FYS 3520 Nuclear Physics, Structure and Spectroscopy
Midterm Exam Spring 2015 (home exam)

Deadline to hand it in has been extended to is tuesday 7^{th} of April noon.
It can be sent electronically to sunniva.siem@fys.uio.no or on paper to the expedition office at physics.

1. Nuclear properties

Briefly answer the following questions.

a) How big is the atomic nucleus? How big is an atom?

b) What is the density (Mass/Volume) of the nucleus?

c) Does the nuclear density depend on the mass number A?

d) What are isotopes, isotones and isobars?

e) The neutron has no charge, but still it has a magnetic moment, why?

f) What is parity and symmetry?

g) Can a spherical nucleus rotate?

h) What is the heaviest (largest Z and largest A) nucleus we have managed to produce so far (do not use the textbook)

i) Which element Z has the highest number of stable isotopes? Why?

j) Is it hardest to steal a neutron from ^{208}Pd or ^{11}Li or ^{4}He?

l) Why doesn´t the electrons fall into the nucleus?

2. Nuclear binding energy

a) A nucleus has a given mass 207.976627 nuclear mass units (u), (see appendix C in Krane). Which nucleus is it? Write down the chemical name, Z and neutron number. Calculate the binding energy.

b) Now calculate the binding energy using the semi empirical mass formula (Weizäcker). Use the standard values of the coefficients given in Krane p 68.
How well does it agree with the value you found in a)?

c) Estimate the energy needed to remove one neutron from ^{40}Ca nucleus (which has N=Z=20).

d) The masses of the mirror nuclei ^{24}Na and ^{24}Al are 23.990962950 u and 23.999947502 u, respectively. Use this to determine an approximate value of the Coulomb's coefficient in the semi-empirical mass formula.

e) For A=135 find the most stable nucleus using the semi empirical mass formula. Sketch the mass as a function of Z for the A=135 isobars ("mass parabola") and explain how the beta decay flows between nuclei with A=135. Make also a sketch for a case where A is an even number, for example A=128, explain the difference from the odd A case.

f) The following figure shows the binding energy per nucleon. Looking at the figure answer the following questions:

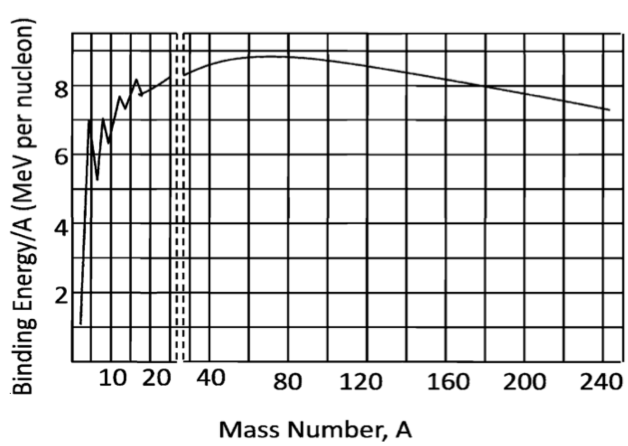
- How is binding energy related to stability? In other words, as the binding energy increases, what happens to the mass of our nucleus? Is it more or less stable?

- For which mass number A (approx.) do we find the most stable nucleus?

- We can "fuse" two nuclei to one (fusion) or split a nucleus (fission). Looking at the binding energy curve: For which nuclei (approx range of A) can energy be produced through fusion? and for which nuclei can energy be produced by fission?

- Can you explain the peaks observed for A<20 in the curve? They are related to which nuclear model studied in class?

- For light nuclei the most stable nuclei have equal number of protons and neutrons, due to which term in the binding energy formula? As A increases which term becomes more important, leading to the stable nuclei having more neutrons than protons? And why?



