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Electric and magnetic giant resonances studied with electron scattering at the S-DALINAC*

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Recent examples of giant resonance spectroscopy with electron scattering at the S-DALINAC are presented. Strength distributions and decay properties of electric resonances in ^{48}Ca are investigated with the (e,e′n) reaction. First results of a systematic search for spin and orbital magnetic quadrupole modes in 180° scattering are presented for ^{48}Ca and ^{90}Zr.

1. Introduction

Electron scattering has traditionally played a vital role in studies of collective excitations of the nucleus. In recent years, coincidence experiments of the type (e,e′x) have been developed as an outstanding tool for investigations of electric giant resonances which overcome the limitations in inclusive experiments imposed by the radiative tail. Initial work at the S-DALINAC focused on charged particle decay of giant resonances [1,2]. Here we present first results using the (e,e′n) reaction which is particularly difficult to measure in the hostile environment of an electron accelerator [3]. The example studied is the doubly magic nucleus ^{48}Ca. Magnetic resonances are excited in transverse electron scattering which is enhanced at backward angles. A facility for 180° scattering recently developed at the S-DALINAC [4] and coupled to a large-solid angle, large-acceptance spectrometer provides excellent features for the investigation even of weak magnetic transitions [5]. Here, some aspects of work concerning the poorly known [6] properties of the spin and orbital M2 response in medium-mass and heavy nuclei are presented.

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2. Electric giant resonances in ^{48}Ca from the (e,e′n reaction)

A setup for neutron detection in coincidence with scattered electrons has recently been developed at the S-DALINAC [7]. It consists of six 5″ × 2″ liquid scintillator detectors each subtending a solid angle of 20 msr. Heavy shielding with lead (10 – 15 cm) and polyethylene (20 – 25 cm) was necessary to suppress the large amount of photons due to bremsstrahlung processes and background neutrons. A detailed description of the setup can be found in [8] including a description of the complex calibration procedures.

Excitation energy spectra in ^{48}Ca for $E_x = 10 - 25$ MeV coincident with neutron decay have been measured at four momentum transfers between $q = 0.22$ fm^{-1} and 0.43 fm^{-1}. The E1 and (E2+E0) cross section parts have been separated and converted to transition strength distributions using RPA form factors [9]. The latter multipolarities cannot be distinguished at low momentum transfer because of the similarity of the form factors. The resulting B(E1) distribution is in good agreement with photonuclear data [10].

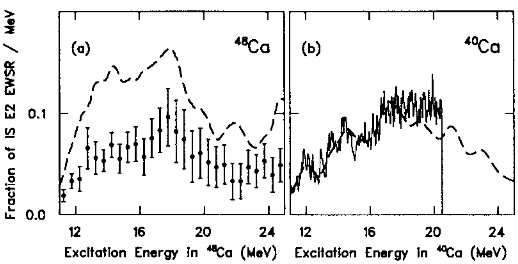

Figure 1. Comparison of the experimental summed B(E2) and B(E0) strength distributions in ^{48}Ca (a) and ^{40}Ca (b) from electron scattering coincidence experiments. Dashed lines: calculations of [11], see text.

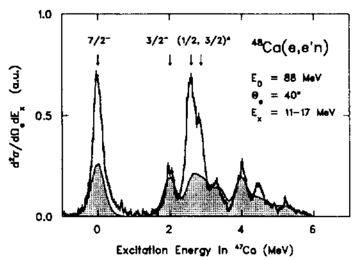

Figure 2. Excitation spectrum of the residual nucleus ^{47}Ca populated in the ^{48}Ca(e,e′n) reaction. The dashed histogram represents a statistical model calculation.

The B(E2+E0) distribution in ^{48}Ca is displayed in Fig. 1(a) converted to a fraction of the E2 energy-weighted sum rule (EWSR) per MeV. It is compared to a microscopic calculation [11] including, beyond the usual RPA level, coupling to the continuum, 1p1h⊗phonon configurations and the g.s. correlation induced by them. This approach was highly successful in the description of the fragmented isoscalar E0 and E2 resonances in ^{40}Ca [1], see Fig. 1(b), and also accounts well for the GDR in ^{48}Ca deduced from the present experiment [12]. Surprisingly, while the shape of the B(E2+E0) distribution in ^{48}Ca is reproduced reasonably well, the overall strength is overestimated by a factor of about two. At present, this discrepancy is not understood.

