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GAMMA RADIATIONS FROM
EXCITED STATES OF N^{16}

by

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INTRODUCTION

The N^{16} nucleus exhibits a low energy level structure that is rather unique among light nuclei and it is therefore of considerable interest both experimentally and theoretically. The study by Pauli (1) of the reaction $O^{18}(d,\alpha)N^{16}$ indicated excited states at 116 ± 6 , 300 ± 12 , and 391 ± 12 kev with no indication of levels between 391 kev and 1.24 Mev. The study by Thirion, et al. (2) of the reaction $N^{15}(d,p)N^{16}$ confirmed this level structure, indicating excited states at 0.11, 0.29, and 0.39 Mev. Angular distribution measurements of the proton groups to the first three excited states of N^{16} , produced in the reaction $N^{15}(d,p)N^{16}$, have been measured by Zimmerman (3) at $E_d = 2.75$ Mev in the laboratory system. The angular distributions are in general agreement with stripping theory predictions and indicate angular momentum transfers $l_n = 0$, $l_n = 2$, and $l_n = 0$ leading to states at 0.113, 0.300, and 0.391 Mev, respectively. These values of l_n indicate spin and parity assignments of 0^- or 1^- to the 0.113 Mev state; 1^- , 2^- , or 3^- to the 0.300 Mev state; and 0^- or 1^- to the 0.391 Mev state. Studies of the beta decay of N^{16} to O^{16} and of the ensuing gamma rays have shown the ground state of N^{16} to be 2^- (4, 5).

Elliott and Flowers (6) have recently published intermediate coupling shell model calculations for N^{16} . Their calculations predict four low-energy levels, closely spaced and having spins of 0^- , 1^- , 2^- , and 3^- with no order indicated. Their calculations further predict another group of levels several Mev above this group with no levels in between. These predictions are in remarkable agreement with current experimental evidence.

More recent experiments to establish the spins, parities, and precise energies of the first four states of N^{16} have been performed by Wilkinson (7) and Freeman (8). Wilkinson studied the gamma rays resulting from the $N^{15}(d,p)N^{16}$ by means of NaI scintillation techniques and observed gamma rays of energy 387 ± 5 , 268 ± 5 , and 118 ± 3 kev. Relative initial population of the first three excited states of N^{16} were determined by using the angular distribution results of Zimmerman (3). Gamma-gamma coincidence techniques were used to detect possible cascading. It was found that a peak at 275 kev was a composite of a 287 kev gamma-ray transition to the ground state and of a cascade gamma ray from the 387 kev to the 118 kev level. Spin and parity assignments were made in accordance with the limited assignments indicated by the stripping observations of Zimmerman. Spins and parities assigned were 2^- , 0^- , 2^- or 3^- , and 1^- to the ground state and first three excited states, respectively.

Freeman and Hanna (8) have measured proton-gamma and gamma-gamma coincidence spectra from the $N^{15}(d,p)N^{16}$ reaction at $E_d = 2.6$ Mev in the laboratory system. The angular correlation of protons to, and the gamma rays from, the second excited state have also been measured. These results, taken in conjunction with stripping data and β -decay data have allowed spin and parity assignments to be made for all three excited states of N^{16} . The following spins and energies have been assigned to the three excited states: 0^- at 120 ± 1 kev, 3^- at 298 ± 5 kev, and 1^- at 395 ± 3 kev.

A comparison of experimental internal conversion coefficients to theoretical internal conversion coefficients allows one to deduce the parity change and angular momentum change of the nucleus resulting from

an internal conversion or a gamma-ray transition to a lower energy state. In this investigation the reaction $N^{15}(d,p)N^{16}$ has been used to determine the experimental internal conversion coefficient of the first excited state in N^{16} .

MATERIALS AND METHODS

Internal Conversion Coefficients (General)

Internal conversion and gamma-ray emission are competing processes which allow an excited nucleus to decay to a lower energy state. If the excitation energy is less than the binding energy of a nuclear particle, decay will generally occur by internal conversion or by gamma-ray emission. In internal conversion the nucleus interacts directly with an orbital electron. The excitation energy is transferred to the electron and the electron emerges with a kinetic energy equal to the energy of excitation less the binding energy of the electron. In gamma-ray emission practically all of the excitation energy emerges in the form of electromagnetic radiation.

