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Autor: Gibbs, W.R. / Grüebler, W.E.
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Reaction $N^{14}(d, n)\, O^{15*}$ (5,20; 5,25 and 6,15 MeV)

by **W. R. Gibbs*)** and **W. E. Grüebler**)**
Institut de Physique, Université de Neuchâtel

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I. Introduction

It is well known that deuteron induced reactions at bombarding energies of a few MeV proceed by a direct interaction mechanism in which one of the nucleons of the incident deuteron is stripped off and captured by the target nucleus. Plane wave theories of such reactions developed by BUTLER[1]) and others[2])[3]) have had reasonable success in fitting the observed angular distributions of emitted particles at small angles. However the angular distributions of the outgoing particles generally show a larger intensity at backward angles than predicted by such theories. This fact led MADANSKY and OWEN[4]) to propose the idea of heavy particle stripping in which the emergent particle comes from the target nucleus while its remaining core is captured by the incident deuteron. More recently attempts have been made to include refinements to the theory in the form of distortion of the incident deuteron wave and the outgoing nucleon wave and by including the interior of the nucleus in the calculations[5]). This Distorted Wave Born Approximation theory (DWBA) has been very successful in many cases.

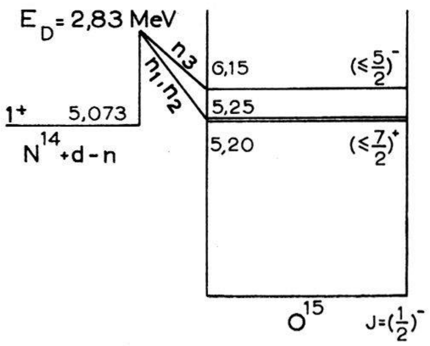

Fig. 1
Level scheme of O^{15}

The purpose of this investigation is to examine the extent to which the DWBA can explain the shape of the angular distribution and particularly the backward peaking.

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*) Now at Los Alamos Scientific Laboratory, New Mexico/USA.
**) Present address: University of Wisconsin, Madison/USA.

The angular distributions of the neutron groups leading to the doublet state of O^{15} with $E^* = 5{,}20$ and 5,25 MeV and to the 6,15 MeV state have been studied. The energy of the incident deuterons was $(2{,}83 \pm 0{,}05)$ MeV. A level diagram showing these states is given in Figure 1. Previous measurements of angular distributions for these levels were made by EVANS[6]) between 0 and 35°.

II. Experimental Method

The experimental arrangement adopted was very similar to the one described previously[7]). Deuterons from the University of Neuchâtel Van de Graaff generator were analysed by a 90° bending magnet before stricking a gas target. The energy of the analysed beam was stabilized to better than $\pm$ 2 keV. By collimation, the beam was limited to 2,5 mm diameter in the gas target. The beam entered the gas cell through a nickel foil with a thickness of 1,25 μ, giving an energy straggling of about 10 keV. The gas cell had a length of 2 cm and was filled with 400 mm Hg. pure Nitrogen, which represented an energy loss of about 100 keV for 3 MeV deuterons. Charge reaching the target was measured by a current integrator.

A gas recoil fast neutron spectrometer was used for the measurement of the neutron energies. This spectrometer has been described in detail previously[7]). The energy and efficiency calibration was carried out using neutrons of the *p-T* and *d-d* reaction of known energies. The distance between the middle of the gas target and the entrance to the central volume of the spectrometer was 30 cm.

