Ecole Joliot Curie 2012

Aspects of Pairing in Atomic Nuclei

Augusto O. Macchiavelli

Atomic nuclei are unique many-body systems. A central theme of study in nuclear structure has been the understanding of the elementary modes of excitation of the nucleus, and their evolution with A (size), I (rotational frequency) , (N-Z) (Isospin) and E* (Temperature).

Nuclei, their properties and structure, are of paramount importance to many aspects of physics. These are exciting times in the field of physics of nuclei: New developments in theory and computer power are shaping a path to a predictive theory of nuclei and reactions. Existing and planned exotic beam facilities worldwide and new detector systems with increased sensitivity and resolving power not only will allow us to answer some burning questions we have today, but most likely will open up a window to new and unexpected phenomena.

One fascinating aspect of the structure of the nuclei is that of pairing. This rich area started just over 50 years ago by the observation by Bohr, Mottelson and Pines of a possible analogy between the excitation spectra of nuclei and that of superconductors. Subsequent work showed that many nuclear properties are influenced by pairing correlations. It is, of course, a subject of relevance to other finite fermion systems such as ^{3}He clusters, Fermi-gas condensates, quantum dots, metal clusters, ….

Trying to cover 50 years in two lectures is, of course, a daunting task. Hopefully I will be able, at least, to convey some of this exciting physics to you. The book by Brink and Broglia on *Nuclear Superfluidity* is an excellent resource that I strongly recommend.

Lecture I:

In this lecture we will review basic nuclear structure concepts that are needed to understand the effects of a pairing force. We will study the main ingredients of the effective nucleon-nucleon interaction, construct a simple model of pairing and discuss some methods to solve the model Hamiltonian. In particular, the BCS solution and the concept of quasi-particles will be used to explain the pairing gaps and moments of inertia.

A simple model, consisting of two j-shells will be solved numerically to help understand the competition between the single-particle separation energy and the pairing strength and the concepts of pairing vibrations and rotations, in analogy to the more familiar case of quadrupole deformations.

Lecture II:

With the material discussed earlier, we will be in a position to evaluate possible signatures of pairing phase transitions driven by angular momentum, temperature and mass number.

A good fraction of the second lecture will be devoted to discuss the use of two nucleon transfer reactions as specific probes of pairing correlations, with particular emphasis on the enhancement of pair-transfers.

We will conclude by outlining some new pairing phenomena expected in exotic nuclei: Neutron-proton pairing along the N=Z line and pairing in weakly bound systems.

A set of problems and some computer programs will be provided during the school.

References and suggested reading

Books

Nuclear Superfluidity , D.M.Brink and R.A.Broglia

NuclearTheory, A. M. Lane

Nuclear Structure from a Simple Perspective, Richard F. Casten

The Nuclear Shell Model and

Basic Ideas and Concepts in Nuclear Physics, Kris Heyde

The Practitioner's Shell Model, G. Bertsch

Simple Models of Complex Nuclei, I. Talmi

Nuclear Structure, Volumes I and II, A. Bohr and B. Mottelson

Articles

A.Bohr, B.R.Mottelson and D.Pines, Phys. Rev. 110, (1958)

S.T.Belyaev, Mat. Fys. Medd.Dan. Vid. Selsk. **31**, 11 (1959)

D.R.Bes and R.A.Sorensen, Adv. Nucl. Phys. **2**,129 (1969)

R.A. Broglia, O. Hansen, C. Riedel, Adv. Nucl. Phys. **6** , 287 (1973)

D.J.Dean and M.Hjorth-Jensen, Rev. Mod. Physics 75, 607 (2003)