1.75-Mev Resonance in $C^{13}(p,\gamma)N^{14}$†

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The energy and width of the well-known 1.75-Mev resonance in the $C^{13}(p,\gamma)N^{14}$ reaction have been investigated by bombarding a thick target of 60% C^{13} with electrostatically-analyzed protons. The resonance energy was determined to be 1746.9±0.8 kev, relative to the $Li^7(p,n)Be^7$ threshold at 1881.1 kev. The observed width was 510 ev. When account is taken of the thermal motion of the target atoms, an upper limit to the resonance width may be set at 400 ev; the contribution to this value of the spread in the beam energy is unknown. If one uses the radiation width previously measured by Seagrave ($\omega\Gamma_\gamma = 14.8$ ev), the resonance cross section is $\sigma_R > 64$ mb. The dimensionless reduced proton width (for d-waves) is $\theta_p^2 < 1.5\times10^{-3}$.

INTRODUCTION

THE 1.75-Mev resonance in the $C^{13}(p,\gamma)N^{14}$ reaction ($N^{14*} = 9.16$ Mev) has been observed by several investigators,[1–3] who have obtained a resonance energy of 1754 kev and a width of 2.1±0.2 kev. The angular distribution[1] of the γ rays to the ground state of N^{14} limits the angular momentum and parity of the resonance level to the values 1^+, 2^-, or 2^+. The large value of the radiation width ($\omega\Gamma_\gamma = 14.8$ ev) obtained by Seagrave,[2] indicates an $E1$ transition to the ground state and consequently $J=2^-$, $T=1$ for the 9.16-Mev state. A recent report from the Duke University group[4] indicated that is resonance had a width of less than 0.8 kev. In view of this result, a re-examination of this resonance has been made in an effort to obtain a more precise measurement of the width.

EXPERIMENTAL PROCEDURE AND RESULTS

A C^{13} target (about 75 kev thick to 2-Mev protons) was prepared by cracking methyl iodide (enriched to 60% C^{13}) onto a hot tantalum strip. This target was mounted in a target chamber at a distance of approximately $\frac{3}{4}$ in. from a liquid-air trap. By trapping as close as possible to the target, carbon buildup was essentially prevented and no displacement of the resonance to within 50 ev was observed in three runs.

The proton beam from the Kellogg Laboratory 3-Mev electrostatic accelerator was analyzed with a 90° cylindrical electrostatic analyzer of 1 meter radius. The entrance and exit slits of the analyzer were less than 0.5 mm in width. The γ rays were detected with a 2 in.×2 in. NaI(Tl) crystal placed at 90° with respect to the beam.

Initial runs over the thick-target step at the resonance indicated that the width was less than about 650 ev. It is difficult to obtain a reliable measure of such a small width when the energy of the electrostatic accelerator and the voltage of the analyzer must be changed in small steps. Therefore the accelerator and the analyzer voltages were maintained constant corresponding to a bombarding energy approximately 700 volts above the resonance energy and positive voltage from batteries was applied to the target. The proton energy at the target was then lowered in steps of 100 volts across the resonance. Only those runs during which the analyzer voltage was constant to within 0.003% were accepted. This spread corresponded to a deviation in the mean beam energy of ±50 ev or a deflection of ±1 mm on the most sensitive scale of the galvanometer used to measure the voltage across the plates of the electrostatic analyzer. The zero position of the galvanometer was checked before every run. Three runs across the resonance were made in this manner; the results are presented in Fig. 1.

The measured resonance width (corresponding to the energy difference between the points at $\frac{1}{4}$ and $\frac{3}{4}$ of the maximum yield) is 510 ev. The contribution to this value of the spread in the beam energy is not known since there is no convenient method of measuring this quantity in the energy region near 1.75 Mev. The

TABLE I. Properties of the 1747-kev resonance in $C^{13}(p,\gamma)N^{14}$.

Resonance energy (E_R)	1746.9±0.8[a]
Excitation energy in N^{14}	9.164 Mev
Proton width ($\Gamma_p \cong \Gamma$)	<400 ev
Total radiation width ($\omega\Gamma_\gamma$)	14.8 ev[b]
Radiation width 9.16→0 Mev	13.3 ev[c]
Radiation width 9.16→6.44 Mev	1.5 ev[c]
Dimensionless reduced width (d waves)	$<1.5\times10^{-3}$
($\theta_p^2 = \gamma_p^2 \times 2Ma/3\hbar^2$, $a = 1.41(13^{\frac{1}{3}}+0.1)\times10^{-13}$ cm)	
Thick-target yield	1.15×10^{-8} disintegrations/proton[b]
Resonance cross section (σ_R)	>64 mb
γ-ray spectrum	90% 9.16→0 Mev, 10% 9.16→6.44 Mev[c]
J, π, T	2, −, 1[d]

[a] Relative to the $Li^7(p,n)Be^7$ threshold at 1881.1 kev, Jones *et al.* (reference 4).
[b] Seagrave (reference 2).
[c] Woodbury *et al.* (reference 3).
[d] Day (reference 1).

