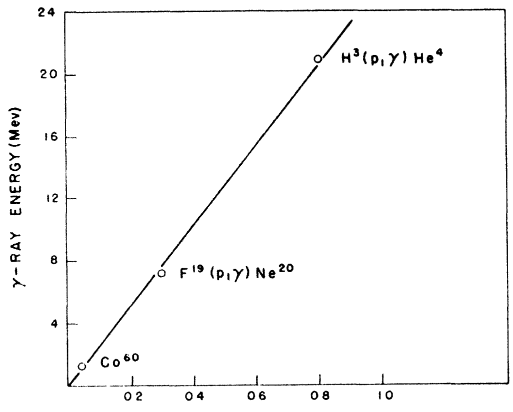

FIG. 1. Calibration curve for NaI(Tl) crystal used in this experiment. The γ-ray pulse heights are maximum heights measured from integral bias curves.

each case the maximum pulse height was determined by measuring the end points of the respective integral bias curves. Figure 1

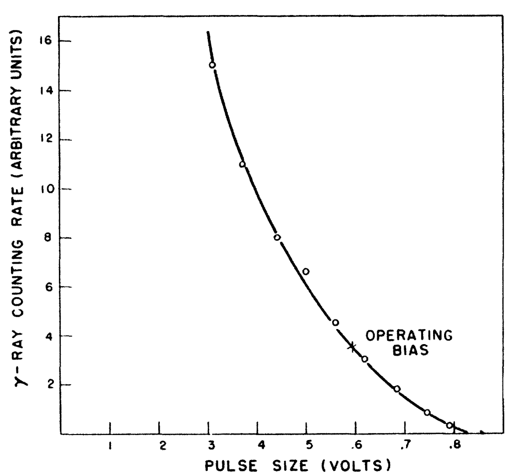

FIG. 2. Integral bias curve produced by γ-rays from a 50-kev target of Zr-H^3 bombarded by 1.4-Mev protons and measured by a NaI(Tl) crystal (3.8-cm diameter, 3.0-cm height).

shows the results, from which it can be seen that the response is linear with respect to energy. The integral bias curve produced

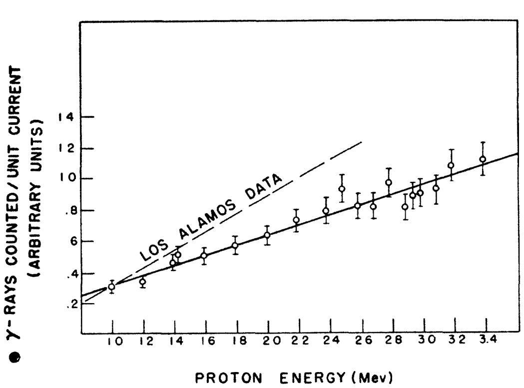

FIG. 3. Excitation curve for the $H^3(p, \gamma)He^4$ reaction.

by the $H^3(p, \gamma)He^4$ γ-rays was quite steep (Fig. 2), which agrees with the measurements of Good *et al.*[4] for a similar detector.

Only about 1 microampere of beam was used in order to prevent overheating of the target. Furthermore, all points were repeated during one run to make sure that tritium was not lost from the target.

The resulting excitation curve is shown in Fig. 3. The steepness of the pulse distribution of γ-rays made the constancy of the over-all gain of the system very critical and limited the experiment to ± 10 percent accuracy even though the counting statistics were about 3 percent. Nevertheless, it is quite evident that no large resonance exists up to 3.4-Mev proton energy. This is in agreement with the calculations of Flowers and Mandl.[5] The experiment, however, does not rule out a weak (up to 30 percent) broad resonance superposed on the rising cross section.

It should be noticed that the slope of this excitation curve is less than that measured by Argo *et al.*[1] This difference in slope can possibly be explained by the fact that the crystal used in this experiment subtended a half angle of about 25°, while that in the Los Alamos experiment subtended about 5°. Consequently, we detected a larger fraction of the angle-independent part of the $(A+B\sin^2\theta)$ γ-ray distribution, which appears to be a considerably slower function of energy than the $\sin^2\theta$ term.[1]

We should like to express our thanks to Dr. M. Tuve for making this collaboration possible, Dr. N. P. Heydenburg for his over-all aid, Dr. E. O. Salant for suggesting the experiment, and Dr. T. W. Bonner of the Rice Institute for the loan of the tritium target.

* Research carried out under contract with AEC.
† On leave from the Rice Institute, Houston, Texas.

