UNIVERSITY COLLEGE LONDON

University of London

EXAMINATION FOR INTERNAL STUDENTS

For The Following Qualification:-

M.Sci.

Astronomy 4C15: High Energy Astrophysics

COURSE CODE	:	**ASTR4C15**
UNIT VALUE	:	**0.50**
DATE	:	**29-APR-04**
TIME	:	**10.00**
TIME ALLOWED	:	**2 Hours 30 Minutes**

04-C0091-3-40

TURN OVER

Answer THREE questions.

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

Symbols and quantities used in expressions:

Gravitational constant	$G = 6.67 \times 10^{-11}\ m^3\ kg^{-1}\ sec^{-2}$
Velocity of light	$c = 3 \times 10^8\ m\ sec^{-1}$
Mass of the Sun	$M_\odot = 2 \times 10^{30}\ kg$
Mass of the proton	$m_p = 1.67 \times 10^{-27}\ kg$
	$1\ eV = 1.6 \times 10^{-19}\ J$
	$1\ Parsec\ (pc) = 3.08 \times 10^{16}\ m$

PLEASE TURN OVER

1. Consider two stars, one with mass m_0 and velocity $0.8\ c$ and another one with mass $3m_0$ and at rest in the reference of a distant observer. Suppose that the two stars collide and merge into one star.

(a) What is the initial total linear momentum of the system? **[3 marks]**

(b) What is the initial total energy of the system? **[3 marks]**

(c) What is the velocity of the system after merging? **[3 marks]**

(d) What is the rest mass of the resulting star? **[3 marks]**

(e) Why is this rest mass larger than $4m_0$? **[4 marks]**

(f) When the resulting star cools down, will it be accelerated? Justify your answer. **[4 marks]**

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2. The evolution of a photon spectrum $n(\nu)$ of Comptonized emission from a hot electron cloud of density n_e and temperature T can be described by the Kompaneet's equation:

$$\frac{\partial n}{\partial t} = \frac{1}{\nu^2}\frac{\partial}{\partial \nu}\left[\nu^4\left(\frac{n_e\sigma_T k_B T}{m_e c}\right)\frac{\partial n}{\partial \nu}\right] - \frac{nc}{(1+\tau)R} + \delta(\nu - \nu_0) \ .$$

Here, $\delta(...)$ means delta function, c is the speed of light, k_B is the Boltzmann constant, m_e is the electron mass, σ_T is the Thomson cross-section, ν_0 is the frequency of injected photons, R is the characteristic linear size of the electron cloud, and τ is the Thomson optical depth, which is approximately equal to $n_e\sigma_T R$. The intensity of the emission is given by $I(\nu) = \nu^3 n(\nu)$.

(a) For the stationary case, show that when $\nu > \nu_0$ the Kompaneet's equation becomes

$$\frac{1}{\nu^2}\frac{\partial}{\partial \nu}\left[\nu^4\frac{\partial n}{\partial \nu}\right] = \frac{n}{\tau(1+\tau)\theta} \quad ,$$

where $\theta = \left(\dfrac{k_B T}{m_e c^2}\right)$. **[4 marks]**

(b) Consider a solution $n(\nu) \propto \nu^{-(3+\alpha)}$ to the stationary equation above. Show that the power-law index α satisfies the following equation:

$\alpha(3+\alpha) = [\tau(1+\tau)\theta]^{-1}$. **[4 marks]**

(c) Show that

$$\alpha = -\frac{3}{2} \pm \sqrt{\frac{9}{4} + \frac{4}{y}} \ ,$$

where the Compton y parameter is defined as $y \equiv 4\theta\ \tau(1+\tau)$. **[3 marks]**

(d) Consider the solution

$$\alpha = -\frac{3}{2} + \sqrt{\frac{9}{4} + \frac{4}{y}} \ .$$

Show that when the temperature is low ($\theta << 1$) and the optical depth is moderate ($\tau \sim 0.1 - 1$), the intensity

$I(\nu) \propto \nu^{\frac{3}{2} - \sqrt{\frac{4}{y}}}$. **[4 marks]**

(e) Sketch $Log\ I(\nu)$ against $Log\ \nu$ for $(\tau, \theta) = (2, 0.01)$ and $(2, 0.02)$. **[5 marks]**

