Final project PHZ5305: Interaction matrix elements and Hartree-Fock

1. Goals

1. List all the possible single-particle states (n, l, j, m_j, t_z) up to ^{16}O.
2. List all the possible two-body states coupled to $J^\pi = 0^+$.
3. List all the possible antisymmetrized two-body matrix elements (me2b) coupled to $J^\pi = 0^+$ in the format (a, b, c, d, v), where a, b, c, and d are indices of spingle-particle states, and assign them a value v based on experimental data whenever possible, and randomly otherwise (centered around zero).
4. Write a Python code that reads the list of single-particle states and the me2b generated, and solves the Hartree-Fock equation. Assume that the single-particle energies (including the kinetic energy) are given in the harmonic oscillator basis.
5. Consider the following closed-shell nuclei: ^{4}He, ^{12}C, and ^{16}O. Find their experimental ground state binding energies, and design a Python code to optimize the me2b so that you can reproduce all three energies simultaneously.

2. Modalities

1. Write a detailed report in LaTeX including the references you used, the checks you did (graphs encouraged), and the issues you had (if any), and any extensions you have done or considered. The report should be *publication quality.*

You are allowed to work alone or in groups of 4 maximum, and use any resources you want. The evaluation will be based on the quality of both the code (if any) and the report, which are expected to reflect a solid understanding of the work done. Exceeding the stated goals will be rewarded. Highly collaborative behavior such as helping each other, including "competitors" and not letting anyone alone will also be accounted for through the general level of the grading.

3. Tips

1. Start working on the report as early as possible. Reaching publication quality is difficult and requires feedback from many people when inexperienced. A publication is often structured as follows: Introduction, Methods, Results, Conclusions. The bibliography must be exhaustive, balanced, and accurate.