It would, of course, be preferable to separate these "almost elastically" scattered neutrons experimentally. This could perhaps be done by (n',γ) coincidences. Such an experiment would require higher neutron fluxes than those which can be used with an associated particle time-of-flight system (which is limited by the counting rate in the alpha counter), and would present probelms in measuring low-energy gamma rays in a background of 14-MeV neutrons and higher energy gammas. A pulsed beam time-of-flight system could produce higher fluxes and alleviate the background problem somewhat, but would lack the inherent "collimation" of the associated particle technique.

ACKNOWLEDGMENTS

The Monte Carlo calculations were performed on the Burroughs 205 computer of the University of Virginia Computer Center. The authors wish to thank Dr. A. P. Batson and the staff of the computer center for their advice, and the University of Virginia for providing computer time for the calculation. We are grateful to the late Dr. Frank Bjorklund for having sent us the theoretical calculations for 15.2-MeV neutrons.

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Cross Sections for Charged Particle Reactions Induced in Medium Weight Nuclei by Neutrons in the Energy Range 12–18 MeV†

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Data are presented for (n,p) cross sections in Mg^{24}, Al^{27}, Ti^{48}, and Zn^{64}; and (n,α) reactions in Al^{27}, P^{31}, Mn^{55}, and Co^{59}. The neutron energy range was from 12 to 18 MeV. The experimental results are compared with statistical model calculations using an energy dependence of the level density of the form $\exp[2(aE^*)^{1/2}]$. Results of this comparison show that with the proper choice of the level-density and pairing-energy parameters the statistical model theory gives total (n,p) and (n,α) cross-section values in fair agreement with the experimental data. However, some of the parameters show marked deviations from expected trends.

I. INTRODUCTION

THE major impetus for measuring reaction cross sections in the medium and heavy elements is that such measurements are capable of yielding information about mechanisms by which the interaction between the incident nucleon and target nucleus proceeds. Recently there have been many measurements of total cross sections, angular distributions, and energy spectra of the reaction products produced in intermediate and heavy nuclei by incident particles of intermediate energy. In cases where final states are unresolved, the experimental results have been interpreted in terms of the statistical model of Weisskopf and Ewing.[1,2] This model has been only partially successful in explaining results of observations. The application of the statistical model has been reviewed by Le Couteur,[3] Peaslee,[4] and Gugelot.[5] Recent work on the application of the statistical model, particularly to (p,α) and (p,p') reactions, has been reviewed and extended by Sherr and Brady.[6] That the statistical model correctly explains many of the observed results is now generally accepted. However, there are many details still to be worked out.

The most sensitive way to check the predictions of the model is to compare calculated and measured energy spectra and angular distributions. If the model is to be applicable in a given reaction, the energy spectra must be "evaporation like" and the angular distributions must be nearly isotropic. In cases where applicability of the statistical assumptions is indicated, the energy spectra can be used to study the consistency of the assumed level density function and calculated compound nucleus formation cross sections.

Total reaction cross-section calculations are less model dependent since they lack information about spatial distribution; however, they can still provide useful information about the reaction mechanism. The results of such calculations must be consistent with observations for any acceptable model.

In the present report, total cross-section data on (n,p) and (n,α) reactions for elements varying in A from 24 to 64 are compared with statistical model calculations. The details of the experimental work are given in Sec. II and the formalism for the calculation of the reaction cross sections is discussed briefly in Sec. III.

† Partially supported by the U. S. Atomic Energy Commission.
[1] V. F. Weisskopf and D. H. Ewing, Phys. Rev. **57**, 472 (1940).
[2] J. M. Blatt and V. F. Weisskopf, *Theoretical Nuclear Physics* (John Wiley & Sons, Inc., New York, 1952), p. 340.
[3] K. J. LeCouteur, *Nuclear Reactions* (North-Holland Publishing Company, Amsterdam, 1959), Vol. 1, p. 318.
[4] D. C. Peaslee, Ann. Rev. Nuclear Sci. **5**, 99 (1955).
[5] P. D. Gugelot, reference 3, p. 39.
[6] R. Sherr and F. P. Brady, Phys. Rev. **124**, 1928 (1961).