The internal conversion coefficient is defined (9) to be the ratio of the transition probability per unit time, λ_e , for internal conversion to the transition probability per unit time, λ_γ , for gamma-ray emission, i.e.,

$$\alpha \equiv \lambda_e / \lambda_\gamma = N_e / N_\gamma$$

where experimentally N_e and N_γ are the number of conversion electrons and gamma rays emitted per unit time, from a sample of identical nuclei undergoing the same nuclear transformation characterized by a particular energy.

The internal conversion coefficient depends upon the following parameters (10):

- (a) The transition energy $K m_0 c^2$.
- (b) The atomic number (Z) of the emitter.
- (c) The shell or subshell from which the electron is ejected.
- (d) The multipolarity L , or angular momentum of the radiating field, i.e., of the competing gamma radiation.
- (e) The character of the nuclear transition, electric or magnetic, which in turn, uniquely determines the nuclear parity change once L is fixed.

Internal Conversion Coefficients (Theoretical Calculations)

Rose, et al. (11) have calculated unscreened K and L internal conversion coefficients for $Z = 10$ to $Z = 96$ over a wide range of energies and have more recently published K and L internal conversion coefficients which take into account screening effects for several Z values greater than 25 and for approximately the same range of energies as for the unscreened coefficients (12).

Dancoff and Morrison (13) have made calculations of K internal conversion coefficients including relativistic effects. These calculations neglect the K -binding and screening effects. The expressions of Dancoff and Morrison for the K internal conversion coefficients for $Z < 30$ are readily calculable and are given by the following expressions:

Electric:

$$\alpha_K^{\ell} = \frac{2Z^3\alpha^4}{\nu^3} \left(\frac{\nu+2}{\nu}\right)^{\ell-\frac{1}{2}} \left[\frac{(\ell+1)\nu^2+4\ell}{\ell+1}\right] \quad \left\{\frac{Ze^2}{\hbar\nu} \ll 1\right.$$

Magnetic:

$$\beta_H^{\ell} = \frac{2Z^3\alpha^4}{\nu} \left(\frac{\nu+2}{\nu}\right)^{\ell+\frac{1}{2}} \quad \left\{\frac{Ze^2}{\hbar\nu} \ll 1\right.$$

where α = fine structure constant $1/137$ and $\nu = E_{\gamma}/m_0c^2$.

Mills (14) has pointed out that a good approximation to the screened calculations for $Z < 25$ may be obtained by plotting the ratio of the screened coefficients of Rose to the Born approximation coefficients of Dancoff and Morrison as a function of Z . Mills has plotted the ratio as a function of Z , obtaining a family of curves corresponding to different gamma-ray energies for E_1 , M_1 , E_2 , and M_2 radiation. In extrapolating the curves to lower values of Z the assumption was made that the ratio would be unity at $Z = 0$. The values of screened coefficients obtained by this method are believed to contain an uncertainty of about 10 percent for $Z < 25$.

The theoretical conversion coefficients for E_1 , M_1 , E_2 , and M_2 radiation corresponding to the energy of the first excited state of N^{16} have been obtained by this method from the curves of Mills (14).

Internal Conversion Coefficients (Experimental)

To determine internal conversion coefficients experimentally the number of conversion electrons N_e , and the number of gamma rays N_{γ} , emitted per unit time from the same sample of nuclei undergoing the same

energy characteristic nuclear transformation must be measured. The conversion coefficient is given by the ratio of N_e to N_γ .

A magnetic spectrometer is particularly suitable for the measurements of electron spectra. Mitchell (15) outlines the necessary assumptions and method of determining relative intensities of photoejected electrons using a magnetic spectrometer. The method applies, in principle, to the relative intensity determination of internal conversion electrons as well. If the resolution of the spectrometer is constant and targets are not too thick, the shape of the conversion line should approximate the shape of the transmission curve of the spectrometer. If $n(B\rho)$ $d(B\rho)$ is the number of conversion electrons counted in an interval $d(B\rho)$, then the total number of conversion electrons counted "under the line" will be

$$\int_{line} n(B\rho) d(B\rho)$$

This quantity is assumed to be proportional to the total number of conversion electrons emitted from the source per unit time.

