The Reaction $C^{12}(\gamma,3p)Li^9$†

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(Received July 3, 1953)

A carbon target was bombarded in a partially-converted 270-Mev electron beam. The 0.168-second Li^9 delayed neutron activity produced in the block was compared with the β activity produced in a polystyrene foil bombarded in the same beam. The measured integrated cross section for $C^{12}(\gamma,3p)Li^9$ is $(6.9\pm2)\times10^{-5}$ Mev barn.

THE integrated cross section for the reaction $C^{12}(\gamma,3p)Li^9$ has been measured to be $(6.9\pm2)\times10^{-5}$ Mev barn. The Li^9 was identified and measured by its characteristic delayed neutrons, which have an apparent half-life of 0.168 second.[1] They were counted in a water moderator $B^{10}F_3$ proportional counter system which partially enclosed the carbon target. The counts were separated in a 5-channel delay gate, each channel counting for 0.167 second. The system was calibrated with a radium beryllium source.

The carbon target, $3\frac{1}{2}$ inches in diameter by 7 inches long, was bombarded in the direct beam of the Stanford Mark III linear electron accelerator, operating near 270 Mev. A tungsten converter, 0.04 inch thick, was placed ahead of the target to convert the beam. The bombardment was monitored by counting the 20.5-minute C^{11} activity[2,3] produced in a 2.5-mil polystyrene foil sandwiched between the converter and the target. Marshall's value, 0.086 Mev barn, was used for the $C^{12}(\gamma,n)C^{11}$ integrated cross section.

In the bombardment, the beam was pulsed for 0.735 second, a 0.1-second pause allowed the short half-lived activities to die out, the delay gate counted for 0.833 second, and the cycle was repeated; the data here (Fig. 1) represent a 10-minute run. A previous experiment, done with a different neutron counting system and at 170-Mev electron beam energy gave a result equal, within probable error, to the one quoted.

In the earlier run, the background resulting from the substitution of copper for the carbon target was very small and exhibited no decay. In the later run, a large neutron count was noted when aluminum and sodium nitrate were substituted for the target. The activity had a measured half-life of about 4.2 seconds and has been attributed to N^{17} from the reactions $Al^{27}(\gamma;2\alpha,2p)N^{17}$ and $Na^{23}(\gamma;\alpha,2p)N^{17}$. The integrated cross section for the $Al^{27}(\gamma;2\alpha,2p)N^{17}$ reaction is estimated on this basis at roughly 5×10^{-4} Mev barn.

The background subtraction for the data presented has been chosen to give the best fit with the known half-life of Li^9. The integrated cross section quoted is an approximation, computed from

$$\left[\int\sigma(E)dE\right]_{Li^9}=\frac{I(C^{11})}{I(Li^9)}\frac{N(Li^9)}{N(C^{11})}\frac{D_f}{D_t}\left[\int\sigma(E)dE\right]_{C^{11}},$$

where $I(C^{11})$ is the photon intensity of the bremsstrahlung radiation at the center of gravity of the plot of $I(E)\sigma(E)$ *vs* energy for the reaction $C^{12}(\gamma,n)C^{11}$. $I(Li^9)$ is the equivalent intensity for the $C^{12}(\gamma,3p)Li^9$ reaction. $N(Li^9)$ and $N(C^{11})$ are the total numbers of Li^9 and C^{11} atoms produced, D_f and D_t are the densities in atoms of C^{12} per square centimeter, of the monitor foil and the target, respectively, and $[\int\sigma(E)dE]_{C^{11}}$ is the integrated cross section for the $C^{12}(\gamma,n)C^{11}$ reaction.

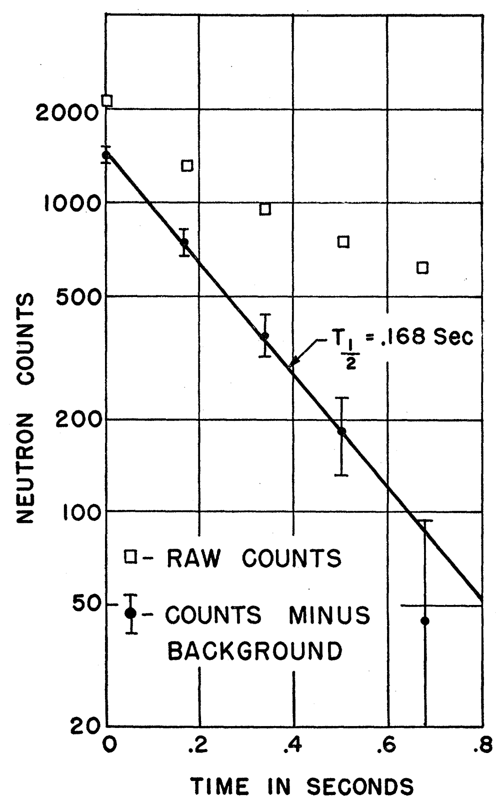

FIG. 1. Delayed neutron activity from carbon target as function of time.

