of Zn^{68}, causes it to give an unusually large contribution to the thermal capture cross section. The value of Γ_γ that is obtained for this somewhat arbitrary weighting of resonance contributions is 0.35 ev.

For comparison with the predictions of the "cloudy crystal ball" model of the nucleus, it is desirable to try to obtain a value for the strength function $\bar{\Gamma}_n^0/\bar{D}$ for the zinc isotopes; $\bar{\Gamma}_n^0$ is the average reduced neutron width and $\bar{D}$ is the average level spacing per spin state. Because of the small number of resonances that were observed, Zn^{67} is the only individual isotope for which such a calculation is at all meaningful. Referring again to Table II, we see that at least four resonances were observed in Zn^{67}. The fact that the two transmission dips observed at 1620 and 2300 ev may not be due to single resonances causes no difficulty in the present case; for an energy interval ΔE containing many resonances, $\bar{\Gamma}_n^0/\bar{D}$ is equal to $(1/\Delta E)\sum_r(g\Gamma_n^0)_r$, and for scattering resonances a transmission dip gives the correct value of $\sum_g \Gamma_n$, independent of the number of resonances causing it.

The Zn^{67} data are thought to be reliable, in the above sense, over the range 0–3000 ev. For this energy range, then, $\bar{\Gamma}_n^0/\bar{D}$ is found to be 3.1×10^{-4} ev$^{-\frac{1}{2}}$. This value of $\bar{\Gamma}_n^0/\bar{D}$ is somewhat higher than those of neighboring nuclei,[8] although the difference may not be statistically significant. Its disagreement with the predictions of the cloudy crystal ball theory for a simple square-well potential seems to be real, however. For a well having the parameters[9] $V_0=43.5$ Mev and $\zeta=0.03$, the equations on page 456 of reference 6 give $\bar{\Gamma}_n^0/\bar{D}=0.3\times10^{-4}$ for $A=67$. It is most unlikely that a statistical fluctuation or adjustment of well parameters could account for the factor of 10 by which the calculated and measured values of $\bar{\Gamma}_n^0/\bar{D}$ differ.

[8] Argonne values of $\bar{\Gamma}_n^0/\bar{D}$ for light nuclei were summarized by V. F. Weisskopf, *International Conference on the Peaceful Uses of Atomic Energy, Geneva, 1955* (United Nations Publication, New York, 1956), Vol. 2, p. 27.

[9] The data on $\bar{\Gamma}_n^0/\bar{D}$ for A between 45 and 65 are best fitted by a well depth of 43.5 Mev. R. E. Cote and L. M. Bollinger, Phys. Rev. **98**, 1162 (1955).

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Differential Cross Sections for $C^{12}(d,d)C^{12}$ and $C^{12}(d,p)C^{13}$†

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Differential cross sections have been measured as a function of incident deuteron energy for elastic scattering and for the (d,p) reactions to the ground and 3.09-Mev levels of C^{13}. The cross sections have been measured at several angles from 25° (c.m.) to 169° (c.m.) in the deuteron energy range of 1.9 to 3.4 Mev and have an average accuracy of about 5%. Eleven angular distributions were also taken, nine for the reaction $C^{12}(d,p)C^{13}$ and two for the reaction $C^{12}(d,p)C^{13*}$. Many resonances were observed in the elastic scattering, and resonances observed in the (d,p) reactions corresponded to several of these. Interference between the stripping and compound nuclear contributions to the (d,p) reaction is clearly indicated.

INTRODUCTION

THE use of (d,p) and (d,n) reactions as a spectroscopic tool for nuclear states was established by the work of Butler and others.[1] Recently considerable theoretical and experimental emphasis has been placed upon the investigation of the mechanism of these reactions, and in particular upon the deviations of the reaction cross sections from the pure stripping formalism of Butler.[2–4] A particular feature of interest receiving attention from both theory and experiment is the competition between compound nucleus formation and stripping.[4–6] The present investigation has been carried out in an effort to study in detail this competition. In addition, since the magnitudes of the cross sections are sensitive to details of the mechanism of the reaction, care has been taken to obtain reliable absolute cross sections.

C^{12} was selected as the target for deuteron bombardment for several reasons: (1) Since accurate knowledge of the target thickness was essential, it was desirable to use a gas target. Hydrocarbon gases of high purity are readily available and provide excellent carbon targets. (2) At low energies the $C^{12}(d,p)C^{13}$ reaction had been

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[1] S. T. Butler, Proc. Roy. Soc. (London) **A208**, 559 (1951); Bhatia, Huang, Huby, and Newn, Phil. Mag. **43**, 485 (1952).

[2] J. Horowitz and A. M. L. Messiah, J. phys radium **14**, 695 (1953); N. C. Francis and K. M. Watson, Phys. Rev. **93**, 313 (1954).

[3] W. Tobocman, Phys. Rev. **94**, 1655 (1954); W. Tobocman and M. H. Kalos, Phys. Rev. **97**, 132 (1955).

[4] I. P. Grant, Proc. Phys. Soc. (London) **A67**, 981 (1954); R. G. Thomas, Phys. Rev. **100**, 25 (1955).

[5] Stratton, Blair, Famularo, and Stuart, Phys. Rev. **98**, 629 (1955); Berthelot, Cohen, Cotoon, Faraggi, Grjebine, Leveque, Naggiar, Roclawski, Conjeaud, and Szteinsnaider, Compt. rend. **238**, 1312 (1954).

[6] Bonner, Eisinger, Kraus, and Marion, Phys. Rev. **101**, 209 (1956).

shown[7] to exhibit pronounced resonance structure, characteristic of compound nucleus formation. It was felt that the competition between compound nucleus formation and stripping could be most definitively investigated near a compound nuclear resonance, since the formal treatment of "isolated" resonances is well established.[8] (3) Since C^{12} is $J=0^+$, and since C^{13} ground state and first excited state are $J=\frac{1}{2}^-$ and $J=\frac{1}{2}^+$, respectively, we have the simplest possible combination of spins for (d,p) reactions on a single target. This simplicity should aid in data analysis.

