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.

1. i) A quark and an anti-quark can fuse to form a W boson of mass 80 GeV. For a proton anti-proton colliding beam machine, where both beams are of equal energy, what beam energy is required to produce W bosons? You may assume that together the three valence quarks carry around $\frac{1}{2}$ of the proton's total momentum. **[3]**

ii) Show that the yields of W^+ and W^- are equal in such collisions. **[3]**

iii) What proton beam energy is required to achieve W production if the proton beam is replaced by a stationary neutron target? The neutron mass is 940 MeV. **[3]**

iv) How would the yield of W^+ and W^- change with the stationary neutron target in comparison to the colliding beam scenario? **[2]**

v) Proton anti-proton collisions produced the first evidence for the production of top quark pairs. Draw the Feynman diagram responsible for the dominant production of top quarks in such collisions. Label the gauge boson, fermions and the couplings. **[5]**

vi) By what other gauge boson exchange can top quark pairs be produced in proton anti-proton collisions and how would you expect the cross section to differ from that in (v) and why? **[4]**

2. i) An e^+e^- collider of counter rotating 45 GeV e^+ and 45 GeV e^- beams has a diameter of 8 km. Each beam has 12 bunches with each bunch containing 3×10^{11} particles. The bunches have a cross sectionial area of 0.02 mm^2. What is the luminosity of this machine expressed in cm^{-2}s^{-1}? If the cross section for Z_0 production is 60 nb (1 b = 10^{-28} m^2), how many Z_0 would be produced per hour? **[7]**

ii) The energies of the e^+ and e^- beams are varied around their nominal value of 45 GeV. The cross section for Z_0 production is measured as a function of the energy in the centre of mass system (E). Write down the expression for the variation of the square of the invariant amplitude as a function of E and the mass and width of the Z_0 boson for the process $e^+e^- \to Z_0 \to X$, where X represents the possible final states resulting from the decay of the Z_0. What other factors apart from the invariant amplitude determine the cross section? What can a measurement of the total width of the Z_0 reveal? **[5]**

iii) What are the characteristics of events resulting from the decays : $Z_0 \to b\bar{b}$ and $Z_0 \to e^+e^-$? Mention briefly the types of detector with which you would observe these events. **[8]**

3. i) Explain what is meant by helicity and why it is particularly important when describing the behaviour of neutrinos? **[4]**

ii) What force governs the interactions of neutrinos? Draw the Feynman diagram for the processes $\pi^+ \rightarrow \mu^+\nu_\mu$ and $\pi^+ \rightarrow e^+\nu_e$ **[5]**

iii) Draw a diagram in the rest frame of the pion to show the helicity of the μ^+ and the e^+ for these decays. **[4]**

iv) Which decay dominates? Why? **[7]**

4. i) Outline the main principles of operation of a fission reactor with reference to the different modes of operation of a thermal reactor and a fast breeder reactor. **[8]**

ii) What are the three main waste products of a nuclear reactor and in what relative proportion are they produced? **[4]**

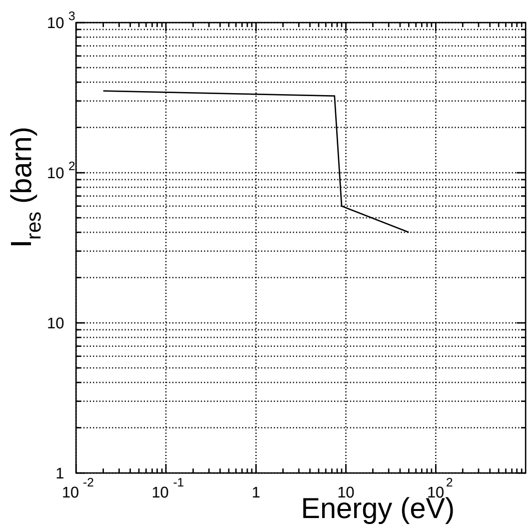

Figure 1: The resonance integral I_{res} for Tc-99

iii) The plot in Figure 1 shows a graph of I_{res}, the resonance integral for Technicium^{99}. Why is Tc-99 a particularly nasty waste product? Explain briefly what is meant by the resonance integral shown in the graph and identify the neutron energy needed to transmute Tc^{99} to a harmless element. **[4]**

iv) Explain how one might do this using neutrons from an accelerator, describing the physics processes involved and the preparation of the Tc^{99}. **[4]**

5. i) Explain briefly how the four forces (including Gravity) work together in the formation of stars. **[4]**

ii) Write down the reaction for Hydrogen burning and comment on its probability. Assuming that the entire energy output from the Sun is derived from the PPI chain (accounting for 26.73 MeV per helium nucleus), estimate the flux of neutrinos ($m^{-2}s^{-1}$) at the Earth. Distance of Earth from Sun $\approx 1.5\text{x}10^8$km, Luminosty of Sun is 3.86 10^{26}W, 1MeV = 1.60219 x 10^{-13}J **[6]**

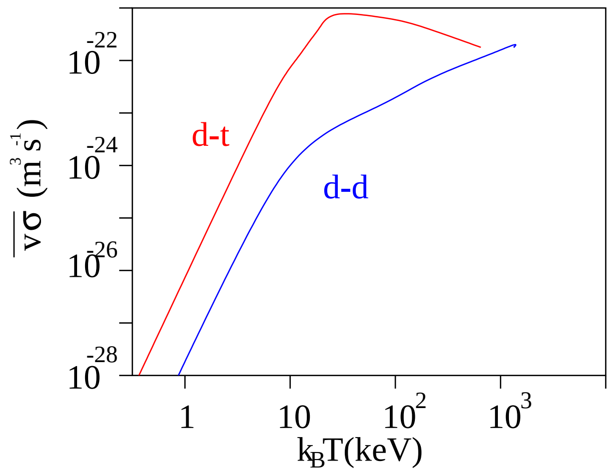

Figure 2: The cross section as a function of temperature for two fusion reactions

iii) Figure 2 shows the cross sections for two fusion reactions. Write down an example of each type of reaction and explain the difference in the shape of the two lines. **[6]**

iv) To achieve temperature T in a d-t plasma, the energy density that must be input to the plasma is given by:

$$E_{IN} = 4\rho_d(3k_BT/2)/\text{unit volume}$$

Explain what is meant by a plasma and the origin of the factor 4 in the above equation. Describe how such a plasma might be contained if $k_BT \approx$ 20 keV **[4]**

END OF PAPER