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Stripping Mechanism for Reactions with Small Q Value: The Reaction $Li^7(d,p)Li^8$†

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A number of angular distributions of protons from the reaction $Li^7(d,p)Li^8$ have been measured for a range of incident deuteron energies below 2.5 Mev. These agree remarkably well with a simple form of Butler-Born stripping theory, uncorrected for Coulomb and nuclear effects. A description is given for this unusual agreement in terms of the small Q value, -0.188 Mev, for the reaction.

A resonance in the proton yield is found at an incident deuteron energy of 1.4 Mev which has not been observed in measurements of the β yield from this reaction. Angular distributions measured on and around the resonance show no influence of this on the unusually good stripping patterns.

INTRODUCTION

THE stripping reactions of small Q value tend to have been neglected, owing to the practical difficulties of separating the product proton groups from the scattered deuterons, particularly in the forward angles, where the major structural features of stripping angular distributions lie. In such cases, for low bombarding energies, the simple expedient of using absorbing foils between target and counter, to stop the deuterons but allow the protons through, cannot be used. Many such reactions can however be effectively studied with magnetic analyzers of high resolving power. The further difficulty, even in conjunction with a magnetic spectrometer, in the case of low-energy protons, namely of the actual detection in the presence of an intense background of neutrons and gamma rays, can also be largely overcome. Yet another of the practical difficulties in the case of small-Q reactions at low bombarding energies, is that of measuring the angular distributions at the most forward angles. To do this the product protons must traverse both the full thickness of the target and its backing material, so that these have to be adequately thin to allow them through.

In the case of lithium for the energy range in question, the additional complication exists that proton groups from oxygen and carbon—the presence of which is inevitable if the lithium target is prepared in air, or at any time even briefly exposed to air—coincide with those from lithium for certain angular spans which are of interest.

The bombardment of lithium with deuterons has been studied by a number of workers in a variety of ways. Among these should be mentioned the observation of protons from the (d,p) reaction by Holt and Marsham[1] for an incident deuteron energy of 8.0 Mev, and by Levine, Bender, and McGruer[2] for an incident deuteron energy of 14.4 Mev. The (d,p) reaction produces Li^8, which decays by β emission to Be^8, which in turn breaks up into two α particles. Some of the earliest work on the reaction Li^7+d was studied through the observation of the β- and α-particles emitted. Rumbaugh, Roberts, and Hafstad[3] determined an excitation function for incident energies up to 1 Mev, from the α particles.

Using the β particles, Bennett, Bonner, Richards, and Watt,[4] Baggett and Bame,[5] and Bashkin[6] have measured the excitation function for the reaction. There is general agreement that there are resonances at 0.80 and at 1.04 Mev. Baggett and Bame find a slight change in slope at a deuteron energy of 1.4 Mev, which they consider to indicate a broad resonance. Bashkin, however, finds no suggestion of a resonance at about 1.4 Mev, despite careful search. His excitation function is substantially flat above about 1.9 Mev, which leads him to suggest that this may indicate that stripping, rather than compound nucleus formation, is tending to dominate.

It was largely this conclusion of Bashkin which led to an effort to detect the protons from the reaction $Li^7(d,p)Li^8$ at low bombarding energies, with the view to studying the competition between compound nucleus formation and stripping, by careful measurement of the angular distributions associated with various parts of the excitation function, from the clearly resonant region below 1 Mev to the suggested stripping region above 2 Mev.

EXPERIMENTAL DETAILS

(a) Magnetic Spectrometers

The difficulties associated with the measurement of protons from a reaction of small Q value at low bombarding energies, have already been mentioned. The use of magnetic analysis suggests itself. Two magnetic spectrometers were used in this series of experiments—the smaller bent the protons through an angle of 50°, and had an angular range for distribution measure-

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† The experimental work described here was done in the Cavendish Laboratory, University of Cambridge, England.

[1] J. R. Holt and T. N. Marsham, Proc. Phys. Soc. (London) **A66**, 1032 (1953).

[2] S. H. Levine, R. S. Bender, and J. N. McGruer, Phys. Rev. **97**, 1249 (1955).

[3] L. H. Rumbaugh, R. B. Roberts, and L. R. Hafstad, Phys. Rev. **54**, 657 (1938).

[4] W. E. Bennett, T. W. Bonner, H. T. Richards, and B. E. Watt, Phys. Rev. **71**, 11 (1947).

[5] L. M. Baggett and S. J. Bame, Jr., Phys. Rev. **85**, 434 (1952).

[6] S. Bashkin, Phys. Rev. **95**, 1012 (1954).

ments from 22° to 158°. The resolving power—expressed as $(\Delta E/E)\times 100$—was 8%. This figure is slightly deceptive, in that the momentum profile had an extended tail on the low-energy side. Further factors indicating the need for an improved spectrometer, were certain unsatisfactory features in the ion-optics of the system, and the limitation in angular scan to 22° in the forward direction.