III. Results

a) *Spectrum*

Figure 2 shows a neutron spectrum taken with the gas recoil fast neutron spectrometer from the reaction $N^{14}(d, n)O^{15}$ at an angle of 30° from the direction of the incident deuteron beam. The propane gas pressure in the spectrometer was 290 mm Hg. The spectrum shows three peaks. The peak labeled as n_1, n_2 corresponds to the two unresolved neutron groups, leading to the 5,20 and 5,25 MeV levels of O^{15}. The other neutron group n_3, leads to the 6,15 MeV level of O^{15}. The remaining peak near the n_1, n_2 group is due to the $C^{12}(d, n)N^{13}$ reaction. This reaction arises from thin carbon deposits on both sides of the nickel foil and on the beam stopper in the gas target, which are built up by organic vapour in the vacuum system of the generator. Measurements with the gas target filled with H_2 give the background which arises from the $C^{12}(d, n)N^{13}$ reaction. This background spectrum is also shown in Figure 2. Subtraction of this background gives the real intensity of the n_1, n_2 neutron group. The energy of the neutron group n_3 is too small for the propane pressure used so that the peak does not show up clearly in this spectrum. For this reason we carried out another series of measurements with a gas pressure of 150 mm Hg. in the spectrometer. Figure 3 shows such a measurement at an angle of 7,5° from the incident direction. In the same figure is also shown the background measurement.

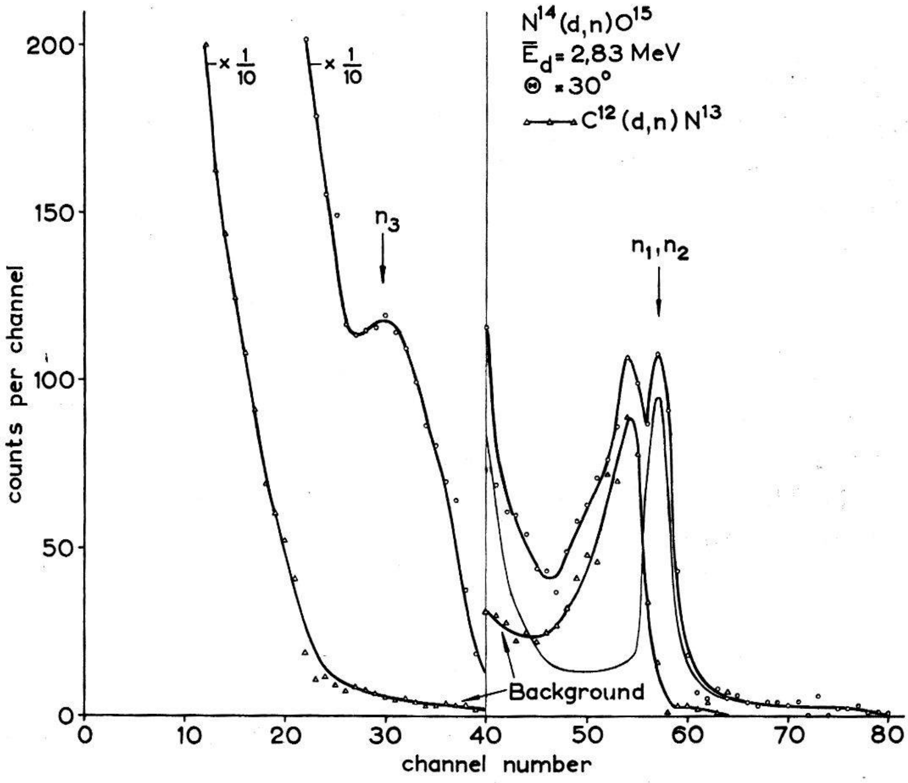

Fig. 2

Neutron spectrum from the reaction $N^{14}(d, n)\ O^{15}$ and background spectrum at 30° from the incident deuterons beam. Propane gas pressure in the spectrometer 290 mm Hg.

