ACKNOWLEDGMENTS

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Neutron Thresholds in the $V^{51}(p,n)Cr^{51}$, $Mn^{55}(p,n)Fe^{55}$, $Zn^{70}(p,n)Ga^{70}$, and $As^{75}(p,n)Se^{75}$ Reactions

C. R. Gossett and J. W. Butler
Nucleonics Division, United States Naval Research Laboratory, Washington, D. C.

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The two-counter slow-to-fast ratio technique has been used with proton energies up to about 2 Mev in a study of neutron thresholds from the following four reactions. In the $V^{51}(p,n)Cr^{51}$ reaction, the ground-state threshold was measured to be 1.564±0.002 Mev. No excited states were observed in the region of excitation from zero to 0.41 Mev. In the $Mn^{55}(p,n)Fe^{55}$ reaction, the ground-state threshold was measured to be 1.034±0.002 Mev. Excited-state thresholds were found at 1.455±0.003 and 1.982±0.002 Mev, corresponding to energy levels in Fe^{55} at 0.414±0.003 and 0.931±0.002 Mev, respectively. In the $Zn^{70}(p,n)Ga^{70}$ reaction, the ground-state threshold was measured to be 1.457±0.002 Mev. No excited states were observed in the region of excitation from zero to 0.53 Mev. In the $As^{75}(p,n)Se^{75}$ reaction, the ground-state threshold was measured to be 1.669±0.002 Mev. An excited state threshold was found at 1.960±0.002 Mev, corresponding to an energy level in Se^{75} at 0.287±0.002 Mev. A two-counter detector of high sensitivity and a low-background experimental arrangement are described.

I. INTRODUCTION

LOW-LYING excited states of nuclides in the medium-weight region are of particular interest to the shell model. One method of observing and measuring with good precision the energies of such states is the detection of neutron thresholds from (p,n) reactions. For such reactions the thresholds of the excited states as well as the ground states may be detected by means of the two-counter slow-to-fast ratio method.[1–3] Furthermore, the careful measurement of the ground-state thresholds in such reactions is a precision means of measuring mass differences of neighboring isobars. Four such (p,n) reactions have been examined, and are reported herein. No excited states have been previously reported for two of the nuclides studied: Ga^{70} and Se^{75}.

A preliminary account of a part of the present experiment has been reported[4] at a meeting of the American Physical Society.

II. EXPERIMENTAL PROCEDURE

Two of the target nuclear species, Mn^{55} and As^{75}, are monoisotopic in nature, and a third, V^{51}, has a natural abundance of 99.75%; therefore, standard laboratory cp chemicals were used in preparing these targets. The fourth, Zn^{70}, is present in natural zinc only to the extent of 0.63%. Therefore, enriched Zn^{70} was acquired from the Stable Isotopes Division of the Oak Ridge National Laboratory, with the following isotopic abundances: Zn^{64}, 9.73%; Zn^{66}, 8.40%; Zn^{67}, 4.14%; Zn^{68}, 29.33%; and Zn^{70}, 48.40%. Targets of Mn^{55}, Zn^{70}, and As^{75} were prepared by electroplating techniques, that for Zn^{70} being basically similar to that used for nickel and cobalt in previous experiments,[5] and those for Mn and As being the standard electroplating techniques for these elements. The vanadium target was made by the vacuum evaporation process. Target thicknesses ranged from 2 to 20 kev to the incident protons. Target backings were either gold or silver disks, $1\frac{1}{4}$-in. diam ×0.010-in. thick.

The NRL Nucleonics Division 2-Mv Van de Graaff accelerator was used as a source of protons, providing beam currents of from 1 to 10 μa. The beam-analyzing magnet current was regulated by a proton-moment resonance device. Energy calibration was determined by means of the $Al^{27}(p,\gamma)$ resonance at 0.992±0.001 Mev,[6,7] and the $Li^7(p,n)$ threshold at 1.881±0.001 Mev.[6,8] The proton-beam energy spread was 0.06%

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[1] T. W. Bonner and C. F. Cook, Phys. Rev. **96**, 122 (1954).

[2] Brugger, Bonner, and Marion, Phys. Rev. **100**, 84 (1955).