An existing 180° magnet, of conventional design, was converted to a rotating spectrometer in a simple but effective way, by remounting on a carriage with four sets of wheels, set precisely at appropriate angles, such that the rotation proceeded about a predetermined point. This center of rotation had to be plumb below the center of the target in the reaction chamber. The position of this latter point determined the object-pole face distance and had to be such that a suitable image-pole face separation was obtained. The calculations on the focusing properties of magnetic spectrometers were based on the work of Judd,[7] and actual measurements of image distances were made using a quartz plate. This 180° spectrometer had a measured resolving power of 2%. Two reaction chambers were designed for use with this magnet. One was continuously rotatable with an angular scan from $-5°$ to $+60°$. The initial function of the 180° spectrometer was to obtain measurements at the most forward angles, in particular below 30° where the 50° spectrometer was inoperable, so that this chamber was much used and proved very effective and reliable. The principle on which the design was based was that of a ring, containing the "outlet" tube to the magnet, which rotated about an inner main body with beam entrance tube. This inner chamber had an aperture over a certain angular span, surrounded by a gaco rubber ring.

The angular limitations of this reaction chamber led to the design of a simple two-stage device in which a large-diameter sylphon bellows was constrained by two guides to bend in a horizontal plane. The bellows could be moved 35° to either side of its undistorted position, giving an angular scan of 70°. Using two beam-entrance positions gave a total angular scan of from 0° to 135°. The physical shape and dimensions of the magnet itself, and the severe limitations of space in the target room, were such that irrespective of the reaction chamber design, a more backward angle could not be reached. Changing from one beam-entrance port to the other was a rapid procedure, as each port had a vacuum sluice-type valve.

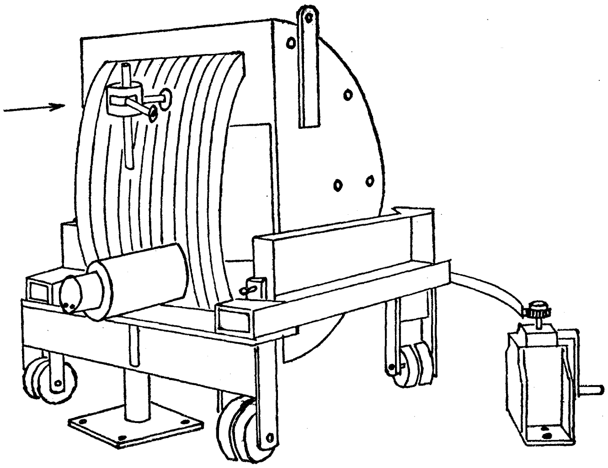

FIG. 1. Schematic diagram of 180° magnetic spectrometer with $-5°$ to $+60°$ reaction chamber.

The 180° spectrometer is shown, with the $-5°$ to $+60°$ reaction chamber in position, in Fig. 1. The rotation mechanism and lead-shielded detector can be seen.

Both magnetic spectrometers were calibrated by elastic scattering of protons from thin nickel foils, making due corrections for foil thickness and recoil. The energy-field current dependence featured a small but regular deviation from linearity in both cases. Both spectrometer systems were tested by angular distribution measurement of Rutherford scattering.

The angular scans of the two magnetic spectrometers were such that only by using both for any particular reaction, could a complete angular distribution be measured. The data to be presented have been obtained in this manner.

(b) Detectors

The main criteria for detectors used with the magnetic spectrometers for the case of low-energy protons, have been mentioned. The narrow confinement of the target room was such that neutron and gamma-ray backgrounds presented a serious problem. The most satisfactory solution was found in a CsI(Tl) photomultiplier combination. This scintillating material is so slightly hygroscopic that it can be used without any covering "window." Polishing to reduce thickness and to get a final finish presents no problem, but in detail was found to depend on the source of the material. As unnecessary thickness increases the background, the CsI(Tl) disks could ideally be reduced to a dimension such that only those protons which the magnets were capable of resolving, were completely stopped. In practice they were reduced to thicknesses between 0.003 and 0.006 inch. Such scintillators, used with conventional photomultipliers, were found to have a resolution between 4% and 5% in energy. The optimum attained was 3%. The response of one of the CsI(Tl) photomultiplier systems to protons is indicated in Fig. 2.

(c) Targets

For the type of reaction in question, a self-supporting, uniformly thin target is highly desirable. Where this is not possible, the choice of a backing material is largely determined by the reaction which is to be studied. In this case, nickel offered a feasible solution. As a self-

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[7] D. B. Judd, Rev. Sci. Instr. 21, 213 (1950).

