Theory of Giant Resonances

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We are continuing a program of self-consistent calculations of multipole resonances. The Green's function formalism and interactions consistent with Hartree-Fock were shown[1,2] to work well for low-lying states. The predicted form factors are very close to collective models.[3] It also predicts a quadruple resonance roughly at $63/A^{1/3}$. This resonance is always quite sharp in the model, contrary to what is observed in light nuclei. We are now calculating the continuum more precisely, so that the broadening from particle decay will be included.

Another problem with the model is that the predicted charged-particle inelastic strength functions, summed over multipolarities, falls short of experimental value by a factor of 3-10. We are improving our distorted wave calculation to account for knockout reactions more accurately, to see if this can explain the discrepancy.

In conjunction with the experimental program to study the decay of the giant resonance in ^{40}Ca, we calculated angular distributions for decay products assuming the validity of DWBA for the excitation mechanism. Different multipoles have sufficiently different decay shapes that the L could be assigned if there were no interference.

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Decay Modes in the Giant Resonance Region of ^{40}Ca

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The giant quadrupole resonance (GQR) manifests itself in inelastic electron[1] and hadron[2] scattering spectra, as a region of enhancement near the giant dipole resonance. The spin and parity have for the most part been deduced from model calculations, but there does not exist at present a full proof that the 3-5 MeV wide bumps in the spectra are predominantely 2^+ states. Studies of these states using capture reactions are hindered by a lack of knowledge of the strength of the competing decay channels. The experiment described here is an attempt to measure the decay modes of the giant resonance region in ^{40}Ca and to use the correlation of the emitted particles to determine the spin and parity of the excitation.

The nucleus ^{40}Ca was chosen for this study because it displays a distinct resonance structure, the energy of which is sufficiently high to permit the emission of charged particles above the Coulomb barrier. Neutron emission from the continuum is hindered (relative to other nuclei) because of the high neutron separation energy. The energetics of the various decay modes are illustrated in Fig. 1. The E2 resonance in ^{40}Ca is thought to be a 5 MeV wide bump at Ex=17.5 MeV. If the resonance like structure in the inelastic scattering energy spectra possesses a well defined spin and parity, then the alpha decay to the ground state of ^{36}Ar must proceed via a single angular momentum transfer, L. Thus at least in principle, a measurement of the angular correlation of the emitted α particles leading to the ground state of ^{36}Ar can provide the multipolarity of the decaying level.

The resonance region was excited with inelastic scattering of 70 MeV ^{3}He particles, extracted from the MSU Cyclotron. A complete kinematic determination of the final state and of the reaction Q value was achieved by means of two surface barrier Si detector assemblies as shown in Fig. 2. These combinations allow the detection of protons in the range 4.7 to 11.3 MeV and alphas in the range 5.5 to 19 MeV.

The data presented in this work were taken with the ^{3}He telescope fixed at -22° (in the convention adopted here 338°) with respect to the incident beam. This angle was chosen because it is close to a minimum in the elastic scattering cross-section and scattering from Hydrogen in the target is not allowed. It is also near a maximum in the inelastic scattering cross-section to the resonance region. The α-p telescope was moved in the reaction plane to twelve angles on both sides of the beam direction.

The target was a self-supporting foil of natural Ca 0.5 mg/cm^2. Two dimensional p-^{3}He and α-^{3}He coincidence energy spectra were measured simultaneously. All spectra taken in the range 37.5° to 140° show clearly kinematic bands corresponding to proton and alpha decay to ^{39}K and ^{36}Ar. The spectra that were obtained in the range 250° to 310° (the α-p and ^{3}He telescopes on the same side of the beam) show considerably smaller yield.

The spectra shown in Figs. 3 and 4 are projections on two axes; (a) the sum projection gives the excitation of the final nucleus, (^{39}K or ^{36}Ar) and (b) the ^{3}He spectrum projection then gives the excitation in ^{40}Ca. All of the spectra shown are corrected for accidentals. Qualitatively the projections shown in Figs. 3 and 4 bears out the following observations: First the alpha modes lead predominantly to the 0^+ g.s. (α_0), 2^+ 1.97 MeV state (α_1) and to the $3^-0^+2^+4^+$ quartet of labels at about ~4 MeV (α_2) in ^{36}Ar. There is no prominent yield to the many other levels above 4.5 MeV. On the other hand, the proton modes show a considerable fragmentation of the reaction yield to the many levels above 2.5 MeV in ^{39}K. Second, projections on the ^{3}He energy axis show that the reaction events are concentrated into gross structures whose centroid tend to be independent of θ, the angle of the outgoing alphas (or protons). Also, the sum of the ^{3}He projections of the α_0, α_1 and α_2 kinematical bands exhibits the characteristic shape and position of the resonance structure in the ^{3}He singles spectra. The latter was proved to follow the kinematics of ^{3}He scattering from ^{40}Ca.[2] An interesting aspect of the experimental results is the competition between ground and excited state decays. In Table 1 are shown the relative decay widths for alpha and proton decays. These ratios are obtained by dividing the counts recorded for a particular alpha (or proton) channel by the sum of counts from all alpha (or proton) channels. It is seen that the decay properties of the regions 13-15.6 MeV and 15.6-21 MeV regions are quite different and that the decays to excited states in ^{36}Ar and ^{39}K are strong compared to ground state decays. The low yield of p and α particles to the ground states of ^{39}K and ^{36}Ar indicates a low particle width for creating these excitations via p or α capture.

