Elastic Scattering of Deuterons by N^{14} from 700 to 2100 keV*

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The elastic scattering of deuterons by N^{14} has been investigated over a laboratory energy range from 700 to 2100 keV. Excitation curves were measured for center-of-mass angles of 90.0, 125.3, 140.8, and 166.5 degrees. Angular distributions from 20 to 165 deg in the center-of-mass system were taken at 200-keV intervals over the entire energy range. Attempts to fit the data with a two-level compound-nucleus scheme were not successful, while optical-model calculations appeared to give a good fit over the entire energy range.

1. INTRODUCTION

THE present work was undertaken to provide detailed information on the elastic scattering of deuterons by N^{14} in the region below 2 MeV. Measurements have been made previously by several groups[1] at higher energies, but there have been no measurements made at energies of a few MeV. The N^{14}-plus-deuteron binding energy is 20.7 MeV so that cross-section measurements made at low energies could give information on excited states in O^{16} above this energy. It is known experimentally from the photodisintegration reaction,[2] $O^{16}(\gamma,n)O^{15}$, and the capture reaction,[3] $N^{15}(p,\gamma)O^{16}$, that levels with widths of approximately 100 keV are present in this energy region of O^{16}. Levels with widths of 500 keV have been observed in the $N^{14}(d,\gamma)O^{16}$ reaction[4] at 2.3 MeV. Theoretical calculations[5] also predict the presence of narrow levels in this energy region with both isotopic spin zero and one. It was thought that an examination of the elastic scattering of deuterons by N^{14} might give information on the levels in O^{16} which would supplement and extend the information obtained from the other reactions.

A number of experiments have been done which have measured angular distributions of the reaction products in this energy region.[6] Attempts have been made to explain proton and neutron angular distribution data by either a compound-nucleus reaction mechanism[7] or a direct interaction mechanism.[8] A knowledge of the elastic deuteron cross section would clearly be very useful in attempting to fit the data, regardless of the assumption made for the reaction mechanism. In addition, in another experiment[9] at this laboratory, the polarization of the neutrons from the $N^{14}(d,n_0)O^{15}$ reaction has been measured. The information obtained from the present experiment was of particular use in attempting to fit the polarization data.

2. EXPERIMENTAL TECHNIQUES

The experimental equipment used for the measurement of the $N^{14}(d,d)N^{14}$ absolute cross sections has been described in detail in a previous paper.[10] In brief, a magnetically analyzed deuteron beam from The Ohio State University electrostatic accelerator bombarded a N^{14} gas target contained in a differentially pumped gas scattering chamber. The target length was defined by two precisely machined slits. The target thickness ranged from 0.8 to 5.8 keV, depending on the bombarding energy and angle of observation. The scattered deuterons were detected with a 300-Ω-cm surface-barrier detector. Typical pulse-height distributions at 685 and 1940 keV are shown in Fig. 1. As can be seen from Fig. 1, at higher energies it was sometimes necessary to subtract a background arising from other reaction particles in order to obtain the number of scattered deuterons. The uncertainties in the absolute cross section from the background subtraction amount to $\pm 6\%$ at most. The error in the relative cross sections should be substantially less than this. In general, where the elastic deuterons were well resolved or where the

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1 F. Ajzenberg-Selove and T. Lauritsen, Nucl. Phys. **11**, 1 (1959). *Nuclear Data Sheets*, compiled by K. Way *et al.* (Printing and Publishing Office National Academy of Sciences—National Research Council, Washington 25, D. C.) NRC 61-5,6-231. O. F. Nemets, F. Picard, L. I. Slusarenko, and V. V. Tokarevsky, Zh. Eksperim. i Teor. Fiz. **45**, 850 (1964) [English transl.: Soviet Phys.—JETP **18**, 583 (1964)].

2 B. M. Penfold and A. S. Spicer, Phys. Rev. **100**, 1377 (1955). F. W. K. Firk and K. H. Lokan, Phys. Rev. Letters **8**, 321 (1962). R. L. Bramblett, J. T. Caldwell, R. R. Harvey, and S. C. Fultz, Phys. Rev. **133**, B869 (1964).

3 N. W. Tanner, G. C. Thomas, and E. D. Earle, Nucl. Phys. **52**, 45 (1964).

4 M. Suffert, G. Costa, and D. Magnac-Valette. *Proceedings of the Conference on Direct Interactions and Nuclear Reaction Mechanisms* (Gordon and Breach, Science Publishers, Inc., New York, 1963), p. 842.

5 G. E. Brown and M. Bolsterli, Phys. Rev. Letters **3**, 472 (1959). V. Gillet, Ph.D. thesis, University of Paris, 1962 (unpublished). V. Gillet and N. Vinh-Mau, Phys. Letters **1**, 25 (1962).