II. EXPERIMENTAL METHOD AND RESULTS

The cross sections reported here were measured by the activation method. The neutrons were produced by the $T(d,n)He^4$ reaction using a 2.4-MeV electrostatic accelerator at the University of Kentucky. The neutron-producing target was 1 mg/cm^2 of Zr-T on a 20-mil platinum backing. The samples to be activated were elemental and were contained in gelatin capsules of dimensions 3/8-in. diam by 3/4-in. long. The deuteron energy was determined by analysis with a 90° magnet. The samples were placed around the neutron source as shown in Fig. 1. The number of samples and time of each activation were largely determined by half-life of the radioactive product. Samples producing residual nuclei whose half-lives were a few hours or more could be activated several at a time, while samples yielding relatively shorter half-lives could be irradiated only one at the time. The neutron energy was varied by varying the deuteron energy and the angle with respect to the deuteron beam at which the samples were placed.

The activity produced in the samples by the neutron irradiation was determined by counting gamma rays following beta decay of the radioactive nuclei in a 3-in.×3-in. NaI(Tl) scintillator spectrometer. Branching ratios for the beta rays and gamma rays were taken from Strominger *et al.*[7] An absorber of aluminum sufficient to stop 3-MeV beta rays was placed between sample and scintillator to eliminate beta rays from the crystal.

The NaI(Tl) spectrometer was calibrated by counting standard samples especially prepared to reproduce the geometry used in counting activations. Except in one case, the standards were prepared from standard solutions obtained from the National Bureau of Standards

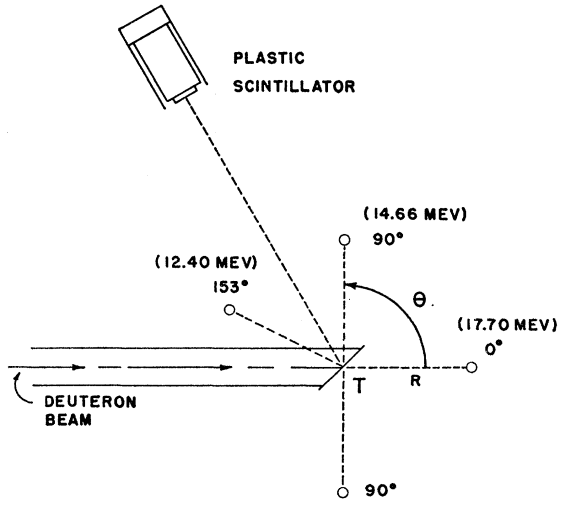

FIG. 1. Schematic diagram of the arrangement of the samples for activation.

[7] D. Strominger, J. H. Hollander, and G. T. Seaborg, Revs. Modern Phys. **30**, 585 (1958).

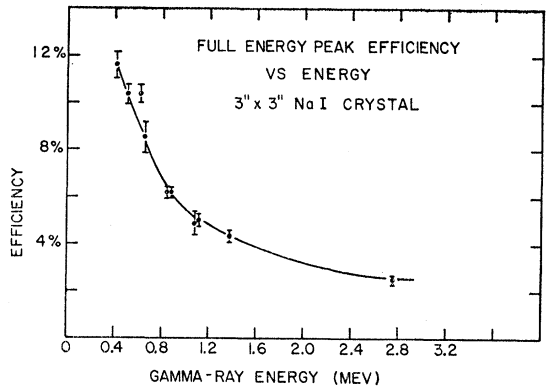

FIG. 2. The photopeak efficiency of the 3-×3-in. NaI(Tl) spectrometer for counting gamma rays.

or the activity was determined in a 2π beta counter.[8] The exception was the Na^{24} standard. The efficiencies for counting the 1.368- and 2.754-MeV gamma rays from this source were found by unfolding the observed pulse-height spectrum into the spectra for the 1.368-MeV gamma, the 2.754-MeV gamma, and the spectrum formed by the summing of these two gamma rays. Details of the unfolding procedure are given elsewhere.[9] The efficiency of the scintillation spectrometer for counting gamma rays in the total absorption peak as a function of the gamma-ray energy is shown in Fig. 2. The estimated error in each point is indicated by the error bars.

