Characterizing and Modelling Weakly Collective Nuclei - Puzzles and Progress

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Weakly collective nuclei occur between those that have a few valence nucleons outside a doubly magic core and those with many valence nucleons that show clear rotational bands. In other words, they fall between the realm of the nuclear shell model and the rotor model. Often these nuclei show level structures that have been identified with quantized surface vibrations. With advances in computing capability, the shell model as a large-basis configuration-interaction problem begins to reach such nuclei. But how successful can the shell model be? And how well do we really understand such weakly collective nuclei?

This presentation will draw some salient observations from a recent review [1] in a volume on the *"Nuclear Shell Model 70 Years after Its Advent: Achievements and Prospects"*, which reviews features in the experimental data on weakly collective nuclei, and discusses the successes and limitations of the large-basis shell model approach. Experimental results obtained by the ANU Nuclear Structure group and their collaborators will be highlighted, with a focus on insights gained by confronting model calculations with experimental data on electromagnetic decays and moments. There is increasing evidence that collectivity in nuclei, which increases with the number of valence protons and neutrons, emerges immediately as deformation and rotation, and that the weakly deformed shapes tend to be triaxial. The existence of low-excitation vibrational states (multiphonon states), which has been one of the foundational concepts of nuclear structure, is strongly questioned. A second direction, which questions fundamental tenets of the shell model in its usual operation form, concerns shape coexistence in the classic doubly magic shell-model cores ^{16}O and ^{40}Ca. The existence of relatively low-excitation deformed multiparticle-multihole states in these nuclei has long been known. However measured electric monopole transition strengths are determining the degree of shape mixing, with increasing evidence that these presumed inert, spherical shell-model cores are in fact deformed in their ground states. One puzzle is that while the shell model (understandably) fails to describe the magnetic moments of the first-excited 2^+ states of nuclei with two nucleons added to these doubly magic nuclei, it better describes the moments as the number of nucleons in the valence space increases.

[1] A.E. Stuchbery and J.L. Wood, *Physics* **4**, 697 (2022).