Exam Nuclear Physics

Bachelor Physics and Astronomy — August 28 2024

Name : [redacted]

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- *The evaluating lecturer is indicated for each question. For practical reasons, please use a separate sheet of paper for each evaluator.*
- *The questions should be handed in along with the open-book part.*
- *Don't forget to put your name on every page.*
- *There is a laptop available with the IAEA digital nuclide chart open, to look up data needed for the exercises. Do not wait till the last moment to use it !*

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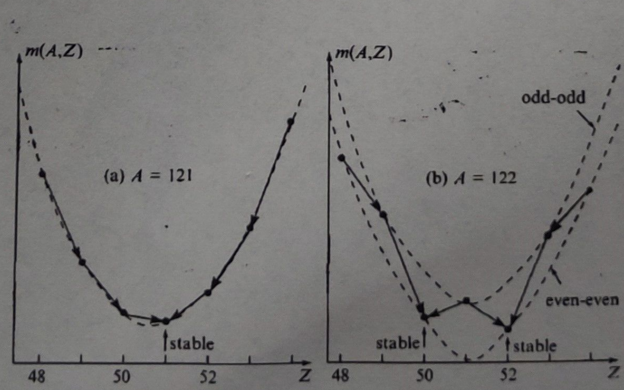
I. Theory - Closed Book

Question 1 (N. Jachowicz) (/4)
Discuss in detail how for direct nuclear reactions, various aspects of cross section measurements can provide information about the structure of the nuclei involved in the reaction and about the properties of the other particles involved in the interaction. When applicable, provide the necessary calculations to corroborate your answer.

Question 2 (N. Jachowicz) (/2)
Discuss what is shown in the figure below. Explain the behavior shown in the curves in detail, as well as the origin of the differences between them.



Question 3 (M. Boone) (/1)
Explain the difference between direct and indirect damage in radiation dosimetry. Which important effect in dosimetry is mainly a consequence of indirect radiation damage ?

Question 4 (M. Boone) (/1)
What are the advantages of using γ sources for (industrial) radiography compared with X-ray sources ? Explain why safety is more challenging than for X-ray sources, and how this is achieved for γ sources.

Question 5 (M. Boone) (/2)
Describe PET imaging. Name a common isotope used for this imaging modality. What determines the fundamental resolution limit on this technique ? What technological aspect further deteriorates the resolution ? Explain how novel total-body PET systems improve the dose efficiency.

Question 6 (M. Boone) (/2)
Discuss the four-factor formula for infinite reactors and explain all (four) factors.

II. Problems - Open Book

Problem 1 (M. Hooft - J Garcia-Marcos) (/3)
Assume we live in a hypothetical universe where all nucleons are spin $\frac{3}{2}$ particles. Describe the nuclear potential as a 3D harmonic oscillator and calculate how the spin-orbit force (with coupling strength $\frac{\omega}{6\hbar}$) splits the $1s$ and $1p$ energy levels. Draw a level scheme for these states. In this universe, what would be the spin and parity of the ground state of ^{17}O ?

HINT: The energy levels of the 3D harmonic oscillator are $\hbar\omega(2k + l + \frac{3}{2}) = \hbar\omega(N + \frac{3}{2})$, where k stands for the radial quantum number.

Problem 2 (M. Hooft - J. Garcia-Marcos) (/2)
The α-decay of ^{253}Es ($I = \frac{7}{2}$, $\pi = +$) leads to a sequence of negative-parity states in ^{249}Bk with $I = \frac{3}{2}, \frac{5}{2}, \frac{7}{2}, \frac{9}{2}, \frac{11}{2}, \frac{13}{2}$. For each state, find the allowed values of l_α.

Problem 3 (J. Knolle) (/3)

1. What is the half-life of ^{239}Pu and ^{240}Pu ? What is the main decay process ? What is the energy of the most abundant decay particle, and in what fraction of decays does a decay particle of that energy appear ?
2. A nuclear power plant is operated with 'reactor-grade' plutonium, consisting of 25% ^{239}Pu and 75% ^{240}Pu nuclei. The fission and neutron capture cross sections are $\sigma_f = 747\,b$ and $\sigma_c = 272\,b$ for ^{239}Pu, and $\sigma_f \approx 0$ and $\sigma_c = 289\,b$ for ^{240}Pu. The total usable energy release per fission of a ^{239}Pu nucleus is 212 MeV. How does the mass of plutonium in the reactor change through fission and neutron capture of the two nuclides ? What is the power output of the reactor if 600 kg/y of the original fuel reacts (assume that any nuclei undergoing neutron capture do not contribute again) ?
3. The start of the nuclear power plant is delayed by 1 y. Which fraction of 600 kg of fuel will decay in that time ? Do the fractions of ^{239}Pu and ^{240}Pu change significantly ? What if the fuel is instead stored for 1000 y ?