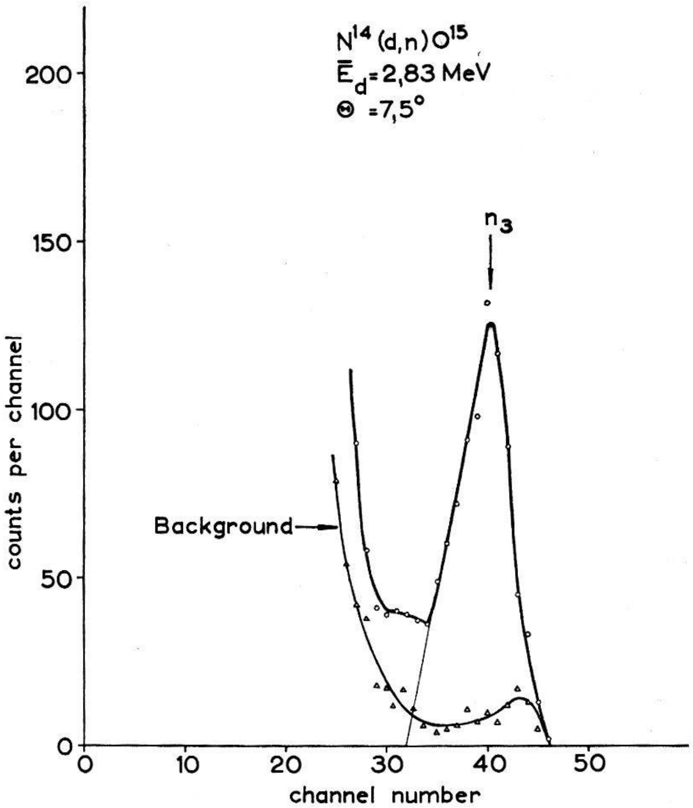

Fig. 3

Neutron spectrum from the reaction $N^{14}(d, n)\ O^{15}$ and background spectrum at 7,5° from the incident deuterons beam. Propane gas pressure in the spectrometer 150 mm Hg.

b) *Angular distribution*

Figure 4 shows the results of the measurements and the calculation for the reaction leading to the 6,15 MeV state. It is seen that an improvement is obtained over the Butler calculation. The agreement is not very good at this point although one may see that it is not necessary to assume much compound nucleus contribution to get the observed shift in peak position. A calculation with $l_p = 0$ was made and gives a very poor fit so that the known assignment (negative parity and spin 5/2 or 3/2) seems to be probably correct. The negative parity is in contradiction to the results of the C^{13} (He^3, n) O^{15} reaction study done at Oak Ridge[8]). The remaining disagreement in peak position may be due to the zero range approximation used in the calculation or to a small contribution from compound nucleus formation. If we take the final state spin for this level to be 3/2, the calculated absolute value for the cross section of 14,3 mb/ster agrees very well with the measured peak value of 12,0 mb/ster.

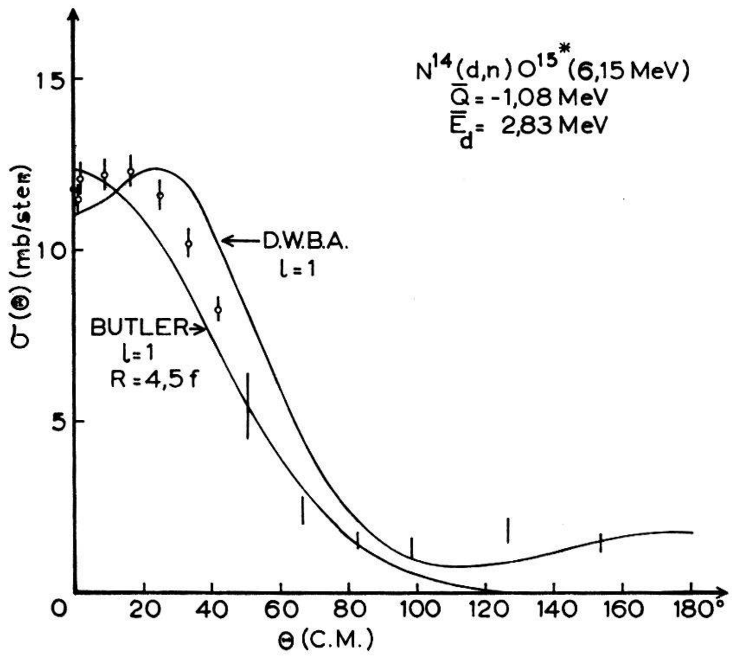

Fig. 4

Neutron angular distribution corresponding to the 6,15 MeV level in O^{15}. The solid curves are calculated from Butler and DWBA theory using the values of parameters shown.