The present investigation was carried out in two separate experiments, henceforth referred to as Part I and Part II. Both experiments were carried out with the same basic equipment, but were separated in time by a period of six months. Part I[9] concentrated on the $C^{12}(d,p)C^{13}$ reaction. The purpose of this part was to check the performance of the equipment and to obtain differential cross sections of good precision over a wide range of energies and angles, and in particular to study the detailed dependence of the angular distributions on energy. The measurements located some strong resonances in the (d,p) cross section which were reasonably well separated from one another. Part II[10] was a detailed study of the differential cross sections for three processes, $C^{12}(d,p)C^{13}$ to the ground state of C^{13}, $C^{12}(d,p)C^{13*}$ to the first excited state of C^{13}, and $C^{12}(d,d)C^{12}$ elastic scattering, at and near a few selected resonances.

EXPERIMENTAL ARRANGEMENT

The details of the equipment used for this experiment will be described in a separate publication,[11] and therefore we include only a schematic description here. The measurements were conducted in a large, differentially pumped gas chamber. A rough sketch of the equipment, as it was used for Part II of the investigation, is shown in Fig. 1. The chamber is $1.2\times1.5\times0.24$ meters. The incident beam is defined by the slits of the collimator to have an angular spread of ±12 minutes. The detector is mounted behind the slit system on the movable arm. This system defines the acceptance angle, gas target length and solid angle seen by the detector. For this system, the acceptance angle was $\pm2.5°$ and the solid angle was approximately 10^{-3} steradian.

During Part I, a large ion chamber was used as detector in place of the proportional counter shown in Fig. 1. Also a six-position absorber changer was

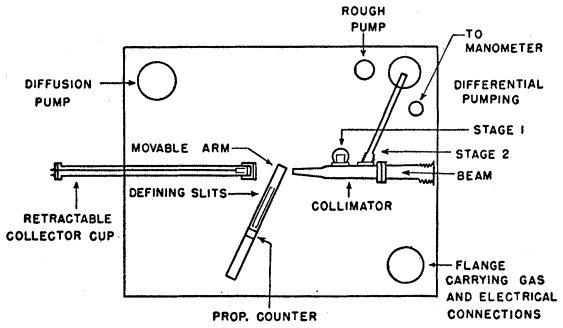

FIG. 1. Schematic diagram of scattering chamber as it was used for Part II. Chamber is 4 ft×5 ft in area, $8\frac{3}{4}$ in. deep. For Part I, the proportional counter was replaced by a large ion chamber.

located before the detector. This arrangement allowed any of four foils, a thick aluminum plate, or no absorber to be positioned in the path of the reaction products. The size of the ion chamber was such that it prevented accurate collection of the incident beam by the collector cup at detector angles $<65°$. Therefore a proportional counter was fixed at 90° to monitor the incident beam for detector angles $<70°$. It was biased to record all three groups measured in detail in Part II.

Several modifications were made for Part II. The proportional counter shown (Fig. 1) was substituted for the ion chamber, and the foil changer was repositioned. These changes allowed the collection of the incident beam for all detector angles from 11° to 167°. Therefore a monitor counter was not necessary. In addition, a pressure control system designed by one of us (D.F.H.) was added to maintain a constant target gas pressure.[11,12] This instrument held the pressure constant to within $\pm0.05\%$.

The incident beam from the electrostatic generator had an energy resolution of $\pm0.1\%$. The target gas used was propane[13] of the "extra-pure" grade (contamination $<0.1\%$) and also (in Part I) iso-butane[13] of the same grade.

EXPERIMENTAL PROCEDURE

The method of taking data and calibrating the equipment was the same for both parts of the investigation, except that during Part I greater emphasis was placed upon obtaining angular distributions in some detail, whereas in Part II the data were almost entirely taken in the form of excitation curves.

For part I, a Ta foil of about 1 mil thickness was placed before the ion chamber window, so that only the protons from the $C^{12}(d,p)C^{13}$ reaction would have sufficient energy to pass into the ion chamber and be counted. For this arrangement some uncertainty in cross section was encountered, because the pulse-height spectrum of the ion chamber had a long, low tail similar

[7] Heydenburg, Inglis, Whitehead, and Hafner, Phys. Rev. **75**, 1147 (1949).
[8] E. P. Wigner and L. Eisenbud, Phys. Rev. **72**, 29 (1947); T. Teichmann and E. P. Wigner, Phys. Rev. **87**, 123 (1952).
[9] Described in greater detail in the Ph.D. thesis of K. W. Jones, University of Wisconsin, 1954 (unpublished). Jones, McEllistrem, Douglas, Herring, and Silverstein, Phys. Rev. **98**, 241(A) (1955).
[10] Described in greater detail in the Ph.D. thesis of M. T. McEllistrem, University of Wisconsin, 1955, University Microfilms, Ann Arbor, Michigan. McEllistrem, Chiba, Douglas, Herring, and Silverstein, Phys. Rev. **99**, 632(A) (1955).
[11] Jones, Herring, and McEllistrem, Rev. Sci. Instr. (to be published).
[12] D. F. Herring, Phys. Rev. **99**, 634(A) (1955).
[13] Obtained from the Matheson Chemical Company, Joliet, Illinois.

to that observed by Shire and Edge.[14] In order to obtain good separation of the back-ground and the pulse-spectrum tail, the data were continuously recorded on a 10-channel pulse-height analyzer.[15] Background counting rates were measured by placing a thick aluminum plate before the ion chamber.

For Part II, the proportional counter was operated in conjunction with approximately 20 absorbers of different thicknesses. For the $C^{12}(d,p)C^{13}$-ground state protons, a 1.5-mil Ta absorber was used to stop all other groups from entering the counter. The other two groups (elastically scattered deuterons and protons leaving C^{13} excited) were resolved in pulse height and recorded simultaneously, except at the back angle. The absorbers, counter gas pressure and counter voltage were all adjusted often to provide maximum separation of the two groups and to maintain minimum background rates. The rapid variation of optimum counter operating conditions with angle discouraged us from taking much of the data in the form of angular distributions. As in Part I, the data were continuously recorded on a 10-channel pulse-height analyzer. Both the ion chamber of Part I and the proportional counter of Part II contained argon $+5\%$ CO_2 gas mixtures purified by hot calcium ($\sim$300°C).

