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GAMMA RAYS FROM RESONANCE NEUTRON CAPTURE BY ^{24}Mg

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Abstract: We have observed capture gamma-ray spectra from the 46keV narrow d3/2-wave resonance and the 84keV strong p3/2-wave resonance in ^{24}Mg. In the d-wave resonance capture, radiative decay strength concentrates mostly on the ground-state transition. In the p-wave resonance capture, distinct gamma rays were observed for the E1 transitions to the ground(5/2+), 585keV(1/2+), 1965keV(5/2+) and 2564keV(1/2+) states of ^{25}Mg. The observed partial radiative widths for these transitions were compared with the values obtained from the Lane-Mughabghab optical model formula of the valence capture model. As a result, we found that the model calculations reproduce well the observed widths for the transitions from the p-wave resonance to the 1/2+ states, while for the transitions to the 5/2+ states the calculated values are about two times as large as the observed ones.

(NUCLEAR REACTIONS $^{24}Mg(n,\gamma)$, E=46,84keV; measured $\sigma(E,E_\gamma)$ at 125°. ^{25}Mg deduced resonances, Γ_γ. Natural target.)

Introduction

In ^{24}Mg, three broad p-wave resonances have been observed below the neutron energy of 0.5MeV /1/,/2/. From the uncertainty principle, these resonance states are supposed to be represented by such a simple configuration as 1p-0h (a single neutron plus an inert core). Moreover, low-lying states of the residual nucleus ^{25}Mg have large single-particle components for the angular momentum, l=0 or 2 /3/. Thus we can expect that the single-particle nature becomes dominant in E1 decay from the resonant states. Also, such non-statistical process causes a correlation between radiative widths and single-particle strengths. In fact, some correlation effects have been noted in the $^{24}Mg(n,\gamma)^{25}Mg$ reaction/4/.

The present study is a first step in investigating the mechanism of neutron resonance capture in ^{24}Mg. The paper reports on a characteristic difference between the E1 single-particle transitions to the s-state and d-state from the 84keV p3/2-wave resonance. A discussion will follow on the matrix elements for both transitions.

Experiments

Employing a time-of-flight (TOF) method, we have observed gamma rays from neutron capture in the 46keV d5/2-wave resonance and the 84keV p3/2-wave resonance of ^{24}Mg.

The 1ns bunched proton beam, which was obtained from the 3.2MV Pelletron accelarator in Tokyo Institute of Technology, bombarded a Li-evapolated copper disk, and the $^7Li(p,n)^7Be$ reaction generated pulsed neutrons. The average proton beam current was about 9μA at the 2MHz pulse repetition rate. The capture sample was a metal disk of natural magnesium (8.06×10^{-3} atm/b). Also, the gold disk sample (1.02×10^{-2} atm/b) was used as a standard for capture cross section measurements. Each sample was placed 155mm distant from the neutron source.

Capture gamma rays were detected with the anti-Compton NaI(Tl) detector consisting of a 75mm diameter × 152mm main crystal and a guard crystal for rejection of Compton-scattered gamma rays. The detector was surrounded by a heavy shield constructed from three layers of Pb, Cd and borated paraffin/5/. An aluminium cylinder filled with ^{6}LiH-powder was inserted into the gamma-ray colimator in order to remove the neutrons scattered into the detector through the colimator/6/. The distance from the capture sample to the main crystal was about 80cm. Capture gamma rays were observed at 125° with respect to the proton beam direction. The efficiency and response function of the gamma-ray detector were measured in the previous work /7/,/8/. Before every measurements, we confirmed the reproduction of these characteristics of the detector.

The relative neutron yield for each measurement was measured with the 44mm × 44mm × 1mm ^{6}Li-glass scintillation detector. The neutron energy spectrum on the Mg sample was obtained from capture experiments on Au. The experimental arrangement is shown in fig.1.