The results of the experiment are somewhat clouded by a lack of knowledge of the reaction mechanism of this three-body final state reaction. The reaction can be considered to be excitation of an isolated 2^+ resonance in ^{40}Ca followed by its decay by α-particles and protons. In this case the angular correlation of the emitted particles is calculable and is a distinct measure of the L-value of the particles. Unfortunately for proton decay there are a variety of L-values permitted for each of the observed decays, and for α-particles the quasielastic scattering can not be kinematically distinguished from the sequential decay at some angles.

The present state of this project is that the raw data have been analysed and rough branching ratios have been deduced. The decay modes below the neutron separation energy can be used to check the solid angle and kinematic factors since all of the decay must go via α's and protons. This check appears to be satisfactory and indicates that about 50% of the giant resonance region decays by neutrons or α's and protons too low in energy to be detected. The remainder of the decay is about equal protons and alphas. The final numbers have to be corrected for recoil to lab transformations and other experimental effects.

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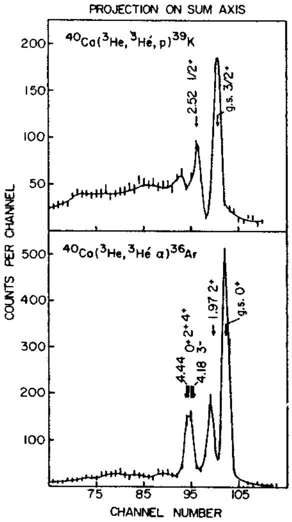

Fig. 3.--Projections on the sum axis of the alpha-^{3}He and proton-^{3}He coincidence spectra.

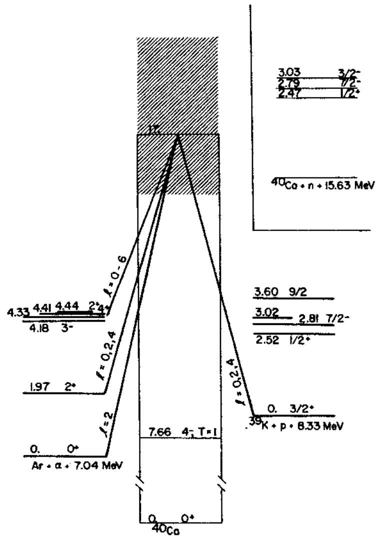

Fig. 1.--The resonance region in ^{40}Ca and its possible particle-decay modes. Several transitions are indicated with arrows, along with the values of the angular momentum transfer in the decay of a 2$^+$ state.

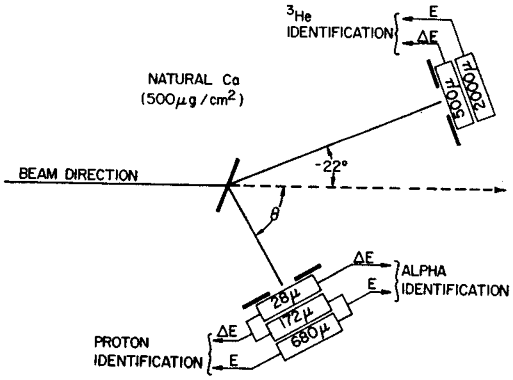

Fig. 2.--Schematic representation of the experimental setup showing the arrangement of the two telescopes and target with respect to the beam direction. Thicknesses of the surface barrier silicon detectors are indicated.

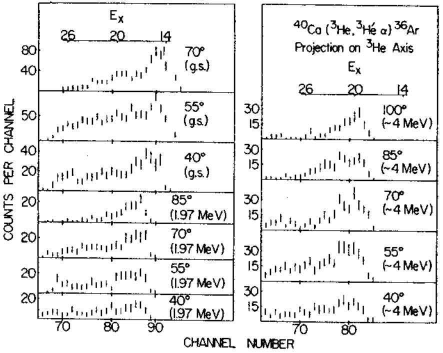

Fig. 4.--Projections on the ^{3}He energy axis of the α_0, α_1 and α_2 kinematical bands.

TABLE 1.--Relative alpha and proton branching ratios.

Ex (MeV)	$\Gamma\alpha_0/\Gamma\alpha$	$\Gamma\alpha_1/\Gamma\alpha$	$\Gamma\alpha_2/\Gamma\alpha$	$\Gamma p_1/\Gamma p$	$\Gamma p_1/\Gamma p$	$\Gamma p\text{-}p_1\text{-}p_2/\Gamma p$
13-15.6	0.28 ±0.045	0.07 ±0.025		0.10 ± .02	0.08 ±0.03	0.42 ±0.05
15.6-21	0.13 ±0.053	0.22 ±0.035	0.30 ±0.04	0.07 ±0.02	0.05 ±0.03	0.27 ±0.08

The error is the jitter of values obtained from different angles with respect to the quoted statistical average values.