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KEELE UNIVERSITY

EXAMINATIONS, 2009/10

Level II

Monday 24th May 2010, 13.00-15.00

PHYSICS

PHY-20009

NUCLEAR AND PARTICLE PHYSICS

Candidates should attempt to answer FOUR questions.

NOT TO BE REMOVED FROM THE EXAMINATION HALL

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1. (a) Explain what is meant by *binding energy* in nuclear and particle physics.

(b) Using the following table:

Particle:	up quark	down quark	neutron	proton	α particle
Mass (MeV/c^2):	336	336	939.573	938.280	3727.413

calculate

i. the binding energy per nucleon for an α particle and [10]

ii. the binding energy per quark for a neutron. [10]

(c) i. Describe the quark structure of a meson. [10]

ii. The following mesons have strangeness $S = -1$:

Meson:	K^-	$\overline{K}^o$	D_S^-	B_S^o
Mass (GeV/c^2):	0.49	0.50	1.97	5.37

Deduce, with explanation, the quark structure of each. [25]

(d) The Ω^- has strangeness $S = -3$ and decays predominantly as follows:

$$\Omega^- \rightarrow \Lambda^o + K^-$$

Strangeness is not conserved in this decay.

i. State which interaction is responsible for the decay. [10]

ii. Deduce, with explanation, the most likely quark structure of the Λ^o. [25]

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2. The energies, spins and parities of low lying excited states in some nuclei are gi[ven] as follows:

State:	1st		2nd		3rd		4th	
^{58}Ni:	1.454 MeV	2^+	2.776 MeV	2^+	2.902 MeV	1^+	2.942 MeV	0^+
^{74}Se:	0.559 MeV	2^+	1.122 MeV	0^+	1.216 MeV	2^+	1.331 MeV	4^+
^{166}Yb:	0.102 MeV	2^+	0.331 MeV	4^+	0.668 MeV	6^+	1.098 MeV	8^+

(a) State and explain the spin and parity for the ground states of these nuclei. [15]

(b) Using the information in the table of part (a), describe and explain which nuclear model is most applicable to each of these three nuclei. [50]

(c) Calculate, using the most appropriate excited state, best estimates for:

i. the phonon frequency for the vibrational nucleus and [15]

ii. the moment of inertia of the rotational nucleus. [20]

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3. A radioactive source is manufactured which initially contains 1.00 μg of pure ^{2}... which decays to stable ^{206}Pb.

(a) Calculate the initial number of ^{206}Bi nuclei in the source. [10]

(b) After 14 days the activity of the source has decreased to a fraction 0.211 of its original activity. Calculate the half life of ^{206}Bi. [25]

(c) Calculate the initial activity of the source. [10]

(d) Calculate the number of ^{206}Pb nuclei in the source after 3 weeks. [15]

(e) Sketch plots as a function of time t of:

i. the number N_{Bi} of ^{206}Bi nuclei and the number N_{Pb} of ^{206}Pb nuclei, indicating on the axes the initial number of ^{206}Bi nuclei and the numbers of each when these are equal and the time at which this occurs, [15]

ii. the total number $N_{total} = N_{Bi} + N_{Pb}$ of ^{206}Bi and ^{206}Pb nuclei and [5]

iii. $\ln N_{Bi}$ indicating the numerical values where the plot meets the axes. [20]

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4. (a) State how the binding energy per nucleon is related to nuclear stabi[lity]. Sketch the binding energy per nucleon as a function of mass number. [10]

(b) The atomic numbers Z and masses M ($1\,\text{u}=931.5\,\text{MeV/c}^2$) of some atoms are given below:

Atom	Z	M(u)
^{65}Ni	28	64.930088
^{65}Cu	29	64.927793
^{65}Zn	30	64.929245
^{1}H	1	1.007825
n	0	1.008665

i. Calculate the binding energy of the only stable mass number $A = 65$ nucleus listed. [30]

ii. For each of the other $A = 65$ nuclei, explain whether it decays by α, β^+ or β^- emission. [20]

(c) ^{66}Ni β-decays to ^{66}Cu ground state. The maximum energy of the β particle emitted is 225.6keV and the atomic mass of ^{66}Cu is 65.928872u.

i. Calculate the atomic mass of ^{66}Ni. [20]

ii. Discuss the kinetic energy of the daughter nucleus. [10]

iii. Explain why the β particles have a range of energies. [10]

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5. (a) Write equations for and state what happens in the following α particle induced reactions on a ^{12}C target:

   i. Elastic scattering. [10]

   ii. Two neutron pickup reaction. [10]

   iii. Fusion reaction to an excited nuclear state which γ decays with no ejectile. [10]

(b) For non-relativistic elastic scattering of an α particle from a larger target nucleus, at 180° from the incident direction, show that the energy T'_α of the scattered α particle is related to its incident energy T_α by

$$T'_\alpha = \left(\frac{m_X - m_\alpha}{m_X + m_\alpha}\right)^2 T_\alpha$$

where m_X and m_α are the masses of the target nucleus and α particle respectively. [50]

(c) Quantitatively describe the distribution of the initial kinetic energy between the scattered α particle and recoiling nucleus in the situation of part (b) if the target is:

   i. ^{12}C [10]

   ii. ^{4}He. [10]

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6. (a) Describe what happens during a neutron-induced fission reaction, explai
the radioactivity of the fragments and why neutrons are emitted. [30]

(b) Explain what is meant by *fast* and *thermal* neutrons. [20]

(c) Using the mass information given below, calculate the energy released in the thermal neutron induced fission reaction:

$$n + {}^{235}\text{U} \rightarrow {}^{135}\text{Xe} + {}^{99}\text{Sr} + 2n$$ [20]

	u (1u=931.5 MeV/c^2)
n	1.008665
^{99}Sr	98.933315
^{135}Xe	134.907207
^{235}U	235.043923

(d) Assuming the average energy emitted per thermal-neutron-induced fission on ^{235}U is 190MeV, determine the minimum mass of ^{235}U, in kg, consumed in order to fuel a power station for one year, if the annual energy generated is 1.3×10^{15}J. [30]

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