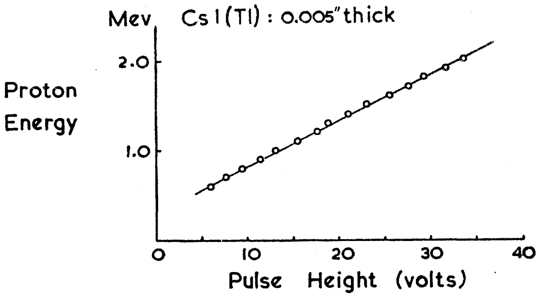

FIG. 2. Response of CsI(Tl) to protons.

supporting foil, thicknesses of 0.000025 in. are available. Backed by copper, a highly uniform layer of nickel, as thin as 0.000002 in., can be obtained. Such backed foils were mounted in a target frame—designed so as to allow freedom of tension in the foil—and the copper backing then removed by a solution of trichlor acetic acid in ammonium hydroxide. The remnant unbacked nickel foil in its holder had to be manipulated with extreme care in the water wash which followed. A jig was used to obviate any lateral movement.

In this experiment, $Li^7(d,p)Li^8$, only the preparation of the target by evaporation in situ in a hard vacuum, was suitable. Both the delicacy of the thin nickel backings and the desirability of having a suitable thickness of the evaporated material, suggest the need for a method of controlled evaporation of thin, uniform layers of material. An apparatus was designed to fit all the reaction chambers described, in which highly controlled deposition by evaporation was achieved. Any target thickness, from about 1 kev (to 440-kev protons) in any number of increments of as small as 1 kev (to 440-kev protons), could be made.

(d) General Features and Practice

To all reaction chambers a monitor was fitted, consisting of a CsI(Tl) photomultiplier arrangement similar to that used in conjunction with the magnetic spectrometers. A reaction group or scattered group was isolated by a single-channel pulse-height analyzer, from these.

All measurements were made using a velodyne-type current integrator.

The output from the scintillation detectors used with the magnet spectrometers was fed to a 80-channel pulse-height analyzer, and all intensity measurements were made from the relevant part of the recorded spectrum. Such measurements were corrected for the actual live time of the multichannel analyzer during the recording period.

All the experiments used the deuteron beam of the electron-beam stabilized, van de Graaff accelerator of the Cavendish Laboratory, which at that time had a maximum potential of 2.5 Mv.

EXPERIMENTAL RESULTS

A typical magnet scan is given in Fig. 3. This particular one was taken with the 180° magnet, and differs from the scans taken with the 50° magnet only in that the latter have a higher background. A number of groups are resolved, and their origin is as indicated in Fig. 3. No group is shown from the reaction $C^{12}(d,p)C^{13}$, as this appeared only after many hours of bombardment, due to the effectiveness of an 8-in. long conduction trap, cooled to liquid nitrogen temperature, through the relatively narrow aperature of which the incident beam had to pass. The very prominent group, due to the reaction $H(d,p)D$ was a severe embarrassment, however. The hydrogen originates not in the target, but in the molecular hydrogen component of the incident beam which, on striking the target, breaks up and is partially absorbed on the target. The presence of protons from this $H(d,p)D$ reaction was most unfortunate in that even for bombarding energies as high as 2.4 Mev, it was impossible to resolve them from those from the lithium reaction at the most forward angles. The angular span for which this was true, increased as the incident deuteron energy was decreased.

After determining the optimum magnet setting, the output of the CsI(Tl) detector was analyzed by a conventional Hutchinson-Scarrott multichannel analyzer. A typical spectrum is given in Fig. 4. It is clear that an accurate assessment of the true intensity of the proton group can readily be made, similarly it is clear how great an error would be made if magnetic analysis were carried out without pulse-height analysis.

Excitation functions for the reaction $Li^7(d,p)Li^8$ were measured with the 50° magnet at 30°, 40°, 60°, and at 90°, all being values for laboratory space coordinates. The maximum energy range for such measurements extended from 0.7 to 2.5 Mev. The presence of protons from the reaction $H(d,p)D$ made measurements at 30° and 40°, and below 1.25 Mev very difficult and, where overlap became appreciable, inaccurate.

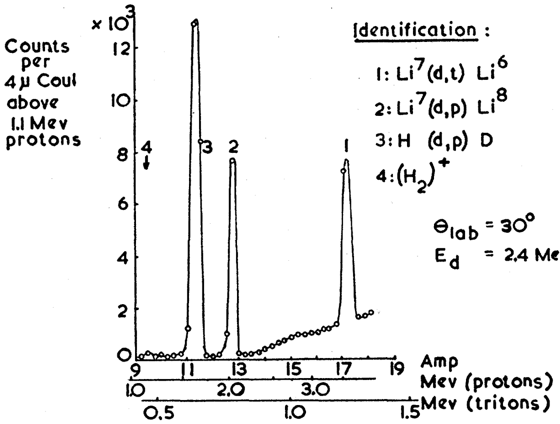

FIG. 3. Typical magnetic scan with 180° magnet for charged particles from Li^7+d.