† The research reported in this document was supported jointly by the U. S. Navy (Office of Naval Research) and the U. S. Atomic Energy Commission.

[1] Gardner, Knable, and Moyer, Phys. Rev. 83, 1054 (1951).
[2] L. Marshall, Phys. Rev. 83, 345 (1951).
[3] L. Katz and A. G. W. Cameron, Can. J. Phys. 29, 518 (1951).

The intensity ratio is estimated using Heitler's[4] curves for the bremsstrahlung in the case of screening. The center of gravity of the C^{11} excitation curve, weighted by the Bethe-Heitler bremsstrahlung curve, is taken to be 24 Mev.[3] The corresponding point for Li^9 is estimated to be 62 Mev, making the intensity ratio 2.96:1.

It is a pleasure to give due thanks to W. K. H. Panofsky, who suggested the problem and gave invaluable encouragement and advice and identified the N^{17} decay. Thanks are also due Phyllis Hanson, George Masek, and Donald Hagerman, who provided 10^{14} electrons.

[4] W. Heitler, *Quantum Theory of Radiation* (Oxford University Press, London, 1944), p. 179.

PHYSICAL REVIEW VOLUME 92, NUMBER 3 NOVEMBER 1, 1953

Total Neutron Cross Section of Phosphorus*

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The total cross section of phosphorus for neutrons has been measured in good geometry by the transmission method with a resolution of 2 kev. The energy range is from 125 kev to 850 kev, the neutrons being produced by the $Li^7(p,n)Be^7$ reaction. Red phosphorus contained in a thin steel cylinder was used as scatterer. The neutrons were detected by a hydrogen recoil counter. The neutron beam was monitored by a BF_3 long counter. The average cross section is 3 barns with an average level spacing of about 25 kev.

INTRODUCTION

SPOT measurements on the total cross section of phosphorus have been made at Argonne over an energy range of 0.024 to 0.83 Mev.[1] With a resolution of approximately 80 kev, Ricamo[2] found an average total cross section of 3 barns in an energy range from 2.0 to 3.5 Mev using a D(d,n) reaction. Snowdon and Whitehead[3] have recently reported measurements from 100 to 700 kev with a resolution of 40 kev. However, this is insufficient to resolve even the major resonances.

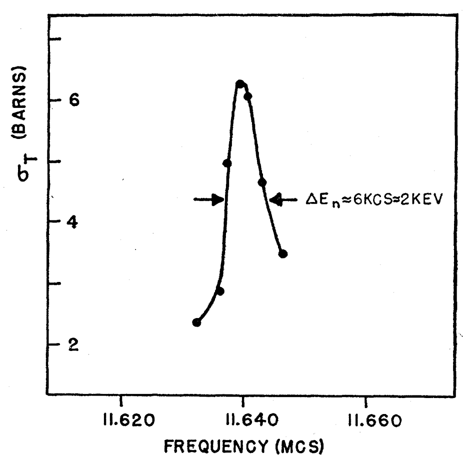

FIG. 1. Total cross section of sulfur near 588 kev. A target thickness of about 2 kev is estimated from the observed width of this resonance since the natural width $\Gamma_n \lessapprox \sim 1$ kev. This target thickness agrees with that obtained from measurements of the geometric peak near the Li(p,n) threshold. The scale of abscissas indicates the proton resonance frequency on the magnet control.

Preparation of Scatterer

Yellow phosphorus burns spontaneously in air and is extremely poisonous. Red phosphorus shows none of these characteristics at normal temperatures and pressures and was used throughout this experiment.

To avoid even the small corrections for scattering and absorption by containers, attempts were made to press red phosphorus into slugs of the desired size (length 2 inches, diameter 1 inch). Slugs were pressed up to 2000 psi but were found to be too soft for practical use. Rather than try higher pressures, the phosphorus was packed into a steel cylinder, 5 mils in wall thickness, and the necessary corrections made.

Neutron Source

Neutrons were obtained from the $Li^7(p,n)Be^7$ reaction using the Rockefeller electrostatic generator as the proton source.[4]

The energy resolution is primarily limited by the finite thickness of the lithium target. Measurements of this energy spread were accomplished by two methods: (a) the geometric peak of the neutron yield[5] in the

* This work was supported by the Bureau of Ships and the U. S. Office of Naval Research.

[1] Fields, Russell, Sachs, and Wattenberg, Phys. Rev. **71**, 508 (1947).

[2] R. Ricamo, Nuov cimento **8**, 383 (1951).

[3] S. C. Snowdon and W. D. Whitehead, Phys. Rev. **90**, 617 (1953).

[4] W. M. Preston and Clark Goodman, Phys. Rev. **82**, 316 (1951).

[5] Willard, Preston, and Goodman, U. S. Office of Naval Research Technical Report No. 45, Laboratory for Nuclear Science and Engineering, Massachusetts Institute of Technology, September 27, 1950 (unpublished).