The incident energy was calibrated by measuring the $Li^7(p,n)Be^7$ threshold, whose energy is known to $\pm 0.06\%$,[16] with a thin Li target mounted in the center of the scattering chamber. The threshold was measured both with the chamber evacuated and filled with gas. These two measurements calibrated the energy of the incident beam, and measured the energy loss of the beam in the target gas. The target thickness seen by the detector was adjusted to be about 5 kev near 90° (c.m.) and about 10 kev at large and small angles. The excitation curves of Part I were taken in energy intervals of 30 kev and those of Part II were taken in intervals of 6 kev.

CROSS-SECTION UNCERTAINTIES

The measured yields are reduced to center-of-mass cross sections via the following relation:

$$\left(\frac{d\sigma}{d\omega}\right)_{\text{c.m.}}=\frac{Y}{NnG}(\sin\theta_{\text{lab}})\left[\frac{\sin^2\theta_{\text{lab}}}{\sin^2\theta_{\text{c.m.}}}\cos(\theta_{\text{lab}}-\theta_{\text{c.m.}})\right],$$

where Y is the measured net yield, N is the number of incident deuterons, n is the number of target nuclei/cm^3, $G/(\sin\theta_{\text{lab}})$ (in units of cm) is the solid-angle-weighted target length defined by the detection slit system. G is to a first approximation independent of angle.[17,18]

The uncertainty of the measurements is divided into a statistical component, a group separation component and other systematic uncertainties. The largest component is the statistical uncertainty on the net yield, Y. Sizable neutron backgrounds affected the statistics for both Parts I and II. For Part I, the background was usually from 10–20% of the total yield, and the statistical uncertainy on Y after background corrections ranged from 1% to 10%. For Part II, the background counting rate for the (d,p)-ground state ranged from 10% to 30%; for the elastically scattered deuterons, from 1 to 10%; for the (d,p)-3.086 Mev state, from 10 to 20%. An effort was made to obtain data for all three groups to an uncertainty of 3% (statistical+group separation), and this is the uncertainty for the scattered deuterons and the ground state protons. For the protons to the 3.086-Mev state of C^{13}, the uncertainty in Y is about 5%. Additional uncertainty entered this group at some angles because of the difficulty in separating it from the much more intense deuterons, and also from higher C^{13}-state proton groups which were not recorded.

The systematic uncertainties are very similar for the two experiments, and will be discussed in detail for Part II. An over-all check of the accuracy of the equipment and also in particular the accuracy of the angle settings was provided by measuring the p-p scattering cross sections and comparing them with the more precise values of Worthington *et al.*[18] In order to make the comparison, our p-p data have been corrected for contamination present in the target gas. Measurements indicate a contamination $\leq 0.17\%$. We have corrected the data for an assumed air contamination of 0.1%, with the additional assumption that the air contamination scattering is approximately Coulomb. Observations were made on both sides of the beam, to aid in checking angle settings. The results showed an asymmetry about 0°, which could be accounted for (at all angles) if the 0° calibration was in error. The asymmetry was completely removed by correcting this calibration 0.2°. The comparison of our (corrected)[19] measurements with those of reference 18 indicate that our measurements have a remaining uncertainty of $\pm 1.5\%$.

If we write: $(d\sigma/d\omega)_{\text{c.m.}}=(Y/NnG)A(\theta)$, then the uncertainties in N, n, and G combine to form an angle-independent systematic uncertainty.

1. G: Measurements of the dimensions of the detection slit system are made to an accuracy such that the uncertainty on G is about $\pm 0.1\%$.

2. N: Leakage of the beam collection system was measured to be about 0.04% for the incident beams of 0.2 μa. An uncertainty in N of $\pm 0.1\%$ is assigned from leakage. The integrator used was one designed by Worthington.[17,18] As used in this experiment, its operation and calibration are reliable to $\pm 0.1\%$. The con-

[14] F. S. Shire and R. D. Edge, Phil. Mag. **46**, 640 (1955).
[15] C. W. Johnstone, Nucleonics **11**, No. 1, 36 (1953).
[16] Jones, Douglas, McEllistrem, and Richards, Phys. Rev. **94**, 947 (1954).
[17] H. R. Worthington, Ph.D. thesis, University of Wisconsin, 1954 (unpublished).
[18] Worthington, McGruer, and Findley, Phys. Rev. **90**, 899 (1953).
[19] A subsequent check (by D.F.H.) of the slit alignments and angle calibration found errors sufficient to account for this discrepancy.