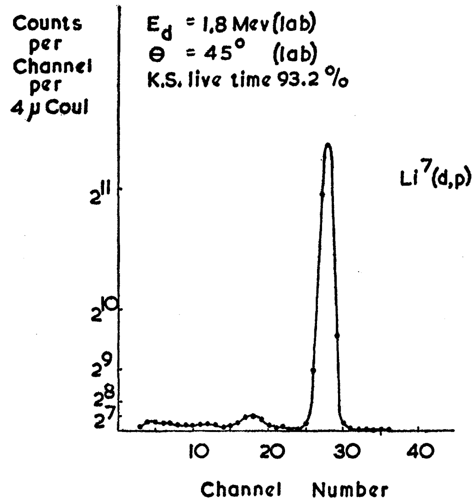

FIG. 4. Typical kicksorter spectrum from the 180° magnet system for protons from the reaction $Li^7(d,p)Li^8$.

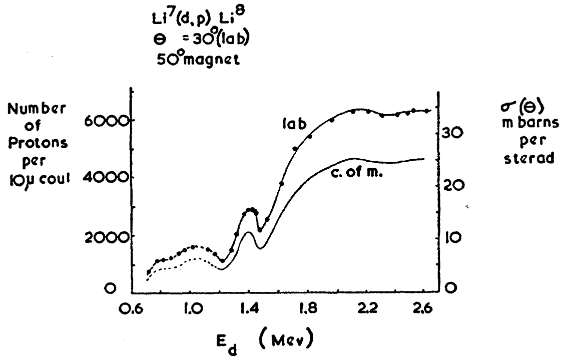

FIG. 5. Excitation function for protons from the reaction $Li^7(d,p)Li^8$.

An excitation curve is presented in Fig. 5. For the reasons given above, there is considerable uncertainty about the form of this below 1.2 Mev, but in this region it is not inconsistent with the presence of resonances at 0.8 and 1.0 Mev. One excitation function has been modified by a correction for the variation with energy of the "penetrability" of the incident deuteron. This is given in Fig. 6. An example of an excitation function as measured with the 180° magnet is given in Fig. 7.

In general trend these excitation functions are similar to the results of Baskin for total cross section, and of Baggett and Bame. One distinguishing feature is that where Bashkin's yield curve remains essentially constant from 1.9 to 3.0 Mev, the proton yield curves presented here show a very broad maximum at about 2.05 Mev, followed by further broad structure. Of particular interest is the clear resonance found at 1.4 Mev. Baggett and Bame had reported a small change in gradient in their excitation function at this energy, but Bashkin had subsequently searched this energy region for a similar feature with no success. Since the target thickness is known, both the true position and half-width of the resonance can be determined, and are found to be

$$E_{\text{res}}=1.375\ \text{Mev}\pm 10\ \text{kev}.$$

$$\Gamma/2=51\ \text{kev}\pm 5\ \text{kev}.$$

Angular distributions were measured at various incident deuteron energies, chosen primarily as the excitation functions indicated these to be regions of interest. The highest energy, 2.5 Mev, represents the maximum energy available at the time the experiment was performed. Distributions were studied on the 1.4-Mev resonance, above it at 1.5 Mev, below it at 1.2 Mev, as well as at 1.9 Mev and at 1.0 Mev. These are reproduced, after correction for solid angle in the center-of-mass system, in Figs. 8 to 13. The theoretical curves accompanying these diagrams are calculated from the non-Coulomb, noninteraction stripping formalism of Friedman and Tobocman,[8] using for convenience the

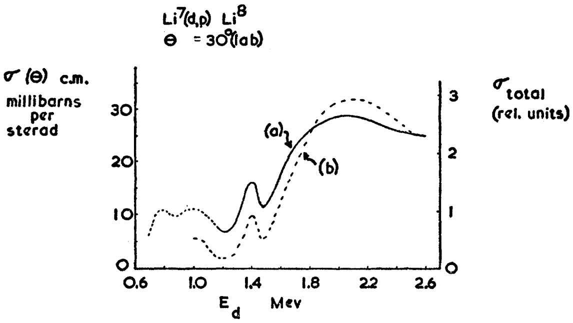

FIG. 6. Excitation function for protons from the reaction $Li^7(d,p)Li^8$: (a) with a deuteron penetrability correction; (b) form of the total cross section.