Experimentally one takes a series of counts at a sufficient number of field settings to obtain the profile of the conversion line. Let the counts per unit time* be N for a given field B . The momentum interval accepted by the spectrometer is proportional to B , it follows that $n(B\rho) d(B\rho) \propto N/B\rho d(B\rho)$. The area under the profile given by a plot of $N/B\rho$ vs $B\rho$ is

$$A = \int_{line} \frac{N}{B\rho} d(B\rho) = K I_K$$

* The number of counts N may also be expressed as counts per unit charge or any other quantity appropriate to the measurement.

where K is a proportionality constant and I_k is the total number of conversion electrons emitted from the source during the interval of measurement. The relative intensity of two lines is given by

$$\frac{I_1}{I_2} = \frac{A_1/K}{A_2/K} = \frac{A_1}{A_2}$$

If I_1 is known absolutely then an absolute value for I_2 is obtained by this method. In this experiment a calibrated Bi^{207} source served as a reference standard.

Gamma-ray yields can be determined by several different methods. Sodium-iodide scintillation spectrometry is a method commonly used and was used in this experiment. For complicated gamma-ray spectra the number of counts in the full-energy gamma-ray peak is most easily determined. The full-energy gamma-ray peak in a NaI crystal results from the direct photoelectric conversion of the incident gamma ray and by Compton conversion followed by the photoelectric conversion of the recoil photon. Therefore, the full-energy peak efficiency is dependent upon both the energy of the incident gamma ray and the size of the NaI crystal. The full-energy peak efficiency does not yield itself readily to calculation and must therefore in general be determined experimentally. For sufficiently low-energy gamma rays the counts in the full-energy peak represent practically all the counts produced in the crystal. For a gamma-ray energy of 120 keV the total efficiency for a 1 inch diameter by 1 inch thick NaI(Tl) crystal differs from the photoelectric efficiency by less than 2 percent. Since the full-energy efficiency should be somewhat greater than the photoelectric

efficiency, the use of the total efficiency in lieu of full-energy efficiency at this energy should introduce a maximum error in the gamma-ray yields of only a few percent.

In this experiment the total efficiency curves of Wolichi (16) were used to determine the gamma-ray yields.

Target Preparation

None of the commercially-available N^{15} -enriched compounds were considered satisfactory target materials. All of the commercial compounds were characterized by unsuitably low temperatures for melting or decomposition.

Chromium nitride has a decomposition temperature of about $1700^{\circ}C$. Although chromium has an atomic number of 24, this was not considered too objectionable for the intended experiments.

Chromium targets were prepared by heating chromium foils in a N^{15} -enriched gas atmosphere, of about 35 cm of Hg pressure for periods of 15 to 45 minutes. An induction heater was used to elevate the temperature of the foils to about $1300^{\circ}C$. A diagram of the target preparation system is shown in Figure 1.

In preparing the targets for this experiment the target foil was placed on a solid tantalum disc. The foil was weighted down with a small piece of quartz tubing in order to maintain contact with the disc. The tantalum disc was placed on a quartz tubing stand of the proper height to insure maximum induction. The gas chamber was evacuated to a vacuum of

Fig. 1. The gas chamber of the target preparation system used to produce CrN^{15} by heating Cr foils in N^{15} gas at about 1300 °C.

approximately 10^{-7} mm of Hg at which time the target was out-gassed at a temperature of about 500° C. The target was allowed to completely cool and the system to again reach a vacuum of 10^{-7} mm of Hg pressure before letting the N^{15} gas, enriched to 99 percent N^{15} , into the chamber. The induction heater was then adjusted to give the desired temperature of approximately 1300° C.

Targets were produced from self-supporting chromium foils and chromium foils on nickel backings. The foils were produced by electroplating chromium from a chromic acid solution onto nickel or copper backings. The self-supporting foils were obtained by etching away the copper backing with nitric acid. In order to produce a "soft chrome" foil which is also more porous (17), the plating solution was heated to about 95° C and maintained at this temperature during the plating process. A simple plating system consisting of a 600 milliliter beaker, a lead anode, a copper or nickel foil cathode, a battery charger and a hot plate was used. The plating solution consisted of 1 part CrO_3 to 10 parts distilled water. Enough concentrated H_2SO_4 was added to produce a ratio of CrO_3 to SO_4 of 100. A plating current of about 8 amperes produced a 1 mg/cm^2 deposit in about 15 minutes.

