UNIVERSITY COLLEGE LONDON

University of London

EXAMINATION FOR INTERNAL STUDENTS

For The Following Qualification:-

M.Sci.

Astronomy 3C33: Interstellar Physics

COURSE CODE	:	**ASTR3C33**
UNIT VALUE	:	**0.50**
DATE	:	**16-MAY-03**
TIME	:	**10.00**
TIME ALLOWED	:	**2 Hours 30 Minutes**

03-C0085-3-40

TURN OVER

Answer **THREE** questions.

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

H atom mass:	m_H	=	1.67×10^{-27} kg
Boltzmann constant:	k	=	1.38×10^{-23} J K^{-1}
Permittivity of vacuum:	ϵ_0	=	8.85×10^{-12} F m^{-1}
Electron charge:	e	=	1.6×10^{-19} C
Hydrogen case B recombination coefficient:	α_B	=	$2 \times 10^{-16} T_e^{-3/4}$ m^3 s^{-1}
Isothermal sound speed:	c_s^2	=	$kT/(\mu m_H)$
Gravitational constant:	G	=	6.67×10^{-11} N m^2 kg^{-2}
Solar Mass:	$M_\odot$	=	1.99×10^{30} kg
Velocity of light:	c	=	3.00×10^8 m s^{-1}
Parsec:	pc	=	3.09×10^{16} m

1. Describe how supersonic motions can lead to the formation of a shock waves. [3]
The *Rankine-Hugoniot conditions* can be expressed as the conservation of the following quantities across an (adiabatic) shock:

$$\phi \equiv \rho u, \quad \zeta \equiv P + \rho u^2, \quad \xi \equiv \frac{1}{2}u^2 + \frac{5P}{2\rho}$$

where ρ, P and u are the gas density, pressure and velocity (defined in the rest frame of the shock). Explain the meaning of these quantities, and how they would differ for an *isothermal* shock. [3]

By use of these equations, show that the density behind a strong adiabatic shock is four times the pre-shock density. What is the density contrast across an *isothermal* shock? [5]
What is the post-shock velocity (in the observer's frame) of the gas in (a) adiabatic, (b) isothermal shocks? [2]

A supersonic stellar wind generates a thin shell of swept up shocked interstellar gas, whose equation of motion is given by

$$r^4 \dddot{r} + 12r^3\dot{r}\ddot{r} + 15r^2\dot{r}^3 = \left(\frac{3}{2\pi}\right)\frac{\dot{E}_\star}{\rho_0}$$

where $\dot{E}_\star$ is the rate at which energy is fed into the gas through the shock front and ρ_0 is the interstellar gas density. Assuming that the solution takes the form $r \propto t^\alpha$ show that $\alpha = 3/5$ and calculate the conversion efficiency of wind mechanical energy to shell kinetic energy. [7]

2. With the aid of sketches, *briefly* describe the *early*, *intermediate* and *final* stages of evolution of an ionized region. [6]

In the *intermediate* stage, the pressure is $P_0 = \rho_0 V_s^2$ in the neutral gas, and $P_i = \rho_i c_i^2$ in the ionized gas, where ρ_0 and ρ_i are the densities of the neutral and ionized gas repectively, V_s is the speed of a shock propagating through the neutral gas, and c_i is the sound speed in the ionized gas. Show that the equation of motion of the ionization front is given by:

$$r^{3/2}\dot{r}^2 = c_i^2 R_s^{3/2} \quad \text{where} \quad R_s = \left(\frac{3S_\star}{4\pi\alpha_B n_0^2}\right)^{1/3}$$

where the symbols have their usual meanings. Hence, show that

$$\lambda = \left(1 + \frac{7}{4}\phi\right)^{4/7}$$

where $\lambda = r/R_s$, $\phi = c_i t/R_s$ and $\phi = 0$ at $\lambda = 1$. [8]

An HII region surrounds a star emitting $S_\star = 7 \times 10^{48}$ ionizing photons s^{-1}, and expands into an atomic hydrogen medium with $n_0 = 2\times10^8$m^{-3}. The temperature of the ionized gas is 10^4K. Calculate the time that it takes for the region to reach its *final* state, assuming that this occurs when $\lambda = 30$. Comment on your result.

