KEELE UNIVERSITY

DEGREE EXAMINATIONS, 2009

Level 2 (PRINCIPAL COURSE)

Tuesday 26th May 2009, 9:30 - 11:30

PHYSICS

PHY-20009

Nuclear and particle physics

Candidates should attempt to answer FOUR questions.

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

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1. (a) Describe the charge numbers, strangeness S, charm C, and relative mass of the 6 quarks. [20]

(b) Deduce the quark structure of the following mesons, none of which contain a top quark:

i. K^+; $S = 1, C = 0$, mass=495 MeV/c^2, [10]

ii. D^+; $S = 0, C = 1$, mass=1866 MeV/c^2, [10]

iii. F^+; $S = 1, C = 1$, mass=1971 MeV/c^2, [10]

iv. B^+; $S = 0, C = 0$, mass=5271 MeV/c^2. [10]

(c) The K^+ can be produced via the strong interaction:

$$\pi^+ + n \rightarrow \Lambda^o + K^+$$

i. Discuss the conservation of baryon number B, strangeness and charm in this reaction and state the values of these quantities for all particles involved. [20]

ii. Assuming no top or bottom quarks are involved deduce, with explanation, the quark structure of the Λ^o. [20]

2. (a) Explain which feature of the strong nuclear force results in stable light nuclei tending to have equal atomic Z, and neutron N, numbers, so $N \approx Z$. [10]

(b) Explain why $N > Z$ for large stable nuclei. [10]

(c) Describe the spin dependence of the nuclear force and therefore explain why stable ^{2}H exists but not ^{2}He or a nucleus of two neutrons. [25]

(d) Explain why an α particle has spin zero. [5]

(e) The ground states of the ^{2}H and the ^{6}Li nuclei have the same spin quantum number, 1. Explain this with reference to parts (c) and (d). [10]

(f) The lowest energy shell model state is $1s_{1/2}$ and the next is $1p_{3/2}$. Draw simple shell model diagrams for

i. ^{3}H [20]

ii. ^{7}Li [20]

and deduce the spin-parity for the ground state in each case.

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3. (a) Describe the contributions to the total angular momentum quantum number of a nucleon within a nucleus and discuss the values this can take. [20]

(b) Explain how the ground state spin quantum numbers result from the angular momentum of individual nucleons for

i. nuclei with even atomic and neutron numbers and [10]

ii. nuclei with an odd mass number. [15]

(c) Describe why a collective rotational model rather than a shell model is needed to describe the energies of the lowest 2^+ states in even-even nuclei in the mass number A region $150 < A < 190$ and $A > 230$. [15]

(d) The rotational energy for a state of spin quantum number I is given by

$$E_I = \frac{I(I+1)\hbar^2}{2\mathcal{I}}$$

for moment of inertia $\mathcal{I}$. Use the 76.5 keV energy of the lowest 2^+ state in the even-even nucleus ^{174}Yb to calculate the moment of inertia for this nucleus. [15]

(e) State and explain the multipolarity of the γ ray arising from the de-excitation of the state of part (d) and whether it is electric or magnetic. [25]

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4. (a) Show that α decay produces an α particle with a kinetic energy T_α such that

$$T_\alpha = \frac{Q}{1 + \frac{m_\alpha}{m_D}}$$

where Q is the total energy release of the decay and m_α and m_D are the masses of the α particle and daughter nucleus respectively. [20]

(b) Using the information below, calculate the energy of α particles emitted in the α decay of ^{224}Ra to the ground state of the daughter nucleus. [25]

	u (1u=931.5 MeV/c^2)
^{4}He	4.002603
^{220}Rn	220.011384
^{224}Ra	224.020202

(c) i. Approximately 95% of ^{224}Ra α decays populate the ^{220}Rn ground state and approximately 5% populate the first excited state, with small fractional percentages populating higher energy states. Explain this. [25]

ii. Describe other factors which could potentially affect which states in the daughter are most likely to be populated. [30]

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5. (a) For the following reactions, replace the question mark with the appropriate nucleus or particle:

   i. ^{12}C(^{4}He,^{3}He)? [5]

   ii. ^{7}Li(p,?)^{4}He [5]

   iii. ^{208}Pb(?,^{23}Na)^{208}Pb [5]

   iv. ?(α,αn)^{8}Be [5]

(b) Using the information below, calculate the Q value for the ^{12}C(^{12}C,^{11}C)^{13}C reaction. [20]

	u (1u=931.5 MeV/c^2)
^{11}C	11.01143
^{12}C	12.00000
^{13}C	13.00335

(c) In the laboratory frame, where a projectile of mass m_a and kinetic energy T_a is incident on a stationary target nucleus, the ejectile kinetic energy T_b at angle θ_b may be determined from

$$\sqrt{T_b} = \frac{F \pm \sqrt{F^2 + (m_Y + m_b)[m_Y Q + (m_Y - m_a)T_a]}}{m_Y + m_b}$$

where

$$F = \cos\theta_b \sqrt{m_a m_b T_a}$$

m_b and m_Y are the masses of the ejectile and residual nucleus respectively and Q is the reaction Q value. For the reaction of part (b):

   i. Define and calculate the threshold energy. [40]

   ii. Determine the range of projectile energies for which there are two possible ejectile energies. [20]

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6. (a) State what is meant by neutron induced fission, explaining the two stages by which it occurs. [15]

(b) A plot of number of fragments versus mass number, for thermal neutron induced fission on ^{235}U shows a broad peak around mass number 138. Assume that on average each fission produces one more neutron. Describe and explain another broad peak in the plot. [15]

(c) Show that the ratio of the two fission fragment kinetic energies is approximately inversely proportional to the ratio of their masses, stating any approximations made. [25]

(d) Using the information below, calculate the Q value for the fission reaction

$$^{235}\mathrm{U} + n \rightarrow ^{138}\mathrm{Xe} + ^{96}\mathrm{Sr} + 2n \qquad [15]$$

	u (1u=931.5 MeV/c^2)
n	1.008665
^{96}Sr	95.921650
^{138}Xe	137.913989
^{235}U	235.043924

(e) Estimate the kinetic energy of;

i. the ^{96}Sr nucleus, [20]

ii. the ^{138}Xe nucleus. [10]