The neutron flux was measured at 112° to the deuteron beam by a $1\frac{1}{2}$-×$1\frac{1}{2}$-in. plastic scintillator. The 112° measurement was normalized to the relative differential cross section measurements for $T(d,n)He^4$ of Bame and Perry.[10] The neutron flux at other angles could then be read from the normalized curves. The plastic scintillator was calibrated at a neutron energy of 14.6 MeV by counting the recoil alpha particles from the $T(d,n)He^4$ reaction. Details of this method are given elsewhere.[11] The total efficiency of the $1\frac{1}{2}$-×$1\frac{1}{2}$-in. scintillator for counting 14.6-MeV neutrons was measured to be 13.5±0.7%.

Integral pulse-height spectra from the plastic scintillator for deuteron energies of 0.28 and 1.1 MeV are shown in Fig. 3. The 0.28-MeV spectrum shows the shape expected from a single neutron group.[12] At a deuteron energy of 1.1 MeV, two groups of pulses are evident. The lower group whose end point is about channel 50 was produced by gamma rays from the C^{13*} first excited state, following $C^{12}(d,p)C^{13*}$. The threshold for this reaction is 0.43 MeV. For deuteron energies

[8] J. S. Nader, G. R. Hagee, and L. R. Setter, Nucleonics **12**, 29 (1954).

[9] R. L. Alexander, M.S. Thesis, University of Kentucky, Lexington, Kentucky, 1961 (unpublished).

[10] S. J. Bame and J. E. Perry, Phys. Rev. **101**, 247 (1956).

[11] B. D. Kern and W. E. Kreger, Phys. Rev. **112**, 926 (1958).

[12] C. D. Swartz and G. E. Owen in *Fast Neutron Physics*, edited by J. B. Marion and J. L. Fowler (Interscience Publishers, Inc., New York, 1960).

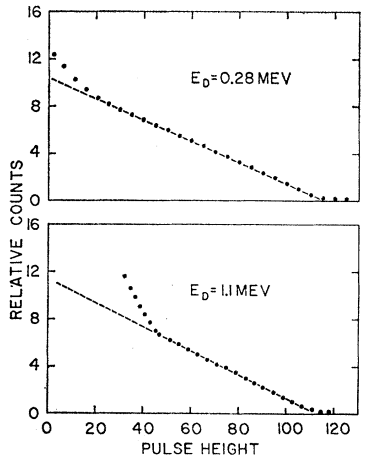

FIG. 3. Integral pulse-height spectra produced by $T(d,n)He^4$ neutrons for deuteron energies of 0.28 and 1.1 MeV. The detector was a $1\frac{1}{2}$-in. $\times 1\frac{1}{2}$-in. plastic scintillator.

above 0.9 MeV where all activation runs were made, the number of recoil protons was determined by summing channels above channel 50 and extrapolating to zero pulse height following the spectral shape determined at 0.28 MeV.

A detailed discussion of the procedure for reducing the data to cross sections is given by Kern *et al.*[13]

The measured values of the cross sections are plotted as a function of neutron energy in Figs. 4 and 5. The (n,p) total reaction cross sections were measured for Mg^{24}, Al^{27}, Ti^{48}, and Zn^{64}. The (n,α) cross sections for Al^{27}, P^{31}, Mn^{55}, and Co^{59} were measured.