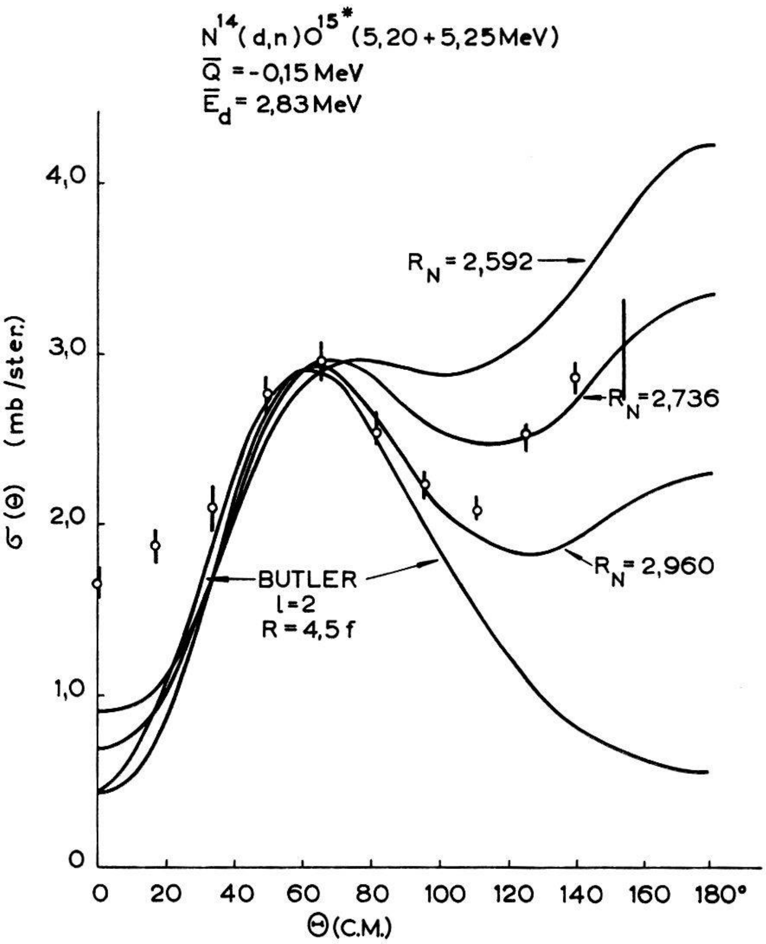

Fig. 5

Neutron angular distribution corresponding to the unresolved doublet (5,20/5,25 MeV) in O^{15}. The solid curves are calculated from Butler and DWBA theory with $l_p = 2$ and using the values of parameters shown.

Figure 5 shows the data points for the sum measurement and the calculations for the doublet state. The angular distribution shows a backward peaking which cannot be explained on the basis of the simple plane wave Butler theory of stripping, as shown in Figure 4, although could be explained as heavy particle stripping. The three DWBA calculations correspond to three different $l_p = 2$ bound state wave functions. These wave functions are computed by matching slope and value of an harmonic oscillator wave function to the Coulomb analog of the decaying Hankel function at the radius R_N. There is only this one parameter available to adjust both radius and depth of the harmonic oscillator potential. This parameter must reflect the differences in single particle potentials which cause the state to be split. Thus only R_N is expected to change from one doublet state to the other. Figure 6 shows two of these bound state wave functions with different R_N. The shape of the wave functions changes relatively little, but the effect on the angular distribution is quite considerable as can be seen in Figure 5.