6 See F. Ajzenberg-Selove and T. Lauritsen, Ref. 1 and *Nuclear Data Sheets*, Ref. 1.

7 D. L. Booth, F. V. Price. D. Roaf, and G. L. Salmon, Proc. Phys. Soc. (London) **71**, 325 (1958). W. M. Jones, D. G. Waters, and V. M. Rout, Nucl. Phys. **26**, 203 (1961).

8 J. L. Weil and K. W. Jones, Phys. Rev. **112**, 1975 (1958); Theo Retz-Schmidt and Jesse L. Weil, *ibid.* **119**, 1079 (1960); Serge Gorodetzky, Pierre Fintz, and André Gallmann, Compt. Rend. **255**, 879 (1962).

9 H. M. Epstein, Ph.D. thesis, The Ohio State University, 1962 (unpublished), H. M. Epstein, D. F. Herring, and K. W. Jones, Phys. Rev. **136**, B131 (1964).

10 R. F. Seiler, C. H. Jones, W. J. Anzick, D. F. Herring, and K. W. Jones, Nucl. Phys. **45**, 647 (1963).

elastic cross section was substantially larger than the reaction cross sections, the estimated errors on the cross sections are about $\pm 3\%$. The uncertainties in the energy scale are about ± 10 keV.

3. EXPERIMENTAL RESULTS

The $N^{14}(d,d)N^{14}$ elastic-scattering cross section was first measured as a function of energy at the maximum obtainable laboratory angle, $\theta_{lab}=164.25°$. At this angle the low-order Legendre polynomials are approaching their maximum values and resonance effects in the scattering are most pronounced. Data were taken in approximately 5-keV steps, which corresponds roughly to the target thickness used. Excitation functions were also measured for center-of-mass angles of 90° where all odd Legendre polynomials vanish, for 125.3° where P_2 vanishes, and for 140.8° where P_3 vanishes. The results are shown in Fig. 2. The estimated probable error is $\pm 3\%$ on data below 1.9 MeV and $\pm 6\%$ above 1.9 MeV.

From examination of the 164.25° yield curve it can be seen that there is no evidence for the presence of any narrow levels. For this reason it was decided to take data in the form of angular distributions at 200-keV intervals from 700 to 2100 keV, the highest energy available to us. Figure 3 shows the measured angular distributions plotted as the ratio of the measured cross section to the Rutherford cross section. The error bars show typical probable errors in the ratio.

4. ANALYSIS OF DATA

Attempts to fit the observed cross sections were made from two points of view, the compound-nucleus model and the optical model. The compound-nucleus calculations were inconclusive because of the complexity of the scattering formalism for spin 1 on spin 1 and because it appeared that at least three levels should be considered. Good fits were obtained with the optical-model calculations, although there were a number of sets of parameters which could fit the data reasonably well in this energy region.

4.1 Compound-Nucleus Calculations

Two features of the experimental data shown in Figs. 2 and 3 deserve comment. First, narrow resonances are not apparent in the excitation functions even though experimental work[2,3] and theoretical work[5] indicate that narrow levels in O^{16} exist in this energy region. It may be that the deuteron width for these levels is too small for them to be seen in the $N^{14}(d,d)N^{14}$ cross section or that an isotopic spin selection rule is important.

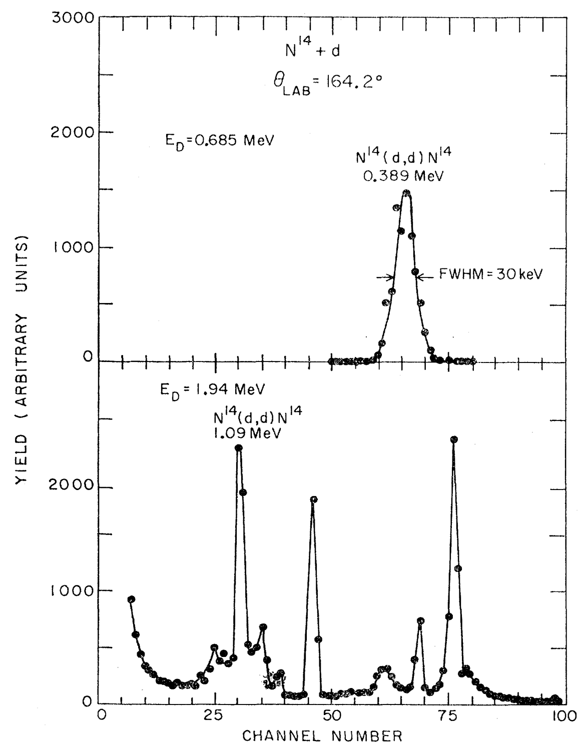

FIG. 1. Typical pulse-height spectra obtained from the bombardment of N^{14} by deuterons showing the region around the elastic deuteron peak.