1 Argo, Gittings, Hemmendinger, Jarvis, and Taschek, Phys. Rev. **78**, 691 (1950).
2 Jarvis, Hemmendinger, Argo, and Taschek, Phys. Rev. **79**, 929 (1950).
3 A. B. Lillie and J. P. Conner, Rev. Sci. Instr. **22**, 210 (1951).
4 Good, Moak, Robinson, and Reese, Bull. Am. Phys. Soc. **26**, No. 3, 50 (1951).
5 B. H. Flowers and F. Mandl, Proc. Roy. Soc. (London) **A206**, 131 (1951).

Fast Neutron Energies Determined by the Use of Resonant Scatterers*

P. H. STELSON AND W. M. PRESTON
Laboratory for Nuclear Science and Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts
(Received May 28, 1951)

IN this note we wish to suggest and illustrate a method of measuring fast neutron energies which utilizes total neutron cross-section resonances. Essentially, the method consists of measuring scattering cross sections, using as a scatterer an element such as lithium, beryllium, or sulfur whose cross section is a known function of neutron energy,[1-3] and as a source neutrons of unknown energy produced by monoenergetic protons incident on thin targets of the nuclei of interest. The identification of resonances then allows one to deduce the energy of the neutrons and hence the Q-value of the reaction. The method has been used to determine (a) the Q-value for the reaction $Mn^{55}(p, n)Fe^{55}$, (b) the position of an excited state of Mn^{53} produced by the reaction $Cr^{53}(p, n)Mn^{53}$, and (c) an upper limit for the width of the ground state of the B^9 nucleus produced by the reaction $Be^9(p, n)B^9$.

The (p, n) thresholds for light elements are quite sharp and are convenient as voltage reference points. However, for heavier elements with low (p, n) thresholds, the higher coulomb barrier causes the yield near threshold to be very low and the measurement correspondingly more uncertain. Richards *et al.*[4] obtained a threshold value of 1.18 ± 0.01 Mev for the $Mn^{55}(p, n)Fe^{55}$ reaction, while McCue and Preston[5] found a threshold value of 1.02 ± 0.02 Mev. Therefore, we have employed the method mentioned above to determine the Q-value for this reaction.

The total neutron cross section of beryllium in the region of the

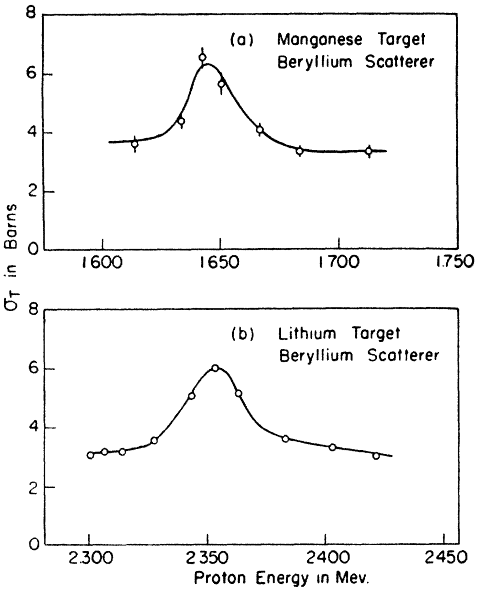

FIG. 1. The resonance at 625 kev in the total neutron cross section of beryllium is shown in (a) as a function of the energy of the protons incident on a thin manganese target and in (b) for protons incident on a thin lithium target.

large resonance at 625 kev was measured using a beryllium metal scatterer 1.90 cm in thickness and 5.08 cm in diameter placed a mean distance of 7.6 cm from the target in the forward direction. A BF_3 long counter with the front face 30 cm from the target was used as a neutron detector. The geometry of the arrangement results in rather poor absolute values (too low) for the cross section, but these were not of primary interest; the arrangement was chosen to secure practical counting rates. Figure 1(a) shows the resonance in beryllium obtained by bombarding an 8-kev manganese target with the proton energies indicated. Figure 1(b) shows this resonance as measured by bombarding a 3-kev lithium target with protons. Taking a Q-value of -1.645 Mev for the $Li^7(p, n)$ reaction and applying corrections for the target thickness and average angle subtended by the scatterer, one obtains a value of 0.623 Mev for the position of the resonance. Using this value and applying corrections for target thickness and average angle subtended by the scatterer to the data obtained with the manganese target, one calculates a Q-value of -1.006 ± 0.010 Mev and hence a threshold of 1.024 ± 0.010 Mev for the $Mn^{55}(p, n)Fe^{55}$ reaction, where the error is estimated from the errors in the determination of the proton energy, peak position of the resonance, and target thickness.

