KEELE UNIVERSITY

DEGREE EXAMINATIONS, 2009

Level 3 (PRINCIPAL COURSE)

20th January 2009, 9:30 - 11:30

PHYSICS/ASTROPHYSICS

PHY-30023

Particles, accelerators and reactor physics

Candidates should attempt to answer THREE questions

Tables of physical and mathematical data may be obtained from the invigilator.

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1. (a) Discuss the conservation of baryon and lepton numbers, strangeness, charm and isospin for particles interacting via each of the electromagnetic, strong nuclear and weak nuclear interactions. [20]

(b) Discuss the conservation of strangeness and lepton numbers for

i. the decay of the strangeness $S = 0$, ϕ meson to the $S = -1$, K^- meson and its antiparticle:

$$\phi \rightarrow K^- + K^+$$ [10]

ii. the decay of the K^+ particle:

$$K^+ \rightarrow \mu^+ + \nu_\mu$$ [10]

(c) The K^+ has zero charm and does not contain top or bottom quarks. Determine

i. its quark structure and [10]

ii. its 3 axis component of isospin T_3. [5]

(d) State and explain which field particle is involved in the decay of the K^+ in part (b)ii. [5]

(e) Write down and illustrate charge conservation, for each of the individual quarks in this K^+ decay. [20]

(f) Discuss why particle physics experiments tend to produce an abundance of mesons, but free quarks are not observed. [20]

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2. (a) State the fundamental interactions of the Standard Model and compare the masses, charge numbers and spin quantum numbers of the particles that mediate these interactions. [15]

(b) The total energy E_{CM}, in eV, in the centre of mass frame of reference for colliding particles labelled A and B is given by

$$E_{CM}^2 = m_A^2 + m_B^2 + 2E_AE_B - 2\underline{p}_A \cdot \underline{p}_B$$

where m is rest mass in eV/c^2, $\underline{p}$ is momentum in eV/c and E is total energy in eV. Show that for equal speed and rest mass particles in a high energy head on collision, this simplifies to a good approximation to

$$E_{CM} = 2E_A$$ [20]

(c) The mass of a Z^o boson is 91.2 GeV/c^2. Determine the minimum energy of each colliding proton beam in the LHC in order for Higgs/anti-Higgs pairs to be created assuming head on collisions, if the Higgs particle is 1.8 times the mass of a Z^o. [15]

(d) State the key advantages and disadvantages of cyclic and electrostatic accelerators. [10]

(e) Describe and explain the key features of a cyclic particle collider for use in particle physics studies. [40]

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3. (a) Describe the key components and the operation of a Van de Graaff accelerator with a gas discharge source. [25]

(b) Discuss the limitations of a Van de Graaff accelerator and the advantages a tandem accelerator has in comparison. [20]

(c) A particular Van de Graaff accelerator and a single stripping tandem accelerator both operate with a voltage of 10 MV. Calculate the energies of;

i. protons accelerated by the Van de Graaff, [5]

ii. protons accelerated by the tandem, [5]

iii. α particles accelerated by the Van de Graaff, [5]

iv. α particles accelerated by the tandem. [5]

(d) A nucleus of energy 60 MeV emerges from the tandem of part (c) after all electrons are removed by the stripper. Determine the atomic number of the nucleus. [10]

(e) ^{12}C nuclei are accelerated by the tandem accelerator of part (c).

i. Calculate the maximum energy of ^{12}C ions produced. [5]

ii. Explain why the chosen ^{12}C beam extracted from the accelerator may not have the maximum energy of part (e)i. [20]

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4. (a) Define the *mean free path* of a neutron. [5]

(b) Explain why neutrons are much more penetrating than protons or photons when interacting with matter. [20]

(c) Name and define the four categories of neutron energy. [10]

(d) Contrast what is meant by *moderation* and *thermalisation* of neutrons in a reactor. [10]

(e) Compare the following aspects of thermal and fast reactors:

i. The energy of neutrons used for fission. [5]

ii. Moderation requirements. [10]

iii. Cooling requirements. [10]

(f) Explain the process of resonance loss in a reactor, how this affects neutron flux and what is meant by *resonance escape probability.* [10]

(g) Calculate the reaction rate for a flux of $10^{14}\,\mathrm{m^{-2}s^{-1}}$, 66 eV neutrons passing through 1g of ^{238}U, for which the neutron capture cross section is $2\times10^{-25}\,\mathrm{m^2}$. [20]

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5. (a) Explain the sources of n, β and γ radioactivity in a nuclear reactor. [30]

(b) Explain the difference between the *shielding* and the *containment vessel* in a nuclear reactor. [10]

(c) Describe what is meant by a radiative capture reaction and write down the equation for radiative capture of a neutron by ^{12}C. [10]

(d) Describe and explain the purpose of control rods in a nuclear reactor and why they are lowered into a reactor from above. [15]

(e) The reaction rates, measured for thermal neutron capture for the same neutron flux of $2\times10^{14}\,\mathrm{m^{-2}s^{-1}}$ and for the same number of ^{12}C and ^{11}B atoms, are found to be $9\times10^{7}\,\mathrm{s^{-1}}$ and $1.52\times10^{13}\,\mathrm{s^{-1}}$ respectively. The thermal neutron radiative capture section for ^{12}C is 4.5 mb. Calculate

i. the thermal neutron radiative capture cross section for ^{11}B and [15]

ii. the reaction rate for the ^{11}B if the neutron flux is increased to $10^{15}\,\mathrm{m^{-2}s^{-1}}$. [10]

(f) Thermal neutron radiative capture cross sections for many materials are typically a few mb, as in the case of ^{12}C. Discuss the value of the cross section obtained in part (e)i in relation to part (d). [10]