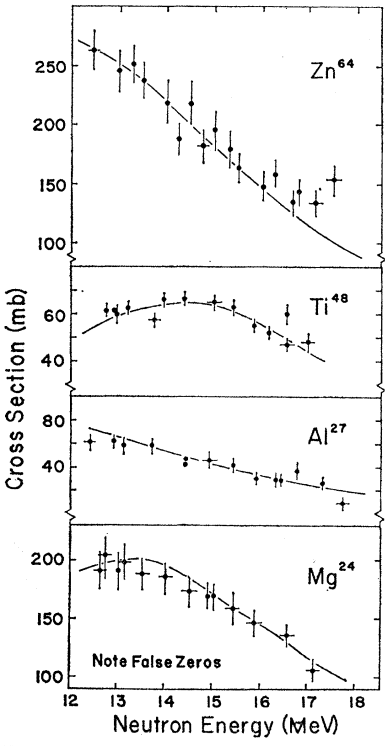

FIG. 4. Total cross sections for (n,p) reactions in some medium weight nuclei. The solid curves were calculated from the statistical theory. See text.

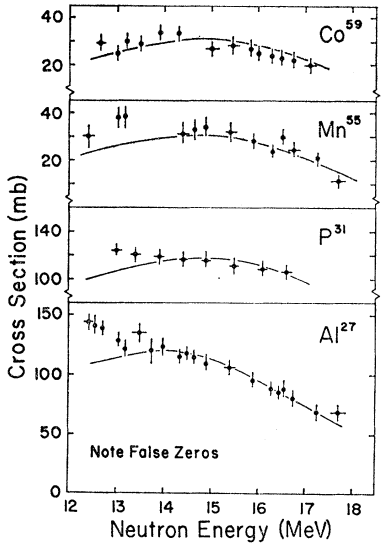

FIG. 5. Total cross sections for (n,α) reactions in some medium weight nuclei. The solid curves were calculated from the statistical theory. See text.

For each reaction studied, relative cross sections were first measured as a function of neutron energy. These relative cross sections were then normalized to an absolute measurement at one or more neutron energies. Absolute cross-section measurements made during this experiment were: (n,p) reactions in Mg^{24}, Al^{27}, and Ti^{48}; and (n,α) reactions in Al^{27}, P^{31}, and Fe^{56}. Table I gives a list of the absolute cross-section determinations which were made with a complete list of the reactions studied. References to previous measurements are also given in column 5. The absolute cross section for the $Co^{59}(n,\alpha)Mn^{56}$ reaction was obtained by first measuring this cross section relative to the $Fe^{56}(n,p)Mn^{56}$ cross section and then measuring the $Fe^{56}(n,p)$ cross section at 14.4 MeV. The $Mn^{55}(n,\alpha)V^{52}$ cross section was measured by comparison with two reactions, $Cr^{52}(n,p)V^{52}$ and $Si^{28}(n,p)Al^{28}$, whose cross sections were measured previously by Kern, Thompson, and Ferguson.[13] The $Zn^{64}(n,p)Cu^{64}$ cross section was determined by comparison with the $Cu^{65}(n,2n)Cu^{64}$ reaction cross section as measured by Rayburn.[14]

In Figs. 4 and 5, the neutron energy spread for the points is indicated by horizontal lines. The vertical bars indicate the relative standard deviation of the points. Included in this error estimate are errors from the following sources: (1) sample position; (2) weight of sample; (3) relative errors in $T(d,n)He^4$ differential cross sections; and (4) counting statistics. The absolute errors in the cross sections are somewhat greater than indicated by the error bars since they do not include the error in the absolute value of the cross section as given in Table I.

III. STATISTICAL MODEL CALCULATIONS

The statistical model theory gives the following expression[2] for the total reaction cross section for reaction,

[13] B. D. Kern, W. E. Thompson, and J. M. Ferguson, Nuclear Phys. **10**, 226 (1959).

[14] L. A. Rayburn, Bull. Am. Phys. Soc. **3**, 337 (1958).

