NATIONAL UNIVERSITY OF SINGAPORE

PC3232 Nuclear and Particle Physics

(Semester I: AY 2009-10)

Time Allowed: 2 Hours

INSTRUCTIONS TO CANDIDATES

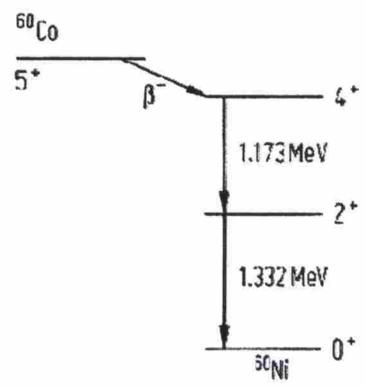
1. This examination paper contains four questions and comprises 5 printed pages.
2. Answer any three questions.
3. Answers to the questions are to be written in the answer books.
4. This is a CLOSED BOOK examination.

1)

a) Name the three main interactions of a photon with matter and describe briefly the characteristics of each of them.

b) Draw a spectrum as it would appear in a semiconductor detector for a radioactive source producing only 1.64 MeV gamma ray photons, and show clearly evidence for all three interactions in part a).

c) The decay scheme of ^{60}Co is shown below. In a measurement using a semiconductor detector, the number of counts in the photopeaks of the 1.173 MeV and the 1.332 MeV transition are 15320 and 14732. Is the ratio of these two numbers consistent with unity? If not, why is that so?



2)

The shell model predicts a sequence of levels according to:

$$1s_{1/2}, 1p_{3/2}, 1p_{1/2}, 1d_{5/2}, 2s_{1/2}, 1d_{3/2}, etc$$

a) Explain in reasonable detail the principles underlying the shell model of the nucleus, and explain how this model is able to predict the magic numbers 2, 8, 20, 28, 50.

b) Using the shell model, calculate the spin/parity assignments of the ground states of

i) ^{21}Na (Z=11)

ii) ^{31}P (Z=15)

iii) ^{16}O (Z=8)

c) Consider the levels of ^{10}B. The ground state has spin and parity of 3^+, and the excited levels in order of increasing energy have 1^+, 0^+, 1^+, 1^+, 2^+, 3^+, etc. Is there an explanation within the shell model of the fact that the lowest levels all have positive parity? The first excited level is at 0.72 MeV, and the second at 1.74 MeV. If only the second state is populated, what are the energies of the decay gammas observed? Roughly estimate their relative intensities.

3)

a) Consider Rutherford's experiment in the case where an alpha particle of energy 4.8 MeV rebounds back on its original trajectory from a gold foil. Use arguments based on the conservation of energy to show that the mass of the atom must be concentrated in a positively charged nucleus whose diameter is less than 100 fm.

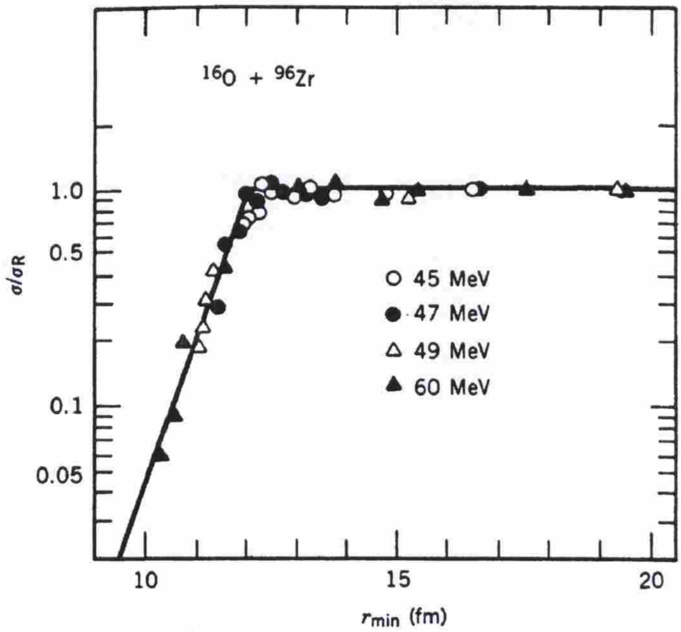
b) The figure below shows measurements of the elastic scattering cross-section for ${}^{16}_{8}O$ incident on ${}^{96}_{40}Zr$, plotted relative to the Rutherford cross-section. The horizontal axis presents the distance of closest approach, r_{min}.

i. Identify the physical processes that lead to the shape of the graph. How could different r_{min} values be measured with a fixed energy?

ii. Assuming that nuclei are hard spheres with radius $R = r_0\, A^{1/3}$ with r_0=1.2 fm, predict the value of r_{min} for which the Rutherford scattering model is expected to break down.

iii. What would the largest incident energy be where one would still expect pure Rutherford scattering based on this model?

iv. Discuss why the Rutherford scattering model breaks down earlier than expected from this model.



4)

a) Explain the difference between nuclear fission and fusion and explain why each process releases energy.

b) Two isotopes of hydrogen ^2H (deuterium, D) and ^3H (tritium, T), fuse to form ^4He and a neutron. Determine the energy released by this fusion reaction.

c) Antiprotons are created when a beam of high-energy protons strikes a hydrogen target. In the laboratory system, derive the minimum proton kinetic energy required for the reaction to take place.

Table 1: masses

Isotope	Mass [u] ($1u = 931.502\ MeV/c^2$)	No of protons	No of neutrons
n	1.008665	0	1
^1H	1.007825	1	0
^2H	2.014102	1	1
^3H	3.016049	1	2
^3He	3.016029	2	1
^4He	4.002603	2	2

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T.O.