3. Nuclear forces

a) How can we measure the binding energy of the deuteron? (there are sevaral ways, explain at least one).

b) The nuclear forced is often described as “charged independent”. Does it mean that a system of two protons is the same as a system of one proton and one neutron? Why don’t we observe a bounded system of two protons or two neutrons in nature?

c) We can make nuclear reactions in the laboratory by bombarding the nuclei in a target with a beam of charged particles with high energy. If the beam consists of e.g. alpha-particles, the energy must be sufficient to overcome the Coulomb barrier if we want to achieve a fusion reaction. How can we calculate the Coulomb barrier? And which energy should the alpha-particles have in order to penetrate into ^{197}Au? Hint: The attractive nuclear force dominates when the nuclei are in “contact” i.e. r = radius (^{197}Au) + radius (^{4}He).

d) What is the range of the nuclear force? Why is it so short?

4. The nuclear Shell model

The following figure (last page) shows the nuclear energy levels obtained with a realistic potential. Inside the red rectangle corresponds to also including the spin-orbit coupling term, use this part of the figure to answer the following questions.

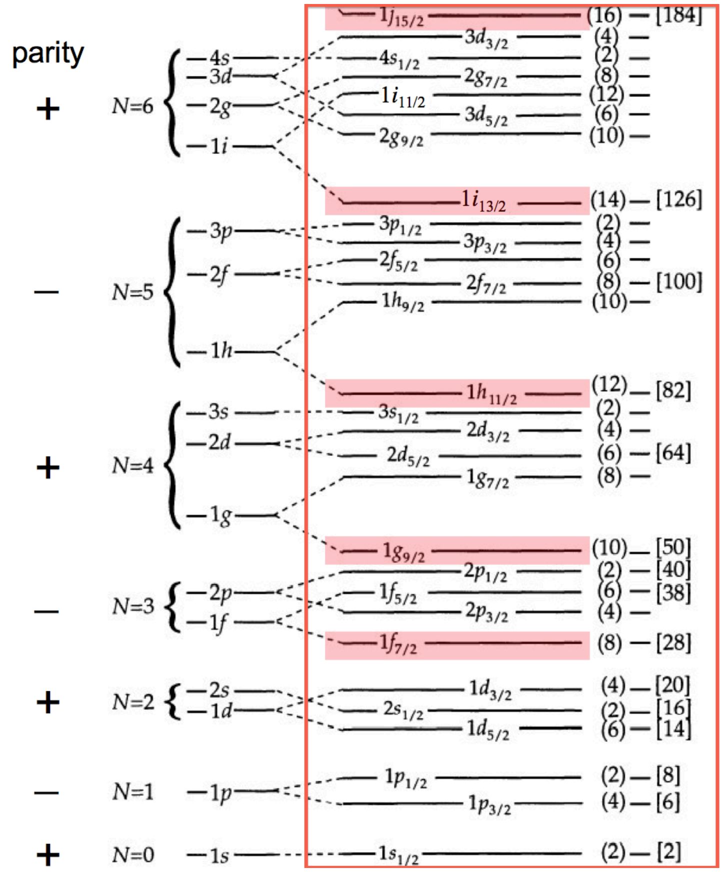
a) Consider the case of ^{48}Ca (N=28, Z=20). Which orbitals are occupied by the neutrons and by the protons?
What is the total spin and parity for the ground state of ^{48}Ca?

b) What does ^{4}He, ^{16}O and ^{48}Ca have in common?

c) Now we add a **neutron** to ^{48}Ca, getting ^{49}Ca. What is the total spin and parity of the ground state in ^{49}Ca.

d) Now we add a **proton** to ^{49}Ca. Which nucleus do we get? What is the total spin and parity of the ground state?

e) How many particles can you have in the $d_{5/2}$ orbital? And in the $h_{11/2}$ orbital?



f) What is the term in the nuclear potential that causes the splitting of the orbital 1p into the two orbitals $1p_{1/2}$ and $1p_{3/2}$? Does the size of the energy splitting depend on the angular momentum quantum number l?
Why is the energy of the $1p_{3/2}$ lower that the one for $1p_{1/2}$?

g) Consider ^{40}Ca (N=20, Z=20). If we now take one neutron from the level $1d_{3/2}$ and promote it to the level $1f_{7/2}$, we would have an excited state. What are the posible values for the spin and parity of this excited configuration?

Good Luck!