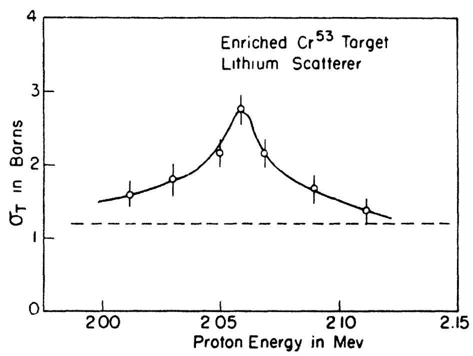

FIG. 2. The total cross section of lithium is shown as a function of the energy of the protons incident on a thin enriched Cr^{53} target. The dashed line is the cross section expected for the ground-state neutrons. The resonance is due to neutrons leaving Mn^{53} in an excited state.

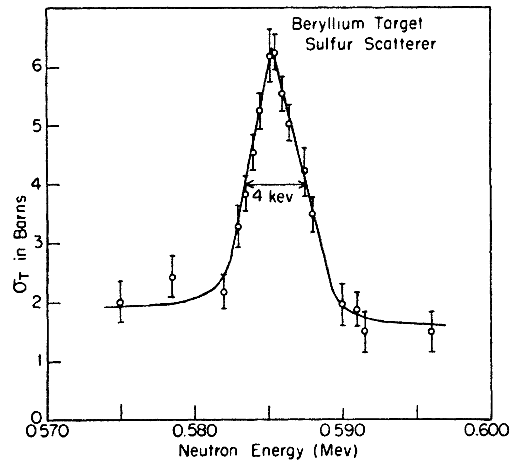

FIG. 3. The resonance at 585 kev in the total cross section of sulfur as measured by neutrons from the $Be^9(p, n)B^9$ reaction.

A photographic plate, proton-recoil investigation of the neutron spectrum resulting from the proton bombardment of an enriched Cr^{53} target indicated a ground state Q-value of -1.37 ± 0.05 Mev for the (p, n) reaction and a first excited state in the residual nucleus Mn^{53} at approximately 370 kev, corresponding to a Q-value of -1.74 ± 0.05 Mev.[6] We have been able to detect the neutrons which leave Mn^{53} in the excited state by measuring the total cross section of lithium, which has a large isolated resonance at 265 kev. A metallic lithium scatterer 10 cm in thickness and 2.54 cm in diameter encased in a thin-walled steel container was placed a mean distance of 8.5 cm from a 15-kev target[7] of enriched Cr^{53}. A small propane gas, proton-recoil counter placed a mean distance of 23.5 cm from the target was used as a detector. Figure 2 shows the resonance obtained. The dashed line is the value for the total cross section one would expect for the neutrons which leave Mn^{53} in the ground state. After correcting for target thickness, we have a Q-value for the excited state of -1.771 ±0.010 Mev, agreeing with the photographic plate determination.

The nucleus B^9 is unstable against disintegration into a proton and Be^8 or two α-particles. The review article of Hornyak *et al.*[8] states that one would expect a width of perhaps 10 kev for the ground state, and they interpret the report of Johnson *et al.*[9] as indicating that experiment shows the width to be approximately 120 kev. However, we believe the statement of Johnson *et al.* refers to experimental width and not to natural width. We have determined an upper limit for the width of the ground state of B^9 by measuring the sharp resonance (natural width $\sim$1.5 kev) at 585 kev in the total neutron cross section of sulfur, using neutrons produced by the $Be^9(p, n)B^9$ reaction. The total width of the resonance thus obtained is 4 kev, as shown in Fig. 3. This width is due to the energy spread of the incident neutrons, and the natural widths of the sulfur resonance and the ground state of B^9. We estimate the energy spread of the neutrons because of target thickness and geometry to be at least 3 kev. Using this value and taking 1.5 kev for the natural width of the sulfur resonance, we obtain an upper limit of approximately 2 kev for the width, or a mean lifetime of greater than 3×10^{-19} sec, for the ground state of the B^9 nucleus.

* This work was supported jointly by the ONR and BuShips.
1 R. K. Adair, Phys. Rev. **79**, 1018 (1950).
2 C. K. Bockelman, Phys. Rev. **80**, 1011 (1950).
3 Peterson, Barschall, and Bockelman, Phys. Rev. **79**, 593 (1950).
4 Richards, Smith, and Browne, Phys. Rev. **80**, 524 (1950).
5 J. J. G. McCue and W. M. Preston (to be published).
6 P. H. Stelson (unpublished).
7 Oak Ridge analysis of the enriched Cr^{53} metal: 90.06 percent Cr^{53}, 0.465 percent Cr^{54}, 0.193 percent Cr^{50}, 9.28 percent Cr^{52}. The (p, n) thresholds of Cr^{50}, Cr^{52}, and Cr^{54} are all above the proton energies used.
8 Hornyak, Lauritsen, Morrison, and Fowler, Revs. Modern Phys. **22**, 291 (1950).
9 Johnson, Laubenstein, and Ajzenberg, Phys. Rev. **79**, 239 (1950).