$X(a,b)Y$:

$$\sigma(a,b)=\left\{\sigma_c(E_a)(2M_b/\hbar^2)\times\int_{E_i}^{E_a+Q}\sigma_c(E)\omega(E^*)dE\right\}\Big/\sum_i F_i,$$

where E_a and E are the incident and exit channel energies and $\sigma_c(E_a)$ and $\sigma_c(E)$ are the cross sections for the particles a and b for formation of the compound nucleus with the target and residual nucleus, respectively. E_i is the minimum energy with which the particle b may be emitted and leave the residual nucleus in a bound state.[15] E_a+Q is the maximum channel energy available for the outgoing particle. The level density for excitation energy E^* in the residual nucleus is given by $\omega(E^*)$.

In the calculations for $\sigma(n,p)$ and $\sigma(n,\alpha)$ presented in this report, the form used for $\omega(E^*)$ was

$$\omega(E^*)=C\exp[2(aE^*)^{1/2}],$$

where a is the so-called "level-density parameter," C is a constant factor, and E^* is the excitation energy in the residual nucleus given by

$$E^*=E_n+Q-E+n\delta.$$

Here E is the channel energy of the exit particle, δ is the "pairing" parameter introduced to account for odd-even[16–18] effects observed in level densities of nuclei and n is 1, 0, or -1 depending on the odd-even character of the residual nucleus. For odd-N, odd-Z residual nuclei, $n=1$; for odd A, $n=0$; and for even N, even A, $n=-1$. The above convention for n is arbitrary. Other possible choices which have been used are $n=0$, -1, -2, and $n=2$, 1, 0 for odd-odd, odd-A, and even-even nuclei, respectively. For the case of the $Mg^{24}(n,p)Na^{24}$ calculation, going from the 0, -1, -2 choice to the 2, 1, 0 choice makes a difference of 25% in the computed cross section at a neutron energy of 14 MeV. The sensitivity of the calculated cross section to the choice of the n values for other cases depends upon the target nucleus and the reaction considered.

For incident neutron energies of about 20 MeV, there are usually five open channels for single-particle emission. These are the (n,n), (n,p), (n,d), (n,t), and (n,α) reaction channels. The compound nucleus formation cross sections used in the calculations for the proton, deuteron, and alpha-particle channels were taken from the tabulation of Shapiro.[19] The Coulomb potential cutoff radius of $(1.5\times10^{-13})A^{1/3}$ cm was assumed for the proton channel and $(1.5A^{1/3}+2.21)\times10^{-13}$ cm was taken for the α-particle and deuteron channels. The integral for the triton channel was calculated assuming the same formation cross section and cutoff radius as were used for deuterons. The effect of the triton channel integral on the calculated cross section is small for this energy range making this latter assumption unimportant. The compound nucleus formation cross sections of Beyster *et al.*[20] were used for the neutron channel. These latter cross sections are based on an optical model using a Woods-Saxon complex potential.

Q values were obtained from the tables of nuclear mass differences by Everling *et al.*[21]

The procedure which was adopted for comparing the experimental data with the statistical model was to allow a and δ in the level density formula to be free parameters and to choose them so that a good fit to the data was obtained. The extracted parameters can then be compared with those from other measurements.

The computation was programmed for the IBM 650 computer at the University Computing Center. For a given reaction, a was assumed in the form $a=bA$ and δ

TABLE I. List of reactions studied with data on the absolute cross-section determinations. Additional data are plotted in Figs. 4–5.

Target nucleus	Reaction	E_n (MeV)	σ (mb)	References to other measurements
Mg^{24}	(n,p)	14.4	177±18	a, b, c
Al^{27}	(n,p)	14.4	50±7	c, d, e
	(n,α)	13.8	121±12	a, e, f, g, c
		14.4	118±12	
		14.9	112±11	
P^{31}	(n,α)	13.0	125±15	c, h
		14.4	117±14	
		16.6	106±13	
Ti^{48}	(n,p)	12.98	60±7	c, e
		13.75	57±8	
		16.60	60±9	
Mn^{55}	(n,a)			c, h
Fe^{56}	(n,p)	14.4	108±10	c, i, a, j, k
Co^{59}	(n,α)			l
Zn^{64}	(n,p)			c, m, n