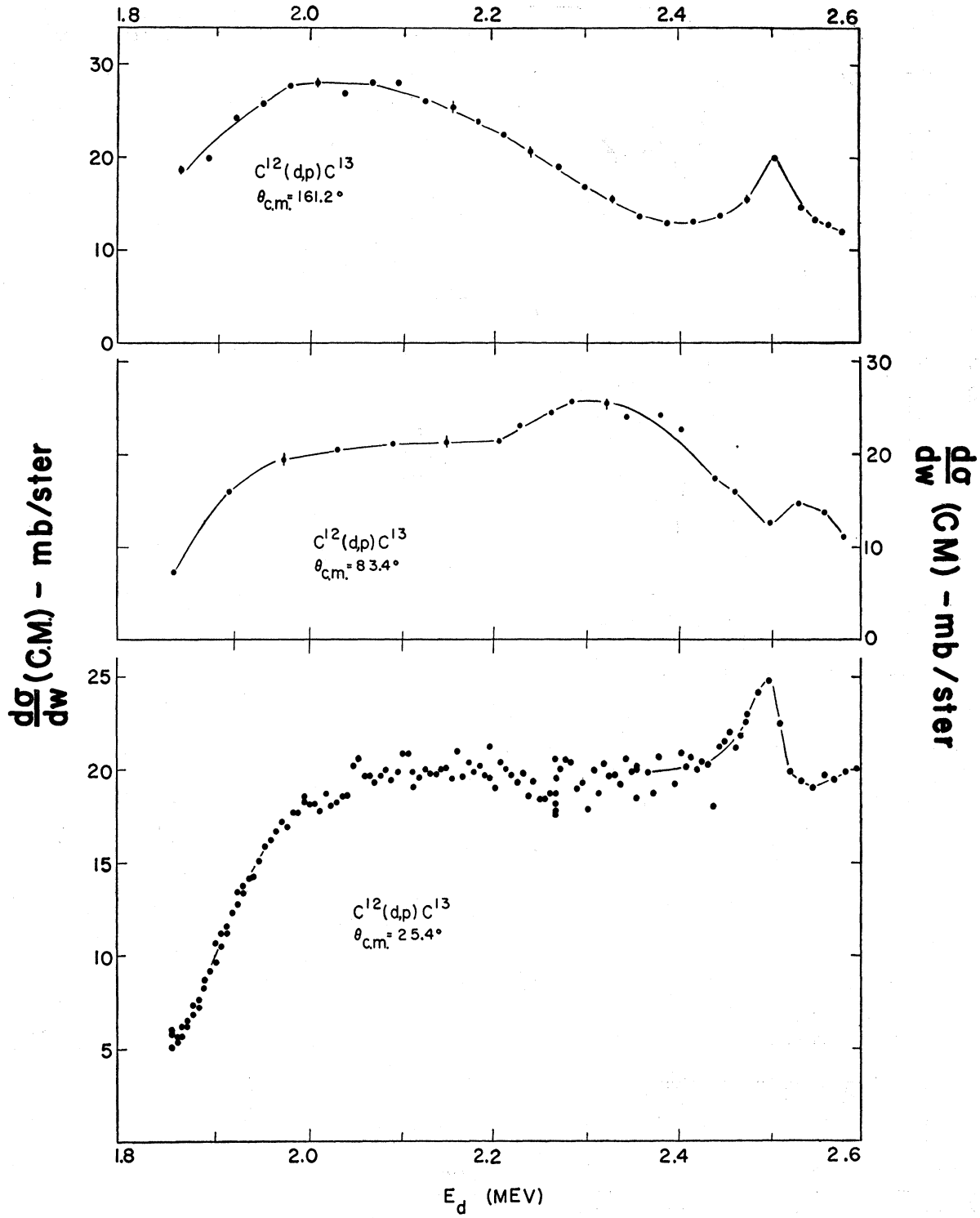

FIG. 2. Excitation curves for $C^{12}(d,p)C^{13}$-ground state reaction at various c.m. angles from Part I (top two curves) and from Part II (bottom curve).

denser calibration is accurate to $\pm 0.1\%$, and an uncertainty of 0.1% is assigned to this calibration. Since the beam traversed 50 cm of target gas before entering the collector cup, an appreciable amount of beam is scattered out of the cup's acceptance angle. The correction for this effect was calculated to be about 0.15%,[17]

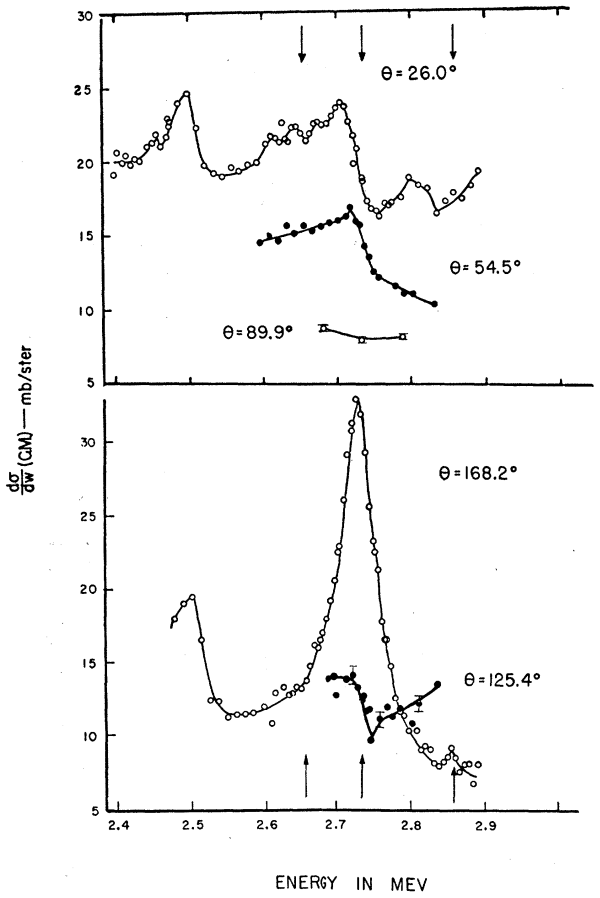

FIG. 3. Excitation curves of Part II over energy region including 2.5- and 2.74-Mev resonances for $C^{12}(d,p)C^{13}$-ground state. Note that ordinates do not begin at 0. Arrows indicate energies at which angular distributions were taken off and on "resonances."

and results in an uncertainty of $\pm 0.1\%$ in N. Therefore the total uncertainty on N is $\pm 0.4\%$.

3. n: As has been mentioned, the target gas pressure was controlled to $\pm 0.05\%$. The pressure was read with a Wild cathetometer.[20] The accuracy of the control and the accuracy of the pressure readings suggest an uncertainty of $\pm 0.25\%$. The purity of the target gas obtained from Matheson allows an uncertainty of $\pm 0.1\%$. However an additional uncertainty on n caused by air leaks must be considered. The air leaks were measured in two ways. One method was to operate the differential pumping system with the propane input shut off and then observe the equilibrium pressure caused by leaks. The other method was to close the chamber from all pumps and measure the rate of rise of the pressure in the chamber. These tests were in agreement, and suggested a contamination of $\pm 0.05\%$. No correction was made, but an uncertainty of $\pm 0.1\%$ is included because of contamination. The temperature of the target gas was measured throughout the experiment, and n was corrected for temperature variations. These corrections allow an uncertainty of 1°C or 0.3%.

TABLE I. Total rms uncertainty at various c.m. angles (in %) for measurements of Part II.

Process \ $\theta_{c.m.}$	~169°	~125°	~90°	~55°	~25°
$C^{12}(d,d)C^{12}$	4.4	5.3	3.4	4.5	
$C^{12}(d,p)C^{13*}$	5.6	5.6	4.4	8.4	
$C^{12}(d,p)C^{13}$	4.7	5.5		4.1	4.1

[20] Cathetometer constructed by Heerbrugg Company of Switzerland. We wish to thank Professor J. R. Dillinger for lending us this instrument, and for providing us with the information as to its accuracy.