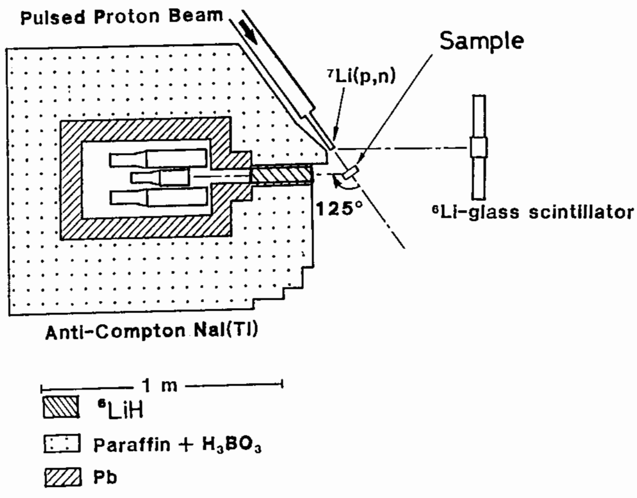

Fig.1 Experimental arrangement.

Capture gamma-ray data were stored in a mini-computer as the two-dimensional data of TOF and pulse-height (PH).

Data Analysis

Capture gamma rays from the d-wave and p-wave resonances are completely distinguishable from each other on the TOF axis, as shown in fig. 2. Therefore, we could measure the one-dimensional pulse-height spectrum for each resonance, by setting up a suitable TOF window. To obtain the gamma-ray spectra, the pulse-height spectra were unfolded by an iterative method/9/, using the response function of the gamma-ray detector. Correction was made for the gamma-ray self-shielding in the sample.

The partial radiative width $\Gamma\gamma p$ was deduced from the gamma-ray yield $N\gamma p$ using the following relation, in which the interference between resonance and off-resonance capture was neglected to a good approximation.

$$N_{\gamma p} = C n \phi_0 g \frac{\Gamma_n \Gamma_\gamma}{\Gamma} + C n \phi_0 \sigma_\gamma(off)$$

with

$$\alpha \equiv \int \pi ƛ^2(E) \frac{\Gamma \eta(E)}{(E - E_r)^2 + (\Gamma/2)^2} dE$$

where C is a correction factor, n is the sample thickness, ϕ_0 is the number of incident neutrons, g is the statistical factor, ƛ(E) is the de Broglie wave length of the incident neutron with energy E, and $\eta(E)$ is the neutron flux distribution normalized to one neutron. The resonance parameters, Er, Γ and Γn are the resonance energy, total width and neutron width, respectively. Correction was made for the neutron self-shielding in the sample and for the neutron multiple scattering in the sample. Also, we determined the number of incident neutrons ϕ_0 so that the capture cross section of Au obtained by a pulse-height weighting method produced the ENDF/B-V evaluated value. The off-resonance capture cross section $\sigma\gamma$(off) was calculated by the direct capture theory in the distorted wave Born approximation, using the HIKARI code /7/. Here, it was ascertained that the off-resonance capture contributes less than 5% to the partial radiative widths for the transitions to the 1/2+ states.

The resonance parameters of the p-wave resonance were taken from the data of Weigmann et al./1/. For the d-wave resonance, the work of Mughabghab et al./2/. gives the resonance spin 3/2, while Cocceva et al. reported the resonance spin 5/2 /10/. Therefore, we did not deduce the partial radiative widths of this resonance.

Results and Discussion

The gamma-ray pulse-height spectrum from the 46keV d3/2-wave resonance is shown in fig 3. From this spectrum, it is found that the radiative decay strength of the resonance concentrates mostly on the ground-state transition, probably M1 transition. We deduced the capture kernel for this transition, assuming that the resonance width is very narrow. The kernel is

$$g \frac{\Gamma_n \Gamma_{\gamma 0}}{\Gamma} = 0.37 \pm 0.06 \text{eV}$$

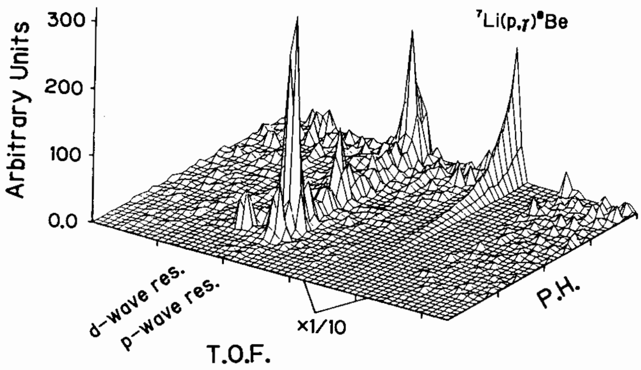

Fig.2 Two-dimensional capture gamma-ray spectrum for Mg. The background was subtracted.

