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Width of the 3841-keV level in ^{17}O

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The width of 3841-keV level in ^{17}O was precisely measured in nuclear resonance fluorescence experiments performed at the Stuttgart Dynamitron facility. The result of Γ(3841 keV) = (92 ± 6) meV is compared with upper limits quoted in the literature. Possible particle-hole configurations of the 3841-keV level are discusssed.

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The interest in the ^{17}O nucleus arises from its being a light nucleus with a $1d_{5/2}$ neutron outside the doubly magic ^{16}O nucleus. The first excited state at 873 keV is almost a pure $2s_{1/2}$ configuration. The above configurations were evidenced by the ^{16}O(d,p) reaction [1] where very strong l_n=2 and l_n=0 transitions were found to proceed to the ground and first excited states, respectively. The spin and parity of the level at 3841 keV are $5/2^-$ with 100% branching to the ground state. According to the shell model, the odd parity levels in ^{17}O must involve particle-hole excitations such as $2p$-$1h$ and $3p$-$4h$ components to describe the corresponding levels. The particles are expected to occur mainly in the $2s$-$1d$ shells and the holes in the $1p$ shell. It may be noted that the single-particle $1f_{5/2}$ configuration can also occur in the 3841-keV $5/2^-$ state but its contribution is expected to be small owing to the very high excitation energy of the pure $1f_{5/2}$ state. This expectation is borne out experimentally because only a weak $l_n = 3$ transition was found to proceed to this level using the ^{16}O(d,p) reaction. The pronounced $2p$-$1h$ character of this level was revealed by the strong transition intensity leading to it by both the ^{15}N(α,d) and the ^{15}N(^{3}He,p) reactions [2,3]. The corresponding angular distribution of the emitted particles in the two reactions was found to proceed by $L = 2$ where L is the combined angular momentum transfer of the two nucleons entering ^{15}N. This also shows that the main particle-hole configurations of this state are $d^2_{5/2}p^{-1}_{1/2}$, $d_{5/2}s_{1/2}p^{-1}$, $d^3_{5/2}s_{1/2}p^{-3}$, and $d^4_{5/2}p^{-3}$ where p without subscript may refer to both $p^{-1}_{3/2}$ and $p^{-1}_{1/2}$-hole states. This is because the predominant configurations of the ^{15}N ground state are $2p^{-1}_{1/2}$, $d_{5/2}s_{1/2}p^{-3}$, and $d^2_{5/2}p^{-3}$ and that the transferred particles entering the ^{15}N nucleus in the above two reactions are captured into the $2s_{1/2}$ and $1d_{5/2}$ orbits. In a similar manner, the $4p$-$3h$ character of the 3841-keV level is evidenced by the fact that it was strongly populated by the ^{13}C(^{7}Li$,t$) reaction [4].

Theoretically, the odd parity energy levels of ^{17}O were studied by several groups [5,6]. In those calculations, the configuration space was limited as it included the $1s_{1/2}$ and $1d_{5/2}$ shells for the particles and the $1p_{1/2}$ shell for hole occupation. Thus the $1d_{3/2}$ and higher shells such as $1f_{7/2}$ and $1f_{5/2}$ for particle excitation and the $1p_{3/2}$ for hole occupation were left out inactive. To our knowledge there is no published theoretical calculation of the width of this level. There is, however, a lifetime measurement [7] carried out using the Doppler shift attenuation method (DSAM) by employing the ^{14}C(α, $n\gamma$) reaction; it will be discussed in some detail below.

The fact that the 3841-keV level has spin and parity J^π=$5/2^-$ makes it relatively easy to photoexcite it via $E1$ transition from the $5/2^+$ ground state of ^{17}O. For this purpose we used the bremsstrahlung beam obtained from the 4.1-MeV electron beam of the Dynamitron accelerator of the University of Stuttgart. The electron beam was focused on a 4 mm thick, water cooled gold radiator target which ensured the complete stopping of the electrons. The resulting bremsstrahlung beam was passed through a 1 m long lead collimator having a 1 cm diameter hole and through a hardener consisting of a 3 mm lead which served to reduce the relatively high intensity of the low-energy photons from the bremsstrahlung. Details of the scattering arrangement are given in Ref. [8].

The width of the 3841-keV level was determined by comparing the scattering intensity to that from other nuclear levels of known widths having nearby energies such as the 3957-keV level in ^{27}Al (with Γ_0 = 185±15 meV) [9] and the 3684-keV level in ^{13}C (with Γ_0 = 403±30 meV) [10] which can serve together with other very well known transitions in ^{27}Al and ^{13}C at lower energies as an excellent standard for calibrating the energy and photon flux.