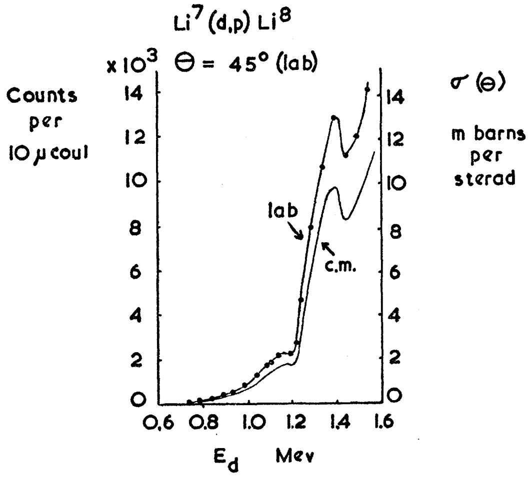

FIG. 7. Excitation function for protons from the reaction $Li^7(d,p)Li^8$.

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[8] F. L. Friedman and W. Tobocman, Phys. Rev. 92, 93 (1953).

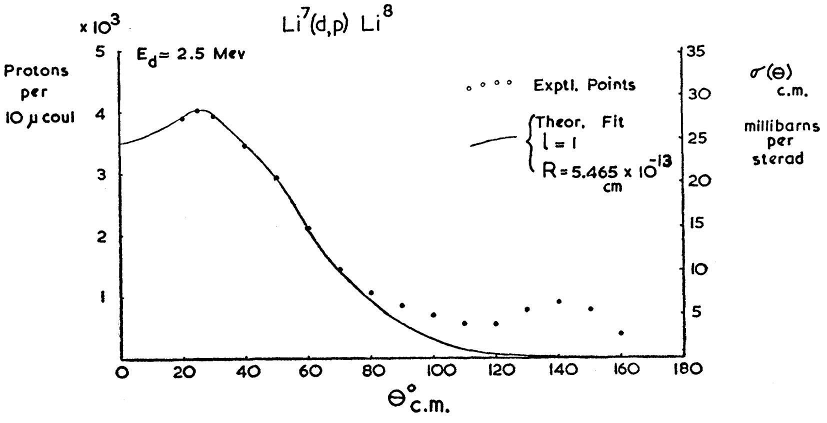

FIG. 8. Angular distribution of protons from the reaction $Li^7(d,p)Li^8$, for 2.5-Mev deuterons.

tables and graphs of Enge and Graue,[9] based on this formalism. Most of the other simple stripping derivations have been tried, with no significant difference. Figure 14 is included to indicate the sensitivity to R value of the angular distributions.

The "radius" of the nucleus appears in the differential cross section for stripping as an adjustable parameter. In attempting to find the best match between experimental and theoretical curves, every change in R necessitates a complete recalculation of the angular distribution. If the l value is not zero, however, the angular position at which the experimental distribution has its maximum can be used to determine the R value for each possible l value. The most reasonable of these R values can then be selected on the normal criteria. This R value will be "unique" in that it will produce a distribution with a peak at the correct angle—only one distribution need, therefore, be calculated. A set of curves for the determination of such "best-fit radii" has been given by Lubitz.[10] This method was applied wherever the position of the maximum was well-defined. Even in such cases, at least two further R values were

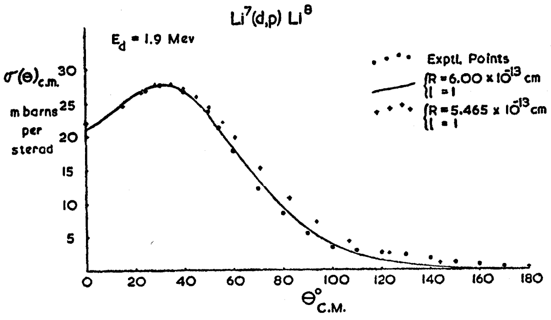

FIG. 9. Angular distribution of protons from the reaction $Li^7(d,p)Li^8$, for 1.9-Mev deuterons.

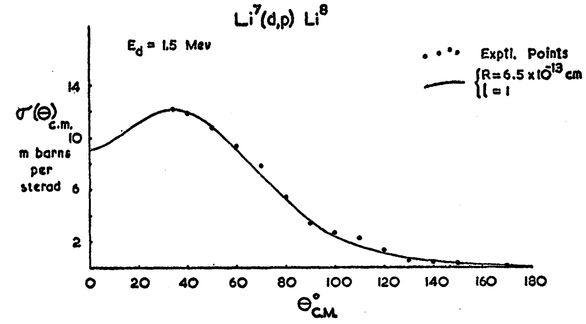

FIG. 10. Angular distribution of protons from the reaction $Li^7(d,p)Li^8$, for 1.5-Mev deuterons.

