Study of halo formation with (e,e'p) and (e,e'd) reactions

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The separation of the longitudinal and transverse responses in quasielastic electron scattering at intermediate values of momentum transfer has been firstly achieved in 1980 [1]. Subsequent theoretical studies [2] have found that the experimentally observed reduction of the longitudinal response function with respect to Fermi-gas model prediction may be a result of the existence of nuclear correlations. Essential result obained in these studies [2] is that the short-range and the tensor parts of the nucleon-nucleon interaction deplete the shell-model orbitals and this depletion affects the longitudinal and transverse response functions in a very different manner. The quasielastic scattering cross section for (e,e'p) is written in terms of the Coulomb form factor F_C^2 and transversal form factor F_T^2 as [3]:

$$\frac{d\sigma}{d\Omega dE_2} = 4\pi\ \sigma_{Mott}(\Delta^2/q^2)^2[F_C^2(q,\omega) \\ +(q^2/\Delta^2)(\frac{1}{2} + (q^2/\Delta^2)\tan^2\frac{\theta}{2})\ F_T^2(q,\omega)] \tag{1}$$

where $\Delta^2 \equiv q^2 - \omega^2$. Using the nonrelativistic approximation to the Dirac spinor and keeping only terms to the order of q^2/m^2, de Forest obtained for the quasielastic scattering from a nucleus [4]

$$F_C^2(q,\omega) = K \sum_{M_i M_f} |< J_f M_f \mid \sum_j [e_j + (q^2/8m^2) \\ (e_j - 2\mu_j)] e^{i\vec{q}\cdot\vec{r}_j} \mid J_i M_i >|^2\ \delta(E_f - E_i - \omega) \tag{2}$$

$$F_T^2(q,\omega) = K \sum_{M_i M_f} |< J_f M_f \mid \sum_j [(e_j/im)\vec{\bigtriangledown}_t^{(j)} \\ -(i\mu_j/2m)\vec{q}\times\vec{\sigma}^{(j)}] e^{i\vec{q}\cdot\vec{r}_j} \mid J_i M_i >|^2\ \delta(E_f - E_i - \omega) \tag{3}$$

where $K = f^2(\Delta^2)(2J_i + 1)^2/4\pi$ with $f(\Delta^2)$ denoting the electric and magnetic form factors of the proton and neutron (assumed to be all equal). In impulse approximation, the electron interacts with one single nucleon or nucleon cluster while leaving the rest of the nucleus as a spectator. Hence, the energy-conservation δ function reduces, respectively, to $\delta(\epsilon_p(\vec{p}+\vec{q}) - \epsilon_p(\vec{p}) - \omega)$ and $\delta(\epsilon_d(\vec{p}+\vec{q}) - \epsilon_d(\vec{p}-\omega)$ for the (e,e'p) and (e,e'd) reactions. If the final nuclear states are not measured in the experiment, the F_C^2 and F_T^2 will be combintations of functions of the type $\int \rho(p)H(p)d\vec{p}\delta(\epsilon(\vec{p}+\vec{q}) - \epsilon(\vec{p}) - \omega)$, with $H(p)$ being 1, $p\ cos\phi$, $p^2cos^2\phi$, or or p^2. Here, ϕ is the angle between the momentum $\vec{p}$ of the active nucleon (or nucleon cluster) and the momentum transfer $\vec{q}$. The $\rho(p)$ is the momentum-space density distribution. In our calculation, we do not use the Fermi gas model. Instead, we use the density distribution given by the BDCM [5] that takes fully into account the nuclear core excitation and reproduces the measured energy levels of the nucleus. We define the longitudinal and transverse nuclear reponses, respectively, as $S_L = F_C^2$ and $S_T = F_T^2$ and we are interested in the longitudinal-to-transverse ratio defined by

$$R = (\Delta^2/q^2)^2 \frac{S_L}{S_T} = \frac{A}{B} - \frac{1}{2}(\Delta^2/q^2). \tag{4}$$

The removal of the kinematic singularity allows the nuclear structure effect to be more clearly revealed. In Fig. 1 we show calculations for ^{6}Li. Since what is of interest is the density distribution of the valence *pn* pair, we propose to consider the (e,e'd) process. The selection of this deuteron channel has also the added benefit of cutting down background events. As we can see from the figure, the configuration mixing causes the reduction of R. This reduction indicates that the core excitation (responsible for the halo formation) decreases the relative importance of S_L. Our result is in agreement with the findings of Ref. [2]. In conclusion, the quasielastic scattering can be used to probe the dynamics of nuclear correlations. While this dynamics can only be probed at very large momentum transfers (of the order of several GeV/c) in elastic scattering (e,e), it can already be studied in quasieleastic scattering at moderated momentum transfers (of the order 100 MeV/c). In addition, the elastic scattering probes all the nucleons in a nucleus while the quasielastic scattering can be channeled to probe selected nuclear clusters. The ratio of response functions is a prefered observable as it minimizes the final-state distortion effects. The use of R as observable is further preferable as it does not contain singularities of kinematical origin.

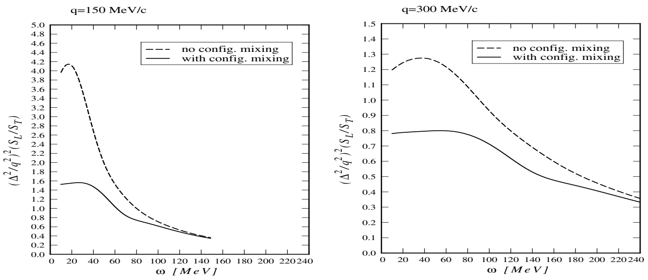

Figure 1: Calculated singularity-free longitudinal-to-transverse response ratio R. Left side: q=150 MeV/c. Right side: q=300 MeV/c.

References

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