EXCITATION CURVE FOR THE REACTION $^{15}(d,n^{7})^{16}$

by

Thomas A. Rabson

A THESIS
SUBMITTED TO THE FACULTY
IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF
MASTER OF ARTS

Houston, Texas
April, 1957  Approved: W. Bonner
INTRODUCTION

A magnetic lens pair spectrometer was used to study the nuclear pairs emitted by $^{16}_0$ when left in the excited state by the reaction $^{15}_N(d,n\eta)^{16}_0$. The deuteron beam for this reaction was obtained from the Rice Institute 6 Mev Van de Graaff accelerator. The 6.05 Mev nuclear pair line from $^{16}_0$ was investigated (See Fig. 4). The spectrometer magnet current was then adjusted to the peak of this curve, and an excitation curve was run for deuteron energies from 2.2 Mev to 4.7 Mev.

The 6.05 Mev state of $^{16}_0$, which is the first excited state, is a $0^+$ state as is the ground state. Since gamma ray transitions are forbidden the nucleus decays to the ground state by emitting nuclear pairs.
EQUIPMENT

A diagram of the pair spectrometer used in this experiment can be seen in Fig. 1. A brief description of it will be given here as more complete descriptions may be found elsewhere.¹

Only pairs emitted at a certain acceptance angle are allowed to pass through the spectrometer by the acceptance baffle. These pairs are then focused by the magnetic field of the coils indicated in the diagram. The pairs also must pass through a ring baffle at the center of the spectrometer. Because there is no iron in the instrument, the field is proportional to the current through the magnet coils. Upon calibration by a known level all other energies may be determined.

At the back end of the spectrometer the electrons and positrons pass through an exit foil and are detected outside the vacuum by two crystals. Because there is no preferred crystal for the electron or positron to enter it is assumed that for a fixed proportion of the cases the electron enters one crystal and the positron enters the other. This causes the two crystals to emit simultaneous light flashes which are detected by two separate photomultiplier tubes. After suitable amplification
these pulses are fed to a coincidence circuit which gives an output pulse when two simultaneous signals are applied to it. The resolving time of the circuit is about $4 \times 10^{-9}$ seconds. Background due to chance coincidences becomes high only when the rate of activity is such that the probability is high for two pulses occurring in the two crystals within $4 \times 10^{-9}$ seconds.

The deuteron beam for this experiment was obtained from the Rice Institute 6 Mev Van de Graaff accelerator. The energy of the beam was measured by means of an analyzing magnet in conjunction with a Pound magnetometer.$^2$
TARGET

The target used in this experiment was a .25 mil tantalum foil on which some $\text{N}^{15}$ gas had been deposited either by adsorption or formation of chemical bonds. This was done by heating the foil to approximately 1200°C in an atmosphere of 400 microns of 98% pure $\text{N}^{15}$ gas in which a glow discharge was being maintained. The foil was one of the electrodes maintaining the discharge. A diagram of the apparatus used for making the target is shown in Fig. 2.

The other electrode was made by fastening a brass cap to the top of the tube in which the target was made. The tantalum foil was placed on a tantalum disk which in turn rested on a pyrex stand. The tantalum disk was grounded by means of a strip of tantalum foil extending from the base of the pyrex tube up the side of the stand to the disk. In order to hold the foil secure against the force of the electric field necessary to maintain the glow discharge, a stainless steel ring was placed on top of the foil. The ring also tended to aid in the heating of the foil. The power to maintain the glow discharge was obtained from a 2000 volt transformer whose primary was connected to an autotransformer thereby giving a continually variable voltage.
TARGET MAKING APPARATUS

Figure 2

Brass

Pyrex Tube

Stainless Steel Ring

Ta Foil

Ta Disk

Ta Strip (Electrical Connection)

Induction Heater Loop

110 v. a-c

ma

1000 Ω

Pyrex Stand

To Diffusion Pump
The foil was first cleaned with acetone and placed in the previously described apparatus. It was left two days with the diffusion pump maintaining a pressure of about $10^{-4}$ mm. of Hg. Liquid nitrogen was placed in the trap, and the pressure dropped to $5 \times 10^{-6}$ mm. of Hg. The system was then closed off from the diffusion pump and $^1\text{N}$ gas was let in to a pressure of 400 microns. The total volume of the system into which the gas was released was approximately 0.3 liters.

The glow discharge was started with the voltage at 300 volts. The induction heater was started and the foil heated to about 1200°C. This process was continued for 5 minutes, by which time the pressure had dropped to 200 microns and, in order to maintain the glow discharge, the voltage had been raised to 1500 volts. At the end of this time the system was pumped out again and the entire process repeated.

The target was then investigated by studying the reaction $^1\text{N}^{15}(p,\alpha\gamma)^{12}\text{C}$, which has already been observed by Schardt, Fowler, and Lauritsen. In particular, the resonance at $0.898 \pm 0.001$ Mev, which is only 2.25 Kev wide was looked at. The results, shown in Fig. 3, indicate the target to be not more than 3 Kev thick to 0.9 Mev protons. The same reaction was used to investi-
Excitation Curve $N^15(p,\alpha\gamma)C^{12}$

Figure 3

Proton Energy - MeV

Number of Counts / 16
gate the $^\text{14}N$ target used by Marion, Brugger, and Bonner\textsuperscript{2} which had been found to be 60 Kev thick to 2 Mev deuterons. This utilized the fact that $^\text{15}N$ is .37\% abundant in the atmosphere. Its thickness was roughly 15 Kev to 0.9 Mev protons, which is consistent with the previous results. The relative yields of the two targets indicates the presence of about 1/3 as much total nitrogen on the foil used in this experiment as on the $^\text{14}N$ target.