[3] Butler, Dunning, and Bondelid, Phys. Rev. **106**, 1224 (1957).

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[5] J. W. Butler and C. R. Gossett, Phys. Rev. **108**, 1473 (1957).

[6] R. O. Bondelid and C. A. Kennedy, Naval Research Laboratory Report NRL-5083 (unpublished).

[7] Bumiller, Staub, and Weaver, Helv. Phys. Acta **29**, 83 (1956); Bumiller, Staub, and Müller, Helv. Phys. Acta **29**, 234 (1956).

[8] Jones, McEllistrem, Douglas, and Richards, Phys. Rev. **94**, 947 (1954).

for the precise energy determinations and 0.12% for the excitation-curve data.

A liquid nitrogen cold trap was placed close to the target to prevent the buildup of contaminants from the vacuum system. The effectiveness of this technique has previously been discussed.[5] Such contaminants have two deleterious effects: a contribution to the neutron background, and a shift in the incident proton energy at the target through energy loss in the contaminant layer covering the target. Conventional experimental techniques were followed with regard to beam current integration, electron repeller bias voltages, electrostatic strong-focussing lenses, etc.

The two-counter slow-to-fast ratio method was employed to detect neutron thresholds. The principle of this technique has been described previously,[1,3] but is briefly outlined as follows, with reference to Fig. 1. The smaller detector (nearer the target) is more sensitive to "slow" neutrons (i.e., neutrons emitted at bombarding energies near their threshold and therefore in the kev region) than to "fast" neutrons (of energy greater than about 0.1 Mev), due to the inherent sensitivity of the boron lined proportional counters and the small amount of moderator used. The larger, or "fast," counter has a relatively flat energy response from a fraction of a Mev to several Mev, due to the larger amount of moderator present. Because the smaller, or "slow," counter partially shields the fast counter from slow neutrons originating at the target, and because the fast counter has its axis perpendicular to the neutron beam, thus requiring the neutrons to penetrate 2–3 in. of additional moderator before being counted, the fast counter sensitivity drops off in the region where the slow counter efficiency increases. Thus if the ratio of slow- to fast-neutron counts is plotted as a function of bombarding energy, a new group of slow neutrons, corresponding to a threshold for neutron emission, will be detected as a rise in this ratio. Since the outgoing neutrons acquire most of the excess proton energy above the threshold, a continued increase in the bombarding energy will result in a fall in the ratio.

The slow-fast counter arrangement used is basically similar to that used for a previous experiment.[3] However, for the present experiment the low neutron yields from some of the reactions necessitated a more sensitive neutron detection system. This was accomplished by using a large number of the more sensitive B^{10} lined detectors and by placing the detectors close to the target.

In order to determine the optimum arrangement for the observation of excited-state thresholds, a number of tests were run with the strong 1982-kev threshold of the $Mn^{55}(p,n)Fe^{55}$ reaction (see Sec. III). For these tests the relative rise of the ratio curve was measured for several arrangements of the number, orientation, and spacing of the counter tubes, and the amount and distribution of the paraffin moderator. The arrangement which proved most satisfactory and which was used for the experiments reported in this paper is shown in Fig. 1, where the circles indicate the cross sections of the B^{10}-lined proportional counter tubes, and the shaded areas the paraffin moderator. Both fast and slow counters were surrounded by 0.020 in. of cadmium. The geometry shown in Fig. 1 was used for the As^{75} and Zn^{70} reactions where the neutron yield was very low. For the V^{51} and Mn^{55} reactions, which gave higher yields of neutrons, the spacing between the target chamber and the front face of the slow counter was $1\frac{1}{2}$ in. and the spacing between the two counters was $1\frac{3}{4}$ in.

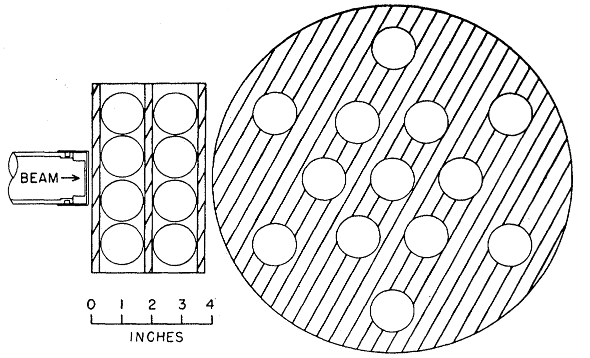

FIG. 1. Geometrical arrangement of target and neutron detectors. The circles indicate cross sections of B^{10}-lined proportional counter tubes and the shaded areas indicate paraffin moderator.

