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	:	**30-APR-03**
TIME	:	**10.00**
TIME ALLOWED	:	**2 Hours 30 Minutes**

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 s^{-1}
Mass of the Sun	$M_\odot = 2 \times 10^{30}$ kg
Mass of the proton	$m_\mathrm{p} = 1.67 \times 10^{-27}$ kg
	1 eV = 1.6 $\times 10^{-19}$ Joule

1. A pion π^- is produced by the collision of a cosmic ray particle with a nucleon in the upper atmosphere. The pion rapidly decays into a muon μ^-, and the muon then decays into an electron and a neutrino. The rest mass of a muon m_μ is about 106 MeV, and the muon-decay timescale is 2.2×10^{-6} s.

(a) If the muon is produced at a height of 18 km above the sea level with a total energy of 30 GeV and it travels downward vertically, what are the Lorentz factor γ and relativistic parameter β of the muon? **[6 marks]**

(b) What is the expected time of flight that the muon takes to reach sea level?

[4 marks]

(c) What is the probability that the muon can reach sea level? **[10 marks]**

2. (a) What is the difference between cyclotron and synchrotron radiation? Which one is narrowly beamed? **[3 marks]**

(b) For synchrotron radiation from an ensemble of electrons with a power-law energy distribution $f(\gamma) \propto \gamma^{-p}$, where $E = \gamma m_e c^2$ and p is the power-law index, the absorption coefficient

$$\alpha_\nu \propto \nu^{-(p+4)/2}$$

and the emission coefficient

$$j_\nu \propto \nu^{-(p-1)/2} .$$

Determine the frequency dependence of the source function S_ν ($\equiv j_\nu/\alpha_\nu$). **[4 marks]**

(c) The intensity of synchrotron radiation from a plasma of thickness Δl is given by

$$I_\nu = S_\nu \left(1 - e^{-\tau_\nu}\right) ,$$

where $\tau_\nu = \alpha_\nu \Delta l$. Show that for optically thick radiation $I_\nu = S_\nu$ and for optically thin radiation $I_\nu = \tau_\nu S_\nu$. **[4 marks]**

(d) Sketch $\log I_\nu$ vs $\log \nu$ for a synchrotron spectrum. **[6 marks]**

(e) How different are the optically-thick part of a synchrotron spectrum and the low frequency part of a black-body spectrum? **[3 marks]**

3. (a) Write a short paragraph describing the Eddington limit and the main physical process that determines this limit. **[2 marks]**

(b) Derive the expression for the Eddington luminosity of a source in terms of only the source mass, expressed in solar masses (you may assume that Thomson scattering is the main source of opacity). **[6 marks]**

(c) Calculate the Eddington limit for a star of 10 solar masses. Compare this with the typical luminosity of a supernova and explain the discrepancy. **[3 marks]**

(d) What is the most efficient form of energy production known in the Universe? Describe the process involved, giving quantitative examples of astrophysical objects where it is important, and say how energy is transferred and released. **[9 marks]**

4. (a) What is the average rate of cosmic ray production in our Galaxy, if the energy density of cosmic rays in the Galaxy is 10^{-13} J m^{-3}? **[2 marks]**

(b) List four possible sources of Galactic cosmic rays. **[2 marks]**

(c) Estimate the cosmic ray output from each category. Which is probably the greatest source of cosmic radiation? **[8 marks]**

(d) Explain the role of cosmic rays and electron-positron pair production in the radio emission from pulsars, describing the physical processes involved. **[8 marks]**

5. (a) Give a detailed account of the events that lead to a supernova explosion. Include a description of the two main types of supernova event. Which type of supernova was SN1987A? **[10 marks]**

(b) Describe briefly the four main phases of supernova remnant development. For phases 1 and 2, give an expression for the size of the remnant in terms of the expansion velocity and time since the event occurred. **[6 marks]**

(c) Currently, in which phase is SN1987A and what is the shock velocity? Calculate the extent of the remnant in SN1987A and estimate the initial shock velocity and amount of mass (in solar masses) swept up so far (you may assume a density for the interstellar medium of 2×10^{-21} kg m^{-3}). **[4 marks]**

END OF PAPER