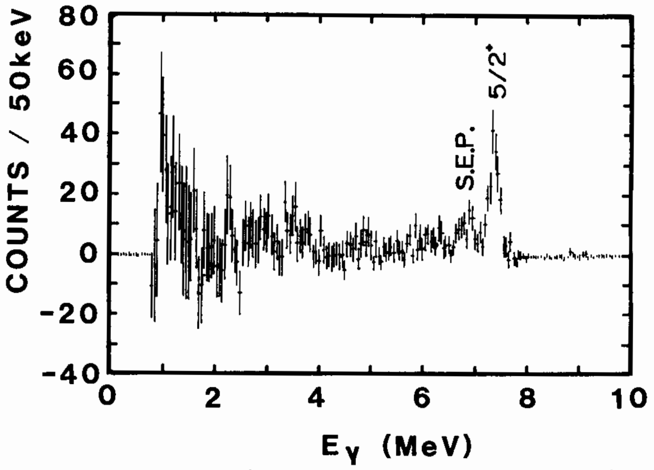

Fig.3 Pulse-height capture gamma-ray spectrum from the 46keV d3/2-wave resonance.

In this data analysis, we did not consider the off-resonance capture cross section. The above equation is changed to compare our result with the recent $^{25}Mg(\gamma,n)^{24}Mg$ experiment of Cocceve et al. as follows:

$$(2J+1) \frac{\Gamma_n \Gamma_{\gamma 0}}{\Gamma} = 0.74 \pm 0.12 \text{eV}$$

where J is the resonance spin. This value is in good agreement with the value 0.84 observed by Cocceve et al./10/ within the experimental error.

The pulse-height and unfolded spectra for the 84keV p3/2-wave resonance are shown in figs. 4 and 5, respectively. As shown in fig.4, the distinct gamma rays were observed for the E1 transitions to the ground (5/2+), 585keV (1/2+), 1965keV (5/2+) and 2564keV(1/2+) states. In the unfolded spectrum, moreover, we find a small peak which is possibly caused by the transition to the 975keV (3/2+) state. We deduced the partial radiative widths for these transitions, as listed in Table 1.

For the total radiative width of this resonance, Block et al./11/, Weigmann et al./1/, Nyströme et al./12/ and Allen et al./13/ reported $\Gamma\gamma$=6.7±0.9eV, 5±1eV, 4.0±0.9eV and 4.4±0.6eV, respectively. The summation of our partial radiative widths produces $\Sigma\Gamma\gamma p$=5.99±0.6eV, which is in good agreement with above total radiative widths.

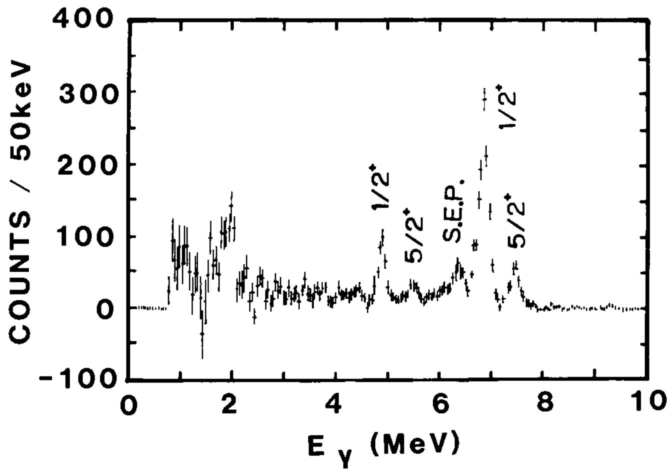

Fig.4 Pulse-height capture gamma-ray spectrum from the 84keV p3/2-wave resonance.

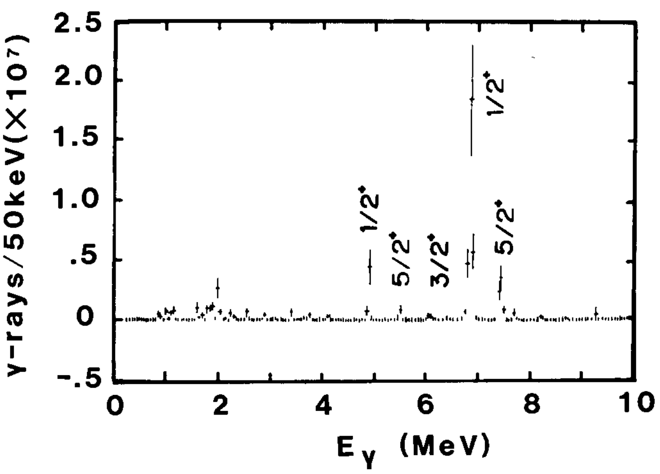

Fig.5 Unfolded capture gamma-ray spectrum for the 84keV p3/2-wave resonance.

