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A RESONANT ABSORPTION MEASUREMENT IN THE REACTION ^{26}Mg(p, γ)^{27}Al

C. VAN DER LEUN and N. C. BURHOVEN JASPERS
Fysisch Laboratorium, Rijksuniversiteit, Utrecht, Netherlands

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Abstract: A resonant absorption measurement at the 1966 keV proton resonance in the reaction ^{26}Mg(p, γ)^{27}Al leads to an absolute determination of the resonance strength, $(2J+1)\Gamma_p\Gamma_\gamma/\Gamma$, of 5.6 ± 1.8 eV. Normalization of previously published strengths of 120 resonances in the reaction ^{26}Mg(p, γ)^{27}Al, reduces these strengths by a factor of 2.7.

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NUCLEAR REACTIONS ^{27}Al(γ, γ), $E = 10.16$ MeV, [γ from ^{26}Mg(p, γ), $E = 1966$ keV]; measured $\sigma(\theta_{p,\gamma})$. ^{27}Al level deduced Γ_γ, Γ_p, Γ. Enriched ^{26}Mg target.

1. Introduction

The strengths of about 120 resonances in the reaction ^{26}Mg(p, γ)^{27}Al, reported in ref. ^{1}), were determined from thick and thin-target yield curves. This method ^{2}) leads to reliable relative resonance strengths, but the absolute values are strongly dependent on the target composition. Especially for this reaction, where the targets are prepared by evaporation of ^{26}MgO onto tantalum backings, the reduction of MgO to Mg during the evaporation and a possible subsequent oxidation of the target introduce uncertainties in the target composition.

For a comparison of the radiative widths of gamma transitions in ^{27}Al with theoretical values, and with radiative widths in other s-d shell nuclei ^{3}), an absolute measurement is required. A resonant absorption measurement ^{4,5}), yielding the strength independent of target composition, was therefore performed for one of the 120 resonances. The results of this experiment are reported here.

2. Experiment

The resonant absorption technique, in which the recoil energy loss upon emission and absorption of a gamma quantum is compensated for by the Doppler shift of capture gamma rays, has been extensively discussed by Smith and Endt ^{4,5}). In the experiment described here, the same experimental set-up was used.

The ground-state gamma rays from the 1966 keV proton resonance in the reaction ^{26}Mg(p, γ)^{27}Al were detected with a 10 cm × 10 cm cylindrical NaI(Tl) crystal, placed at about 35 cm from the target. A lead collimator, 30 cm long, 10 cm high and 10 cm wide, was placed between crystal and target. The collimator slit was filled with

30 × 10 cm^2 Al sheets. Two measurements were performed, one with a 0.2 cm and the other with a 0.4 cm thick Al sheet.

The Doppler shift of the capture gamma rays is dependent on the detection angle.

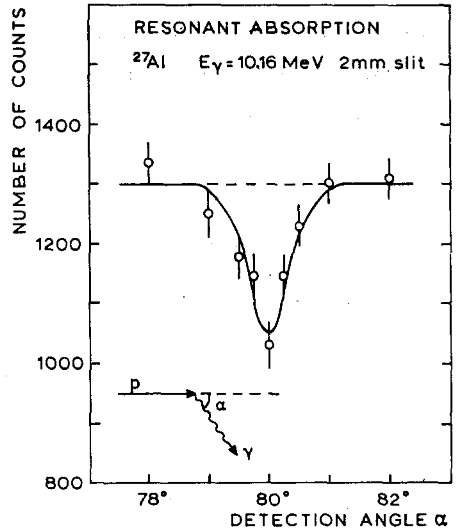

Fig. 1. The absorption of 10.16 MeV gamma rays from the reaction ^{26}Mg(p, γ)^{27}Al at E_p = 1966 keV in a 30 cm long and 0.2 cm thick Al absorber, as a function of the detection angle. The solid curve is a Gaussian of 0.75° full width at half maximum and 19 % maximum absorption.