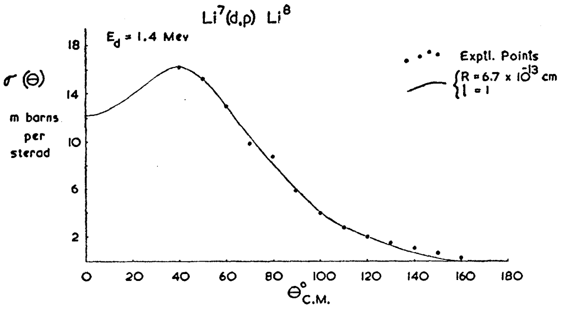

FIG. 11. Angular distribution of protons from the reaction $Li^7(d,p)Li^8$, for 1.4-Mev deuterons.

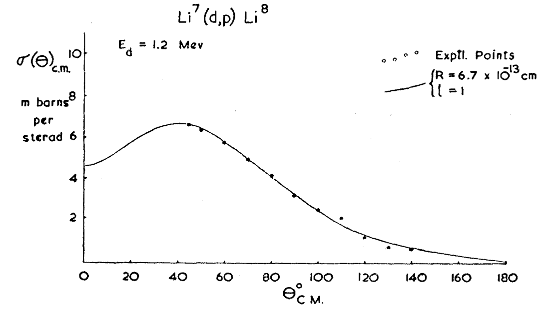

FIG. 12. Angular distribution of protons from the reaction $Li^7(d,p)Li^8$, for 1.2-Mev deuterons.

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[9] H. A. Enge and A. Graue, Univ. Bergen Åbrok Naturviten. Rekke No. 13 (1955).

[10] C. R. Lubitz (privately circulated, 1957).

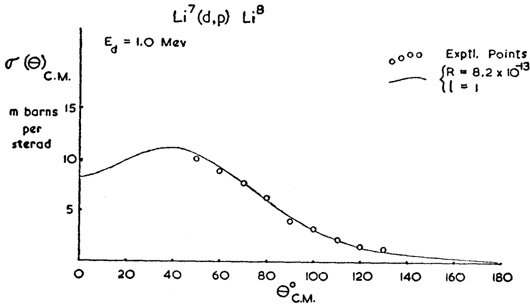

FIG. 13. Angular distribution of protons from the reaction $Li^7(d,p)Li^8$, for 1.0-Mev deuterons.

always tried. Where the position of the maximum was masked by protons from the contaminant $H(d,p)D$ reaction, the appropriate R value was found by trial. It was always striking how sensitive the fitting was to R value—even a 2% change in this value produced distributions which were clearly not as good. Normalization was usually effected at the maximum yield point. No component, isotropic or otherwise, was subtracted for any of the distributions.

All these angular distributions show a striking degree of agreement between the experimental results and the theoretically calculated curves. Holt[11] defines a "good stripping pattern as one in which a theoretical curve can be fitted reasonably closely to the main maximum without subtracting from the experimental curve an isotropic background of more than about 20% of the peak value." On this criterion, the agreement in the distributions presented for $Li^7(d,p)Li^8$ is remarkable. The greatest deviation is found in the distribution with incident deuteron energy of 2.5 Mev. Even here the agreement is good on the Holt criterion, but the feature of interest in this particular case is that the deviation can not be attributed to the simple addition of an isotropic background. It would appear then not to be due to a contribution from compound nucleus formation. But for this example, perhaps the most pleasing feature of the angular-distribution fits, is the agreement at large angles.

It would have been valuable to make similar accurate comparisons at the most forward angles. For reasons already given, not sufficient experimental points are available below the angles at which maximum yield is found, for such a comparison. The tendency, if anything, is to drop more quickly than does the theoretical curve. Green and Middleton[12] have noticed that angular distribution patterns with $l=1$ for reactions with small Q values fall below the theoretical curve at 0°. For similar reactions with $l=2$ angular distributions, Holt[11] has reported that they sometimes lie above the theoretical curve at 0°.

A feature already mentioned, is the surprisingly great sensitivity to R value in fitting experimental to theoretical angular distributions. The succession of such angular-distribution fits presents an opportunity to compare the variation of R value with deuteron energy. The result of such a comparison is shown in Fig. 15. A smooth increase in R with decreasing deuteron energy is found. At the lowest deuteron energy, 1 Mev, the R value demanded is much greater than the trend would predict. This is, however, in the region where the difficulties associated with the $H(d,p)D$ reaction were most severe. The variation of angle at which maximum yield occurs with deuteron energy, can also be expected to be smooth, increasing too with decreasing energy, with the 1-Mev measurement not in agreement with the general trend—this is presented in Fig. 16. The increase in "effective radius" with decreasing deuteron energy is physically sensible in that the Coulomb effect can be expected to become increasingly effective in its influence.

Another feature of great interest arising out of these results concerns the resonance found in the excitation function at 1.4 Mev. Three of the angular distributions already discussed were measured on, below and above this resonance, respectively. In so far as a high degree of agreement between theoretical and experimental curves was found, as also of sensitivity to R value, it was hoped that the effect of the resonance would show itself in these angular distributions. In this way the influence of a component from compound nucleus formation could have been studied. As can be seen from the diagrams, however, the effect of the resonance shows itself only as an increase in intensity, with no significant influence on the agreement between experimental measurements and theoretical curves based on a simple stripping theory.