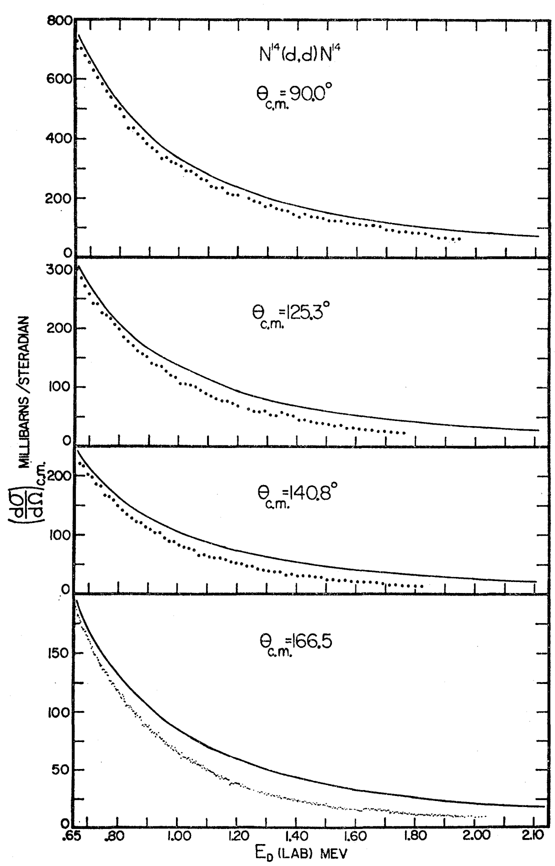

FIG. 2. Excitation curves for $N^{14}(d,d)N^{14}$. The angles of observation are shown in the figure. The solid curves give the calculated Rutherford cross section.

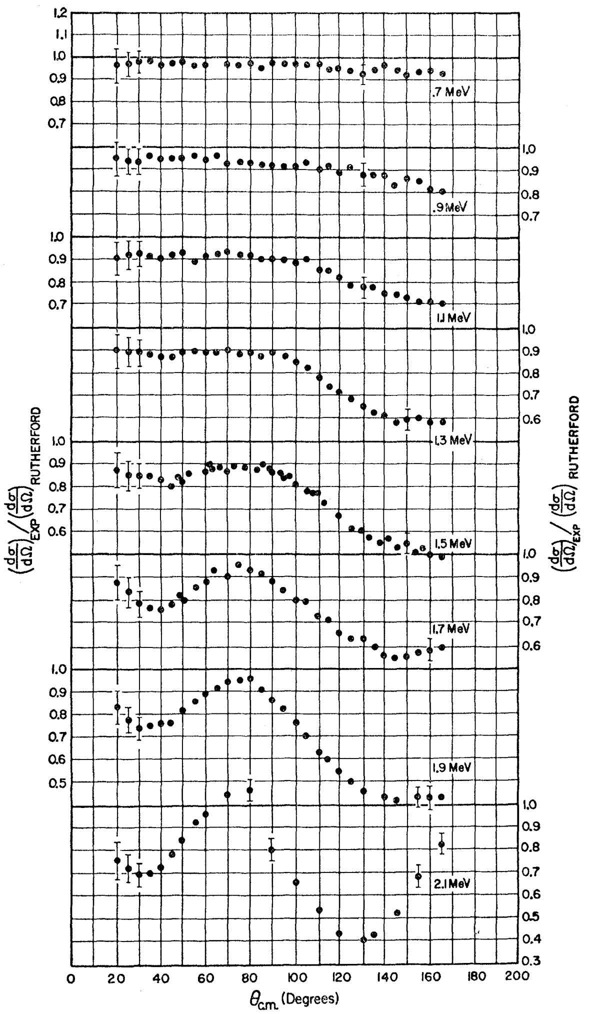

FIG. 3. Angular distributions for $N^{14}(d,d)N^{14}$ plotted as the ratio of the measured cross section to the Rutherford cross section. The error bars show typical probable errors in the ratio.

The second feature of interest is that the strong destructive interference seen at $\theta_{c.m.}=166.5°$ (Fig. 2) is still present in the $\theta_{c.m.}=90°$ data. The destructive interference at 90° can be explained only by the presence of an even parity level. However, an even-parity level (either $l=0$ or $l=2$) would give constructive interference at $\theta_{c.m.}=166.5°$. For this reason, a single level of even parity cannot fit the data.

Several attempts, which have been discussed in detail elsewhere,[11] were made to explain the data assuming two levels. Here we summarize the salient points of the discussion given in Ref. 11. The general shape of the angular distributions shown in Fig. 3 can be explained only if one of the assumed levels is of even parity and the other odd. However, it is not possible to obtain anything but a very poor fit assuming two levels. It was found that in order to obtain the dip characteristic of the data at forward angles, one had to use parameters which forced the cross section well above the data at the back angles. Conversely, a choice of parameters which fit the data at the back angles could not explain the dip at the forward angles. Since the attempts to fit the data assuming two levels did not succeed and because the task of fitting the data assuming three or more levels appeared too formidable, the attempts to explain the cross sections using the compound-nucleus model were abandoned.