[a] B. D. Kern, W. E. Thompson, and J. M. Ferguson, Nuclear Phys. **10** 226 (1959).
[b] A. V. Cohen and P. H. White, Nuclear Phys. **1**, 73 (1956).
[c] E. B. Paul and R. L. Clark, Can. J. Phys. **31**, 267 (1953).
[d] C. S. Kharana and H. S. Hanes, Nuclear Phys. **13**, 88 (1959). R. K. Haling, R. A. Peck, Jr., and H. P. Eubank, Phys. Rev. **106**, 971 (1957).
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[h] *Neutron Cross Sections*, compiled by D. J. Hughes and R. Schwartz, Brookhaven National Laboratory Report BNL-325 (Superintendent of Documents, U. S. Government Printing Office, Washington, D. C., 1958), 2nd ed., p. 363.
[i] J. Terrell and D. M. Holm, Phys. Rev. **109**, 2031 (1958).
[j] S. G. Forbes, Phys. Rev. **88**, 1309 (1952).
[k] S. Yasumi, J. Phys. Soc. Japan **12**, 443 (1957).
[l] H. G. Blosser, C. D. Goodman, and T. H. Handley, Phys. Rev. **110**, 531 (1958).
[m] A. H. Armstrong and L. Rosen, Nuclear Phys. **19**, 40 (1960).
[n] D. R. Koehler and W. L. Alford, Phys. Rev. **119**, 311 (1960).

[15] J. Terrell and D. M. Holm, Phys. Rev. **109**, 2031 (1958).
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[17] H. Hurwitz and H. A. Bethe, Phys. Rev. **81**, 898 (1951).
[18] E. Feenberg, Revs. Modern Phys. **19**, 239 (1947).
[19] M. M. Shapiro, Phys. Rev. **90**, 17 (1953).
[20] J. R. Beyster, M. Walt, R. G. Schrandt, and E. W. Salmi, Los Alamos Scientific Laboratory, Report LA 2099, Los Alamos, New Mexico, 1957 (unpublished).
[21] F. Everling, L. A. König, J. H. E. Mattauch, and A. H. Wapstra, Nuclear Phys. **18**, 529 (1960).

TABLE II. Values of the level density parameter a and the pairing parameter δ corresponding to the curves of Figs. 4 and 5.

Residual nucleus	Exit particle	a (MeV^{-1})	δ (MeV)
Na^{24}	p	1.1	2.6
Na^{24}	α	3.4	3.4
Mg^{27}	p	1.3	1.9
Al^{28}	α	2.0	1.9
Sc^{48}	p	3.2	1.2
V^{52}	α	9.7	3.5
Mn^{56}	α	4.6	1.4
Cu^{64}	p	1.2	1.2

was represented by $\delta=cA^{-1/2}$. A parameter search was made on b and c. These forms for a and δ are consistent with other results.[16] Also, it is apparent that the choice of the dependence of a and δ on the atomic mass number A will not appreciably affect the results because the maximum variation in A is four for any particular calculation. One value of a and one value of δ were extracted for each reaction. The calculated cross sections obtained are shown with the data in Figs. 4 and 5 and the corresponding values of a and δ are given in Table II.

IV. DISCUSSION OF RESULTS

The values of a shown in Table II for the (n,p) reactions are roughly represented by $0.06A$ except for the $Zn^{64}(n,p)Cu^{64}$ reaction. Values of a extracted from (n,α) data are widely scattered. Values of the "pairing energy" δ corresponding to (n,p) reactions are in reasonable agreement with the expression $\delta=10A^{-1/2}$ suggested by Green and Edwards,[16] and with the expression

