<u>ONE HOUR THIRTY MINUTES</u>

A list of constants is enclosed.

UNIVERSITY OF MANCHESTER

Nuclear Physics

28th May 2002, 9.45 a.m. - 11.15 a.m.

Answer **<u>ALL</u>** parts of question 1 and **<u>TWO</u>** other questions

---

Electronic calculators may be used, provided that they cannot store text.

The numbers are given as a guide to the relative weights of the different parts of each question.

1. (a) The binding energy term of the semi-empirical mass formula may be expressed by:

$$B(A,Z) = a_v A - a_s A^{2/3} - a_c Z^2 A^{-1/3} - a_{sym}\frac{(A-2Z)^2}{A} \pm \delta.$$

Use this to explain why there is only one stable isotope in an isobar chain of a given odd-A. [5 marks]

(b) Describe the main features of the nucleon-nucleon interaction. [5 marks]

(c) State the angular momentum and parity selection rules for allowed *Fermi* and *Gamow-Teller* beta-decays. Classify the neutron beta-decay. [5 marks]

(d) List *three* pieces of experimental evidence that supports the existence of a shell structure for the nucleus. [5 marks]

(e) Explain why, in a prolate-deformed nucleus, α-emission is more probable from the poles than from the equator. [5 marks]

2. Briefly describe the experimental method for measuring nuclear charge distributions via muonic X-ray spectroscopy. [6 marks]

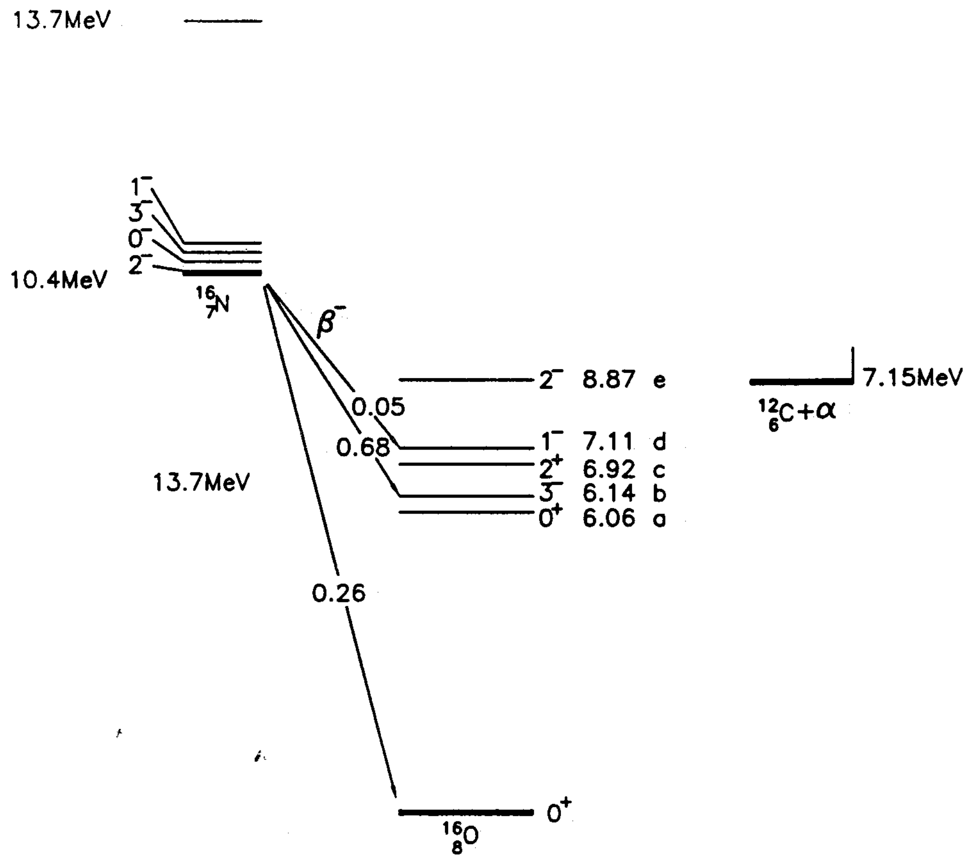
Explain how muonic X-rays provide this information. [6 marks]

Compare the extent of the nuclear information that can be obtained from muonic X-rays with that from optical isotope shift measurements. [6 marks]

Estimate the energy of the muonic K X-ray (2p→1s) for $^{56}_{26}$Fe, assuming the nucleus is a point charge. Compare your answer with the experimental value of 1255 keV and comment on your result. [7 marks]

[Muon mass: $m_\mu = 207\ m_e$.]