4.2 Optical-Model Calculations

Another approach to the fitting of the scattering data is to apply the optical model. It is observed that the cross section varies slowly with energy and that the large number of energetically possible reaction channels for the (d,α), (d,p) ,and (d,n) reactions should make the compound elastic-scattering contribution small.

Fits to the experimental data were calculated with a digital computer using the parameter search programs of Drisko, Bassel, and Satchler.[12] The program employs a Gaussian least-squares calculation to seek the optical-model parameters which give the best fit to the data. The optical-model potential is of the form

$$V(r)=V_c(r)-Uf(r)-iWg(r)-U_s\frac{1}{r}\frac{df(r)}{dr}\mathbf{L}\cdot\mathbf{S},$$

where $V_c(r)$ is the Coulomb potential, U and W are the strengths of the real and imaginary potentials, $f(r)$ and $g(r)$ are form factors, and U_s is the strength of the vector spin-orbit potential. The present calculations employed a Woods-Saxon form factor for the real potential and several different options for the imaginary form factor. The following options were used:

$$g(r)=f(r)=\left[1+\exp\left(\frac{r-R}{a}\right)\right]^{-1}\text{ with }U_s=0\,,\ \text{(option 1)},$$

$$f(r)=\left[1+\exp\left(\frac{r-R}{a}\right)\right]^{-1}\ g(r)=\frac{d}{dr}\left[1+\exp\left(\frac{r-R_W}{a_W}\right)\right]^{-1}$$

$$\text{with}\quad U_s=0,\quad \text{(option 2)}$$

$$g(r)=f(r)=\left[1+\exp\left(\frac{r-R}{a}\right)\right]^{-1}$$

$$\text{with}\quad U_s=0.\quad \text{(option 3)}$$

For all three cases the nuclear radius was assumed to be given by $R=r_0A^{1/3}$. Coulomb effects were assumed to be accounted for by a sphere with uniform charge density and a radius given by $R_c=r_cA^{1/3}$.

For the first calculations, form factors given in

[11] R. F. Seiler, Ph.D. thesis, The Ohio State University, 1963 (unpublished).

[12] R. M. Drisko, R. H. Bassel, and G. R. Satchler (unpublished).

option 1 were used. The initial parameters chosen were $U=50$ MeV, $W=6$ MeV, $r_0=r_c=1.3$ F, and $a=0.65$ F. Fits to the data were not approached until U had decreased to the order of 20 MeV and r_0 had increased to nearly 2 F. It was found that the best fits could be obtained with an average value of $r_0=1.95$ F. Fixing r_0 and r_c at this value, searches were conducted on the other parameters, and, as a last step, the radii were allowed to vary. It was found that the final searches over the radii did not appreciably change the fits obtained for fixed radii and, further, that the radii themselves did not change appreciably from the fixed value unless the change was accompanied by a corresponding change in the potential strengths. This radius-strength ambiguity seemed to be characteristic of nearly all the calculations attempted at any particular energy, but the only set of parameters which gave a reasonably good fit over all energies included values of the radii near 1.95 F and values of U and W near 19.7 and 4.59 MeV, respectively. A comparison of the calculated cross section with the data is shown in Fig. 4 for the parameters shown in the caption. The parameters listed in the caption gave the best fit to the group of eight angular distributions.

It was decided to fix the well radii at $r_0=r_c=1.95$ F

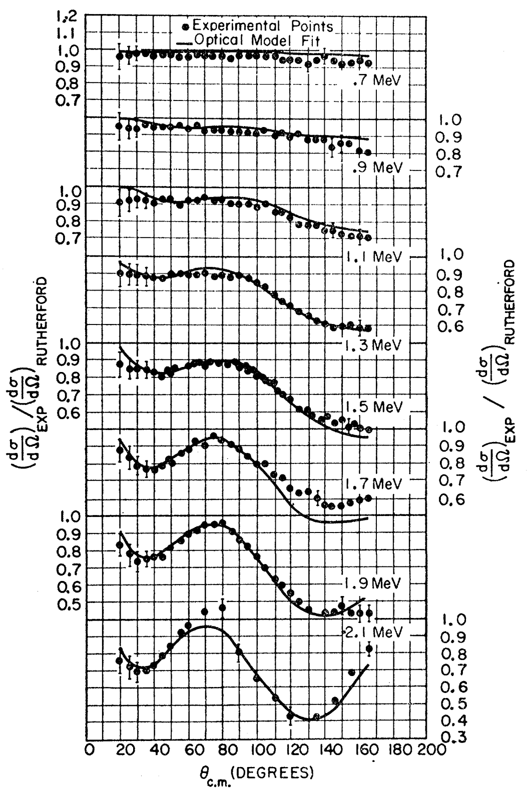

FIG. 4. Optical-model fits to the $N^{14}(d,d)N^{14}$ angular distributions with volume absorption. A single set of optical parameters was used: $U=19.7$ MeV, $W=4.59$ MeV, $r_0=r_c=1.95$ F, $a=0.728$ F, and the form factors given in option 1.