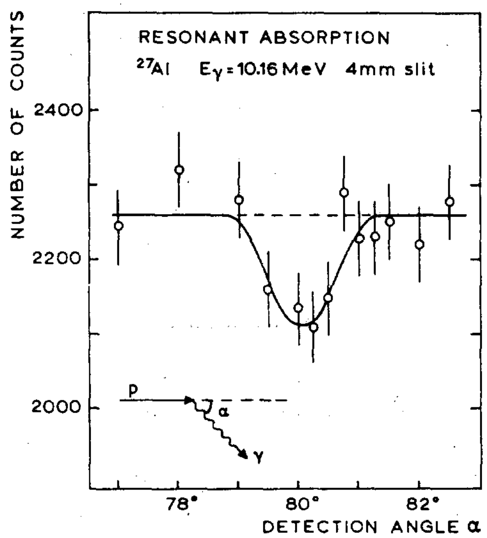

Fig. 2. As fig. 1, but with a 0.4 cm thick Al absorber. The Gaussian has a 1.2° full width at half maximum and the maximum absorption is 6.5 %.

The angle at which the Doppler shift compensates the emission and absorption recoil energy losses, the absorption angle α_r, is given by the relation [4]).

$$\cos \alpha_r = E_0/(2E_p m_p c^2)^{\frac{1}{2}},$$

where E_0 is the gamma-ray transition energy, and E_p and m_p are the kinetic energy and mass of the proton, respectively. For the resonance investigated here, with $E_p = 1.966$ MeV and $E_0 = 10.16$ MeV, α_r is 80.3°. The choice of the 1966 keV resonance for this experiment follows from a comparison of the relative resonance strengths and modes of decay of the 120 observed resonances [1]). The small solid angle of the experimental set-up requires a strong (p, γ) resonance with a strong ground-state transition, γ_0, the only transition participating in the absorption process. Moreover, the resonance should not be too broad, since this leads to a broadening of the absorption dip.

Even with the strong 1966 keV resonance, which decays 74 % to the ground state [6]), the gathering of the data given in figs. 1 and 2 took about 15 hours each. The Van de Graaff beam was 8 μA; the target, 99 % enriched ^{26}Mg, was 15 μg/cm^2 thick. The yield of γ_0 was measured as a function of the detection angle in the 77°–83° range in steps of $\frac{1}{2}$° or $\frac{1}{4}$°. The data were taken by moving the detector back and forth over the range of angles; a second gamma-ray spectrometer served as a monitor. The lines drawn through the points of figs. 1 and 2 are χ^2 fitted Gaussians. The peaks correspond to 19 % and 6.5 % absorption and the full widths at half maximum are 0.75° and 1.2° for the 0.2 and 0.4 cm thick absorbers, respectively.

For the absorption integral, A_α, one finds

$$A_\alpha = \int_0^\pi A(\alpha)\mathrm{d}\alpha = (1.7 \pm 0.4) \times 10^{-3} \text{ rad}.$$

where $A(\alpha)$ is the absorption at the detection angle α. The value given above is an average of the two measurements which give $A_\alpha = (2.3 \pm 0.6) \times 10^{-3}$ and $(1.3 \pm 0.5) \times 10^{-3}$ rad for the 0.2 and 0.4 cm absorbers, respectively. The errors given are statistical and include the uncertainty in the position of the base lines. The background was measured with the slit closed.

3. Analysis

The value of the absorption integral is related to the total level width, Γ, and the ground-state radiative width, Γ_{γ_0}, by the relation [4, 5])

$$A_\alpha = \frac{\pi}{2}\left(\frac{\mathrm{d}\alpha}{\mathrm{d}E_\gamma}\right) F(n\sigma_0)\Gamma, \tag{1}$$

where $\mathrm{d}E_\gamma/\mathrm{d}\alpha$ is the rate of change of the gamma-ray energy with angle, evaluated at α_r, $F(n\sigma_0) = fn\sigma_0$, with $f = 1$, 0.80, 0.67 and 0.59 for $n\sigma_0 = 0$, 1, 2, and 3, respectively (see ref. [4]) for a full description of the function F), n is the number of absorber nuclei per unit area, and

$$\sigma_0 = \frac{2J_r+1}{2J_0+1}\frac{\lambda^2}{2\pi}\frac{\Gamma_{\gamma_0}}{\Gamma}, \tag{2}$$

where J_r and J_0 are the spins of the resonance level and the ground state, respectively, and λ the wave length of the gamma transition.

The analysis proceeds as follows: with the absorption integral A_α known, the product $F(n\sigma_0)\Gamma$ can be calculated from equation (1). For a given Γ one then knows $F(n\sigma_0)$. The corresponding value of $n\sigma_0$ can then be read from the graph [4]) of $F(n\sigma_0)$, and the corresponding Γ_{γ_0} can be calculated from equation (2). If Γ is not known, as is the case here, the resonant absorption measurement still gives a one-to-one relation between Γ and Γ_{γ_0}, and, together with the gamma branching ratio of the level, also one between Γ and Γ_γ.