We calculated the partial radiative widths of the p-wave resonance, using the Lane-Mughabghab optical formula in the valence capture model /14/. In the calculation, the neutron width was taken to be 7.7keV /1/, and the neutron effective charge to be -Ze/A. The Moldauer optical potential parameters/15/ were used to calculate the initial and final state wave functions. The spectroscopic factors of ^{25}Mg were obtained from the work of Endt/3/. The observed widths for both transitions to the 1/2+ state are in excellent agreement with the valence model calculations. On the other hand, the observed widths for the transition to the 5/2+ state are systematically smaller than the calculated values: the ratio of the observed value to the calculated value is 0.33 for the ground state transition and 0.45 for the 1965keV state transition.

Also, the observed weak transition to the 3/2+ state is explained by the small vector coupling coefficient in the valence model fromula.

Fig.6 shows the overlap integrals for the valence capture transitions from the p3/2-wave resonance state to the 2s1/2 and 1d5/2 single-particle states. For the d-state transition, the maximum overlap integral in the nuclear internal region is about 21% of the maximum overlap integral in the nuclear external region, while the percentage is about 7% for the s-state transition: the internal contribution to the d-state transition is quite larger than the internal contribution to the s-state transition. Probably, this fact leads to the results that for the d-state transition the valence model calculation produces the values smaller than the observed ones. It is conceivable that the d-state transition is not completely decoupled from the excitation of the electric giant dipole state.

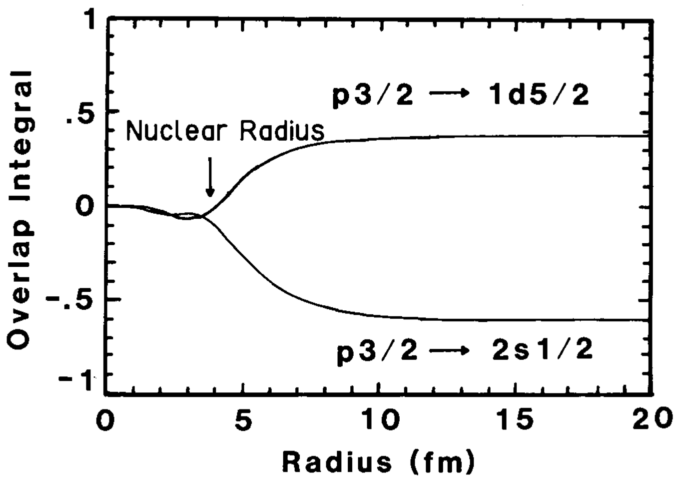

Fig.6 Overlap integrals for the valence capture transitions from the p3/2-wave resonance state to the 2s1/2 and 1d5/2 single-particle states.

Table 1. Observed and calculated radiative widths of the 84keV p3/2-wave resonance.

Ex(keV)	J^{π}	Γγp(eV) Present	Γγp(eV) Bergqvist et al./16/	Γγp(eV) Valence Model	θn^2
0.0	(5/2+)	0.93 ± 0.14	0.63	2.78	0.37
585	(1/2+)	3.98 ± 0.45	2.35	4.31	0.51
975	(3/2+)	<0.16	——	0.10	0.35
1965	(5/2+)	0.20 ± 0.07	0.085	0.44	0.11
2564	(1/2+)	0.68 ± 0.14	0.44	0.69	0.13

The numbers in the last column show the spectroscopic factors of ^{25}Mg/3/.

Summary

We have measured gamma-ray spectra from neutron capture in the 46keV d3/2-wave resonance and the 84keV p3/2-wave resonance of ^{24}Mg. For the d-wave resonance capture, the observed strength of the ground state transition is in good agreement with the recent ^{25}Mg(γ,n)^{24}Mg experiment. For the p-wave resonance, the valence model calculation reproduces successfully the observed partial widths for the E1 transitions to the 1/2+ states in ^{25}Mg ,while the systematic discrepancies were found between the calculated and observed widths for the transitions to the 5/2+ states.

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