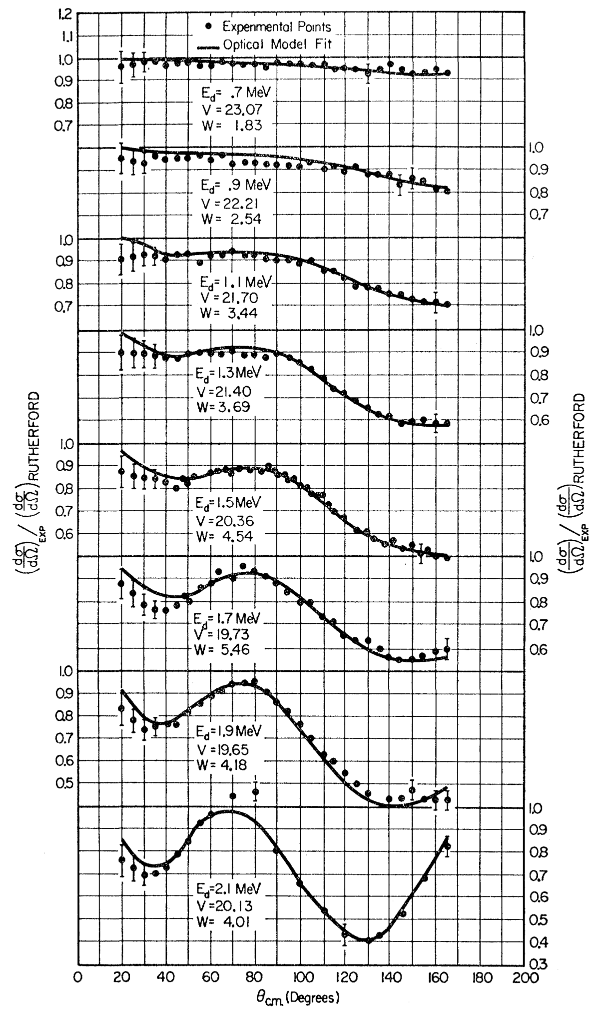

FIG. 5. Comparison of the data with optical-model calculation with volume absorption. The geometry was fixed and the potential strengths were adjusted to obtain the best fit at each energy. The potential strengths thus obtained are shown in the figure.

and the diffuseness at $a=0.728$ F, and adjust the strengths of the potentials to obtain the best fit at each energy. The fits obtained in this fashion are shown in Fig. 5. It was found, as shown in Fig. 6, that the variation in the strength is large (over 20%) for the bombarding energy range covered, and that there is an anomalous behavior of the strengths in the vicinity of 1.7-MeV bombarding energy. It may be that compound elastic effects are particularly important around this energy and that these effects can be compensated for by changing the strengths of the optical potential. There is a rather broad peak seen in the $N^{14}(d,n_0)O^{15}$ zero-degree yield curve at about 1.5 MeV and a strong state in O^{16} is observed in the $O^{16}(\gamma,n)O^{15}$ reaction[2] at an excitation energy in O^{16} equivalent to a state produced by 1.7-MeV deuterons on N^{14}.

Calculations were also performed using the derivative

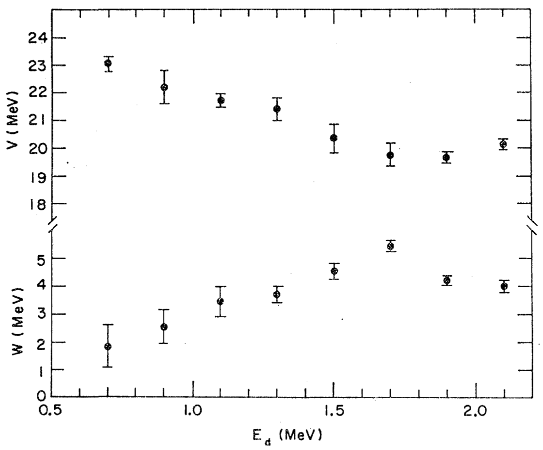

FIG. 6. Optical potentials with volume absorption for best fits to the $N^{14}(d,d)N^{14}$ angular distributions. U and W were adjusted for best fits at each energy with $r_0=r_c=1.95$ F, $a=0.728$ F, and the form factors given in option 1. The error bars show the approximate range of variation for about the same fit to the angular distributions.

form for the imaginary part of the potential given in option 2. The surface absorption calculations produced somewhat better fits to the data, as would be expected since the number of parameters involved has been increased from four to six. However, the variation of the parameters with energy was just as marked as with the volume absorption parameters. The well strengths again present anomalous behavior in the region of 1.7 MeV. Taking what appeared to be a reasonable set of average values for the parameters, fits were calculated to the data. The greatest departures from good fits come again in the region near 1.7 MeV. The fits to the data obtained with the single set of parameters using option 2 are shown in Fig. 7.