EXPERIMENTS AND RESULTS

Apparatus

The source of protons and deuterons used in the various phases of this experiment was The Rice Institute 6 Mev Van de Graaff accelerator.

Relative and absolute gamma-ray yields were made using a 1 inch diameter by 1 inch thick NaI(Tl) crystal mounted on a Dumont 6292 photomultiplier tube. A RCL 256-channel pulse-height analyzer was used to obtain the pulse-height spectrum of the gamma-rays.

An intermediate-image magnetic lens spectrometer (18) was used to obtain the internal conversion electron spectra. The detector used in conjunction with the spectrometer was a 1 inch diameter end-window geiger counter having a 1.4 mg/cm² mica window.

Target Testing

The reaction $N^{15}(p, \alpha \gamma)C^{12}$ was used to test the CrN^{15} targets for N^{15} content and thickness. The yield of the 4.43 Mev gamma-ray from C^{12} served as means of determining both quantities. The thickness of the targets for protons of 1.64 Mev energy was determined by measuring the yield of the 4.43 Mev gamma ray as a function of proton energy between approximately 1.55 and 1.70 Mev proton energy. There is a resonance for this reaction at 1.64 Mev which has a width of 64 ± 3 kev (19). Knowing the resonance width and the experimental width one can calculate the thickness of the N^{15} in kev for protons at this energy. These results are summarized in Table 1 along with other pertinent information relative to the targets tested.

Table 1

Target Number	Chromium Surface Density (mg/cm ²)	Nickel Surface Density (mg/cm ²)	Thickness E _p = 1.64 Mev (kev)	Ratio N ¹⁵ (Cr-CrN ¹⁵ Tar.) to N (CrN Tar.)
2	0.95	5.93	100 kev	0.258
3	3.28	none	395 kev	0.545
4	4.15	4.15	89 kev	0.188
5	0.56	2.47	76 kev	0.163
6	0.95	5.90	134 kev	0.267

A thick CrN target, made from chemically pure CrN powder, was compressed onto a thick silver backing at a pressure of 15 tons per square inch. The resulting target had an average surface density of 18.6 mg/cm². The CrN was assumed to contain a normal abundance of N¹⁴ and N¹⁵. The thick target was bombarded at an appropriate energy in the region of the 1.64 Mev resonance for a particular CrN¹⁵ target under comparison. Since the protons lost all of their energy in the thick target, it was necessary to make an integration of the excitation curve for the reaction N¹⁵(p,αγ)C¹² for proton energies from zero to the bombarding energy in order to determine the appropriate yield from the thick target. Using the measured yields and correcting for the natural abundance of N¹⁵ in normal N the ratio of the amount of N¹⁵ in the CrN¹⁵ targets to the amount of normal nitrogen in the thick target was obtained. This ratio for each target tested is included in Table 1.

Electron Spectrum from $N^{15} + d$

The lens spectrometer was equipped with a positron baffle for this experiment and gave a 2.8 percent momentum resolution for the Bi^{207} K-1.0639 Mev internal conversion line with a corresponding transmission of about 3 percent. This line was also used for calibration of the spectrometer.

The target used had a chromium surface density of 0.58 mg/cm^2 electroplated onto a 2.47 mg/cm^2 nickel backing. The ratio of N^{15} in this target to N in a 18.6 mg/cm^2 , chemically pure CrN, compressed target was 0.163.

The reaction product under investigation, N^{16} , decays to O^{16} by β -emission with a half-life of 7.4 seconds. Under conditions of continuous bombardment, equilibrium of this activity is rapidly achieved and maintained during the major portion of each experimental point. Preliminary runs of this experiment showed the associated β rays to be contributing a large number of counts to each experimental point. In an attempt to eliminate the major portion of this effect a "beam chopper" was placed in the drift tube about 3 feet in front of the target. The basic part of the "beam chopper" is a magnetically operated tantalum gate. The gate is made to open, allowing passage of the beam to the target, or close, stopping the beam, by a reversal of current through the associated solenoids. In this experiment the beam chopper was controlled by a periodic timer having a 2 second open and 8 second closed cycle. Thus for each 2 second bombardment the N^{16} produced was allowed to decay for a period slightly longer than one half-life.

