New opportunities in transfer reactions

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Forewords- Transfer reactions are unique tools to probe the evolution of single particle energies, and therefore to determine the evolution of shell gaps as the neutron to proton ratio evolves. The nuclear shell structure takes root in the properties of the nucleon-nucleon (NN) interaction. Therefore, by studying the changes of shell gaps, and the evolution of single particle energies, we expect to learn upon the role of NN interactions to conduct these changes. However, the route is not straightforward for several reasons. Among one of the difficulties, one needs to achieve transfer reactions around the Fermi energy involving unstable nuclei. This requires working in inverse kinematics with low beam intensities of about 10^5 pps. This recently became feasible with the combination of radioactive ion beams at Fermi energies such as those available in HRIBF, SPIRAL1 and Rex-Isolde, and of high efficiency and large granularity charged particle and gamma-ray detectors.

Experimental requirements / constraints – The first part of the lecture will provide semi-quantitative values of experimental cross sections, momentum matching and geometries for different categories of transfer experiments. Typical experimental set-up will be presented together with detector performances. Achieved energy and angular resolutions will be given. In a second step, the role of optical potentials to derive spectroscopic factors will be addressed. The practical quenching factors and sum rules will be discussed briefly as well.

*Physics cases- P*hysics cases will be mainly related to shell evolution. Among the possible choices (which are not yet firmly established), some of listed below.

1-A reduction of the spherical N=20 shell gap far from the valley of stability has been invoked to account for the observed trend in neutron separation energies, charge radii and first excitation energies in the Mg isotopes. In parallel a new spherical shell gap at N=16 appeared far from stability. Enlightening experiments have been achieved to demonstrate these effects.

2-It was recently found that the neutron shell gaps N=14 and N=28 were increasing by about 2.8MeV far from stability, while filling the neutron d5/2 and f7/2 orbits, respectively. This effect, which will be illustrated using the 40Ca(d,p)41Ca and 48Ca(d,p)49Ca (done in direct kinematics), has been ascribed to three body forces. A similar effect would be found at the N=50 shell closure, i.e. the N=50 gap should grow by about 2.8MeV while filling the g9/2 orbit between 68Ni and 78Ni. Results obtained using 68Ni(d,p)69Ni at GANIL and 78Zn(d,p)79Zn at Rex-Isolde will be used to illustrate this purpose.

3- The evolution of the N=28 gap far from stability seems to be guided by the spin orbit and tensor interactions. Selected experiments using (d,p), (p,d) and (d,3He) experiments will be proposed to try to delineate these effects.

Critical points- While presenting these examples, some of the critical points related to transfer experiments will be emphasized, such as the role of the choice of the optical potential, the way to extract spectroscopic factor for states lying into the continuum, the derivation of effective monopole interactions from experimental observables.