Hydrogen-containing materials, such as the heavy concrete floor of the laboratory, the walls, and ceiling, degrade the energy of the neutrons, and reflect some of them back toward the detectors. The threshold detection sensitivity above the ground-state threshold is therefore adversely affected, because these lower energy neutrons, which left the target as fast neutrons (corresponding to the ground or lower excited states), are detected in both the slow and fast counters, thus producing an effective background over which a new threshold must be observed. Therefore, it is experimentally advantageous to remove the target and detectors as far as possible from other matter, especially hydrogenous matter.

In this laboratory such an isolation of the target and detectors is readily achieved. The Van de Graaff accelerator is a vertical machine, the base plate resting on the fourth floor of its building. The energy-defining magnet, which rests on the third floor, is on a rotatable base. Normally, the beam tube from the magnet to the target is parallel to and about 8 ft from the nearest outside wall, and is 43 in. above a steel-reinforced concrete floor. For the present experiment, however, the magnet base was rotated 90° to allow the proton beam to pass through the nearest outside wall. The beam tube outside the building was supported from a truss bridge which spans the 60-ft distance to the adjacent building. The bottom of this bridge is about 40 ft above the ground. The proton beam tube was supported about 12 ft below the bottom of the bridge with the target placed about a fourth of the distance from the outer wall to the next building. The detectors and associated electronic equipment were supported by a rolling carriage, also suspended from the truss bridge. Since the floor of the carriage is made of a light aluminum grill, and since the whole carriage assembly and truss bridge were designed to be as light as possible, the detectors were sufficiently removed from solid materials that the primary neutron scatterer was air. For some neutron absorption or scattering experiments, air scattering can have a serious effect, but for the present experiment, the moderating effect of the air is not a serious problem.

As an example of the effectiveness of the target suspension bridge technique, one neutron threshold (the 1.455-Mev threshold with a Mn^{55} target, see Sec. III) was not detectable inside the building in the normal position, but was clearly detectable outside the building in the position described above.

For the four reactions studied, ratio function data and fast counter yield curves were taken from just below threshold to about 2 Mev as shown in Sec. III. All thresholds thus detected were re-examined for a precise determination of the threshold energy. These runs (not shown) were made with better beam resolution (as mentioned above) and with bombarding energy intervals much smaller, 0.5 to 1.0 kev, than those used for the ratio excitation curves, 4 to 10 kev. Separate bombarding energy calibrations were made for each run. The position of the threshold was determined by drawing straight lines through the datum points below threshold and above for the linear portion of the rise, usually 2 to 5 kev. The intersection of these two straight lines was considered to be the threshold.

Ambient neutron background due to the accelerator and other sources was low and was negligible above the ground-state thresholds; therefore, it was not subtracted to obtain the experimental curves presented in Sec. III. The fast counter yield curves have not been corrected for the energy response of the counter.

III. RESULTS

$V^{51}(p,n)Cr^{51}$

The fast-counter yield curve (solid curve) and ratio curve (open circles) for the $V^{51}(p,n)Cr^{51}$ reaction are shown in Fig. 2. Inspection of the ratio curve reveals no thresholds other than the ground state up to the maximum bombarding energy, 1.98 Mev, used with this reaction. This proton energy range corresponds to exploration of the region from zero to 0.41 Mev of excitation of the residual Cr^{51} nucleus. The lowest known excited state (presumably the first excited state) of Cr^{51} is at an energy of 0.750±0.011 Mev, as reported by Heydenburg and Temmer,[9] using the $Ti^{48}(\alpha,n\gamma)Cr^{51}$ and $V^{51}(p,n\gamma)Cr^{51}$ reactions and a scintillation gamma-ray spectrometer.

