EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Letter of Intent to the ISOLDE and Neutron Time-of-Flight Experiments Committee for experiments with HIE-ISOLDE

Studies of isospin symmetry and mirror nuclei

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Abstract

We propose to carry out a number of discriminating tests of mirror symmetry and isospin mixing using Coulomb excitation and single-particle transfer reactions.

1. Introduction

The exchange symmetry between neutrons and protons is one of the most basic and fundamental principles of nuclear physics. It yields startling symmetries in the behaviour of nuclei located near the N = Z line, and resulted in the introduction of the isospin quantum number, T. States of the same isospin, T, in a set of nuclei with the same mass number are termed isobaric analogue states, IAS, and the near-identicality of such states demonstrates the power of the isospin concept. Energy differences between IAS are due to isospin non-conserving forces, such as the Coulomb interaction between protons.

2. Physics case

We propose to make a number of detailed and specific tests of isobaric symmetry:

Mirror pairs: Neglecting the mass difference between the ground states of mirror nuclei, the layout of excited states in mirror nuclei ought to be identical. In practice, this degeneracy is lifted to a greater or lesser extent through effects such as the Coulomb interaction, radial shifts and the electromagnetic spin-orbit interaction [1,2]. The focus of such comparisons in mirror nuclei has been mainly related to the excitation energy of excited states and also to the mass region, A=40 – 50, where the nuclear structure is dominated by occupancy of the $f_{7/2}$ orbital. We propose to make much more discriminating tests of the nuclear wavefunctions involved through Coulomb excitation and single-particle transfer reactions. In terms of the former approach, a recent example is the work of

Schumaker et al. who carried out a detailed comparison of collective behaviour in ^{21}Na and ^{21}Ne using Coulomb excitation of a radioactive ^{21}Na obtained from the ISAC-1 facility at TRIUMF [3]. With HIE-ISOLDE, it will be possible to carry out multi-step Coulomb excitation which will provide a wealth of matrix elements. Furthermore, using the rotational-invariant technique prescription, the centroids and fluctuation widths of the intrinsic E2 moment for certain states can be determined in a model independent way, provided the relative signs and magnitudes of the connecting E2 matrix elements are measured [4].

In addition, we consider the possibility of investigating in detail the parentage of states in mirror nuclei, exploiting the unique opportunity to make simultaneous (d,n) and (d,p) measurements since HIE-ISOLDE will provide a range of beams of self-conjugate nuclei.

T=1 triplets: It is expected that the B(E2) (2^+ -> 0^+) strengths in a T=1 triplet should obey the following relationship:

$$\sqrt{B(E2;T_z=0)} = \left(\sqrt{B(E2);T_z=+1)} + \sqrt{B(E2;T_z=-1)}\right)$$

Deviations from this relationship would indicate isospin mixing or other charge-symmetry breaking effects. The level of isospin mixing is not well known experimentally as it is extremely challenging to measure. It is suggested to rise from a fraction of a percent for light nuclei to of the order of 5% around mass 80. Such isospin mixing plays an important role in corrections to the extracted ft-values for super-allowed beta-decay used as tests of the CVC hypothesis [5] but is presently calculated but not measured. There have been attempts to extract the isospin mixing from lifetime measurements across T=1 triplets e.g. [6]. We propose that Coulomb excitation may be a very sensitive and complementary approach and does not suffer from systematic effects like uncertainty in stopping powers used in lifetime measurements.

3. Experimental setup

The Coulomb excitation measurements will continue to require the MINIBALL array. The best situation for making direct comparisons of either mirror nuclei or isobaric triplets would be to generate a cocktail beam and have a means of discriminating the scattered particles by Z. In this case, the Coulomb excitation yields can be normalized together thus largely eliminating systematic errors when making comparisons between different isobars. This possibility can be realized using a large-angle Bragg detector. Such a device can give Z sensitivity up to around Z=40.

The transfer reactions envisaged are more difficult to achieve with the present set-up since a rather special set-up would be needed in order to make simultaneous (d,p) and (d,n) measurements. One possibility would be a solenoidal-field spectrometer such as HELIOS at Argonne National Laboratory, modified to include scintillator detectors within the high-field volume which could be used to detect both neutrons and gammas, and distinguish them by time-of-flight.

4. Beam requirements

Typical examples for mirror symmetry comparison through Coulomb excitation would be ^{23}Mg and ^{23}Na (stable); ^{35}Ar and ^{35}Cl (stable), ^{39}Ca and ^{39}K (stable). An example where all three members of an isobaric triplet are available at HIE-ISOLDE would be A=38: ^{38}Ca, ^{38}K and ^{38}Ar (stable).

For Coulomb excitation, we require beams of around 5 MeV/u. For transfer reactions such as (d,p), we require up to 10 MeV/u, in principle, but in some cases it may be possible to achieve something at the lower energy. A HELIOS-type device would place challenges on the present time structure of the beam as well as requiring a small emittance.

5. Safety aspects

A large angle Bragg detector would ideally contain a substantial volume of isobutane or P10 gas but may have to use non-flammable gases in the ISOLDE hall, unless special arrangements were made.

6. References

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