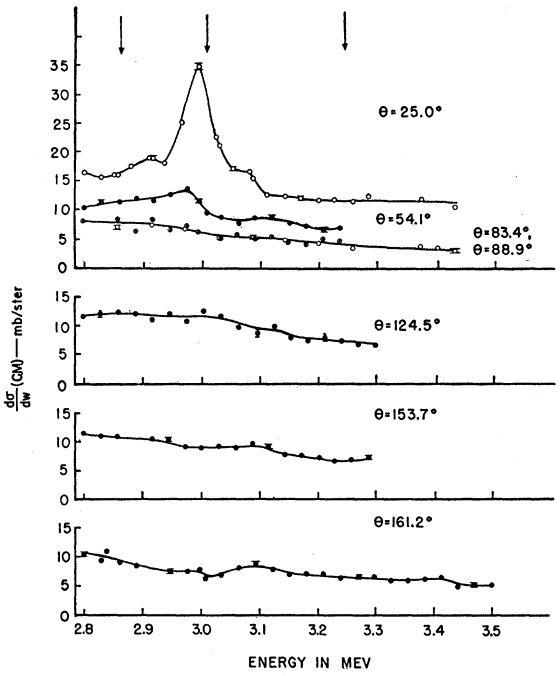

FIG. 4. Excitation curves of Part I at various c.m. angles. Arrows indicate energies at which angular distributions, (Fig. 6) were taken off and on "resonances."

The total uncertainty of n is the sum of these contributions, and is $\pm 0.8\%$.

$A(\theta)$: The principal uncertainty in angle setting was the uncertainty in fixing the 0° position. This position was fixed both by sighting through the collimator at the detector slit system and also by maximizing (with respect to the position of the detector arm) the incident beam on an insulated stop. The stop was placed just beyond the detector slit system and before the counter window. The uncertainty in this calibration is $\pm 0.2°$ and the random uncertainty in angle setting is about $\pm 0.05°$. The rms sum of these is $\pm 0.21°$. The resultant error in $A(\theta)$ varies from about 1.5% at small and large angles to 0.1% near 90°.

The sum of the angle independent errors is $\pm 1.3\%$. Since the p-p cross-section measurements indicated a

discrepancy of at least $\pm 1.5\%$, this figure has been arbitrarily increased to $\pm 2\%$. The $A(\theta)$ uncertainty (at each angle) has been added to the angle independent uncertainties to give the total systematic uncertainty. The final uncertainties are the rms sum of the total systematic and statistical uncertainties, and these are listed for each reaction in Table I.

For Part I of the experiment the sum of angle-dependent and angle-independent systematic errors was $\sim 7\%$ at small and large angles and $\sim 4\%$ near 90°. Since the angular uncertainty in Part I was primarily caused by random fluctuations in the angle settings, the rms sum of these errors was actually used to obtain the total uncertainty. The rms sum of these errors ranged from 3 to 4.5%. The total uncertainty for the Part I ground state cross sections is the rms sum of these errors (3–4.5%) and the statistical uncertainty. It was ~ 5–7% at small and large angles and $\sim 10\%$ near 90°, where the cross section for $C^{12}(d,p)C^{13}$ was small.

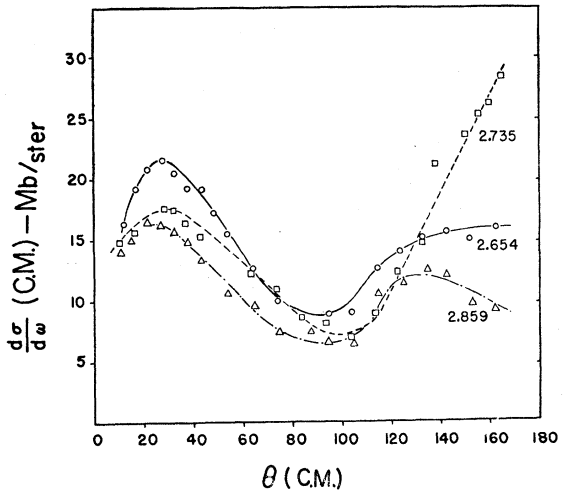

FIG. 5. Angular distributions for $C^{12}(d,p)C^{13}$-ground state taken off and on 2.74-Mev resonances at energies indicated on curves.

ENERGY UNCERTAINTY

The uncertainty of the resonant energies quoted is compounded of the $Li^7(p,n)Be^7$ threshold uncertainty (0.06%), the uncertainty in our measurement of the threshold (0.05% and possible random fluctuations (always $<0.1\%$). This brings the total uncertainty on the incident beam before it enters the gas to $\pm 0.14\%$. This is combined with the uncertainty on the energy loss in the gas (± 2 kev) and also with the uncertainty in determining the position of the resonance in the data.

EXPERIMENTAL RESULTS

The excitation curves for the ground state reaction, $C^{12}(d,p)C^{13}$, are shown in Figs. 2, 3, and 4. Large anomalies are observed at 2.5, 2.74, and 3.01 Mev. More detailed angular distributions (Figs. 5 and 6) have been taken at and near the two largest anomalies.

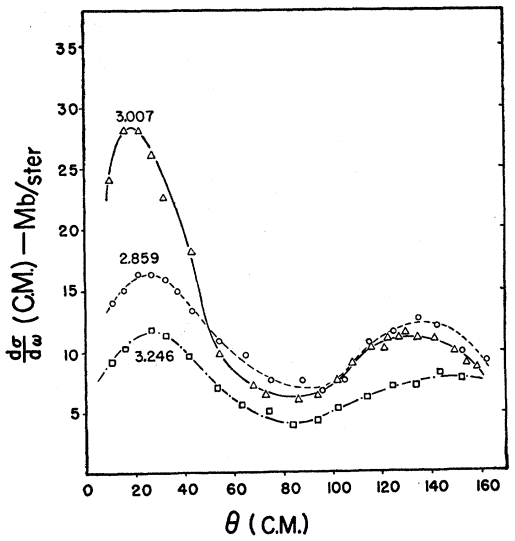

FIG. 6. Angulardistributions for $C^{12}(d,p)C^{13}$-ground state taken off and on 3.01-Mev "resonance" at energies indicated on curves.