The composite target consisted of a 3.34 g of ^{17}O enriched water (46.5% ^{17}O, 41.2% ^{18}O, 12.3% ^{16}O) inserted into a thin-walled lucite cylinder (0.3 mm thick, 12.0 mm internal diameter, and 27.0 mm high) and of amorphous ^{13}C (99% enriched) with a total weight of 77 mg which was contained in a very thin foil of polyethelene. Two pure aluminum rectangular plates (12.0 mm × 27.0 mm) having a total weight of 0.722 g sandwiched the ^{13}C sample with a similar geometry.

It should be emphasized that in comparing the intensities of the scattered radiation from ^{17}O with that of the ^{13}C level, the contribution of natural carbon (containing 1.11% of ^{13}C) contained in Lucite and the polyethelene foil was accounted for. The scattered radiation was de-

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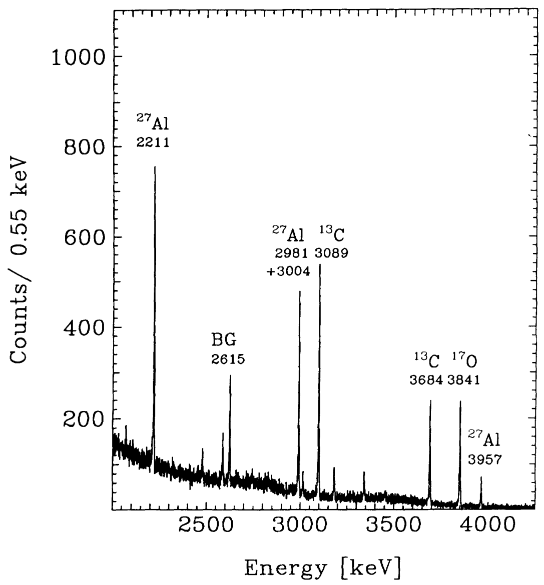

FIG. 1. Pulse height spectrum of photons scattered from the enriched water target (^{17}O, 46.5%), containing ^{27}Al and ^{13}C, measured by the Ge(HP) detector (85% efficiency) at a scattering angle of 130° and using bremsstrahlung with a maximum photon energy of 4.1 MeV. The labeled lines are the photopeaks while the lower intensity unlabeled lines correspond to the first and second escape peaks.

tected using two Ge(HP) detectors placed at 17 cm from the target and at angles of 130° and 127° on both sides of the beam. The efficiencies of the detectors were 85% and 31% relative to that of a 7.5 cm × 7.5 cm NaI crystal. The two detectors were shielded using 2.5 and 1.6 cm lead for suppressing the high flux of nonresonant low-energy scattered radiation. Data were taken with electron energies of 4.1 MeV with a typical average current of 150 μA. The total running time was 96 h. The relative efficiencies of the two detectors and the energy calibration were determined in an off-line fashion using a ^{56}Co source and an identical geometry to that of the actual target.

Figure 1 shows the scattered radiation spectrum from the "composite" target as obtained using the 85% Ge(HP) detector and an electron beam energy of 4.1 MeV. The origin of the various peaks are labeled in the figure where the 2615-keV line arises from the background emitted by thorium contained in the concrete of the walls and the shielding surrounding the experimental system.

The resulting value of the width obtained in the present work is

$$\Gamma(3841 \text{ keV}) = (92 \pm 6) \text{ meV} .$$

It is based on comparing the scattered intensity with that of the ^{27}Al line at 3957 keV and the 3684-keV line of ^{13}C as explained above. The compiled width of the 3841-keV level ([7,9,11] is listed to be larger or equal to 26 meV. As mentioned above, this value is based on a single measurement of its lifetime obtained using the Doppler shift attenuation method [7] by employing the ^{14}C(α,$n\gamma$) reaction. Only a lower limit for the lifetime of this level could be obtained with DSAM. This is because the actual lifetime is much shorter than the lowest limit which can be determined by the DSAM and hence is outside the realm of applicability of the DSAM. Therefore, for levels with such short lifetimes, it is most suited to carry out the measurements using the nuclear resonance photoexcitation method where the scattering signal increases inversely with the lifetime. Therefore, the sensitivity of the method increases accordingly for shorter lifetimes.

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