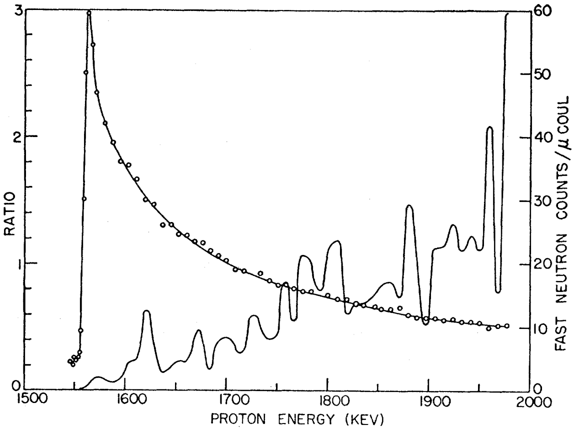

FIG. 2. Excitation function for the $V^{51}(p,n)Cr^{51}$ reaction. The solid curve represents the fast-counter yield (not corrected for the energy response of the counter), and the open circles indicate the ratio function. The ground-state threshold appears at 1564 kev.

The position of the ground-state threshold was determined to be 1.564±0.002 Mev. Previous measurements of this ground-state threshold are reported by Richards *et al.*[10] at 1.562±0.006 Mev, and by Gibbons *et al.*[11] at 1.5656±0.0015 Mev. It may be seen that the present experiment is in excellent agreement with both of these previous experiments.

From the threshold energy, the Q value for the reaction is calculated to be -1.534 ± 0.002 Mev. A comparison of the present results for the $Q_{p,n}$ value with the results of experiments using other reactions and with the mass spectrometer measurements may most readily be made in terms of the mass excess difference of the initial and final nuclides of the (p,n) reaction. Thus the present experiment yields a Cr^{51}-V^{51} mass excess difference, $\Delta E(Cr^{51}\text{-}V^{51})$, of 0.751±0.003 Mev, where the mass excesses of the n, H^1, and H^2 used in this and succeeding calculations are those given by Wapstra.[12] The adopted value of the electron capture Q value given by Lidofsky[13] yields directly a $\Delta E(Cr^{51}\text{-}V^{51})$ value of 0.750±0.005 Mev.

Because the residual nuclides of (p,n) reactions are almost always unstable, comparison with mass spectrometer doublet measurements may be made only where a precise reaction Q value is known linking this residual nuclide with another stable nuclide. In the present case, such a link between Cr^{50} and Cr^{51} is obtained from the $Q_{n,\gamma\gamma}$ value reported by Van Patter

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[9] N. P. Heydenburg and G. M. Temmer, Phys. Rev. **99**, 617(A) (1955).

[10] Richards, Smith, and Browne, Phys. Rev. **80**, 524 (1950).

[11] Gibbons, Macklin, and Schmitt, Phys. Rev. **100**, 167 (1955).

[12] A. H. Wapstra, Physica **21**, 367 (1955).

[13] L. J. Lidofsky, Revs. Modern Phys. **29**, 773 (1957).

and Whaling[14] who combined the measurements of Kinsey and Bartholomew[15] with those of Heydenburg and Temmer.[9] Then using the mass spectrometer doublet measurements for Cr^{50} and V^{51} of Giese and Benson,[16] one obtains a $\Delta E(Cr^{51}\text{-}V^{51})$ value of 0.752 ±0.013 Mev. As may be seen, all ΔE values are in excellent agreement.

$Mn^{55}(p,n)Fe^{55}$

Figure 3 shows the fast-counter yield curve (solid curve) and the ratio curve (open circles) of the $Mn^{55}(p,n)Fe^{55}$ reaction as a function of proton energy. For these curves the target thickness was 70 $\mu g/cm^2$ or 7 kev to 1.5-Mev incident protons. The ratio curve shows a break or sudden rise at 1.455±0.003 Mev, indicating an excited-state neutron threshold. This threshold corresponds to an energy level at 0.414±0.003 Mev in Fe^{55}. The second break, about 43 kev higher in bombarding energy than the first, is not another threshold, but is a satellite of the first break. Such satellites are discussed below. One additional threshold was observed at 1.982±0.002 Mev, corresponding to an excited state at 0.931±0.002 Mev in Fe^{55}. This threshold is quite pronounced, and (perhaps as a result of its relative intensity) displays several satellite breaks. The insert (solid circles) shows on an expanded energy scale the ratio curve from about 1.95 Mev to 2.06 Mev.