The anomaly near 3.0 Mev shows an unexpected behavior. Only the stripping peak appears strongly influenced by the "resonance," as is apparent in Fig. 4. (Similar behavior has been reported for a resonance in

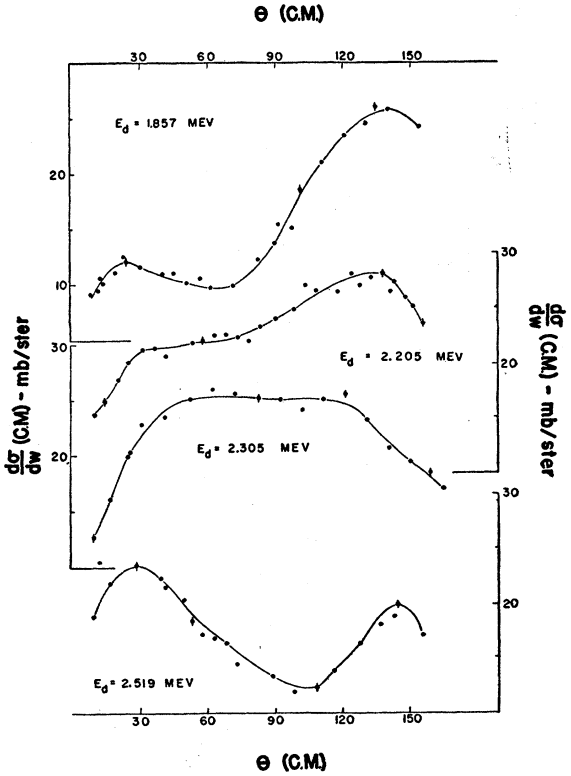

FIG. 7. Angular distributions for $C^{12}(d,p)C^{13}$-ground state taken at energies indicated on curves. The energy dependence of these distributions demonstrates the onset of the stripping distribution. Note that the ordinates do not begin at 0.

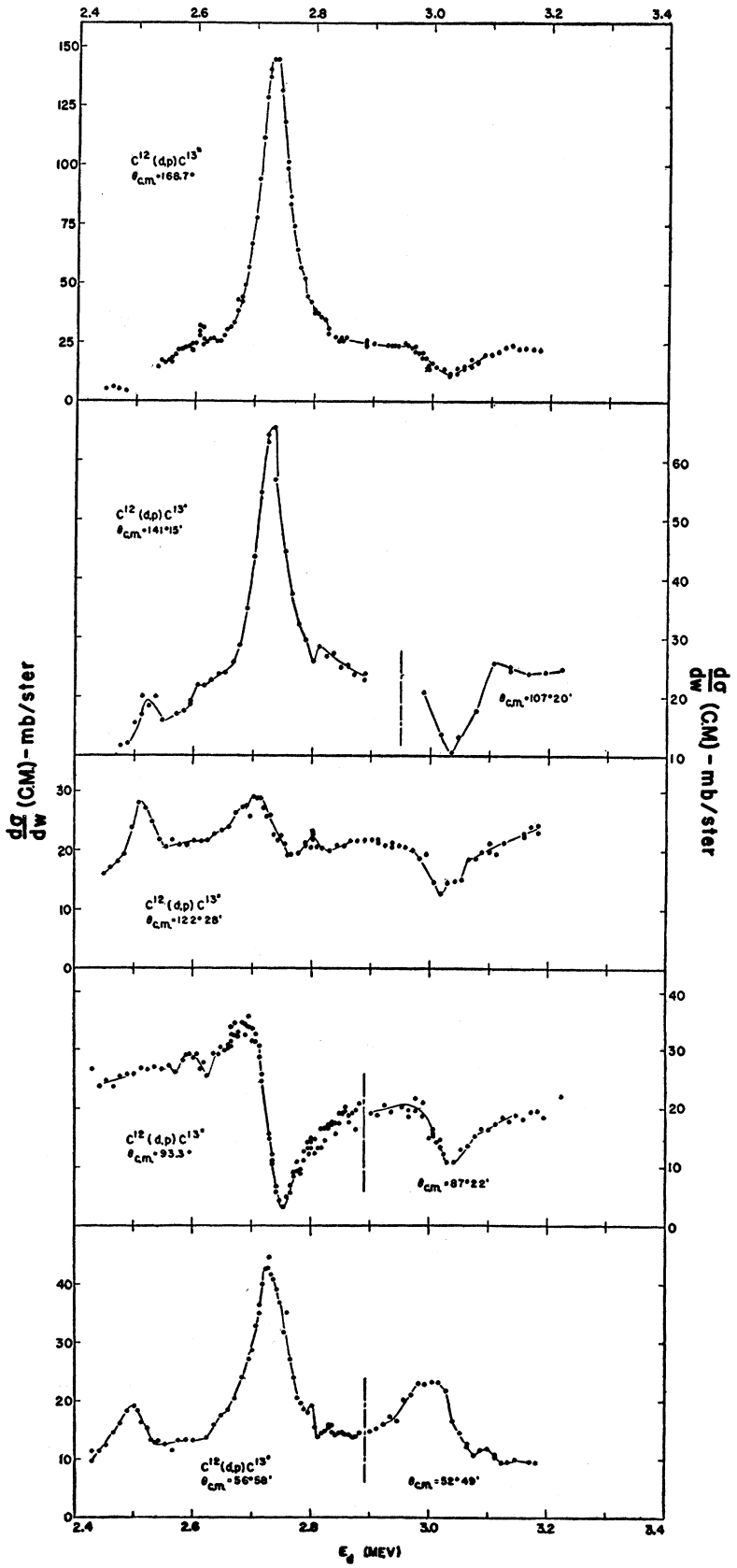

FIG. 8. Excitation curves of Part II for $C^{12}(d,p)C^{13*}$ first excited state. Note that ordinates do not always begin at 0.

