

KEELE UNIVERSITY

DEGREE EXAMINATIONS, 2009

Level 2 (PRINCIPAL COURSE)

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

PHYSICS

PHY-20009

Nuclear and particle physics

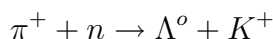
Candidates should attempt to answer FOUR questions.

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<sup>2</sup>, [10]
  - ii.  $D^+$ ;  $S = 0, C = 1$ , mass=1866 MeV/c<sup>2</sup>, [10]
  - iii.  $F^+$ ;  $S = 1, C = 1$ , mass=1971 MeV/c<sup>2</sup>, [10]
  - iv.  $B^+$ ;  $S = 0, C = 0$ , mass=5271 MeV/c<sup>2</sup>. [10]

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



- 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  $\Lambda^0$ . [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  ${}^2\text{H}$  exists but not  ${}^2\text{He}$  or a nucleus of two neutrons. [25]
- (d) Explain why an  $\alpha$  particle has spin zero. [5]
- (e) The ground states of the  ${}^2\text{H}$  and the  ${}^6\text{Li}$  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.  ${}^3\text{H}$  [20]
  - ii.  ${}^7\text{Li}$  [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
- nuclei with even atomic and neutron numbers and [10]
  - 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  $^{174}\text{Yb}$  to calculate the moment of inertia for this nucleus. [15]

- (e) State and explain the multipolarity of the  $\gamma$  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  $\alpha$  decay produces an  $\alpha$  particle with a kinetic energy  $T_\alpha$  such that

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

where  $Q$  is the total energy release of the decay and  $m_\alpha$  and  $m_D$  are the masses of the  $\alpha$  particle and daughter nucleus respectively. [20]

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

	u (1u=931.5 MeV/c <sup>2</sup> )
$^4\text{He}$	4.002603
$^{220}\text{Rn}$	220.011384
$^{224}\text{Ra}$	224.020202

- (c) i. Approximately 95% of  $^{224}\text{Ra}$   $\alpha$  decays populate the  $^{220}\text{Rn}$  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.  $^{12}\text{C}(^4\text{He}, ^3\text{He})?$  [5]  
 ii.  $^7\text{Li}(p, ?)^4\text{He}$  [5]  
 iii.  $^{208}\text{Pb}(?, ^{23}\text{Na})^{208}\text{Pb}$  [5]  
 iv.  $?(^{\alpha}, \alpha n)^8\text{Be}$  [5]

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

	u (1u=931.5 MeV/c <sup>2</sup> )
$^{11}\text{C}$	11.01143
$^{12}\text{C}$	12.00000
$^{13}\text{C}$	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  $\theta_b$  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

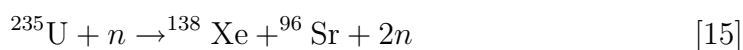
$$F = \cos \theta_b \sqrt{m_a m_b T_a}$$

$m_b$  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  $^{235}\text{U}$  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



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

- (e) Estimate the kinetic energy of;
- the  $^{96}\text{Sr}$  nucleus, [20]
  - the  $^{138}\text{Xe}$  nucleus. [10]