The nature of the satellites is not understood. Several possible causes have been discussed in a previous communication.[3] The experimental arrangement in the present experiment is somewhat different from the previous experiment, as noted in Sec. II. Specifically, the target chamber is made of $\frac{1}{32}$-in. aluminum instead of 0.010-in. stainless steel, and the proportional counters are steel-wall tubes, B^{10}-lined, and filled with a typical proportional counter gas whereas in the previous experiment the counters were copper-wall tubes filled with BF_3 gas. Since the satellites were observed in both experiments, the target container, counter tube walls, and counter tube gas are thus eliminated as the causative agent.

Resonances in the compound nucleus could possibly be responsible, but this possibility seems unlikely because of the regularity of the satellites and the fact that there is no clear association between the resonances (as revealed by the fast-counter curve) and the satellites. Another possibility is that the satellites in some way reflect the fine structure response of the slow and/or fast counters, possibly through scattering resonances in carbon. The nature of these satellites is being further investigated, and the results obtained will be reported in a future communication.

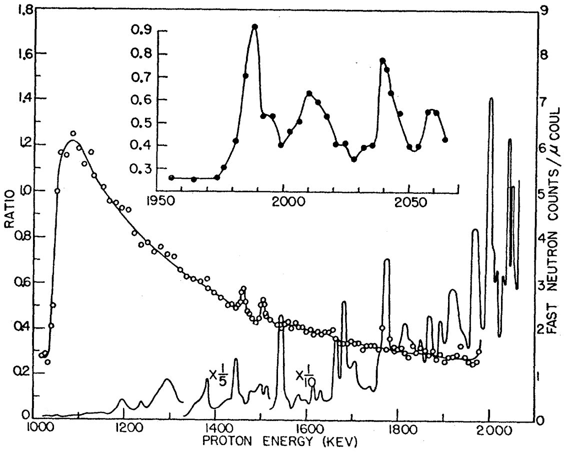

FIG. 3. Excitation function for the $Mn^{55}(p,n)Fe^{55}$ reaction. The solid curve represents the fast-counter yield (not corrected for the energy response of the counter), and the open circles indicate the ratio function. The solid circles show an enlarged view of the ratio function from about 1950 to 2060 kev. In addition to the ground-state threshold at 1034 kev, two excited-state thresholds are observed at 1455 and 1982 kev. Additional rises in the ratio curve are interpreted as satellite peaks associated with the thresholds, but not representing new thresholds.

The ground-state threshold was determined to be 1.034±0.002 Mev. Previous measurements of the ground-state threshold are reported by Stelson and Preston[17] at 1.024±0.010 Mev, McCue and Preston[18] at 1.020±0.010 Mev, and Trail and Johnson[19] at 1.039±0.005 Mev. The value of the present experiment lies between those of references 17 and 19 and is in agreement with both; however, it is in slight disagreement with the value of McCue and Preston. The spread in values obtained by different experimenters for this threshold is probably at least partly due to a resonance which occurs near the foot of the threshold rise, causing a nonlinearity in this rise. Chapman and Slattery[20] report a private communication from Trail and Johnson giving a revised Q value of 1.015±0.005 Mev. When this Q value is converted to threshold bombarding energy, 1.033±0.005 Mev, it is seen to be in excellent agreement with the present experiment.

The highest threshold observed in the present experiment at 1.982±0.002 Mev was also observed by Chapman and Slattery[20] who report a value of 1.975 ±0.010 Mev, in satisfactory agreement with the present experiment. They did not search for the ground-state or lower excited-state thresholds because of the low neutron yields for this reaction below the second excited-state threshold.

The energies of the first two excited states of Fe^{55} are reported to be 0.413 Mev and 0.933 Mev by Sperduto and Buechner[21] from the magnetic analysis

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[14] D. M. Van Patter and W. Whaling, Revs. Modern Phys. **29**, 757 (1957).

[15] B. B. Kinsey and G. A. Bartholomew, Phys. Rev. **89**, 375 (1953).

[16] C. F. Giese and J. L. Benson, Phys. Rev. **110**, 712 (1958).