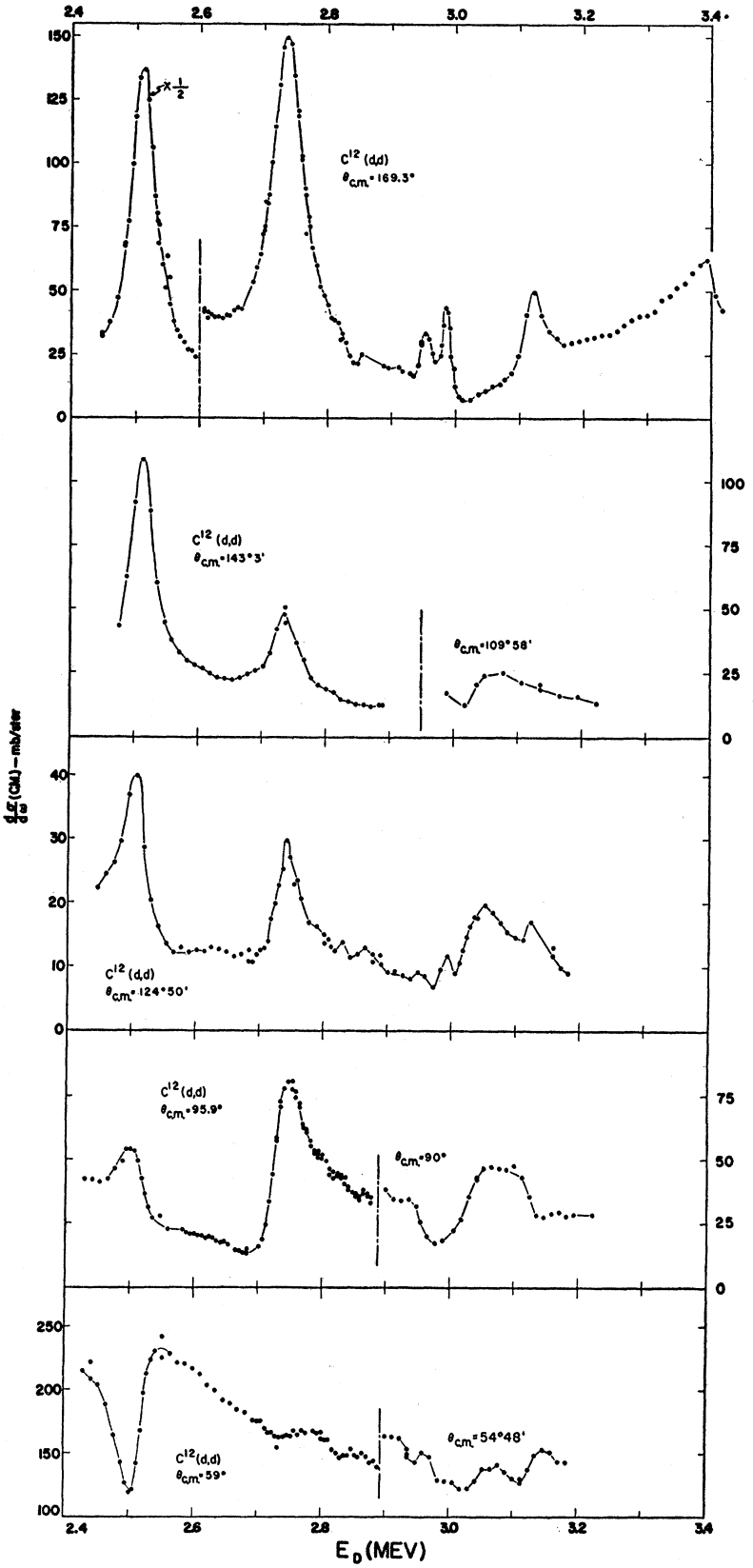

FIG. 9. Excitation curves of Part II for elastic deuteron scattering from C^{12}. Note that the ordinate of the 59° curve does not begin at 0, and also that the ordinate scale of the back-angle data over the 2.5-Mev resonance has been reduced by a factor of 2.

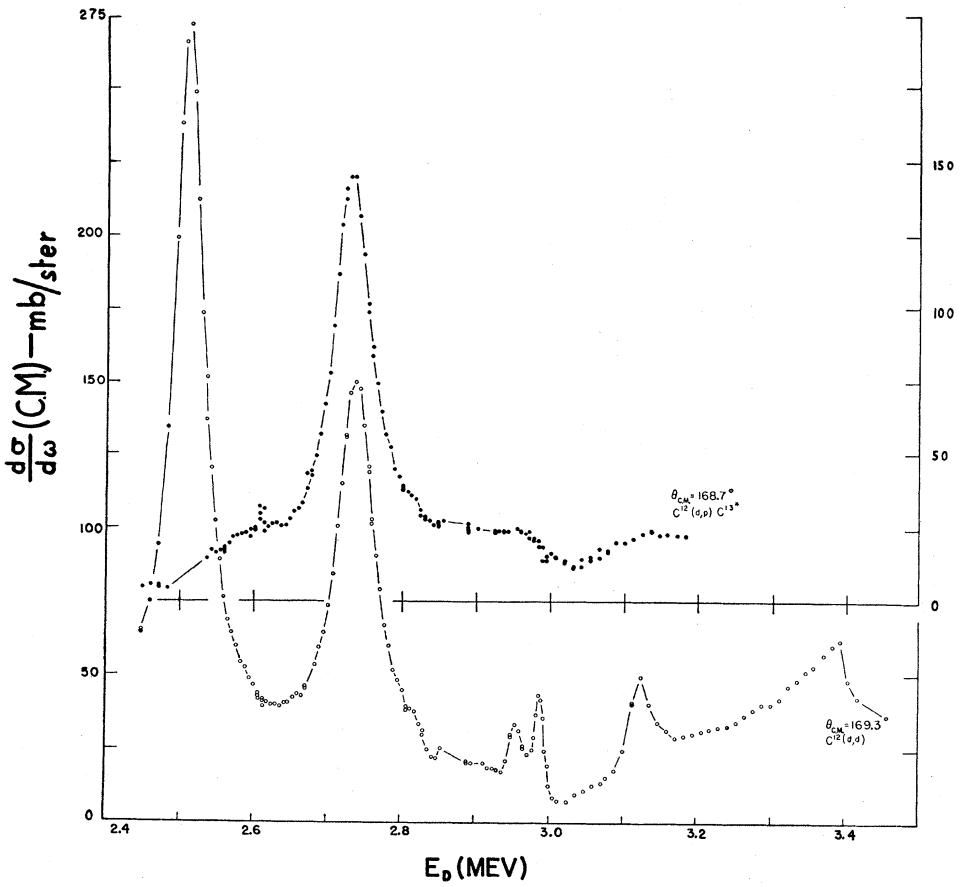

FIG. 10. Elastic scattering data and $C^{12}(d,p)C^{13*}$ first excited state at back angles. Left ordinate scale is for $C^{12}(d,d)C^{12}$, right scale for $C^{12}(d,p)C^{13*}$.

the $O^{16}(d,p)O^{17}$ reactions[5] and recently for the same carbon resonance.[6]) For $E_d=2.74$ Mev, Fig. 3 shows cross section variations of an entirely different character. Here the effect at the Butler angle is subordinate to the strong back angle resonant effects. In addition it should be noted that the data at the stripping peak ($\theta=25°$ c.m.) show constructive interference below the resonant energy but destructive interference on the high-energy side of the resonance. This change in sign of the interference is characteristic of compound nucleus formation.