The effect of the spin-orbit term in the optical potential was investigated for both surface and volume absorption. It was found that the fits to the data could be improved, but at the cost of a large variation in the parameters. It was possible to fit the data to within experimental error for all eight angular distributions with the exception of the 2.1-MeV data near 80 deg, where the fit was about 5% outside the experimental error. The spin-orbit strengths required to make these fits, however, vary from 0.14 to 39 MeV. The fits to the angular distributions for a fixed set of parameters were also calculated for both cases. Figure 8 shows the fits obtained with volume absorption and a spin-orbit strength of 8 MeV. The inclusion of a spin-orbit potential does not appear to be necessary to fit the present elastic data. Perey and Perey[13] have pointed out that, at least in some cases, the effects produced by a vector spin-orbit potential can be compensated for by small changes in the central potentials.

It has been pointed out[13,14] that a number of ambiguities exist in the strengths of the optical potentials. We made no extensive effort to search for other strengths which would also fit the data, but did carry out some calculations at four energies with the form factors of option 2 and $U\approx 85$ MeV, $W\approx 22$ MeV, and radii of about 1.3 F. The fits obtained were clearly inferior to the one obtained with the weaker potentials, but the general form of the angular distribution was reproduced moderately well.

5. RESULTS AND CONCLUSIONS

The lack of success in fitting the data with the compound-nucleus calculation in not at all surprising in view of the complexity of the calculations. A better

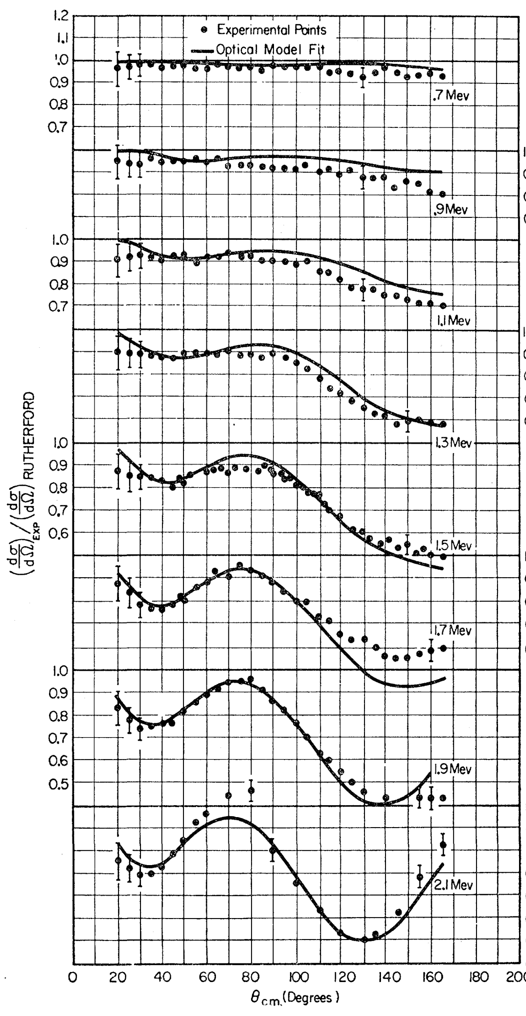

FIG. 7. Optical-model fits to the $N^{14}(d,d)N^{14}$ angular distributions with surface absorption. The parameters used were $U=18.9$ MeV, $W_d=15.09$ MeV, $r_0=r_c=1.95$ F, $r_W=1.76$ F, $a=0.728$ F, $a_W=0.877$ F, and the form factors listed in option 2.

[13] C. M. Perey and F. G. Perey, Phys. Rev. 132, 755 (1963).

[14] R. M. Drisko, G. R. Satchler, and R. H. Bassel, Phys. Letters 5, 347 (1963).

phase-shift analysis and more data on the reaction cross sections would no doubt make possible a greatly improved fit. We conclude from qualitative arguments that at least two broad levels with opposite parity are needed to explain the data. If narrow levels exist in this energy region, we estimate from our data that $\Gamma_d/\Gamma<0.05$ or that $\Gamma<5$ keV.

We have seen that it is possible to fit the elastic scattering of deuterons by N^{14} in the energy range below 2 MeV using the optical model, although it is not possible to determine the optical-model parameters uniquely. The small well depths and the rather large values of the radii necessary for a fit are disturbing, but it may be that these features are due to compound-nucleus effects. The energy variation of the real and imaginary well depths which is required to obtain the "best fit" (see Fig. 6) at each energy may indicate the existence of a compound-nucleus level at 1.7-MeV bombarding energy.