[17] P. H. Stelson and W. M. Preston, Phys. Rev. **83**, 469 (1951).

[18] J. J. G. McCue and W. M. Preston, Phys. Rev. **84**, 1150 (1951).

[19] C. C. Trail and C. H. Johnson, Phys. Rev. **91**, 474(A) (1953).

[20] R. A. Chapman and J. C. Slattery, Phys. Rev. **105**, 633 (1957).

[21] A. Sperduto and W. W. Buechner, Bull. Am. Phys. Soc. Ser. II, **1**, 223 (1956). [Slightly revised values, W. W. Buechner (private communication).]

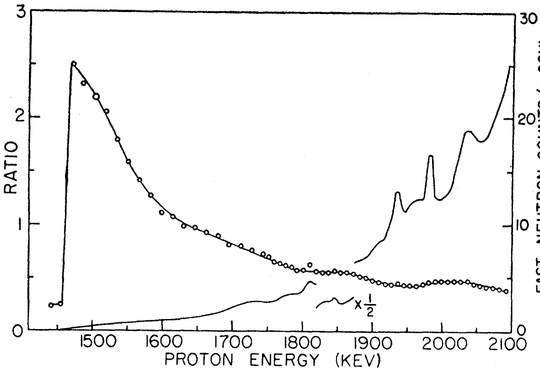

FIG. 4. Excitation function for the $\mathrm{Zn}^{70}(p,n)\mathrm{Ga}^{70}$ reaction. The solid curve represents the fast-counter yield (not corrected for the energy response of the counter), and the open circles indicate the ratio function. The ground-state threshold occurs at 1457 kev. The two anomalies at about 1800 and 1960 kev are not interpreted as thresholds for excited states in Ga^{70}.

of the $\mathrm{Fe}^{54}(d,p)\mathrm{Fe}^{55}$ reaction. These values are in excellent agreement with the values of the present experiment of 0.414±0.002 Mev and 0.931±0.002 Mev.

Mark *et al.*[22] report possible states in Fe^{55} at 0.420 Mev and 0.975 Mev from observation of gamma rays attributed to the $\mathrm{Mn}^{55}(p,n\gamma)\mathrm{Fe}^{55}$ reaction. They state, however, that the 975-kev gamma ray may come from a level in Mn^{55}. In view of the disagreement of their value with that now established for the second excited state of Fe^{55}, and the recent report of a state in Mn^{55} at 0.983±0.005 Mev by Mazari *et al.*,[23] their second hypothesis seems more reasonable. Their value of 0.420 Mev for the first excited state of Fe^{55} is in reasonable agreement with the value of the present experiment.

None of the low-energy gamma rays reported by Adyasevich *et al.*[24] from the thermal-neutron capture by natural iron fit transitions from the two levels reported in this experiment. However, they expected a maximum contribution of only 5% of the total yield to be due to the $\mathrm{Fe}^{54}(n_{\mathrm{th}},\gamma)\mathrm{Fe}^{55}$ reaction.

For the purposes of comparison, the ground-state $Q_{p,n}$ value of the present experiment may be converted to the Fe^{55}-Mn^{55} mass-excess difference, $\Delta E(\mathrm{Fe}^{55}\text{-}\mathrm{Mn}^{55})$, yielding a value of 0.232±0.003 Mev. Lidofsky's[13] adopted value for Q_ϵ leads directly to a value of 0.220 ±0.004 Mev for $\Delta E(\mathrm{Fe}^{55}\text{-}\mathrm{Mn}^{55})$. With the use of the measurements of Quisenberry *et al.*[25] for Fe^{54} and that of Giese and Benson[16] for Mn^{55}, a value of $\Delta E(\mathrm{Fe}^{55}\text{-}\mathrm{Mn}^{55})$ may be calculated with both the (n,γ) and (d,p) Q values. The adopted value for $Q_{n,\gamma}$ of Van Patter and Whaling[14] thus gives for $\Delta E(\mathrm{Fe}^{55}\text{-}\mathrm{Mn}^{55})$ a value of 0.221 ±0.008 Mev. The $Q_{d,p}$ value of 7.077±0.008 Mev of Sperduto and Buechner[21] yields for $\Delta E(\mathrm{Fe}^{55}\text{-}\mathrm{Mn}^{55})$ a value of 0.215±0.010 Mev. The disagreement of the value calculated from the (p,n) threshold of this report with the other values which are in agreement with each other suggests that the neutron threshold value is too high; however, it should be noted that there was a considerable spread in the individual measured values of Q_ϵ, and that an error in either mass spectrometer measurement would equally affect the $\Delta E(\mathrm{Fe}^{55}\text{-}\mathrm{Mn}^{55})$ value calculated from $Q_{n,\gamma}$ and from $Q_{d,p}$.