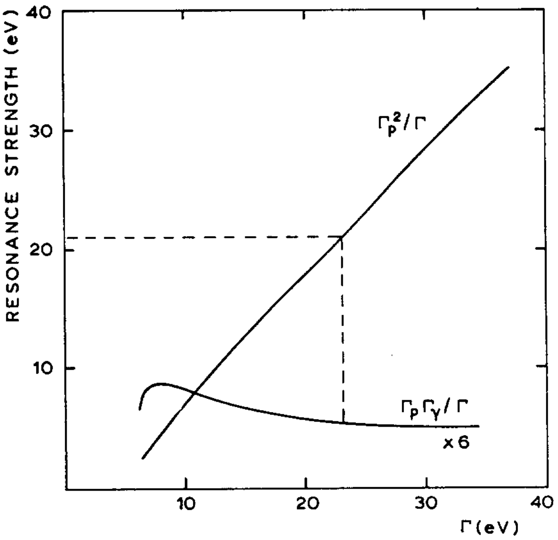

Fig. 3. The strengths of the radiative capture resonance, $\Gamma_p\Gamma_\gamma/\Gamma$, and the elastic proton scattering resonance, Γ_p^2/Γ, as a function of Γ, calculated from the measured absorption integral for the ^{26}Mg+p resonance at E_p = 1966 keV.

For the level studied here, ^{27}Al* = 10.16 MeV, only two decay channels are open: proton emission to the ^{26}Mg ground state and gamma decay. Therefore, $\Gamma = \Gamma_p + \Gamma_\gamma$, where Γ_p is the proton width and $\Gamma_\gamma = 1.35\ \Gamma_{\gamma_0}$ (ref. [6])) is the total radiative width.

From the relation between Γ and Γ_γ, found above, it is possible to calculate the elastic proton scattering and proton-capture resonance strengths, Γ_p^2/Γ and $\Gamma_p\Gamma_\gamma/\Gamma$, respectively. These two strengths are given in fig. 3 as a function of Γ, for the measured value of A_α. From an elastic proton scattering experiment, Walinga [7]) recently found

$\Gamma_p^2/\Gamma = 21 \pm 5$ eV for the 1966 keV proton resonance. With this value, the graphs of fig. 3 indicate a proton-capture resonance strength, $(2J_r+1)\Gamma_p\Gamma_\gamma/\Gamma = 6.3 \pm 2.0$ eV. It might be noted that due to the relative flatness of the $\Gamma_\gamma\Gamma_p/\Gamma$ curve in the area of interest, the proton-capture resonance strength is rather insensitive to the exact value of Γ_p^2/Γ.

With the values found, a correction can be calculated for the increase of the absorption integral due to the thermal motion of the absorbing nuclei [4]). With this new value of A_α, the calculation of the strengths can be repeated. This rapidly converging iteration process leads, with $J_r = \frac{5}{2}$ for the resonance spin [6]), to the final result

$$(2J_r+1)\Gamma_p\Gamma_\gamma/\Gamma = 5.6 \pm 1.8 \text{ eV}.$$

The error is mainly due to the statistical error in the measured absorption integral.

4. Conclusions

Comparison of the (p, γ) resonance strength found above with the previously [1]) published value for the 1966 keV resonance, $(2J_r+1)\Gamma_p\Gamma_\gamma/\Gamma = 15$ eV, indicates that the 120 resonance strengths given in ref. [1]) are high by a factor of 2.7.

This result is in good agreement with the conclusion from Engelbertink and Endt [8]), who find a reduction factor of 2.6 for the old values of the ^{26}Mg(p, γ)^{27}Al resonance strengths, from a comparison of the yields of a large number of resonances measured with targets of different chemical composition. Preliminary data from a resonant absorption measurement at the same resonance, performed at Stellenbosch [9]), indicate a similar reduction factor.

The partial widths for the 10.16 MeV ^{27}Al level are: $\Gamma_\gamma = 1.0 \pm 0.3$ eV, $\Gamma_p = 22 \pm 5$ eV, and $\Gamma = 23 \pm 5$ eV.

The argument for the even parity assignment to the resonance level given in ref. [6]) is slightly weakened by the reduction factor of 2.7 found above. The elastic proton scattering experiment [7]) mentioned above, however, establishes the even parity of this level independent of strengths arguments.

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