PLEASE TURN OVER

3. β Per is an eclipsing Algol type binary system, which consists of a K type giant secondary star and a B type primary star. Both stars have similar radii. The orbital period of the system is about 2.8 days. The K giant star overfills its Roche lobe and transfers material to the B star. An annulus of material is formed around the B star. The annulus may be asymmetric because of the tidal interaction with the K star. The K star is magnetically active, with detection of strong quiescent radio emission. Images obtained by the VLBA radio telescope show 2 lobe-like structures, and these lobes have little variability within an orbital cycle and are visible during the eclipse. The emission from the lobes is about 10% circularly polarized (at the 8-GHz frequency) but the handedness of their polarization is opposite. Radio flares were also detected. Careful analyses of the radio flare light curves showed evidence of several periods: these include the orbital period and another, that could be beat period between the binary orbital period and the precession period of the material annulus around the B star.

(a) Make a sketch of the system. Indicate the approximate orbital inclination and the possible location of the radio emission. **[6 marks]**

(b) Could the quiescent radio emission be synchrotron emission from highly relativistic electrons? Justify your answer. **[3 marks]**

(c) Sketch a global magnetic field configuration of the K star that could give rise to the observed polarization properties. **[3 marks]**

(d) Would the degree of circular polarization of the quiescent radio emission be stronger or weaker if β Per were not an eclipsing system? Justify your answer. **[3 marks]**

(e) The radio studies stimulated the search for flaring activity in the X-ray bands. In a recent XMM-Newton observation X-ray flares were detected from the system, and the flares appeared to be self-eclipsed by the limb of the K star when the star revolved in its orbit. Comment on the following statements: "It is unlikely that the quiescent radio emission and the X-ray flares are emission at the same location and from the same population of energetic electrons. The radio and X-ray flares might be caused by magnetic reconnection events near the surface of the K star, and these events accelerate the energetic electrons which give rise to the radiations." **[5 marks]**

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4. (a) Name the four physical processes that result in the absorption of X-rays and Gamma-rays by matter. Which of these is important for X-rays, of photon energy $0.1 \text{ keV} \leq E_\nu \leq 10.0 \text{ keV}$, passing through the interstellar medium of our Galaxy? Give the reason for the importance of this process. **[5 marks]**

(b) Describe the process of photoelectric absorption and explain, in words and with a sketch, what is meant by the term *absorption edge*. Give an expression for the absorption cross section, σ_K, for photons that can eject K-shell electrons from atoms. Indicate in particular the dependence of σ_K on the radiation frequency ν and on the atomic number, Z, of the absorbing atom. **[5marks]**

(c) If n_Z (in m^{-3}) is the number density of an element of atomic number Z in a path through the Galaxy of length L (m) and if the cross-section for absorption of photons of energy E_ν by element Z is given by $\sigma_Z(E_\nu)$ (in m^2), derive an expression for the fraction of an incident X-ray flux $F_0(E_\nu)$ that will be transmitted through the path L. How should this expression be modified to take account of all the elements in the path L where the abundances of the different elements are given relative to Hydrogen? Explain what is meant by the term *effective cross-section.* **[6 marks]**

(d) Calculate the fraction of an incident flux, F_o, of 0.1 keV photons passing through an interstellar gas column of length 100 pc with effective cross-section $\sigma_{eff} = 10^{-24}$ m^2 at 0.1 keV that will emerge assuming i) a smooth medium of density $\rho = 10^6$ H atoms/m^3 and ii) a cloudy medium with a hot distributed gas of $\rho = 0.1 \times 10^6$ H atoms/m^3 and a small number of cold dense clouds. **[4 marks]**

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5. (a) Describe the process of accretion onto a compact object and write the expression for the accretion energy. Mention four astrophysical situations where it may be taking place. In each case indicate the likely sources of the accreting material and compare the resulting luminosity values. **[5 marks]**

(b) Calculate the energy released following the accretion of 1 kg of matter by a 1 M_o neutron star of radius 10 km. How does this compare with the energy released in the nuclear fusion of 1 kg of Hydrogen to Helium? You should assume a mass conversion efficiency of 0.007 for the fusion process. **[3 marks]**

(c) Describe in detail using sketches, the two principal modes of accretion in Galactic X-ray emitting binary sources. Which of the two is more efficient? In which case is an accretion disk expected to form? Explain the reason for disk formation and give an expression for its luminosity. **[10 marks]**

(d) Galactic X-ray binary systems are often classified in two groups. Indicate the nature and properties of the systems in each of these groups. **[2 marks]**

END OF PAPER