5.1: Characteristics of the Nuclear Force

In this part of the course we want to study the structure of nuclei. This in turns will give us insight on the energies and forces that bound nuclei together and thus of the phenomena (that we'll study later on) that can break them apart or create them.

In order to study the nuclear structure we need to know the constituents of nuclei (the nucleons, that is, protons and neutrons) and treat them as QM objects. From the point of view of QM as we studied until now, we want first to know what is the state of the system (at equilibrium). Thus we want to solve the time-independent Schrödinger equation. This will give us the energy levels of the nuclei.

The exact nature of the forces that keep together the nucleus constituents are the study of quantum chromodynamics, that describes and look for the source of the strong interaction, one of the four fundamental interactions, along with gravitation, the electromagnetic force and the weak interaction. This theory is well-beyond this course. Here we want only to point out some of the properties of the nucleon-nucleon interaction:

- At short distances is stronger than the Coulomb force: we know that nuclei comprise tightly packed protons, thus to keep these protons together the nuclear force has to beat the Coulomb repulsion.
- The nuclear force is short range. This is supported by the fact that interactions among e.g. two nuclei in a molecule are only dictated by the Coulomb force and no longer by the nuclear force.
- Not all the particles are subjected to the nuclear force (a notable exception are electrons)
- The nuclear force does not depend at all on the particle charge, e.g. it is the same for protons and neutrons.
- The nuclear force does depend on spin, as we will prove in the case of the deuteron.
- Experiments can reveal other properties, such as the fact that there is a repulsive term at very short distances and that there is a component that is angular-dependent (the force is then not *central* and angular momentum is not conserved, although we can neglect this to a first approximation).

We will first see how these characteristics are reflected into the Hamiltonian of the simplest (non-trivial) nucleus, the deuteron. This is the only nucleus that we can attempt to solve analytically by forming a full model of the interaction between two nucleons. Comparing the model prediction with experimental results, we can verify if the characteristics of the nuclear force we described are correct. We will then later study how the nuclear force properties shape the nature and composition of stable and unstable nuclei.