Nuclear Structure, PHY981 Lectures, Spring semester 2015

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Overview of first week

- First week:
  - Presentation of topics to be covered and introduction to nuclear structure physics
  - Discussion of quantities like binding energies, masses, radii, separation energies, see chapters 1-4 of Alex Brown's (AB) 2011 lectures
  - Single-particle degrees of freedom, discussion of data
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  - Hamiltonians and single-particle fields, see Suhonen (JS) chapter 3 and AB chapters 9 and 10.

Overview of first week

As a reading assignment, chapters 1-4 of Alex Brown's text are rather useful. You can fetch JS's book from http://link.springer.com.proxy2.cl.msu.edu/book/10.1007/978-3-540-48861-3/page/1 You can find these texts at the webpage of the course as well. The webpage of the course is at http://nuclearstructure.github.io/PHY981/doc/web/course.html. All material can be downloaded from http://nuclearstructure.github.io/PHY981/doc/web/index.html.

Lectures, exercise sessions and syllabus

- Lectures: Tuesdays (2pm-3.50pm, Theory trailer, conference room)
- Detailed lecture notes, all exercises presented and projects can be found at the homepage of the course, https://github.com/NuclearStructure/PHY981.
- Exercises: No allocated time (but a given time can be determined)
- Weekly plans and all other information are on the webpage of the course.
- Syllabus: Lecture notes, exercises and projects. Relevant chapters of Suhonen's text that cover parts of the material are chapters 3-9 and 11. Chapters 1-2 on angular momentum will be used as references for various derivations and only parts of these two chapters will be used. Alex Brown's lecture notes from 2011 can also be used, and the relevant chapters are 1-4, 6-29. Chapter 5 of Brown on angular momentum plays the same role as chapters 1-2 of Suhonen.
- A weekly mail will be sent to all participants.

Main themes and reading suggestions

The various observables we will discuss in the course are thought to be understood via the following five major topics

- Single particle properties and mean-field models, lecture notes, JS chapters 3-5 and AB chapters 7-10 and 14
- Nuclear forces, covered by lecture notes
- The nuclear shell-model, lecture notes, JS chapter 8 and AB chapters 11-22.
- Particle-hole excitations, random-phase approximation and pairing (and perhaps something on collective models), lecture notes and JS chapters 9 and 11.
- Decays and one and two-body transition probabilities, lecture notes, JS chapters 6 and 7, AB chapters 23-29.

To understand how these topics are linked will provide us with fundamental insights about the laws of motion that govern nuclear physics.

Plan for the semester

Projects, weekly exercises, deadlines and final oral exam.

- One project with a possible numerical content that counts 30%, weekly exercises that count 30% and a final oral exam which counts 40% of the final grade.
- Project 1 will be available mid February and to be handed in before spring break (exact dates to be determined)
- For the final oral exam (after spring break, time to be determined) you have to prepare a 25-30 minutes talk based on either a topic chosen by you or a topic defined towards the end of the semester.

Duration of the examination is 45 minutes. The remaining 15-20 minutes are for questions from other topics as well.

Selected Texts on Nuclear Structure and Many-body theory

- Nuclear structure
  - Heyde, *The Nuclear Shell Model*, Springer 1990
  - Lawson, *Theory of the Nuclear Shell Model*, Oxford 1980
  - Ring and Schuck, *Nuclear Many-Body Theory*, Springer 1980
  - Talmi, *Simple Models of Complex Nuclei: The Shell Model and Interacting Boson Model*, Harwood Academic Publishers 1993.
- Many-body theories
  - Blaizot and Ripka, *Quantum Theory of Finite systems*, MIT press 1986
  - Fetter and Walecka, *Quantum Theory of Many-Particle Systems*, McGraw-Hill, 1971.
  - Dickhoff and Van Neck, *Many-Body Theory Exposed*, World Scientific, 2006.

Links and useful software

- PHY981 on github
  - All material is at `https://github.com/NuclearStructure/PHY981/`

- The following link gives you a quick way to download everything, see http://nuclearstructure.github.io/PHY981/doc/web/index.html
- And this link http://nuclearstructure.github.io/PHY981/doc/web/course.html gives direct access to html, ipython notebooks and pdf files of the lectures.

Links and useful software

- Useful links
  - When I write code in C++ I tend to recommend to use the linear algebra library armadillo, see http://arma.sourceforge.net/.
  - To install armadillo see the guidelines at http://www.uio.no/studier/emner/matnat/fys/FYS4411/v14/guides/installing-armadillo/.
  - For mac users I recommend using *brew*, see http://brew.sh/.
  - If you use ipython notebook and want to run a c++ program, follow the instructions at http://nbviewer.ipython.org/github/dragly/cppmagic/blob/master/example.ipynb
  - To set up git, look at http://www.uio.no/studier/emner/matnat/fys/FYS4411/v14/guides/setting-up-git/
  - An excellent IDE for c++ programmers is Qt Creator, see http://www.uio.no/studier/emner/matnat/fys/FYS4411/v13/guides/installing-qt-creator/.

Background enquiry

Write a small summary of what you do. You can send the answer as an email to hjensen@msu.edu

- If you have defined a thesis topic, please send me some details of your thesis project, your interests etc.
- What is your background in computing? And, if you have programmed, which programming language(s) and environments are you most familiar with?
- Also, if you have specific wishes with respect to this course, expectations, topics you'd like me to cover or other things, please feel free to write them down, or swing by my office for a chat.

One of my aims is to be able to tailor this course as close as possible to your specific scientific interests (as far as possible obviously).

First exercise: Exercise 1

Masses and binding energies. The data on binding energies can be found in the file bedata.dat at the github address of the course, see https://github.com/NuclearStructure/PHY981/tree/master/doc/pub/spdata/programs

- Write a small program which reads in the proton and neutron numbers and the binding energies

and make a plot of all neutron separation energies for the chain of oxygen (O), calcium (Ca), nickel (Ni), tin (Sn) and lead (Pb) isotopes, that is you need to plot

$$S_n = BE(N,Z) - BE(N-1,Z).$$

Comment your results.

- In the same figures, you should also include the liquid drop model results of Eq. (2.17) of Alex Brown's text, namely

$$BE(N,Z) = \alpha_1 A - \alpha_2 A^{2/3} - \alpha_3 \frac{Z^2}{A^{1/3}} - \alpha_4 \frac{(N-Z)^2}{A},$$

with $\alpha_1 = 15.49$ MeV, $\alpha_2 = 17.23$ MeV, $\alpha_3 = 0.697$ MeV and $\alpha_4 = 22.6$ MeV. Again, comment your results.

- Make also a plot of the binding energies as function of A using the data in the file on bindingenergies and the above liquid drop model. Make a figure similar to figure 2.5 of Alex Brown where you set the various parameters $\alpha_i = 0$. Comment your results.

- Use the liquid drop model to find the neutron drip lines for Z values up to 120.

Analyze then the fluorine isotopes and find, where available the corresponding experimental data, and compare the liquid drop model predicition with experiment. Comment your results.

A program example in C++ and the input data file *bedata.dat* can be found found at the github repository for the course, see https://github.com/NuclearStructure/PHY981/tree/master/doc/pub/spdata/programs

Deadline for this exercise is **January 26, at noon**. You can hand in electronically by just sending me your github link, or just the file. I digest most formats, from scans to ipython notebooks. The choice is yours.