Nuclear physics

Midsession test 2012

Time allowed one hour.
All questions below need to be addressed.
If math presents a difficulty then give explanation in plain English.
Calculators would not be required.

Formulas and data which may be useful

\[ 1 \text{ fm} = 10^{-15} \text{ m} \]  
\[ 1 \text{ MeV} = \frac{197}{1 \text{ fm}} \]  
\[ r = r_0 A^{1/3}, \quad r_0 = 1.2 \text{ fm} \]  

Bohr radius

\[ a_B \approx 0.5 \times 10^{-10} \text{ m} = 0.5 \times 10^5 \text{ fm} \]

Binding energy of the deuteron

\[ E_{bd} \approx 2.2 \text{ MeV} \]

**Question 1 (40%) Nuclear structure**

Give a brief, qualitative description of the nuclear structure. In particular

- outline the physical origins of nuclear forces
- present the typical distances (in fm) at which these forces are effective and explain which fundamental parameter regulates this distance
- indicate at which distances the nuclear forces are attractive and where they are repulsive
- discuss how the attraction and repulsion of the nuclear forces manifest in nuclear properties; how strongly the nuclear density varies in nuclei?
- estimate the typical density of nucleons in nuclei (fm\(^{-3}\)) and compare it with the typical density of atoms in condense matter (accurate calculations are not required, give only an estimate of the order of magnitude)

**Question 2 (30%) Nuclear reactions**

Consider the neutron - proton collision which results in the creation of the deuteron with emission of a photon
\[ n + p \rightarrow d + \gamma \]

Assume that in the center of mass the kinetic energies of the proton and neutron are low, \( K_p, K_n \ll 1 \text{ MeV} \).

- Find the wavelength of the emitted photon with, say, 10\% accuracy (which does not need calculators). Argue whether this process should or should not be described as the E1 transition?

**Question 3 (30\%) Symmetries**

Consider the four known fundamental interactions, strong, weak, electromagnetic, and gravitational interactions.

Indicate which of them conserve and which break each one of the following physical quantities

- angular momentum
- parity
- isotopic spin

Consider two neutrons, which exist in some nucleus above its closed nuclear shells. Remember that such a pair develops a strong binding and consequently can be treated as a bound state, pair of neutrons (compare Cooper's pairs in condense matter).

Presume that the relative orbital momentum of neutrons in this pair is zero, \( L = 0 \) (the most common binding).

- find the spin \( S \) of this pair
- find the isotopic spin \( I \) and its projection \( I_3 \) for the pair