Further evidence that the optical model is valid is seen in the comparison of the total reaction cross section with that calculated by the optical model. The total charged-particle reaction cross section was measured by integrating the angular distributions for all particles above the elastic deuterons at a bombarding energy of 1.10 MeV. Such a procedure ignores the reaction particles with energies less than the elastic deuteron energy and does not properly evalute the effect of the three-body disintegration of C^{12*} produced in the $N^{14}(d,\alpha)C^{12*}$ reaction. The total neutron reaction cross section for the $N^{14}(d,n)O^{15}$ reactions[15] was found by measuring the residual O^{15} activity after bombardment of a N^{14} gas target. The results of these measurements give a value of 420 ± 80 mb for the total reaction cross section. The optical-model calculations with the best-fit parameters listed in the captions for Figs. 4, 7, and 8 give 418, 410, and 412 mb, respectively. The agreement between the measured and calculated cross sections does support the application of the optical model, but it does not help to distinguish between the various forms of potentials used.

Measurements of the $N^{14}(d,n_0)O^{15}$ angular distributions have been made below 2-MeV bombarding energy by several groups[6] and the neutron polarization at 1.32 MeV was measured by Epstein *et al.*[9] The angular distribution data has been interpreted in terms of compound nucleus formation[7] and in terms of plane-wave plus heavy-particle stripping.[8] Epstein *et al.*, were able to explain their data equally well using either the compound nucleus or direct interaction mechanisms.

If one assumes that the direct interaction mechanism dominates the $N^{14}(d,n_0)O^{15}$ reaction at this energy, then the analysis of Epstein *et al.*, suggests that the deeper potentials mentioned above ($U\approx85$ MeV and $W\approx22$ MeV) are to be preferred to the shallower ones that give the best fits for the elastic scattering. The deeper potential gives a fair fit to the elastic data and significantly better fits to the polarization and angular distribution data. However, Epstein *et al.*, used the SALLY code of Bassel, Drisko, and Satchler[16] for their calculations. This code does not include spin-orbit interactions, and such an omission is certainly not realistic, particularly for the polarization calculations. Epstein *et al.*, also did not consider in detail the effects produced by the inclusion of the nuclear interiors. Recent calculations[17] have shown that optical potentials with different depths will give the same angular distributions if a radial cutoff is used. If the argument that the nuclear interior is of dubious importance because of the weak binding of the deuteron is reasonable, then the differences in the angular distributions and

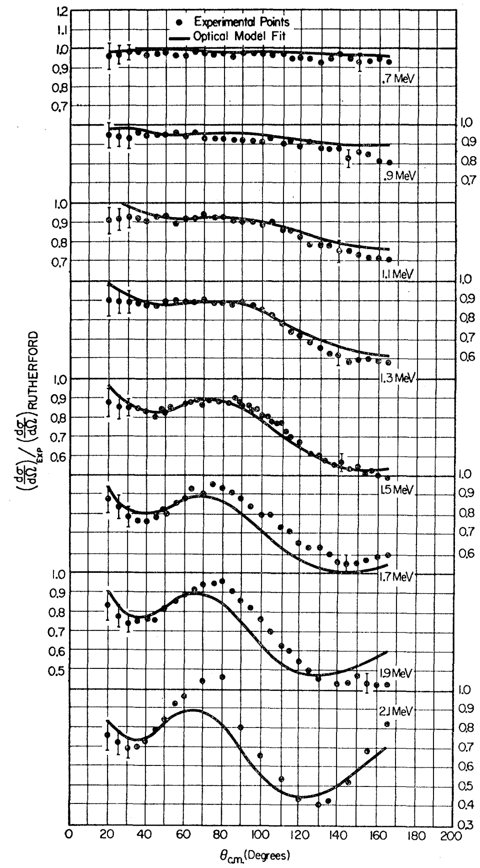

FIG. 8. Optical-model fits to the $N^{14}(d,d)N^{14}$ angular distributions with volume absorption and a vector spin-orbit potential. The parameters used were: $U=19.71$ MeV, $W=4.59$ MeV, $U_s=8.0$ MeV, $r_0=r_c=1.95$ F, $a=0.728$ F, and the form factors listed in option 3.

[15] C. E. Durbin, M. S. thesis, The Ohio State University, 1963 (unpublished).

[16] R. H. Bassel, R. M. Drisko, and G. R. Satchler, ORNL-3240, 1962 (unpublished).

[17] G. R. Satchler, *Proceedings of the Conference on Direct Interactions and Nuclear Reaction Mechanisms* (Gordon and Breach Publishers, Inc., New York, 1963), p. 80.

polarizations obtained with the two potentials would not necessarily be physically significant.