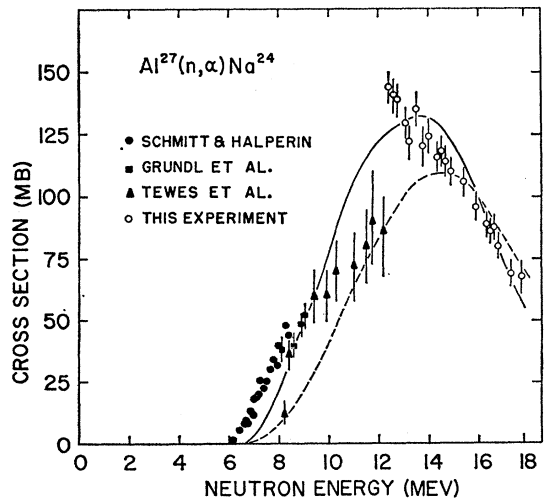

FIG. 6. The comparison of statistical model calculations with the $Al^{27}(n,\alpha)Na^{24}$ total cross section from threshold to a neutron energy of 18 MeV. Charged particle reaction cross sections were taken from Shapiro (reference 19) and the form $\exp 2(aE^*)^{1/2}$ was used for the level density.

$\delta=1.68(1-A/400)$ of Stolovy and Harvey.[22] Again, the (n,α) results are widely scattered.

Fong[23] has calculated values of a from 1-MeV neutron capture cross sections. His results are represented by $a=0.05A$. In his analysis, Fong used the form $\exp 2(aE^*)^{1/2}$ and included odd-even effects with $\delta=0.036A^{-3/4}$ and $n=1$, 0, -1 in agreement with the convention for n used in this report. This form of δ is suggested by the semiempirical mass formula.[24] Lang[25] has recently compiled a large number of values of the parameter a, mostly from neutron inelastic scattering data. He has used the form $(1/E^{*2})\exp 2(aE^*)^{1/2}$ for the level density. Lang's results are approximately represented by $a=0.15A$ with large deviations for values of A less than 100. Odd-even effects are included by using the form of δ suggested by Stolovy and Harvey.[22] Bramblett and Bonner[26] have measured evaporation spectra of neutrons from (p,n) reactions for a number of medium weight elements. These authors have compared values of a for the constant temperature level density with values using the form $\exp[2(aE^*)^{1/2}]$. The difference is $\sim 4\%$ if the odd-even effects are omitted. Bramblett and Bonner have also compared values of a including odd-even effects with those excluding these effects. Their results are roughly represented by $a=0.094A$ excluding odd-even effects and $a=0.07A$ otherwise. Results of Sherr and Brady[6] are consistent with $a=0.05A$.

The statistical model calculations for the (n,p) and (n,α) cross sections presented in this report are in fair agreement with the data. As is evident from Fig. 4 it was possible in all four cases to find values of the parameters a and δ so that a good fit to the (n,p) data was obtained. This was not possible for the (n,α) reactions of Fig. 5. The magnitudes of the calculated (n,α) reaction cross sections are in fair agreement with the measurements but the shapes of the curves are not correct. This tendency is evident in the Al^{27}, P^{31}, and Mn^{55} graphs of Fig. 5.

As is generally known, the calculation of the total reaction cross sections cannot "test" the statistical theory in any strict sense. What such calculations can "test" is the consistency of the statistical model with the assumed compound nucleus formation cross sections and level-density function. The indication is that the statistical model calculations described above are inconsistent with the energy variation of the total (n,α) reaction cross sections. This discrepancy has been previously noted by Williamson.[27] The situation is illustrated by Fig. 6 on which the $Al^{27}(n,\alpha)$ data of Schmitt

[22] A. Stolovy and J. A. Harvey, Phys. Rev. **108**, 353 (1957).
[23] P. Fong, Phys. Rev. **102**, 434 (1956).
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[26] R. L. Bramblett and T. W. Bonner, Nuclear Phys. **20**, 395 (1960).
[27] C. F. Williamson, Phys. Rev. **122**, 1877 (1961).

