x^2}\, dx = \frac{\sqrt{\pi}}{4a^3}$$

$\frac{\pi e^2}{mc} = 0.02653$ cm^{-2} s^{-1}

SECTION A

1. Contrast the main physical properties of *H II regions* and *Planetary nebulae*. [4]

Define what is meant by a Strongren Sphere for an H II region. Would you expect the radius of this to be larger or smaller for an O5 exciting star or a B0 star, and explain why ? [2]

2. Define what is meant by the terms 'Plane-Parallel Approximation' for a stellar atmosphere, and indicate for what types of stars this may be a reasonable approximation. [2]

Define the physical meaning of the *Mean Intensity*, J_ν, and the *Physical Flux*, F_ν. In the case of plane-parallel geometry write down integral expressions for these quantities in terms of the Specific Intensity, I_ν. [4]

3. Define what is meant by a *Resonance Transition* in an atom. [1]

Why are atomic interstellar absorption lines only observed in such resonance transition, and in what regions of the electromagnetic spectrum are most interstellar lines observed ? [3]

Why are OB stars generally used to probe interstellar sight lines in the Galaxy ? [2]

4. Discuss the main observational characteristics of Type I and Type II supernovae. [4]

Why can Type I supernovae be used a standard candles for distance determinations, whilst Type II supernovae cannot ? [2]

5. Define what is meant by the term *Hydrostatic Equilibrium* (H.E.) for a star, and derive the equation of H.E. for a spherically symmetric star. [4]

Define the terms U and Ω in the Virial Theorem expression $2\,U + \Omega = 0$ for a star in H.E. [2]

Using this form of the Virial Theorem, briefly describe what would happen to the internal energy, temperature and emitted energy of a star if it started to contract ? [2]

6. State what is meant by the term *Mean Molecular weight*, (μ), for a gas. [1]

Derive an expression for μ for a fully ionized gas comprising a mixture of hydrogen, helium and heavier elements, with mass fractions of X, Y and Z respectively. [4]

Calculate μ for the cases of: (i) pure hydrogen, (ii) pure helium, and (iii) normal cosmic abundances of X, Y and Z. [3]

SECTION B

7. Define what is meant by the condition of *Ionization Equilibrium* for a pure hydrogen H II region. Describe how gas in an H II region is heated by its interaction with radiation from an exciting OB star, outlining the sequence by which energy injected into the nebula is shared amongst the different particle species. [5]

Describe what is meant by the terms: *permitted*, *recombination* and *forbidden* line emission from a nebula. [4]

Indicate why forbidden lines have to be included to reconcile the observed values of electron temperatures of $T_e \sim 10^4$ K for H II regions, and discuss the basic physical mechanisms that allow forbidden line emission to provide the main cooling process for such nebulae. [5]

Derive expressions for the outer radius R_s and total mass M_s for a pure hydrogen Stromgren Sphere of number density n that is photoionized by the star which emits S_* ionizing photons per second. Calculate R_s, in parsecs, and M_s, in $M_\odot$, for the case where $n = 10^{10}$ m^{-3}, $S_* = 1 \times 10^{49}$ s^{-1} and $\alpha_B = 2 \times 10^{-19}$ m^3 s^{-1}. [6]

8. Outline briefly how Nuclear Fusion reactions provide the main energy production in stellar interiors and why high temperature and density conditions are required. [3]

Describe the chain of nuclear reactions involved in the Proton-Proton Hydrogen burning processes that occurs in the Sun. [7]

Calculate an estimate of how long in years the Sun can continue to power its current luminosity by PP Hydrogen burning. [energy production rate $\epsilon_H = 6.3 \times 10^{14}$ J Kg^{-1}] [5]

Discuss the reactions involved in the 3- α process by which carbon nuclei can be formed from helium nuclei, indicating the density and temperature dependence of the overall reaction rate. [5]

9. Consider emission in a line with central frequency ν_0 from atoms with random thermal motions. The probability that an atom has velocity v with respect to an observer is

$$f(v) = \left(\frac{m}{2\pi kT}\right)^{1/2} \exp\left(\frac{-mv^2}{2kT}\right)$$

where T is the temperature and m is the atomic mass. Show that the Doppler profile function $\phi_D(\nu)$ for emission at frequency $\Delta\nu$ from the line centre is give by, [7]

$$\phi_D(\nu) = \frac{1}{\Delta\nu_D\sqrt{\pi}} \exp\left(\frac{-\Delta\nu}{\Delta\nu_D}\right)^2$$

where $\Delta\nu_D$ is the frequency shift corresponding to the Doppler velocity v_D. Show that the Full Width at Half Maximum of this profile is [5]

$$\Delta\nu(FWHM) = \frac{2\nu_0}{c}\sqrt{\frac{2kT}{m}\ln 2}$$

For an individual interstellar absorption line arising from an ionic species i, with a volume number density n_i, the line opacity can be written as:

$$\kappa_i(\nu) = \frac{\pi e^2}{m_e c} f \phi_i(\nu) n_i$$

where $\phi_i(\nu)$ is the normalised line profile, and f is the line oscillator strength.

Using this form for $\kappa_i(\nu)$, derive an expression for the Equivalent Width, W_λ, of a *weak* line in terms of the column density, N_i of the absorbers. [5]

Estimate the relative abundances of Mg and Fe from the following observed strengths of the weak interstellar absorption lines and associated atomic data: [3]

Mg II 1240.4 Å	$W_\lambda = 13.2$ m Å	$f = 0.000484$
Fe II 1142.3 Å	$W_\lambda = 18.1$ m Å	$f = 0.0069$

10. Define what is meant the by term *Local Thermodynamic Equilibrium* (LTE), and outline under what circumstances LTE may be considered a valid assumption and a poor assumption. [5]

The Boltzmann Distribution for the relative populations of two bound-levels m and n can be written:

$$\frac{N_m}{N_n} = \frac{g_m}{g_n} \exp\left(\frac{-(E_m - E_n)}{kT}\right)$$

Using the Boltzmann distribution, and defining all terms, show that the *Saha* law describing the ionization balance of the gas can be written as:

$$\frac{N_i}{N_0} = \frac{2U_i}{U_0} \frac{(2\pi m_e)^{3/2}}{h^3} \frac{(kT)^{5/2}}{P_e} \exp\left(\frac{-\chi_0}{kT}\right).$$

where N_0 and N_i are respectively the number densities of a neutral species and its next ionization state. [12]

Indicate briefly the steps involved in the computation of real LTE model atmospheres to calculate the detailed emergent radiation flux distribution F_λ. [3]

11. Discuss briefly the main properties of the four main phases of the interstellar medium in the Galaxy according to current models, contrasting their temperature, density and heating source characteristics. [5]

Briefly outline the main observational evidence for the presence of dust grains in the general interstellar medium and sketch the form of the average interstellar extinction curve from IR to ultraviolet wavelengths. [5]

Give a detailed account of the heating and cooling processes involved in the *Diffuse Interstellar Medium*. [10]

END OF PAPER