Other workers have also found such resonances, the best-known example being that reported by Stratton,

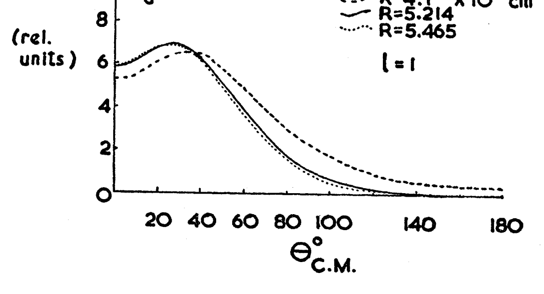

FIG. 14. Sensitivity of theoretical angular distributions to value of R, for protons from the reaction $Li^7(d,p)Li^8$, with $l=1$ and 2.5-Mev deuterons.

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[11] J. R. Holt, *Proceedings of the International Conference on Nuclear Reactions, Amsterdam, 1956* (Nederlande Naturkundige Vereniging, Amsterdam, 1956).

[12] T. S. Green and R. Middleton, Proc. Phys. Soc. (London) **A69**, 28 (1956).

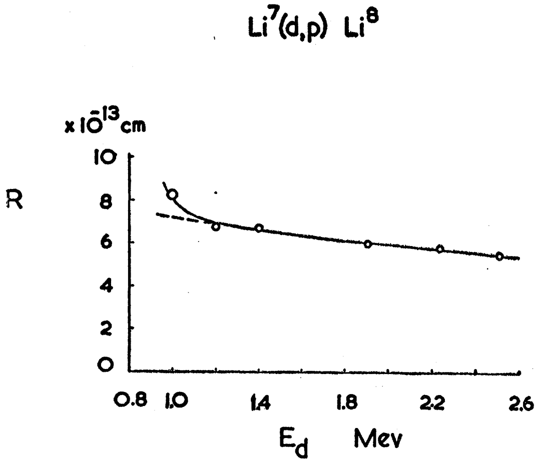

FIG. 15. Variation of R from experimental curves, with deuteron energy.

Blair, Famularo, and Stuart,[13] and by Bertholot, Cohen *et al.*,[14] for the deuteron bombardment of oxygen at 3.01 Mev. In this case the stripping angular distributions themselves are, however, far from good, and very marked variation in pattern in traversing the resonance is apparent, although the nature thereof does not seem to suggest an increase in compound nucleus formation.

DISCUSSION

A feature of particular interest in the results presented, is the apparent absence of Coulomb and nuclear interaction effects in the reaction, deduced from the close agreement between experimental measurements and simple stripping theory over the complete angular range investigated. This can be understood in terms of the low Q value for the reaction, and the fact that it was studied at low bombarding energies. The correlation with Q value was proposed by Wilkinson,[15] and recently elaborated on by him[16] and by the author.[17]

If nuclear and Coulomb effects are to be minimized, the proton in the deuteron should be as far removed from the target nucleus as is compatible with stripping and attachment of the neutron still to take place. Clearly this is most easily achieved if the momentum requirements can be met when the proton-neutron separation in the deuteron is maximal. The momentum of the outgoing proton in a (d,p) reaction is composed of about half the momentum of the ingoing deuteron, and an "internal" contribution from the ground-state wave function of the deuteron. Considering low bombarding energies where the ingoing deuteron contribution will be small, the contribution which must be obtained from the deuteron ground-state wave function will be small for low-Q, large for high-Q reactions. The greater this contribution has to be, the smaller the neutron-proton separation in the deuteron must be, consequently the closer the proton in the ingoing deuteron will be to the source of nuclear and Coulomb perturbing effects. Summarizing, for low bombarding energies, the stripping angular distributions will be more "pure," the smaller the Q value of the reaction is. For high bombarding energies, a similar logic can be developed.

An additional factor contributing to the purity of the simple stripping mechanism found in low-Q, low-energy reactions, arises from the relatively wide separation of the proton from the target nucleus. For a true compound nucleus to be formed this proton will have to move inwards, and this will be discouraged in that it would have thereby to penetrate the Coulomb barrier.

A further feature of interest arises from the resonance in the excitation function which was found at an incident deuteron energy of 1.4 Mev. As the angular distributions appeared to indicate stripping of an unusually high degree of purity, they presented an opportunity to test sensitively the influence of the resonance on the stripping mechanism. The results indicated no observable tendency of the resonance to distort the stripping angular distributions.

If the argument presented here is correct, that is to say that (d,p) reactions of small Q value show unusually good stripping due to the absence of nuclear and Coulomb interaction effects, the polarization of the outgoing protons should be small. This polarization is now being measured to indicate if this is so.

