UNIVERSITY COLLEGE LONDON

University of London

EXAMINATION FOR INTERNAL STUDENTS

For the following qualifications :-

M.Sci.

Astronomy 4C15: High Energy Astrophysics

COURSE CODE	:	**ASTR4C15**
UNIT VALUE	:	**0.50**
DATE	:	**30-APR-02**
TIME	:	**14.30**
TIME ALLOWED	:	**2 hours 30 minutes**

02-C0089-3-50

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.

You may assume the following.

Gravitational constant: $G = 6.67\times10^{-11}$ m^3 kg^{-1} s^{-2}
Planck constant: $h = 6.63\times10^{-34}$ J s
Boltzmann constant: $k = 1.38\times10^{-23}$ J K^{-1}
Velocity of light: $c = 3.00\times10^8$ m s^{-1}
Mass of electron: $m_e = 9.11\times10^{-31}$ kg
Charge of electron divided by its mass: $\frac{-e}{m_e} = -1.76\times10^{11}$ C kg^{-1}
Mass of proton: $m_p = 1.67\times10^{-27}$ kg
Mass of Sun: $M_\odot = 1.99\times10^{30}$ kg
Radius of Sun: $R_\odot = 6.96\times10^8$ m
Magnetic field of Sun: $B_\odot \simeq 100$ G
Thomson scattering cross-section: $\sigma_e = 6.65\times10^{-29}$ m^2
Gaunt factor: $g_{ff} \simeq 1$
Permittivity of vacuum: $\epsilon_0 = 8.85\times10^{-12}$ F m^{-1}
1eV = 1.6×10^{-19} J

1. (a) With the aid of a sketch define the 'impact parameter' b, in an encounter between an electron and an ion of charge Ze. [1]

(b) Given that the power radiated by an accelerated charge is

$$P = \frac{e^2 a^2}{6\pi\epsilon_0 c^3},$$

derive an approximate expression for the total power radiated by an electron encountering an ion of charge Ze in terms of the impact parameter and electron velocity (together with atomic constants). Justify your approximations. [4]

(c) Hence derive the power $P(v,b)dvdb$ radiated per unit volume by electrons with velocity between v and $v+dv$ and impact parameter b and $b+db$, given a density of ions N_i and a density of electrons $N(v)$ in the velocity range between v and $v+dv$. [3]

(d) Convert the expression you obtained for $P(v,b)$ into a function in velocity and frequency $P(v,\nu)$, again justifying any approximations you make. [3]

(e) This radiation is known as bremstrahlung. What is the difference between bremstrahlung in general and 'thermal bremsstrahlung'? [2]

(f) For thermal bremstrahlung radiation the total power radiated per unit volume integrated over frequency is

$$\int P(\nu)d\nu = 1.4\times 10^{-40} Z^2 N_e N_i T^{1/2} g_{ff} \quad \mathrm{Wm}^{-3}.$$

Assuming cosmic abundances and $g_{ff}=1$, express this in terms of T and N_e. What is the ratio of power radiated per unit volume between two plasmas, one with a factor 10 times higher temperature but only half the density of the other? What happens to the cooling rate if the density increases as the plasma cools? [4]

(g) Assuming that each degree of freedom of the plasma has an average kinetic energy of $\frac{1}{2}kT$, derive the 'cooling time' of the plasma. If this plasma is emitting X-rays at a temperature of 10^8K, what must the density be for the plasma to have cooled over the age of the Galaxy ($\sim 10^{10}$ years)? [3]

2. (a) What is the difference between Compton scattering and Inverse Compton scattering? [2]

(b) Using a diagram to define the geometry, derive the Compton scattering formula for the final energy in terms of the initial energy and scattering angle. [8]

(c) What happens to the final energy in Compton scattering in the case of low energy photons? What is the name of the scattering in this case? [2]

(d) In Compton scattering, given a total initial energy of 1 keV, calculate the maximum final velocity of the electron. [6]

(e) Now express this velocity in terms of the thermal velocity of an electron at 1 keV. [2]

3. (a) In Cartesian coordinates in a flat spacetime, write down an expression for the spacetime interval $\Delta\tau$. Derive the relationship between $\Delta\tau$ and $\Delta\tau'$ in frames f and f', and prove that $\Delta\tau = \Delta\tau'$ if the speed of light is constant. [4]

(b) Why is τ called the 'Proper Time'? [2]

(c) What is the relationship between the proper time and the metric? Write down the Schwarzschild metric and use it to derive the proper time in this metric. [3]

(d) Identify two singularities in the Schwarzschild metric. What is the difference between them? What is the Schwarzschild radius? [4]

(e) Prove that a particle cannot be at rest with respect to a mass M if its distance r from M is within the Schwarzschild radius. Show that all particles within the Schwarzschild radius pass through $r = 0$. [4]

(f) Draw a sketch showing the static limit and event horizon for a Kerr black hole. Show the equivalent radius of the event horizon of a Schwarzschild black hole with the same mass. What is the static limit? [3]

4. (a) Describe the two main types of accreting binary systems, explaining how the mass transfer occurs (you may want to draw sketches to illustrate your answer). [7]

(b) Under which physical conditions does the Eddington limit apply? Derive an expression for the Eddington limit for a body with mass M and use this to estimate the Eddington luminosity L_{Edd}, for the Sun. [6]

(c) What is believed to be the dominant mechanism for energy release in active galactic nuclei (AGN)? What is the observational evidence to support the presence of a supermassive black hole in AGN? Quantify your answer. [7]

5. (a) What is the surface gravity of a pulsar with a mass of $2M_\odot$ and a radius of 10km? Derive an expression for the scale height of an atmosphere. Use this expression to estimate the scale height for this pulsar if its atmosphere has a temperature of 10^6K. [4]

(b) Which force dominates within the pulsar atmosphere, magnetic or gravitational? Use a numerical example to quantify your answer. [4]

(c) Give a short description of a pulsar. In the context of pulsars, describe the physical significance of the geometry and strength of the magnetic field. How does this result in the main pulses observed? [6]

(d) Describe, briefly, the absorption process that corresponds to synchrotron emission. Explain how this modifies the spectrum of synchrotron emission, using sketches to illustrate your answer. [6]