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Search for Double Gamow-Teller Strength by Heavy-Ion Double Charge Exchange

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Abstract →

Among two-phonon giant resonances, the double Gamow-Teller resonance (DGTR) is of special interest, not only for the understanding of nuclear phenomena, but also because of links to particle and astroparticle physics via the connection to the double beta decay and its implications for the neutrino mass, lepton number conservation and the missing dark matter of the universe.

Heavy-ion double charge exchange has been suggested as a probe for DGT strength. Studies at NSCL-MSU and GANIL of the (^{6}Li,^{6}He) and (^{12}C,^{12}N) reactions at 35 and 70 MeV/nucleon, respectively, show that heavy ion reactions can be used to extract (single) Gamow-Teller strength [1]. However, the double charge-exchange (DCX) reaction rates are expected to be small. A way of increasing them is to use a projectile and an ejectile which belong to the same $SU(4)$ multiplet in S and T. This is in practice fulfilled only when the projectile and ejectile are located symmetrically around $N = Z$.

The only giant resonance for which both the one- and two-phonon cross sections have been measured with similar reactions is the IVDR, which has been studied by the ($\pi^{\pm}$,π^0) (one-phonon) [2] and the (π^+,π^-) (two-phonon) [3] reactions. Using a B(GT) calibration from single charge exchange, the shell model calculation below, and a simple model for the DCX cross section in terms of the SCX cross sections by Bertsch [4] yields a cross section of 24 μb/sr.

Bertulani [5] has developed an eikonal approximation model for heavy-ion charge exchange reactions, in which he predicted that the cross sections for DGT excitation in heavy-ion reactions should be - at most - in the μb/sr region. It was pointed out that there is a suppression mechanism of heavy-meson exchange in heavy-ion reactions. Instead of a large contribution from ρ mesons in the reaction mechanism - which is the case for reactions induced by pions and nucleons - the larger interaction distance in heavy-ion reactions favour pion exchange. This results in a much weaker charge-exchange, and hence much smaller cross sections. Thus, these two predictions differ by several orders of magnitude.

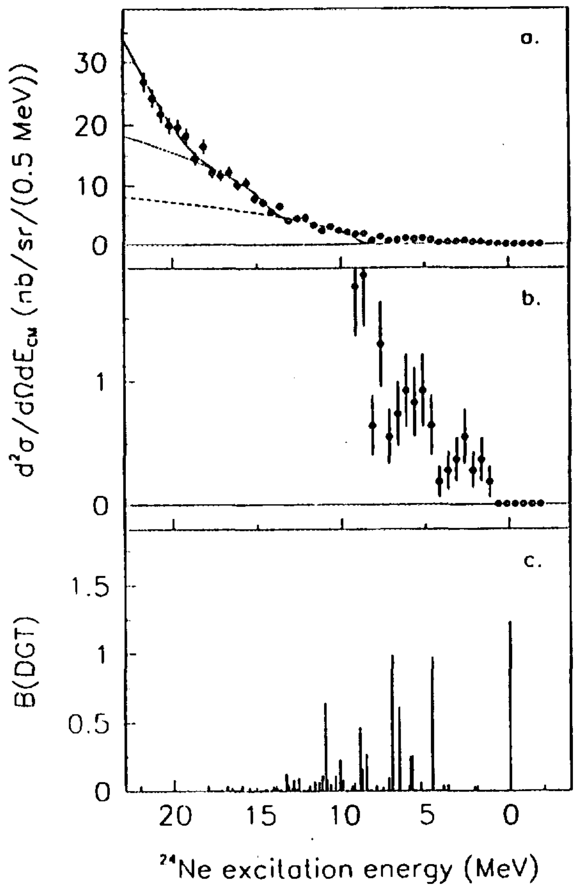

Figure 1: The differential cross section for the $^{24}Mg(^{18}O,^{18}Ne)^{24}Ne$ reaction at $76 \cdot A$ MeV, for the entire solid angle covered. Panel a) shows a fit of a sum (solid) of the phase-space distributions for one-neutron(dashed), two-neutron (dotted) and one-proton breakup(solid). Panel b) shows the ground-state region with an expanded vertical scale. In panel c), our DGT strength calculation calculation is displayed. See the text for details.

Theoretical calculations by B. A. Brown indicate that significant concentration of DGT strength in ^{24}Ne should be found in the ground state and an excited state at 4.7 MeV, with the remaining strength spread broadly at higher energies.

Guided by this, we have carried out a search for Double Gamow-Teller excitations, employing the $^{24}Mg(^{18}O,^{18}Ne)^{24}Ne$ reaction at 100 and 76 MeV/nucleon at NSCL-MSU and GANIL, respectively [6]. The first attempt was made at NSCL-MSU, where an upper limit of the cross sections to low-lying states in the 100 nb/sr region was established. The meagre statistics prompted a second experiment at GANIL, where substantially more intense beams can be delivered, although at a slightly lower energy. The results presented here are from the GANIL run only.

are searched for, using

In the experiment, $^{18}O^{8+}$ ions of $76 \cdot A$ MeV, with an intensity of 100-200 enA, were extracted from the GANIL accelerator system. The momentum analysis of the ejectiles was performed with the energy-loss spectrometer SPEG, covering an angular range from $-1°$ to $+3°$. A self-supporting ^{24}Mg target, 3.5 mg/cm^2 thick, and with an isotopic purity of 99 %, was mounted in the scattering chamber. The energy resolution of 1.0 MeV was dominated by the target energy loss difference for ^{18}O and ^{18}Ne.

The data for the entire solid angle acceptance are displayed in figs. 1a and b. No pronounced peaks are present in the spectrum. In b, which displays the ground-state region, there might be structures at excitation energies of 2.8 and 6.2 MeV in ^{24}Ne. These structures do not correspond to any known states in ^{24}Ne. The statistical uncertainty prevents any far-reaching conclusions. One feature to note, however, is that the low-energy excitation intervals display rather flat angular distributions. This does not support a double Gamow-Teller origin of these excitations, at least not as two consecutive $L = 0$ transitions, which can be expected to be more forward-peaked.

From the data, we can deduce that in the 0–1°(C.M.) interval, the average differential cross section to states which are unambiguous excitations in ^{24}Ne, i.e., which lie below the neutron breakup threshold (E_x = 8.9 MeV), is 20.1 ± 2.9 nb/sr. The error quoted is statistical. The systematic error is estimated to be about 30 %.

+ The present results provide evidence for a strong suppression of double Gamow-Teller excitations. Thereby, they are qualitatively compatible with the Bertulani model. However, we can only deduce an upper limit of the cross section, and it cannot be excluded that the DGT excitation is even weaker. This result seems to preclude the use of heavy ions at intermediate energies for probing double Gamow-Teller strength.

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