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A SEARCH FOR GIANT RESONANCES BY INELASTIC PROTON SCATTERING ON ^{24}Mg*

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A straightforward method is proposed for the observation of giant resonances based on the phase shift analysis of the inelastic transition between a 0^+ ground state and a weakly excited 0^+ state. The method is tested by analysing the differential cross section of inelastic proton scattering leading to the 0^+ ($E_{ex}=6.43$ MeV) excited state of ^{24}Mg.

1. Introduction

One of the most effective tools for the excitation of giant resonances is inelastic hadron scattering. The various possibilities for the observation of giant resonances by means of inelastic scattering can be summarized as follows. In the course of the inelastic collision the target nucleus is excited to some high lying states and then the giant resonances show up in the energy spectrum of the inelastically scattered particles as pronounced maxima above a continuous background [1, 2, 3, 4]. In this case the resonating states are excited as the final states of the target nucleus. Another possibility is the excitation of the giant resonances as intermediate states of the compound system. In this case the excitation probability of a given low lying state is measured as a function of the bombarding energy and the maxima of this excitation function are identified with the giant resonances of the compound (target plus projectile) system. In order to increase the sensitivity of this method it is advisable to select such an inelastic transition where the direct excitation is hindered because of some specific reason. In

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such a case the contribution of a two-step mechanism involving the high lying states as intermediate states, is relatively enhanced.

The direct excitation of the low lying non-normal parity states is hindered, because it may take place only by a spin-flip mechanism. Consequently, the excitation function of the non-normal parity states provides a rather sensitive tool for the study of the giant resonances [5, 6, 7, 8].

In this paper our aim is to explore another possibility for the study of giant resonances. Namely we note that in addition to the non-normal parity, a number of other reasons may lead to the suppression of the direct transition and the relative enhancement of the two-step mechanism. For example if the wave function of the excited state contains with appreciable amplitude many-particle many-hole excitations compared to the ground state then the one-step direct transition is obviously suppressed. If the inelastic cross section of a given low lying state is considerably lower than that of the neighbouring states having the same spin and parity, then it is justified to assume that the transition takes place predominantly by a multi-step mechanism involving highly excited states of the compound system. The measurement of the excitation function of such a weakly excited state provides the possibility to study the resonating high lying states. Of the weakly excited low lying states the 0^+ states are the most appropriate for such a study since in the $0^+ \to 0^+$ transition the partial waves can be associated uniquely to the multipolarity of the giant resonances. In order to test the above suggestion we analyse the inelastic proton scattering on ^{24}Mg leading to the 0^+ excited state, situated at $E_{ex} = 6.43$ MeV.

2. Experimental results and phase shift analysis

The inelastic scattering of protons on ^{24}Mg has been measured at the isochronous cyclotron JÜLICH at proton energies:

$$E = 22.50,\ 23.25,\ 24.00,\ 24.75,\ 25.00,\ 25.25,\ 25.50,\ 25.75,\ 27.00 \text{ and } 28.50 \text{ MeV}.$$

The angular dependence of the scattering cross sections has been observed between 20° and 160° in 5° intervals for the 7 lowest lying states. The description of the experimental details and the tabulated cross section values can be found in [7] and in [8], respectively.

Searching for giant resonances of the compound system the excitation function of the weak inelastic transition to the 0^+ ($E_{ex} = 6.43$ MeV) excited state has been studied by means of phase shift analysis, using the standard formula:

$$\frac{d\sigma'_{pp}}{d\Omega} = \frac{1}{8k^2} \sum_{lJJ'LL'} Z^2(L\,J L'\,J', 1/2l) \,.$$

$$\mathrm{Re}\,(S_L^{J*}\, S_{L'}^{J'})\, P_l(\cos\Theta)\,,$$

where the wave number of the relative motion is denoted by k, the argument of the Legendre polynomial P_l contains the scattering angle Θ, measured in the centre of mass system of reference. The coefficient Z can be expressed in terms of Racah and Clebsch-Gordan coefficients. The S-matrix elements S_L^J are parametrized in the usual way:

$$S_L^J = \eta_L e^{2i\delta_L}.$$

It was checked that the partial waves higher than $L_{max}=6$ give negligible contribution in the energy interval studied here. The spin splitting of the partial waves is neglected. The measured values of the inelastic cross section together with the results obtained from the phase shift analysis are shown in Fig. 1.