This reaction is now also being systematically studied at higher energies. An effort is being made to eliminate or at least drastically reduce the $(H_2)^+$ contamination

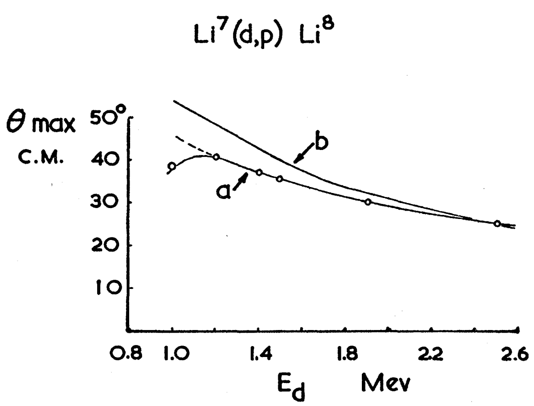

FIG. 16. Variation of angle at which maximum occurs in experimental distributions as a function of deuteron energy.

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[13] T. F. Stratton, J. M. Blair, K. F. Famularo, and R. V. Stuart, Phys. Rev. **98**, 629 (1955).

[14] A. Berthelot, R. Cohen, E. Cotton, H. Faraggi, T. Grjebine, A. Levêque, V. Naggiav, M. Roclawski-Conjeaud, and D. Szteinsznaider, Compt. rend **238**, 1312 (1954).

[15] D. H. Wilkinson (private communication, 1956).

[16] D. H. Wilkinson, Phil. Mag. **3**, 1185 (1958).

[17] J. P. F. Sellschop, Phys. Rev. Letters **3**, 346 (1959).

in the beam so that the study of the most forward angles can be completed.

ACKNOWLEDGMENTS

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Measurement of the Circular Polarization of Resonance-Scattered Gamma Rays Following the Electron Capture of Se^{75}†

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The circular polarization of the 265-kev γ rays following the mixed Gamow-Teller and Fermi electron-capture decay of Se^{75} into As^{75} has been measured. The neutrino momentum was fixed with the help of a resonance scattering process. From the experimentally determined degree of right-hand circular polarization of -0.21 ± 0.15 it was concluded that the sign of the Gamow-Teller to Fermi matrix-element ratio in this beta decay is negative.

I. INTRODUCTION

It is well known that the distribution of beta particles emitted with respect to the nuclear spin is of the form $(1+a\cos\theta)$ in an allowed nuclear beta decay. In a beta-decay process which preserves the nuclear spin, I, two types of beta transitions can occur, Fermi transitions (nonspin-flipping) and Gamow-Teller transitions (spin-flipping). In a mixed Gamow-Teller and Fermi transition the asymmetry coefficient a is strongly dependent on the interference between the two types of interaction. A large interference due to approximately equal contributions of both parts gives rise, in general, to a large asymmetry.

For this type of allowed transition the relative size of the Gamow-Teller and Fermi matrix elements can be estimated theoretically, with the help of nuclear models, and selection rules and wave functions based on them. For example, the isotopic spin selection rule $\Delta T=0$ for Fermi transitions will strongly suppress any Fermi contribution to a $\Delta T\geq 1$ transition. However, more refined arguments taking into account isotopic-spin mixing of the (model dependent) nuclear wave functions due to Coulomb interactions show that Gamow-Teller and Fermi matrix elements may be present simultaneously. Theoretical estimates of these admixtures have been made for several cases.[1–3] In order to help achieve a better understanding of the details of nuclear coupling it seems worthwhile to obtain more experimental information on the relative signs and relative magnitudes of the Gamow-Teller and Fermi matrix elements in such transitions.

In the beta decay of initially unpolarized nuclei, a measurement of the degree of nuclear polarization (with respect to the electron momentum) *after* beta decay determines the asymmetry coefficient a. Experimentally, the polarization in the nuclear state produced by beta decay can be determined from a measurement of the degree of circular polarization of a subsequently emitted gamma ray, the polarization axis being fixed by counting the beta particles in a given direction. Experimental studies of such β-γ circular-polarization correlations have, in some cases, provided data on the Gamow-Teller to Fermi matrix-element ratio.[4–6]

An alternative experimental approach is also possible: instead of counting the electrons directly one can make use of the recoil momentum transferred to the nucleus as a consequence of beta decay. If certain momentum conditions are fulfilled a fluorescent scattering process can be produced. The direction in which the gamma ray capable of producing resonant excitation is emitted is then used as the polarization axis to determine the mean angle of emission of the lepton pair in beta decay, or the direction of the neutrino in an electron-capture process. If the circular polarization of the fluorescent-scattered gamma ray is also measured, the nuclear polarization can then be inferred. An experiment of this

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