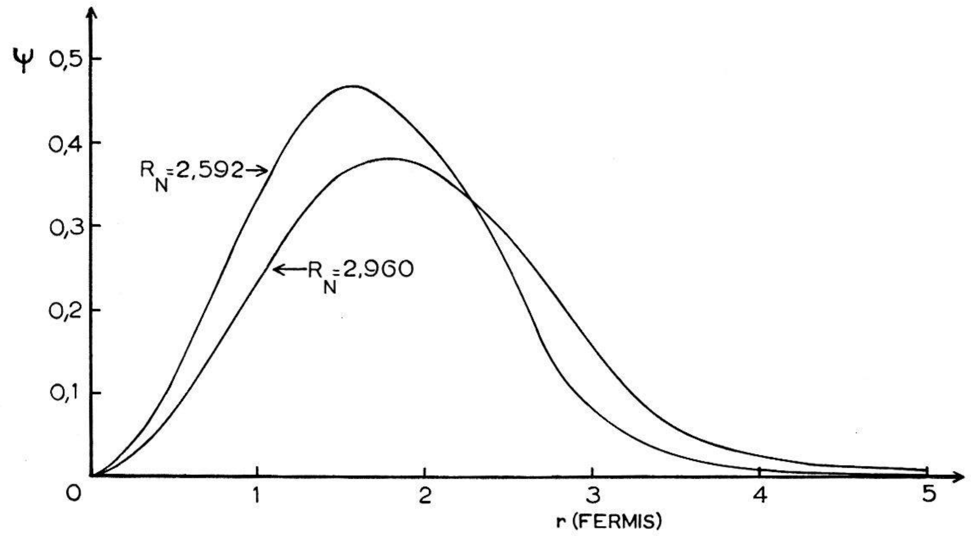

Fig. 6

Bound state wave functions for the DWBA calculations with $R_N = 2{,}592$ and 2,960 Fermis for the doublet state (5,20/5,25 MeV) of O^{15}.

Christiansen and Zeitnitz[9]) have separated these states at $E_d = 2{,}85$ MeV and find a behaviour similar to that of Figure 5. The two states separately show a distribution similar to the sum distribution except that one ($E^* = 5{,}20$ MeV) has a peak at 70° while the other ($E^* = 5{,}25$ MeV) shows a maximum at 60°. The lower excited state produces a slightly higher backward peaking. The absolute magnitudes also agree very well with these measurements. If we choose $J = 5/2$ for the final state spin, the peak cross section for $R_N = 2{,}96$ is 1,82 mb/ster and for $R_N = 2{,}592$ is 1,14 mb/ster while the measured values are 1,35 mb/ster for $E^* = 5{,}25$ and 0,90 mb/ster for $E^* =$ 5,20.

In Table I are listed the optical model parameters used in the calculations. All quantities are given in MeV and Fermis.

Table I

Parameters	V_0	W_0	a	R
Deuteron	$-57{,}5$	-12	0,6	3,6
Neutron	$-50{,}4$	-3	0,5	3

$$V(r) = \frac{V_0 + i\,W_0}{e^{(r-R)/a} + 1}$$

Table II summarizes our results.

Table II

E^* (MeV)	5,20 + 5,25	6,15
Q-Value	$-0{,}15 \pm 0{,}06$	$-1{,}08 \pm 0{,}05$
l_p	2	1
Parity	+	−
Spin	$\leq 7/2$	$\leq 5/2$
$(d\sigma/d\Omega)_{max}$ (mb/ster)	$3{,}0 \pm 0{,}7$	12 ± 2
$(2\,J+1)\,\theta^2$ Butler	0,026	0,014
DWBA	0,35	0,38

IV. Conclusion

The DWBA calculations clearly show that the simple Butler theory is not able to explain the detailed features of the angular distribution.

Our results on the doublet state throw doubt on the presence of heavy particle stripping and show that it is possible to explain the largest part of the backward peaking purely as distortion effects and contributions from stripping taking place in the interior of the nucleus.

V. Acknowledgments

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