Queen Mary University of London — PHYSICS department

Nuclear Physics & Astrophysics
Exercises – 2

Hand in on 1st floor by Friday 15th October 2pm

Proton mass m_p = 1.00727647 u
Neutron mass m_n = 1.00866501 u
Avogadro's number NA=6.022 x 1023 mol-1
$e^2/4\pi\varepsilon_0$ = 1.439976 MeV fm

^{231}Th mass = 231.036299 u
^{4}He mass = 4.002603 u

1. The alpha decay of ^{235}U to Th is observed in an experiment to determine the binding energy of uranium. The experiment assumes the initial nucleus is at rest and the thorium daughter nucleus is also produced at rest. The alpha particle is observed to have a kinetic energy of 4.678 MeV. Give the reaction equation for this decay process. What is the observed Q of the reaction? Using only the accurately known values for the thorium-231 and helium-4 masses given above, calculate the mass of uranium-235 and hence the binding energy of the nucleus. [6]

2. Considering conservation of the following quantities, list which are relevant for the decays listed below: charge, energy-momentum, atomic number, atomic mass number
   a) Alpha decays
   b) Beta decays
   c) Gamma decays [4]

3. Calculate the nuclear radius of ^{14}N in fm. The reaction cross section for the process $^{14}N + n \rightarrow {}^{14}C + p$ is measured to be 0.17 fm^2. Compare this to the geometric cross sectional area of a ^{14}N nucleus and explain why there is a difference. [4]

4. A pure carbon archaeological item of mass 4g is excavated in Stratford. An experimenter measures the activity and records 126 counts in a period of 1 hour, assumed to come from decays of ^{14}C which has a decay constant of 1.2092×10^{-4} y^{-1}. At the same time a background count of 0.010 Bq is also recorded. What is the mean lifetime and the half life of ^{14}C? Assuming living matter has an abundance of 1.0×10^{-12} of ^{14}C, what is the age of the artefact? Using the propagation of errors formula, determine the uncertainty on the measured age of the artefact? [6]

5. A sample of gold is exposed to a neutron beam of constant intensity such that 10^{10} neutrons per second are absorbed in the reaction:

$$^{197}_{79}Au + n \rightarrow {}^{198}_{79}Au + \gamma$$

The nuclide $^{198}{}_{79}Au$ undergoes β-decay to $^{198}{}_{80}Hg$ with a mean lifetime of 3.89 days. How many atoms of $^{198}{}_{79}Au$ will be present after 6 days of irradiation? How many atoms of $^{198}{}_{80}Hg$ will be present at that time, assuming that the $^{198}{}_{80}Hg$ is unaffected by the neutron beam? What is the equilibrium number of $^{198}{}_{79}Au$ [10]

[Hint] Use a trial solution $Ae^{-\lambda_1 t} + B$ for rate of change in number of $^{198}{}_{79}Au$ nuclei.