Exam

Exam week is the third week of January, From Monday 13th to Friday 18th. It is possible to have an exam before Christmas. Please write to Andrea or Gillis to schedule a time. *Remember to bring your hand-ins!*

Questions

Lecture 1: Overview

- Sketch the charge distribution in nuclei. Define the root-mean-square radius. Give typical values for radius and diffuseness. A-dependence? Exemplify methods to measure the charge distribution.
- Discuss the different terms in the semi-empirical mass formula. What is the role of the pairing energy? Indicate typical errors when this formula is used to describe experimental masses. Which nuclei will gain energy when undergoing fission and fusion, respectively (cf. Fig. 3.6)?
- Define the β-stability line and the proton and neutron drip lines. Sketch the stability peninsula. Estimate the number of β-stable nuclei for a fixed mass number, A. Are there any typical differences between odd and even A (cf. Figs. 3.4, 3.5)?

Lecture 2: Nuclear interaction

- Define the isospin! What isospin states are possible for a two-nucleon system? How can isospin be used to define a generalized exclusion principle?
- Discuss some invariance properties for the nucleon-nucleon interaction. How can the most general central static nucleon-nucleon potential be written? Sketch the r-dependence.
- What is the most important velocity-dependent force in the nucleon-nucleon interaction?

Lecture 3: Hartree-Fock method

- What is the basic difference between the Hartree and the Hartree-Fock method? What is the form of the total wave-function in the Hartree-Fock approxima- tion?
- Explain the difference between a central potential $V(r)$ and the corresponding effective potential V_{eff} .
- Consider a spherically symmetric harmonic oscillator potential. What is the energy spectrum expressed in the quantum numbers N and (n, l), respectively? What values of l are allowed for fixed N?

- What is the role of the spin-orbit potential? Which are the preserved quantum numbers of a spin 1/2 particle in a spherical potential well in the presence of a spin-orbit potential?

Lecture 4: 2nd quantization and Shell Model

- Give a general definition of Clebsch-Gordan coefficients.
- Define the anticommutator relations for the creation and annihilation opera- tors. What is the form of a general two-particle operator using these opera- tors?
- Explain the interacting nuclear shell model and its advantages and disadvantages.

Lecture 5,6: Collective excitations in nuclei, Tamm Dancoff

- What are the quantum numbers of magnetic and electric transition operators in nuclei?
- Derive Brilloin theorem (particle-hole excitations are orthogonal to ground state) from the variational principle. Use it to sketch the derivation of Tamm approximation Dancoff.
- What is the dispersion relation? How do we use it to calculate collective excitations in nuclei?

Lecture 7: Deformed nuclei

- Which nuclei are spherical and which are deformed ?
- What quantum numbers are broken in deformed nuclei ?
- How can one describe deformed nuclei ?
- What matrix element determines the splitting of a j-shell at a small quadrupole deformation? What Ω-values come lowest in energy at prolate shape?
- When solving the axially symmetric harmonic oscillator Hamiltonian, one introduces the operators R and S (and $R^\dagger$, $S^\dagger$). Which Cartesian directions are involved in these definitions? Write down the number operator using these operators.

Lecture 8,9: Pairing

- What are the phenomena that indicate the presence of pairing in nuclei ?
- How can the pairing force be written in second quantization ?
- What two derivations can be used to find approximate solutions of the pairing Hamiltonian? (you are not expected to remember the details)
- What is the physical significance of the V_ν and U_ν coefficients?

- Demonstrate that the particle number is not a good quantum number in BCS. How can we study a system with a given number of particles?
- What is the difference between BCS and HFB methods?

Lecture 10: GCM

- How can one restore the particle number when working with HFB states ?
- What is the Hill-wheeler equation ?
- What are the ideas behind the GCM method, when is it useful ?

Lecture 11: Equation of Motion and RPA

- What is the definition of the Equation of Motion? Why is it a useful method?
- Sketch the derivation of Hartree-Fock using equation of motion.
- Sketch the derivation of RPA using equation of motion. What is the difference between RPA and Tamm-Dancoff ?

Lecture 12: Green's functions

- What is the definition of Green's function in the context of many-body physics?
- How do the propagators relate to Feynman diagrams?
- What is the Dyson equation?

Bonus round

- Compare advantages and disavantages of different many-body methods we have seen in the course. Which is the most precise? Which one is faster? Which is most predictive? Which is most descriptive?
- What is your favorite thing we've seen in the course?
- What is the thing you find hardest to grasp?