[6]

3. List the observational signatures of star-forming activity. Explain how molecular emission lines can develop characteristic profile shapes in infall regions. [5]

Sketch the form of the density structure for a *critical Bonnor-Ebert sphere.* [2]

The equation of motion of a spherical shell in a collapsing cloud, of initial (uniform) density ρ_0 and radius r_0, is given by

$$\frac{d^2x}{d\tau^2} = \frac{-\pi^2}{8x^2}$$

where $x = r/r_0$ and $\tau = t/t_{ff}$. Show that $t = t_{ff}$ is the *free-fall* collapse time. [4]

What is the condition for gravitational collapse of a cloud of radius R, in which the sound speed is c_s? Given that

$$t_{ff} = \sqrt{\left(\frac{3\pi}{32G\rho_0}\right)}$$

use this condition to derive the critical mass for collapse [4]

$$M_{crit.} = \left(\frac{3\pi^5}{32}\right)^{1/2} c_s^3 G^{-3/2} \rho_0^{-1/2}$$

A cloud of atomic hydrogen of mass $3 \times 10^3 M_\odot$ is at a temperature of 80K and has a number density n of 2×10^8m^{-3}. Show that it is stable against collapse. If the cloud cools to 50K, whilst remaining *in pressure balance*, will it still be stable?

[5]

4. What do the facts that (a) different elements are depleted by different amounts, and (b) for any given element the depletion varies from sight-line to sight-line, imply about the processes of dust grain formation and destruction? [3]

Derive an approximate expression for the rate of growth of interstellar dust grains resulting from the accretion of atoms (ignoring electrostatic effects). In a certain molecular cloud, the accreting carbon (A=12) atoms are characterized by a thermal velocity of 75 m s^{-1}, a number density of 3×10^3 m^{-3} and a sticking coefficient of 0.4. The dust is composed of material with a density of 1.5×10^3 kg m^{-3}. Estimate the time for a typical grain (radius $a \simeq 0.1\mu$m) to grow from a small nucleus by accretion. Comment on your result. [8]

Sketch and label the *interstellar extinction curve.* Give *brief* descriptions of the *'2200Å bump'*, and the *infra red and visible* interstellar discrete absorption features. [5]

Discuss the processes that lead to the alignment of dust grains in the interstellar medium and how they can lead to the polarization of starlight. [4]

5. Briefly describe three processes by which H_2 can be formed from atomic hydrogen in the absence of other elements. Explain why only one of these formation routes is viable in interstellar clouds and give an expression for the rate at which this process occurs. [7]

Suppose that the main mechanism by which H_2 is formed in diffuse clouds is $CH + H \rightarrow H_2 + C$ ($k = 10^{-17} m^3 s^{-1}$). For a diffuse cloud in which $n = [n(H) + n(H_2)] = 10^8 m^{-3}$, $n(CH)/n = 10^{-8}$ and the H_2 photodissociation rate is $\beta(H_2) = 10^{-10} s^{-1}$, calculate the equilibrium abundance of H_2. What can you conclude from this result? [6]

In a diffuse cloud, water can be formed via:

$$O + e^- \rightarrow O^- + h\nu \qquad k_1 = 1.5 \times 10^{-21} m^3 s^{-1}$$

$$O^- + H_2 \rightarrow H_2O + e^- \qquad k_2 = 7.0 \times 10^{-16} m^3 s^{-1}$$

and the O^- is subject to photodetachment

$$O^- + h\nu \rightarrow O + e^- \qquad k_3 = 5.0 \times 10^{-9} s^{-1}$$

Assuming that the abundance of O^- is in equilibrium, calculate the rate of formation of water molecules via this channel in a diffuse cloud in which $n = 10^8 m^{-3}$, $n(O)/n = n(e^-)/n = 10^{-3}$ and $n(H_2)/n = 0.1$. What is the approximate timescale for the conversion of O to H_2O via this mechanism? [7]

END OF PAPER