The absolute squares of the S-matrix elements η_L^2 are exhibited in Fig. 2 as functions of the bombarding proton energy E.

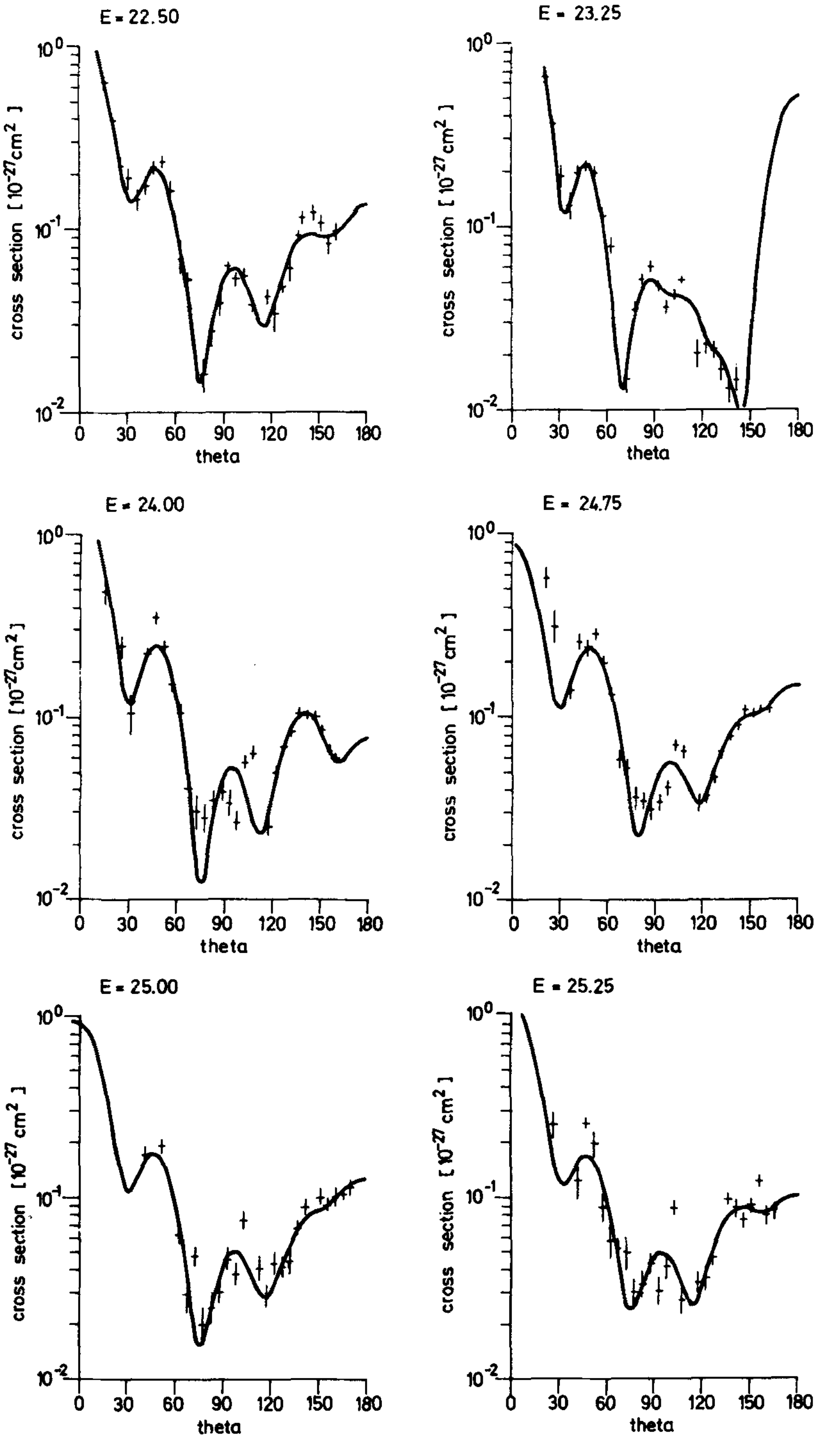
In order to analyse the energy dependence of the transition amplitude it is useful to split up the S-matrix elements into two parts:

