PHY2005 – Nuclear Physics – Assignment 1

March 2022

Attempt all questions.

The assignment will be marked out of 100.

Q1 The measured binding energy of a nucleus *X* is 1.6306 GeV. It contains 84 protons and 124 neutrons.

(a) Calculate the atomic mass of *X* in atomic mass units using a precision to five sig figs. **[15]**

(b) Estimate the average nuclear radius of *X*. **[5]**

(c) Using your own words, briefly explain how the binding energy of a nucleus is related to its stability. **[5]**

Clearly show all working for your calculations.

[m(^{1}H) = 1.007825 u; m_n = 1.008665 u, c^2 = 931.50 MeV/u]

Q2 The general case of a nuclear reaction can be expressed as follows: $a + A \rightarrow B + b$. If the nucleus *A* is at rest, the nucleus *a* moves with kinetic energy of 10 MeV, the nucleus *b* moves with kinetic energy of 12.2 MeV, and the rest masses of *a*, *A*, and *b* are 4.0026 u, 14.0067 u, and 1.0078 u, respectively:

(a) Provide a general expression for the conservation of the total relativistic energy for such a reaction, assuming that the kinetic energy of the recoil nucleus *B* is negligible. **[5]**

(b) Calculate the rest mass of the recoil nucleus *B* in atomic mass units and its mean nuclear radius in fm. **[20]**

Q3

(a) Derive two analytical expressions that allow to calculate the neutron and proton separation energies. **[15]**

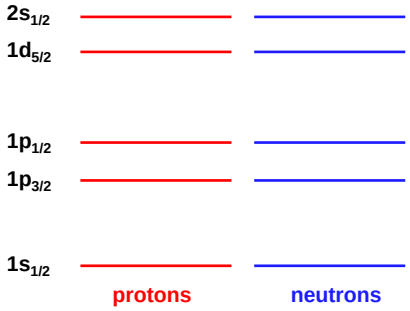
[Hint: start from the binding energy definition (formula)]

(b) Calculate the neutron and proton separation energies in MeV for the ${}^{14}_{6}C_{8}$ nucleus. **[10]**

[m(^{14}C) = 14.003240 u; m(^{13}C) = 13.003355 u; m(^{13}B) = 13.017780 u]

Q4

(a) Fill the given quantum states with protons and neutrons for the nucleus ${}^{29}_{15}P_{14}$ according to the nuclear Shell model and specify its nuclear spin and parity. **[10]**



(b) Calculate the electric quadrupole moment of ${}^{29}_{15}P_{14}$. **[5]**

(c) Using your own word, briefly explain why the nuclear Shell model fails to predict the electrical quadrupole moments of heavy nuclei. Additionally, discuss which nuclear model provides prediction of the electric quadrupole moments for heavy nuclei that agree with the experimental observations. **[10]**