and Halperin,[28] Grundl *et al.*,[29] Tewes *et al.*,[30] and the present experiment have been plotted. The solid curve of Fig. 6 was calculated with $a=4.0$ MeV^{-1} and $\delta=4.1$ MeV while the dashed curve corresponds to $a=1.7$ MeV^{-1} and $\delta=2.6$ MeV. The notable feature of both curves is that they fall well below the data for neutron energies near the threshold for the (n,α) reaction. This result is consistent with the assumption that the transmission of the potential barrier for charged particles is too small for energies near the Coulomb barrier height. Since the sharp-cutoff potential used by Shapiro[19] is known to give just this effect for alpha particles,[31] the use of a more realistic diffuse well such as a Woods-Saxon or similar potential for calculation of the reaction cross sections should remove this discrepancy. Schmitt and Halperin[28] were, in fact, successful in fitting the gross features of their $Al^{27}(n,\alpha)Na^{24}$ data using alpha-particle reaction cross-section calculations by Igo[31] based on a diffuse-edge potential.

The achievement of consistency in the statistical model parameters in regions where the model is applicable will require elimination of some of the variable parameters from the model. A first step in this direction will be to use the more accurate diffuse-well values[31,32] for the reaction cross sections σ_c. More independent information about level densities is needed. The data presently available for studying the statistical assumption are not sufficiently sensitive to the joint variation of so many parameters to give detailed information about the "correct" form for the energy-dependent quantities.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the help of R. Alexander who calibrated the scintillation spectrometer. They also wish to thank W. C. Loomis and R. Stewart who helped in the experimental work.

[28] H. W. Schmitt and J. Halperin, Phys. Rev. **121**, 827 (1961).
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[32] F. G. J. Perey and B. Buck (to be published); R. D. Albert and L. F. Hansen, University of California Radiation Laboratory Report UCRL-6427 (unpublished); F. Bjorklund and S. Fernbach, Phys. Rev. **109**, 1295 (1950); J. S. Nodvik and D. S. Saxon, Phys. Rev. **117**, 1939 (1960); D. S. Saxon, *Proceedings of the International Conference on Nuclear Structure, Kingston* (University of Toronto Press, Toronto, 1960), p. 197.

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Excitation Functions of Some Reactions of 6- to 24-MeV He^3 Ions with Carbon and Aluminum*

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Excitation functions of the reactions $C^{12}(He^3,\alpha)C^{11}$, $C^{12}(He^3,pn)N^{13}$, $C^{12}(He^3,2\alpha)Be^7$, $Al^{27}(He^3,\alpha 2p)Na^{24}$, $Al^{27}(He^3,2\alpha)Na^{22}$, and $Al^{27}(He^3,3\alpha)F^{18}$ have been measured for He^3 energies from 6 to 24 MeV by the stacked-foil technique. The cross section for production of C^{11} reaches a maximum of 340 mb at 8.9 MeV, with smaller maxima at 10.6 and 15.5 MeV. The cross section for N^{13} reaches a broad maximum of 140 mb in the vicinity of 14 MeV, with evidence of a secondary maximum at 10.9 MeV. The cross section for Be^7, measured with somewhat poorer resolution, reaches a broad maximum of about 100 mb in the vicinity of 17.5 MeV. The cross section for production of Be^7 by 24-MeV He^3 bombardment of aluminum is about 0.1 mb.

INTRODUCTION

THE present work was undertaken to measure the total cross sections for formation of three of the products of the reactions of 6- to 24-MeV He^3 ions with carbon. The primary motive was to explore the energy dependence of cross sections of the reactions as a partial guide and supplement to more detailed energy-angular distribution experiments. A secondary motive was to obtain information on the type and magnitude of contamination to be expected from carbon compounds encountered in vacuum systems and targets.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

EXPERIMENTAL

Apparatus and Materials

The measurements of all products except Be^7 were made by the stacked-foil technique. Stacks of foils of measured thickness were bombarded with He^3 ions at selected incident energies from 10 to 24 MeV at the Los Alamos variable-energy cyclotron and the quantities of radioactive products were determined by absolute beta and gamma counting. The use of aluminum catcher foils in the stacks provided the need and the opportunity to measure also the excitation functions of the reactions in aluminum leading to the longer-lived radioactive species. Since Be^7 was produced in amounts too small