$\mathrm{Zn}^{70}(p,n)\mathrm{Ga}^{70}$

Figure 4 shows the results for the $\mathrm{Zn}^{70}(p,n)\mathrm{Ga}^{70}$ reaction, the solid curve representing the fast-counter yield, and the open circles the ratio curve. Only the rise for the ground-state threshold is considered to be sufficiently pronounced to permit the definite assignment of a threshold. The other two slight rises are considered to be anomalies. The first of these may be due to the ground-state threshold of the $\mathrm{Zn}^{67}(p,n)\mathrm{Ga}^{67}$ reaction, since the initial break in slope appears near the expected value for this threshold, which has been reported as 1.812±0.005 Mev by Trail and Johnson[19] and 1.805±0.005 Mev by Chapman and Slattery,[20] and since the target used for this experiment contained about 4.1% Zn^{67} compared to 48.4% Zn^{70}. The second anomaly, which shows a change in slope at a bombarding energy of about 1.96 Mev, could be an excited-state threshold from the $\mathrm{Zn}^{70}(p,n)\mathrm{Ga}^{70}$ reaction; however, the anomaly observed in the present experiment is neither strong enough nor sharp enough to make a definite assignment. It is unlikely that this anomaly is due to an excited-state threshold from the $\mathrm{Zn}^{67}(p,n)\mathrm{Ga}^{67}$ reaction, since Chapman and Slattery report no evidence for excited-state thresholds below a bombarding energy of 2.167 Mev. The region of excitation studied in Ga^{70} in the present experiment was from zero to 0.53 Mev, corresponding to the bombarding energy range from the ground-state threshold to 2.10 Mev. No previous information is available concerning excited states of Ga^{70}.

The ground-state threshold for the $\mathrm{Zn}^{70}(p,n)\mathrm{Ga}^{70}$ reaction was determined to be 1.457±0.002 Mev. The only previous measurement of this threshold was reported by Trail and Johnson,[19] who obtained the

TABLE I. Summary of precise energy determinations for neutron thresholds observed in the present experiment.

Reaction	Proton energy (Mev)	Q value (Mev)	Energy of residual state (kev)
$\mathrm{V}^{51}(p,n)\mathrm{Cr}^{51}$	1.564±0.002	−1.534±0.002	0
$\mathrm{Mn}^{55}(p,n)\mathrm{Fe}^{55}$	1.034±0.002	−1.016±0.002	0
	1.455±0.003	−1.429±0.003	414±3
	1.982±0.002	−1.947±0.002	931±2
$\mathrm{Zn}^{70}(p,n)\mathrm{Ga}^{70}$	1.457±0.002	−1.436±0.002	0
$\mathrm{As}^{75}(p,n)\mathrm{Se}^{75}$	1.669±0.002	−1.647±0.002	0
	1.960±0.002	−1.934±0.002	287±2

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[22] Mark, McClelland, and Goodman, Phys. Rev. **98**, 1245 (1955).

[23] Mazari, Sperduto, and Buechner, Phys. Rev. **108**, 103 (1957).

[24] Adyasevich, Groshev, and Demidov, J. Nuclear Energy **3**, 258 (1956).

[25] Quisenberry, Scolman, and Nier, Phys. Rev. **104**, 461 (1956).

value of 1.47±0.03 Mev, in good agreement with the present result.