$$S_L^J(E)=(S_L^J(E)-\langle S_L^J\rangle)+\langle S_L^J\rangle,$$

where $\langle S_L^J\rangle$ stands for the average S-matrix elements taken over the whole energy range studied here. The average S-matrix can be associated with the one-step (direct) processes and it is expected that the difference $S_L^J(E)-\langle S_L^J\rangle$ corresponds to the multistep processes which may lead to resonating intermediate states.

3. Discussion

According to our basic assumption the inelastic transition 0^+ ($E_{ex}=0.00$ MeV) $\to 0^+(E_{ex}=6.43$ MeV) takes place predominantly via the excitation of high lying states, consequently it is sensitive for giant resonances. This assumption is based upon the experimental fact that the cross section is considerably lower than that of the neighbouring states. If the excited 0^+ state, however, is a member of a collective vibrational multiplet, then the possibility of a weak multi-step channel coupling excitation involving only low lying states, is not ruled out. In order to test this possibility a series of calculations using the method of Coupled Channels has been performed. It was assumed that the 2^+ ($E_{ex}=4.24$ MeV) state is a one-phonon vibrational state and the 0^+ excited state is one of the members of the two-phonon multiplet [9]. Within reasonable limits of the potential parameters we were unable to obtain acceptable cross sections. The typical values of the inelastic cross section for the $0^+\to 0^+$ transition are one order of magnitude higher than the experimental values. This result shows that the excited 0^+ state cannot be interpreted as a member of a vibrational multiplet.


E = 22.50
E = 23.25
E = 24.00
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E = 25.25
cross section [10^-27 cm^2]
10^0
10^-1
10^-2
0 30 60 90 120 150 180
theta