3. Given that the three lowest energy levels of a three-dimensional harmonic oscillator have orbital angular momentum values of $\ell = 0$ (ground state), $\ell = 1$ (at $1\hbar\omega$) and $\ell = 0$ and 2 (at $2\hbar\omega$), sketch the single-particle levels arising from the 1s, 1p, 1d and 2s orbitals for a realistic nuclear potential and account for the level ordering. [9 marks]



The diagram shows low-lying levels of ^{16}N and ^{16}O relative to the ^{16}O ground state. The threshold energy of ^{12}C+α is also shown.

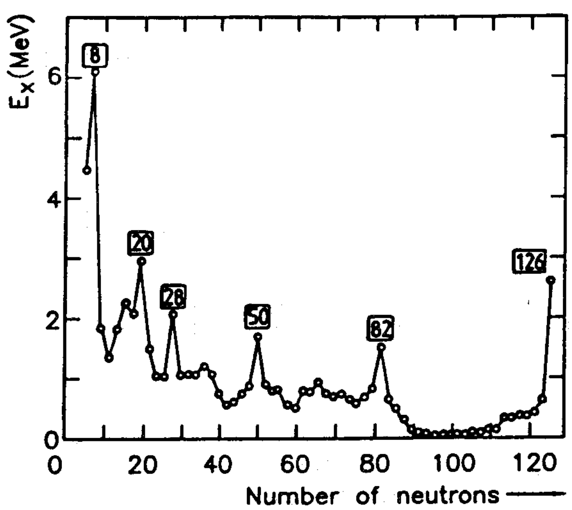
(a) Give the most probable shell model description for the ^{16}N and ^{16}O ground states, and the state labelled b. [4 marks]

(b) Explain why the ^{16}N ground state β^- decay to the ^{16}O ground state is less intense than its β^- decay to the 3^- state. [5 marks]

(c) Give the most probable decay modes of the states labelled a, b, c, d, giving the classification (σ L) of the gamma-ray transitions. [5 marks]

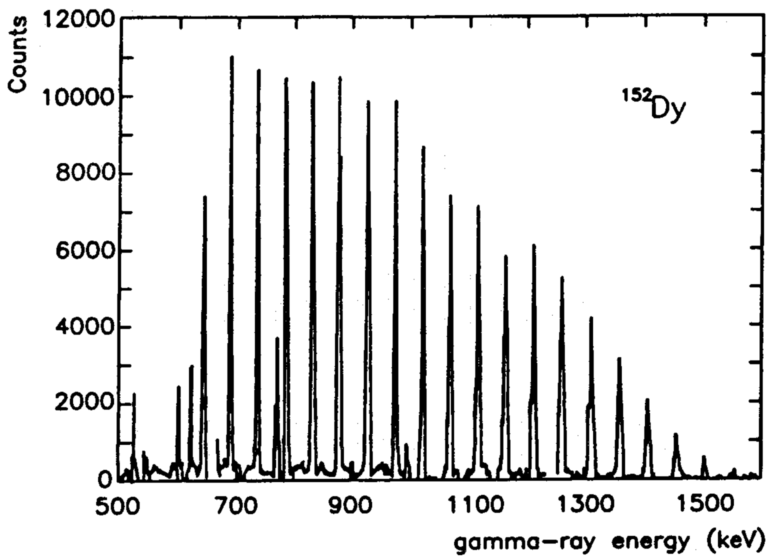
(d) Explain why the state labelled e has no observed α decay. [2 marks]

4. The diagram shows the average energies of the lowest 2^+ states of even stable nuclei as a function of neutron number. Describe the characteristics of the level schemes you would expect to find in even stable nuclei in the regions (a) near N=64; (b) at N=82; (c) near N=100. [15 marks]



Show that, in a rotational band with constant moment of inertia $\mathcal{I}$, the transition energies increase linearly with nuclear spin. [4 marks]

The energy spectrum of γ rays emitted by a sequence of rotational states in ^{152}Dy is shown below. The γ ray transitions are $I \rightarrow (I-2)$ electric quadrupole transitions but the nuclear spins of the individual levels are not known. By considering the difference in the γ ray energies for successive decays, determine a value for $\hbar^2/2\mathcal{I}$ for the rotational band in ^{152}Dy. [3 marks]



Compare your value with the rigid-rotor value $\hbar^2/2\mathcal{I}_{rigid}$ =6 keV appropriate for ground state deformations in the N=100 region, and comment on your answer. [3 marks]