The amount of gas deposited on the back portion of the foil (the thickness of the foil for protons is approximately 1.6 Mev) was measured by turning the foil over and looking at the 0.898 Mev resonance again. The yield was about 1/12 as great as it was on the front side without correcting for background.

The advantages in making a target by the glow discharge method are that it necessitates a smaller quantity of the gas being used because it is done at low pressures, the target can be made quite thin, and the positive ion bombardment aids in cleaning the target blank. The disadvantages are that the total amount of gas held in the target is not as great as when higher pressures with no discharge are used, and targets are difficult to make on very thin foils by this method.
because of the forces set up by the electric field.

The target remained rather stable at high temperatures and showed no great decrease in yield until a hole appeared in the tantalum foil as a result of the heat generated by stopping the deuteron beam.
COUNTING RATE vs. MAGNET CURRENT $N^{15}(d, n \, \sigma)C^{16}$

Figure 4

POTENTIOMETER SETTING

NUMBER OF COUNTS / 16

170 175 180 185 190 195
PROCEDURE

The target was mounted in the spectrometer between two aluminum washer-shaped sheets in order to make good thermal contact. This was done to help dissipate the heat generated by the beam being decelerated in the target.

It was calculated that most of the deuterons would pass through the .25 mil tantalum foil for energies above 2 Mev. Therefore, the total beam charge was measured by means of a Faraday cup placed behind the target to collect the charge. This current was then passed through an integrator to obtain total charge.

The energy of the deuteron beam was measured by means of an analyzing magnet whose field was determined by a Pound magnetometer, which utilizes a proton resonance absorption signal for field strengths to about 7000 gauss and a lithium signal for higher strengths. The frequency scale was converted to an energy scale by calibration to the $0.398 \pm 0.001$ Mev resonance in the $^{15}N(p,\alpha\gamma)^{12}C$ reaction which was studied in measuring target thickness.

A source for background counts would be in chance coincidences if a very high $\beta$ flux were present. This
was measured by inserting a delay line in one side of the coincidence circuit and was found to be negligible.

Another background effect was due to the scattering of high energy gamma rays and neutrons from the walls and coils of the spectrometer and was approximately determined by measuring the coincidence rate with zero current in the spectrometer coils. This effect was also found to be negligible. The effect of all background was minimized by employing a 20 channel analyzer to obtain a pulse height distribution. Only those pulses that were of the approximate size one would expect from the nuclear pairs emitted by $^{16}\mathrm{O}$ were counted.
EXCITATION CURVE $N^{15}(d,n\pi)O^{16}$

PAIR COUNTING RATE

DEUTERON ENERGY MEV

FIGURE 5
GAMMA RADIATION vs. DEUTERON ENERGY $N^{15} + H^2$

Figure 6

NAI COUNTING RATE - COUNTS

DEUTERON ENERGY - MEV

Figure 6
RESULTS AND DISCUSSION

The excitation curve obtained for the reaction $^\text{15}\text{N}(d,n\pi)^\text{16}_0$ is shown in Fig. 5. At least 600 counts were obtained for each point, and the measurable background mentioned above was quite low. Statistical fluctuations were about 4%. The principal reason for the unevenness in the points is undoubtedly the fact that the target was nonuniform and the deuteron beam was not always incident on the same portion of the target.

The following reactions are energetically possible when $^\text{15}\text{N}$ is bombarded with 2 - 5 Mev deuterons:

$$^\text{15}\text{N} + ^\text{2}_\text{H} \longrightarrow ^\text{17}_1^* \quad Q = 14.02 \text{ Mev}$$

$$^\text{15}\text{N} + ^\text{2}_\text{H} \longrightarrow ^\text{16}_0 + n \quad Q = 9.88 \text{ Mev}$$

$$\quad \longrightarrow ^\text{16}_1^* + n$$

$$^\text{15}\text{N} + ^\text{2}_\text{H} \longrightarrow ^\text{12}_0 + \alpha \quad Q = 7.68 \text{ Mev}$$

The process studied here is the third one for the specific case when the $^\text{15}_0$ nucleus is left in the first excited state and emits nuclear pairs.

The excitation curve obtained is explainable on the following basis. The upward slope in the 2 to 3 Mev
region is caused by the increase in the cross section for the $(d,n\gamma)$ reaction as the incident particles have more energy with which to penetrate the coulomb barrier which classically is about 2.8 Mev. After reaching a point at 3 Mev the cross section for the reaction under consideration probably remains constant. The fall off in the pair yield is directly attributable to the fact that at higher energies there are more competing processes that may take place. Higher energy levels in the $^{16}O$ nucleus may be excited. These states have a low probability of cascading into the 6.05 Mev state because it has the same $J$ and parity as the ground state but a much higher energy. This is borne out to some degree by the fact that the total gamma ray emission measured by a NaI crystal showed a continuous increase with increasing bombarding energy. At the higher energies (4-5 Mev) stripping undoubtedly made a contribution to the total yield.

The neutrons produced by this reaction at an incident deuteron energy of 1.2 Mev were studied by Hudspeth and Swann, and it was found that the neutrons leaving the $^{16}O$ nuclei in the first two excited energy levels were several times as intense as those leaving the nuclei in the ground state.
REFERENCES

1) W.A. Ranken, Thesis for M.A., the Rice Institute, March, 1956.


ACKNOWLEDGEMENT

To Professor T.W. Bonner and to the other members of the Rice Institute Physics department I wish to express my gratitude for making this work possible.