ACKNOWLEDGMENTS

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(α,n) Reactions in Some Elements in the Region of $A=100$*

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Absolute (α, n) cross sections and angular distributions from 0 to 160° have been measured for Y, Nb, Rh, Ag, Ag^{109}, and In, from 12 to 18 MeV. The angular distributions show almost complete isotropy, with a systematic trend toward a forward peaking never larger than 5 to 10%. Since, in these elements, neutron emission is expected to be the main contribution to the reaction cross section, the measured (α, n) cross sections have been compared with the predictions of the optical model. Different optical-model potentials for α particles have been tried. Very good agreement with the experimental results has been obtained with the "Igo potential." Reaction cross sections for a square-well potential following Shapiro's calculation for a radius $(1.7\,A^{1/3}+1.21)$ F appear to be in the right order of magnitude, but they do not reproduce the dependence of the excitation function on the incident α energy.

INTRODUCTION

TOTAL reaction cross sections for α particles from 0 to 46 MeV have been predicted by Igo *et al.*[1,2] for a wide range of nuclei using an optical model in which the parameters of the complex potential were obtained from the elastic scattering of α particles.[3,4] The experimental information available on α-reaction cross sections has until now been very scarce. Igo[5] has measured the reaction cross section for α particles at 40 MeV. Recently, Stelson *et al.*[6] have done a systematic study of (α,n) cross sections to 11 MeV from Ni to Ag, setting a lower limit to the α-reaction cross section.

It is of interest to extend these measurements to higher energies and for nuclei where the α cross section for the emission of charged particles is negligible, such that the measured (α,n) cross sections are indeed a check of the predicted total reaction cross sections.

Early work in (α,n) reactions for nuclei of A around 100 was done by Bradt *et al.*[7] in 1947. They measured the (α,n) and $(\alpha,2n)$ cross sections for Rh^{103} and Ag^{109} from 11 to 18 MeV. Goshal[8] in 1948 measured the (α,n), $(\alpha,2n)$ and $(\alpha,3n)$ in natural silver from threshold to 37 MeV, and Temmer[9] in 1949 measured these same cross sections in In^{115}. In all these measurements, done by activation, no absolute cross sections were obtained. Furthermore, the use of range-energy calculation, already out of data, makes it difficult to compare their results with theory.

Bleuler *et al.*[10] in 1953 measured $\sigma(\alpha,n)$ and $\sigma(\alpha,2n)$ in Ag^{109} by activation. They are the first ones to give absolute values for the cross sections. In 1955 Porges[11] measured $\sigma(\alpha,n)$, $\sigma(\alpha,2n)$, and $\sigma(\alpha,pn)$ for Ag^{107} and $(\alpha,2n)$ and $(\alpha,3n)$ in Ag^{109} up to 40 MeV.

In the present work angular distributions and absolute $\sigma(\alpha,n)$ have been measured from 12 to 18 MeV for Y, Nb, Rh, Ag, Ag^{109}, and In. These cross sections have been compared with the predictions of Igo *et al.*[1] with very good agreement. Comparisons have also been made with the reaction cross-section calculation using the optical-model parameters given by Glassgold[12] to fit the elastic scattering of α in Ag at 22 MeV and with the parameters used by Bassel[13] to fit $\sigma(\alpha,\alpha')$ in Ni^{58}.

The calculations of Shapiro *et al.*[14] for α-reaction cross

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

[1] George Igo, Phys. Rev. **115**, 1665 (1959).
[2] J. R. Huizenga and George Igo, Nucl. Phys. **29**, 462 (1962).
[3] D. D. Kerlee, J. S. Blair, and G. W. Farwell, Phys. Rev. **107**, 1343 (1957).
[4] L. Seidlitz, E. Bleuler, and D. J. Tendam, Phys. Rev. **110**, 682 (1957).
[5] G. Igo and B. D. Wilkins, Phys. Rev. **131**, 1251 (1963).
[6] P. H. Stelson and F. K. McGowan, Phys. Rev. **133**, B911 (1964).
[7] H. L. Bradt and D. J. Tendam, Phys. Rev. **72**, 117 (1947).
[8] S. A. Ghoshal, Phys. Rev. **73**, 417 (1948).
[9] G. M. Temmer, Phys. Rev. **76**, 424 (1949).
[10] E. Bleuler, A. K. Stebbins, and D. J. Tendam, Phys. Rev. **90**, 460 (1953).
[11] K. G. Porges, Phys. Rev. **101**, 225 (1956).
[12] W. B. Cheston and A. E. Glassgold, Phys. Rev. **106**, 1215 (1957).
[13] R. H. Bassel, G. R. Satchler, R. M. Drisko, and E. Rost, Phys. Rev. **128**, 2693 (1962).
[14] M. M. Shapiro, Phys. Rev. **90**, 171 (1953).