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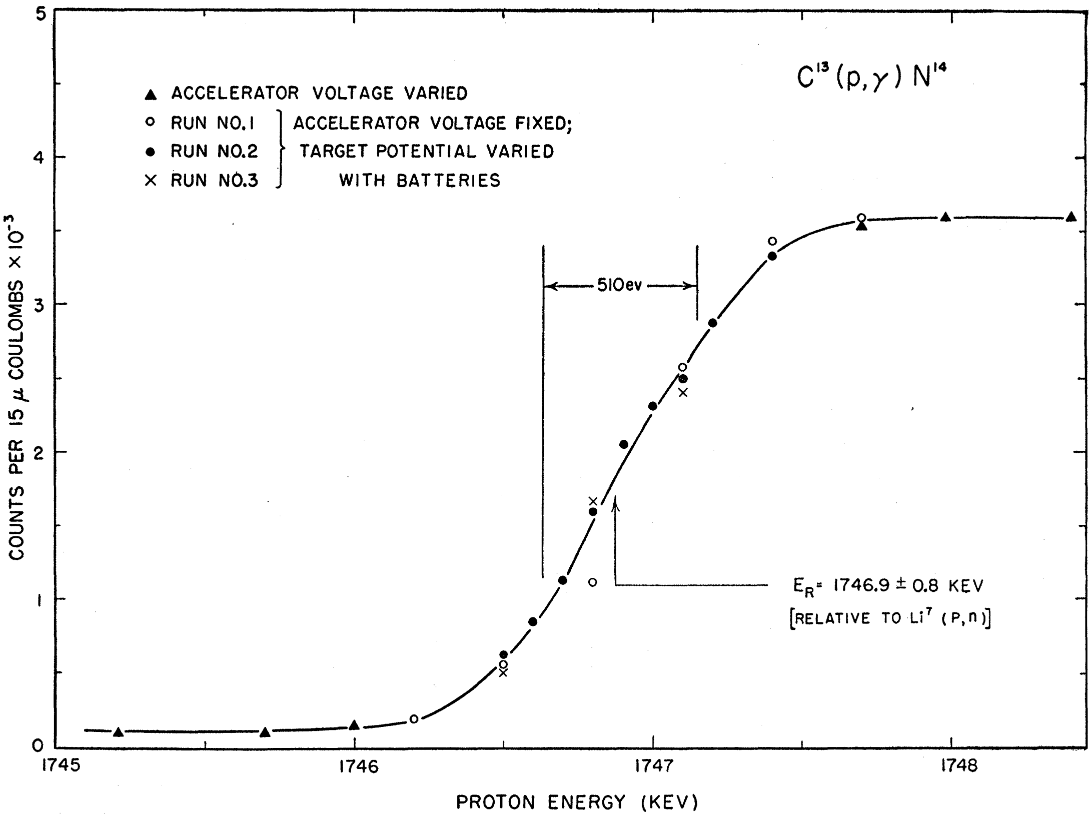

FIG. 1. Thick-target step at the 1747-kev resonance in $C^{13}(p,\gamma)N^{14}$. The energy scale is based on the $Li^7(p,n)Be^7$ threshold at 1881.1 kev.

energy scale was determined by observing the threshold for the $Li^7(p,n)Be^7$ reaction at 1881.1 kev.[5] Relative to this value, the resonance energy is 1746.9±0.8 kev. This value is in good agreement with the recent measurements at Duke[4] (1747.6 kev), using the same calibration.

DISCUSSION

In addition to the spread in the beam energy and the natural width of the resonance, the thermal motion of the target atoms contributes to the observed width. The Doppler broadening of a resonance has been given by Bethe and Placzek[6]:

$$\Delta=4(M_1EkT/M_2)^{\frac{1}{2}},$$

when $E\gg kT$ and where M_1 is the mass of the bombarding particle and M_2 is the mass of the target nucleus. For a target temperature of 320°K, the Doppler broadening is $\Delta=300$ ev for the 1.75-Mev resonance in $C^{13}+p$. Consequently an upper limit may be placed on the resonance width: $\Gamma<400$ ev.

The thick-target yield due to this resonance has been measured by Seagrave[2] who obtained a value of 1.15×10^{-8} disintegration/proton; the corresponding radiation width is $\omega\Gamma_\gamma=14.8$ ev. The resonance cross section may be expressed as[2] $\sigma_R=3.01\omega\Gamma_\gamma/E_R\Gamma_p$, where E_R is the resonance energy in Mev, Γ_p is the proton width in kev, and $\omega\Gamma_\gamma$ is the radiation width times the statistical factor in ev. Using Seagrave's value for the radiation width, we obtain $\sigma_R>64$ mb.

Since the large value of the radiation width indicates an $E1$ transition and $J=2^-$, $T=1$ for the resonance level,[1] the protons which form this state have $l=2$. With the present upper limit to the proton width, the dimensionless reduced proton width becomes $\theta_p^2=\gamma_p^2\times Ma/3\hbar^2<1.5\times10^{-3}$ for $a=1.41(13^{\frac{1}{3}}+1)\times10^{-13}$ cm. The explanation of the occurence of such a narrow level at the relatively high bombarding energy of 1.75 Mev and the consequent small value of θ_p^2 is not as yet known.

A summary of the properties of this resonance is given in Table I.

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