Because of the low momentum transfers of the present experiment favoring E1 excitation one can deduce the decay properties of the GDR in ^{48}Ca. Figure 2 shows the relative population of final states in the residual nucleus ^{47}Ca from the excitation region $E_x =$

11 – 17 MeV in ^{48}Ca (at higher energies two-neutron emission must be considered). The dashed histogram represents a statistical model calculation with the code CASCADE assuming pure E1 excitation. The calculation is normalized not to overshoot the data. Clearly, a large excess is found in the population of the ground state and a group of states around 2.5 MeV. These levels have a dominant one-hole structure with respect to the ^{48}Ca, and the extra strength is thus interpreted to arise from direct decay. One finds a fraction of about 40% independent of the GDR excitation energy [7].

3. Magnetic quadrupole resonances in medium-mass nuclei

Compared to the intensively studied M1 mode little is known about the next higher multipolarity, M2. Two central issues are briefly sketched here. Quenching of the spin part of the M1 (and the closely related GT) operator is experimentally well established. Possible explanations are higher-order core polarization or mixing with the Δ isobar. It was recently demonstrated that the former contributions dominate [13] while the presence of the latter is unclear. The same mechanisms are expected to reduce the M2 strengths as well, although not necessarily by the same amount. The scarce data on M2 strengths available [6] indicated an even more severe quenching than found for the M1 case in medium-mass nuclei [14]. Further, an orbital M2 mode in spherical nuclei was predicted [15] in the nuclear fluid dynamical model (the so-called 'twist mode'). Its experimental proof would be of fundamental interest demonstrating the zero-sound character of giant resonances in nuclei, contrary to the hydrodynamic picture.

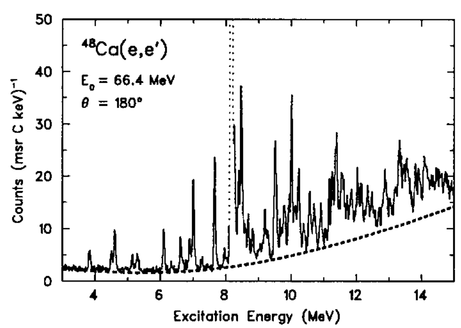

Figure 3. Inelastic electron scattering spectrum of ^{48}Ca taken at $\Theta = 180°$ and $E_0 = 66.4$ MeV. Dashed line: background determined from a fluctuation analysis.

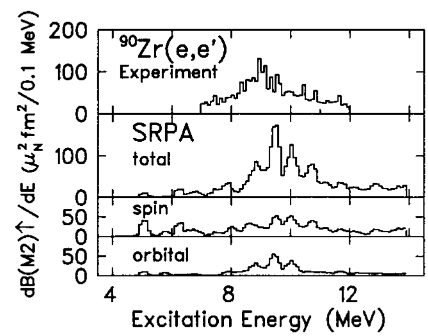

Figure 4. Experimental B(M2) strength distribution in comparison to SRPA results for the total strength and separated into spin and orbital parts.

Recent investigations of ^{48}Ca and ^{90}Zr with 180° electron scattering, where magnetic transitions are enhanced, shed first light on both questions [16]. Figure 3 presents a ^{48}Ca spectrum taken at E_0 = 66 MeV. Most of the transitions visible above 8 MeV can be shown to have M2 character. It was possible to extract the complete strength in the investigated energy range using a fluctuation analysis technique (see e.g. [17]) to fix the background (dashed line in Fig. 3). The resulting B(M2) distribution is presented in Fig. 4 for the example of ^{90}Zr. Furthermore, for the first time a successful microscopic description of the highly fragmented strength distributions was achieved using SRPA. This allows a reliable extraction of the quenching of spin M2 transitions (already included in the calculation shown in Fig. 4) which is found to be very similar to the M1 case.

The separation shown in the lower part of Fig. 4 demonstrates the presence of significant orbital parts and a pronounced constructive interference in the resonance region. Without the orbital part, the good agreement of the SRPA results would be destroyed. This provides strong hints for the existence of the twist mode.

4. Outlook

The successful operation of an experimental setup for (e,e'n) experiments opens the whole field of giant reonances in heavy nuclei where neutron emission dominates. The strength distributions which can be derived from such data serve as a real test of current microscopic models aiming at a description of the fine structure of nuclear modes. Additionally, the role of direct vs. compound decay can be tested. Electron scattering at 180° has proven to be a powerful tool for the study of magnetic resonances. Systematic investigations of the scarcely explored M2 and M3 modes are planned which should help to develop - beyond the intensively studied M1 case - a coherent picture of the role of spin and convection currents in nuclei.

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