In the mass region above zinc there presently exists a paucity of precise reaction Q values and mass spectrometer doublet measurements. Since Ga^{70} is not known to decay by electron capture to Zn^{70}, but only by β^- emission to Ge^{70}, a direct comparison of the (p,n) results with other reactions is not possible, except by utilizing the older mass spectrometer data of Collins *et al.*[26] Their work is in disagreement in many instances with the recent and more precise work of Quisenberry *et al.*[25]

The Ga^{70}-Zn^{70} mass excess difference, $\Delta E(Ga^{70}\text{-}Zn^{70})$, may be computed in terms of the $Ga^{69}(n,\gamma)Ga^{70}$ Q value of Bartholomew,[27] and the mass spectrometer values for Ga^{69} by Collins *et al.* and Zn^{70} by Quisenberry *et al.* This calculation yields a $\Delta E(Ga^{70}\text{-}Zn^{70})$ value of 0.69±0.05 Mev. Another approach is through the $Ga^{70}(\beta^-)Ge^{70}$ Q value of Bunker *et al.*[28] and the mass spectrometer value for Ge^{70} by Collins *et al.* This calculation yields a $\Delta E(Ga^{70}\text{-}Zn^{70})$ value of 0.40±0.06 Mev. The results for $Q_{p,n}$ of the present report yield a $\Delta E(Ga^{70}\text{-}Zn^{70})$ value of 0.653±0.003 Mev. Thus, the present results agree with those from the (n,γ) reaction and the masses of Ga^{69} and Zn^{70}, but are in serious disagreement with those from the β^- decay and the mass of Ge^{70}. This discrepancy suggests that an error exists in either the mass spectrometer measurement for Ge^{70} or in the β^--decay measurement. A similar discrepancy has been noted by Way *et al.*[29] on the basis of earlier data.

$As^{75}(p,n)Se^{75}$

The fast-counter yield curve (solid curve) and ratio curve (open circles) for the $As^{75}(p,n)Se^{75}$ reaction are shown in Fig. 5. For this curve the target was about 7 kev thick to 1.5-Mev incident protons. In addition to the ground-state threshold, a single strong threshold is observed at a bombarding energy of 1.960±0.002 Mev, which corresponds to an excited state of Se^{75} at 0.287±0.002 Mev. Previous to the present experiment, no excited states had been observed in Se^{75}.

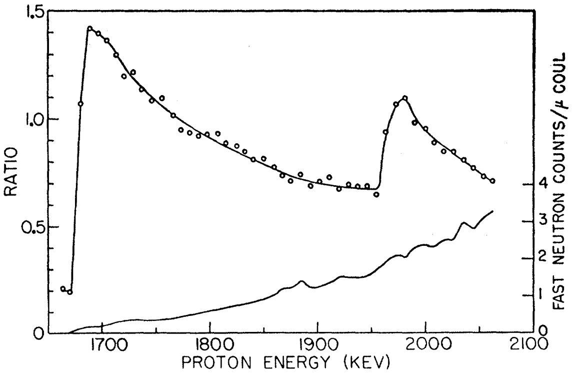

FIG. 5. Excitation function for the $As^{75}(p,n)Se^{75}$ reaction. The solid curve represents the fast-counter yield (not corrected for the energy response of the counter), and the open circles indicate the ratio function. The ground-state threshold appears at 1669 kev and an excited-state threshold at 1960 kev.

The ground-state threshold was determined to be 1.669±0.002 Mev. The only other measurement of this threshold is that of Trail and Johnson[19] who report 1.674±0.005 Mev, in good agreement with the present value.

The electron capture decay of Se^{75} does not proceed directly to the ground state of As^{75} and thus no Q_ϵ value is available for comparison with the (p,n) result. Likewise, no reaction data have been reported to link Se^{75} with other nuclides to allow comparison with the results of the present experiment.

In Table I are summarized the results of the precise energy determinations for all thresholds observed in the four nuclides studied in the present experiment.

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[26] Collins, Johnson, and Nier, Phys. Rev. **94**, 398 (1954).

[27] G. A. Bartholomew (private communication to D. M. Van Patter and W. Whaling, reference 14).

[28] Bunker, Mize, and Starner, Phys. Rev. **105**, 227 (1957).

[29] *Nuclear Level Schemes*, $A=40-A=92$, compiled by Way, King, McGinnis, and van Lieshout, Atomic Energy Commission Report TID-5300 (U. S. Government Printing Office, Washington, D. C., 1955), p. 107.