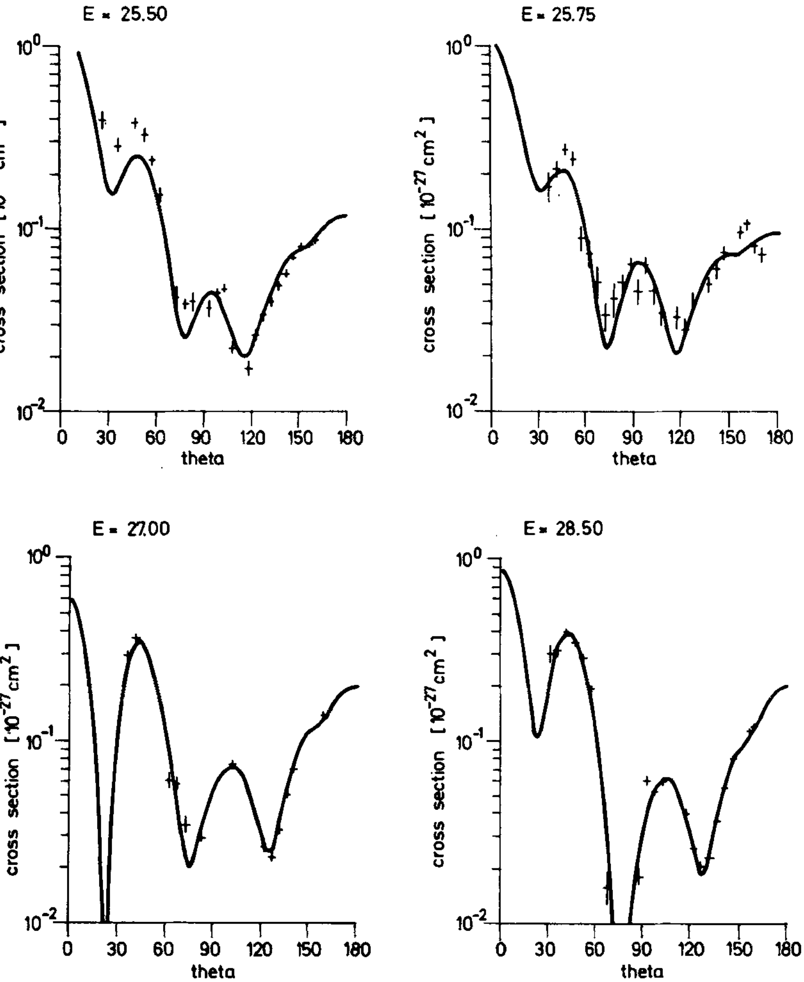

Fig. 1. Differential cross section of inelastic proton scattering on ^{24}Mg, leading to the excited state $0^+(E_{ex}=6.43$ MeV) measured at proton energies between 22.50 and 28.50 MeV. The error bars correspond to the statistical error of the counting rate. The solid lines are obtained by phase shift analysis

The splitting of the S-matrix elements into an average and a fluctuating part has been carried out, as it was indicated in the previous Section, and the fluctuating part was parametrized in the following way:

$$S_L^J(E)-\langle S_L^J\rangle=G_L(E)e^{i\varphi_L(E)}\,.$$

The quantities $G_L(E)$ and $\varphi_L(E)$ can be compared with the results of the analysis carried out for the $0^+\to3^+$ transition in [7]. From this comparison one can see a qualitative

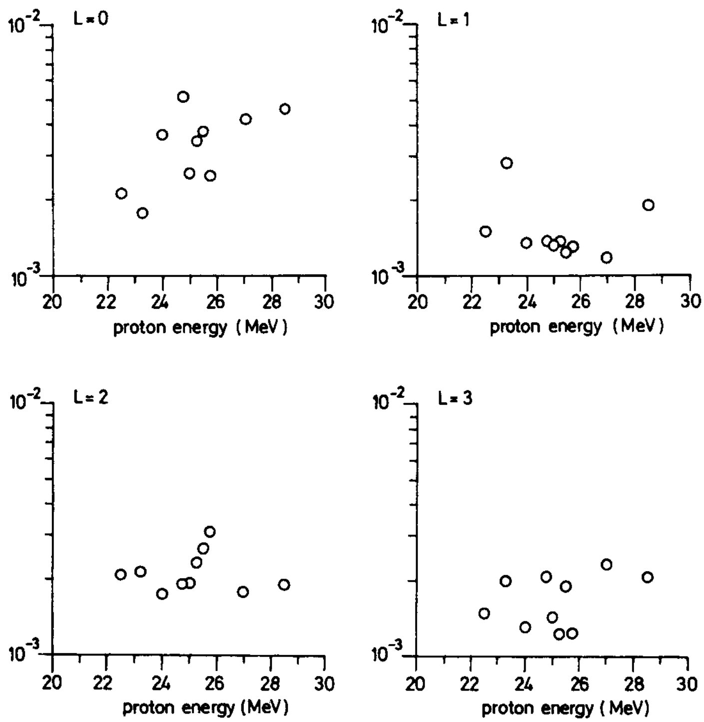

Fig. 2. The transition probability η_L^2 for angular momentum $L=0, 1, 2$ and 3 obtained by phase shift analysis

similarity between the $0^+ \to 3^+$ and $0^+ \to 0^+$ transition as far as the excitation probability of giant resonances with low multipolarity are concerned. However, from the analysis of the $0^+ \to 0^+$ transition no definite conclusions can be drawn due to the poor statistics of the experimental data. In our experiments the conditions were optimised for the measurement of the inealstic cross section of the non-normal parity state 3^+, consequently the counting rates for the $0^+ \to 0^+$ transition were too low.

In order to be able to draw quantitative conclusions on the strength distributions of the giant resonances experimental data of improved quality are needed. More specifically:

1) longer measurements are desirable because of the low cross section values;

2) in order to facilitate the phase shift analysis, measurements at angles sensitive to this particular angular distribution are required;

3) to check the maxima of the strength distributions, measurements at some additional proton energies are necessary.

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