The interpretation of the puzzling behavior at $E_d=3.0$ Mev probably is to be found in the fact that the elastic deuteron data (see below) indicate at least three resonances near this energy.

Angular distributions were taken at nine different energies, five of which are shown in Figs. 5 and 6. Four other distributions are shown in Fig. 7. The latter four show the onset of the stripping type distribution as the deuteron energy is increased from 1.86 Mev to 2.52 Mev.

Figures 8 and 9 contain the excitation data of Part II for the excited state reaction and for elastic scattering. The back angle data of Fig. 9 show at least three distinct and separated resonances near 3.0 Mev, but this separation is not apparent at other scattering angles or in any of the (d,p) data. The behavior of the data and especially the broad dip at the back angle suggest the possibility of an additional, broad level near $E_d=3.0$ Mev. It is interesting to note that the two prominent resonances in the (d,p) reactions ($E_d=2.5$ and $E_d=2.74$ Mev) correspond to the two most prominent resonances in the elastic scattering. Figure 10 is a replot of the elastic scattering and $C^{12}(d,p)C^{13*}$-3.086-Mev state at the back angle. Here we see the almost exact energy coincidence of the resonant structure.

One complete and one partial angular distribution are shown in Fig. 11 for the (d,p) reaction to the 3.086-Mev state of C^{13}. Unfortunately the difficulty of separating these reaction products from the elastically scattered deuterons prevented us from completing the lower energy distribution.

Several resonances were found in addition to the ones specifically mentioned. The energies and widths of all of the resonances, together with the uncertainties on both quantities, are tabulated. Since the resonances observed here correspond to levels in N^{14} from 12.4- to 13.2-Mev excitation, they may be compared with the results of Shire *et al.*[21] and Shire and Edge.[14] They explored the same excitation region in N^{14} with the

[21] Shire, Wormald, Jones, Lunden, and Stanley, Phil. Mag. 44, 1197 (1953).

TABLE II. Resonant energies in lab units, excitation in N^{14}, and level widths (Γ) in c.m. units.

Shire *et al.*[a,b]			Present data		
E_R	E_x in N^{14}	Γ	E_R	E_x in N^{14}	Γ
1.13	12.42	43±4	2.502±0.007	12.41	40±3
1.24	12.50	36±5	2.62 ±0.012	12.50	22±15
1.39	12.60	50±5	2.735±0.006	12.60	47±3
1.51	12.69	14±4	2.81 ±0.010	12.67	22±7
1.64	12.78	14±4	2.954±0.007	12.79	17±8
1.68	12.81	5±2	2.986±0.006	12.82	11±3
1.83	12.92	21±4	3.123±0.0065	12.94	28±10
2.16	13.16		3.39 ±0.012	13.17	47±15

[a] See reference 14.
[b] See reference 21.

$B^{10}+\alpha$ reactions. Their results are included, for comparison, in Table II. The two sets of measurements are in good agreement.

DISCUSSION

Previously reported cross sections for the $C^{12}(d,p)C^{13}$ reaction at $E_d=3.29$ Mev[22] are in serious disagreement with the present measurements; however, we have subsequently been informed that the measurements of Holmgrem *et al.* were made with a target sufficiently thick so that the large anomaly at $E_d\approx 3.01$ Mev could appreciably influence the results.[23] Excitation curves and angular distributions for the $C^{12}(d,p)C^{13}$ reaction have also been reported by Bonner *et al.*[6] Our cross sections agree well with theirs near $E_d=3.0$ Mev, but their values at forward angles and from $E_d=2.0$ to $E_d=2.5$ Mev are 20% higher than ours. A further comparison, of their resonant energies and ours, indicates a discrepancy in energy calibration of about 30 kev, their scale being shifted down in energy with respect to ours between $E_d=2.5$ and $E_d=3.0$ Mev. At $E_d=3.4$ Mev, the two scales are in agreement.

The energy correspondence of large resonances observed at $E_d=2.5$ and 2.74 Mev in all three reactions suggests compound nucleus formation in the (d,p) process. This suggestion is supported by the change in sign of the interference between the resonant and nonresonant amplitudes at the Butler angle over the $E_d=2.74$-Mev resonance. It is interesting to compare

[22] Holmgren, Blair, Simmons, Stratton, and Stuart, Phys. Rev. **95**, 1544 (1954).
[23] H. D. Holmgren (private communication).

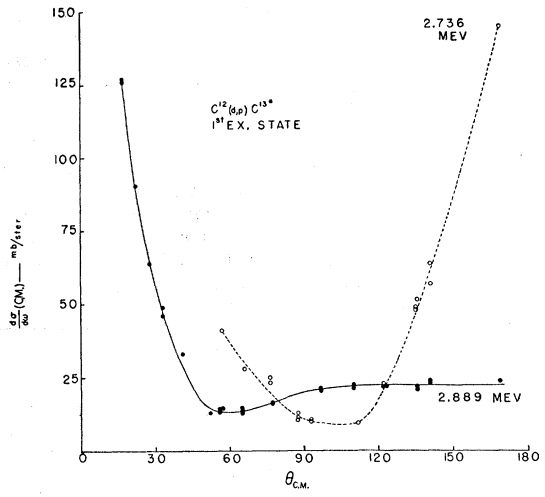

FIG. 11. Angular distributions for $C^{12}(d,p)C^{13*}$ first excited state at energies indicated on curves.

the magnitudes of the stripping cross sections and of the observed resonances. The resonant contributions to the (d,p) reactions are comparable in magnitude to the off-resonance cross sections, indicating that the transition probabilities of the two processes are not very much different. The appearance of separated resonances near $E_d\approx 3$ Mev in the elastic scattering suggests that the $E_d=3.01$-Mev anomaly for the (d,p) reaction is actually the result of the interference of several levels.

Some of the resonances presented here have been analyzed by one of us (M.T.M.) in terms of the dispersion formalism of nuclear reactions; also some of the angular distributions have been analyzed in terms of the stripping formalism. This analysis will be presented shortly.

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