

Proposals for theory oriented topics

Project 1: ^{32}Mg and islands of inversion

It happens that in neutron-rich nuclei magic numbers, such as $N = 8$, $N = 20$, $N = 40$ may not necessarily signify shell closures, but rather corresponds to nuclei with deformed ground states. Discuss experimental evidence and theoretical considerations in ^{32}Mg regions based on the deformed mean-field calculations, schematic and realistic shell model. Why such regions form “islands”?

- [1] K. Heyde and J. L. Wood, J. Phys. **G17** (1991) 135.
- [2] E. K. Warburton et al, Phys. Rev. **C41** (1990) 1147.
- [3] E. Caurier et al, Rev. Mod. Phys. **77** (2005) 427.
- [4] T. Otsuka et al, Prog. Part. and Nucl. Phys. **47** (2001) 319.
- [5] S.M. Lenzi et al, Phys. Rev. **C82** (2010) 054301.

Project 2: Shape coexistence in neutron-deficient Pb-region

A term shape coexistence denotes appearance of spherical and deformed structures at similar excitation energies. $^{208}\text{Pb}_{126}$ is a well-known doubly-magic nucleus, its ground state is spherical and first excited states lie very high in energy. A great variety of different shapes comes into play in neutron-deficient Pb-isotopes. Oblate and prolate quadrupole-deformed states, or even bands, have been observed at low energies in $^{188,186}\text{Pb}$ and neighboring nuclei. Shell model describes these states in terms of particle-hole excitations across the major $N=82$ shell gap. Deformed mean-field models predict coexisting minima of potential energy surfaces. Discuss the mechanism of shape coexisting in terms of the spherical shell model and deformed mean-field picture and point out the complementarity of the approaches.

- [1] J. L. Wood, K. Heyde et al, Phys. Rep. **215** (1992) 101.
- [2] A. Andreyev et al, Nature **405** (2000) 430.
- [3] R. Julin et al, J. Phys. **G27** (2001) R109

Project 3: The changing nuclear shell structure: experimental evidence and theoretical understanding

The seminal work of M.G.Mayer and J.H.Jensen has led to understanding the specific proton and neutron numbers to which enhanced stability in the nuclear mass table corresponds and can be observed in various observables (abundance of elements, excitation

energy of first excited state in even-even nuclei,...). Discuss the early relevance of this and contrast with the case of shell structure in atoms. During the years following, experimental evidence has accumulated that as one moves away from the region of β -stable nuclei, changes in the energy gaps separating filled from the unfilled orbitals show up as a function of N/Z ratio. Magic numbers, characteristic for nuclei near the valley of beta stability may not necessary correspond to the shell closures in very neutron-rich nuclei. Discuss both the experimental evidence for these changes, and what might be at the origin of these single-particle energy variations. On the theoretical side, consider the energy change that a proton moving in a given single-particle state feels when interacting with a filled shell of neutrons. These so-called 'self-energy' corrections are at the origin of the changing mean-field approaching regions in the nuclear mass table, far removed from the valley of stability.

[1] A. Bohr and B.Mottelson, Nuclear Structure, volume1: Single-particle motion, World Scientific Publ.,1998.
 [2] E. Caurier et al., Revs. Mod. Phys. **77** (2005) 427.
 [3] O. Sorlin et al., Progr. Part. Nucl. Phys. **61** 602.
 [4] R. Krücken, to be publ. in Contemp. Phys. and arXiv:1006.2520.
 [5] T. Otsuka et al., Phys. Rev. Lett. **87** (2001) 082502.
 [6] T. Otsuka et al., Phys. Rev. Lett. **95** (2005) 232502.
 [7] T. Otsuka et al., Phys. Rev. Lett. **97** (2006) 162501.
 [8] M. Bender et al., Phys. Rev. **C80** (2009) 064302.
 [9] N. Smirnova et al., Phys. Lett. **B686** (2010) 109.

Project 4: Isobaric mass multiplet equation

The isospin symmetry is an important, but approximate symmetry of the nuclear Hamiltonian. The eigenstates of the isospin-conserving Hamiltonian (for a nucleus with Z protons and N neutrons) can be characterized by the total isospin T and its projection $M_T = |N - Z|/2$, such as $|\alpha T M_T\rangle$, where α represents other quantum numbers. The states in mass- A nuclei labeled by the same α, T and $M_T = -T, -T + 1, \dots, T - 1, T$ are degenerate (isospin multiplets).

Show that the two-body Coulomb interaction acting among protons represents a combination of a scalar, vector and tensor operators in isospace. Evaluate the energy shift of a state $|\alpha T M_T\rangle$ due to the Coulomb interaction and derive the isobaric mass multiplet equation. Is the isospin still a good quantum number? Discuss this problem in terms of the group theory. At what conditions can we get the isospin mixing in nuclear states?

[1] J.P Elliott, P.G.Dawber, Symmetry in Physics, volume1. The Macmillan Press, London,1979.
 [2] J. Jaenecke, Phys. Rev. **147** (1966) 735.
 [3] J. Britz, A. Pape, M. S. Anthony, Atom. Data Nucl. Data Tables **69** (1998) 125.