The transmission of the spectrometer begins to decrease upon reaching a certain minimum electron energy. The exact energy at which the transmission begins to decrease depends upon the spectrometer configuration

being used. A Fermi plot of the Pm^{147} β spectrum yields a straight line from its end-point energy of 230 kev to about 10 kev provided the transmission of the spectrometer is constant. A Pm^{147} source was prepared and a Fermi plot made of the β spectrum in order to determine the energy at which transmission corrections should be made. The Fermi plot of the Pm^{147} β spectrum is shown in Figure 2.

A deuteron bombarding energy of 2.84 Mev was used to bombard the N^{15} target. The target was placed in the spectrometer with the nickel backing toward the beam. The deuterons lost approximately 340 kev of energy in passing through the nickel backing and an additional 90 kev in passing through the chromium. The energy of the deuterons entering into the reaction $\text{N}^{15}(\text{d},\text{p})\text{N}^{16}$ was between 2.4 and 2.5 Mev. The beam chopper was operated as previously described, as a result the effects of the N^{16} β -decay was reduced almost a factor of five. The electron detector was a 1 inch diameter, D-37A, end-window geiger counter with a 1.4 mg/cm^2 window. A NaI detector and a geiger counter were used to monitor the gamma rays from the reactions taking place. These two counters gave a continuous check on the condition of the target. The monitors, the D-37A geiger counter, and the beam chopper were all controlled by the periodic timer, thus all counters were on during the 2 second bombardment of the target and off during the 8 second decay period. The timer was controlled by a beam current integrator which could be pre-set to stop the timer after a given number of integrator counts. An approximate beam current of $1/2$ microampere was maintained throughout this phase of the experiment. The electron spectrum obtained is shown in Figure 3.

Fig. 2. Kurie plot of the Pm^{147} β spectrum.

Fig. 3. The internal-conversion electron spectrum for the 120-kev transition in N^{16} , produced in the reaction $N^{15}(d,p)N^{16}$ at $E_d = 2.84 \text{ Mev}$.

Gamma Radiation from $N^{15} + d$

For the gamma-ray yield determinations, the target was mounted with the nickel backing toward the beam at an angle of 45° to the deuteron beam. The aluminum target holder had a thin wall, 30 mils thick, directly behind the target position in order to keep the gamma-ray absorption as low as possible. It was necessary to mount a 37 mg/cm^2 Sn absorber between the target and the Al target holder to prevent unwanted reactions from taking place in the aluminum. The deuterons on the Sn produced a very small gamma-ray background, although it did attenuate the 120 keV gamma rays about 10 percent.

Spectra and yields were obtained with two different sizes of NaI(Tl) crystals, a $1/2$ inch diameter by $1/2$ inch thick crystal and a 1 inch diameter by 1 inch thick crystal. The NaI crystal was mounted on a Dumont 6292 photomultiplier tube. The pulses produced in the crystal were fed into a RCL 256-channel pulse-height analyzer. The spectrometer was calibrated using the 123 keV gamma ray from Co^{57} , the 511 keV annihilation gamma ray from Na^{22} , and the 662 keV gamma ray from Cs^{137} .

The current integrator was observed to operate unreliably for beam currents of less than 0.1 microamperes. The procedure followed was to maintain a constant deuteron beam of 0.1 microamperes and to adjust the target to detector distance to give an acceptance ratio of 1 on the pulse-height analyzer. Measurements were made at 0° and 90° with respect to the beam and indicated the gamma rays to be isotropic within a few percent. A 2.47 mg/cm^2 nickel foil was bombarded to determine the contribution of the nickel and the Sn. The spectra obtained at 0° using the 1 inch diameter by 1 inch thick NaI(Tl) crystal are shown in Figure 4.

Fig. 4. The gamma-ray spectrum resulting from the bombardment of N^{15} with 2.84 Mev deuterons.

Results

Internal conversion lines were observed at 105 ± 2 kev and 119.8 ± 0.4 kev. The electron yields of these two lines were determined in the manner previously described. The electron yields were 2.78×10^4 electrons/37.03 microcoulombs and 12.26×10^4 electrons/37.03 microcoulombs for the 105 and 119.8 kev lines, respectively.

The gamma-ray spectrum from the N^{15} target showed peaks at 120 ± 5 kev, 155 ± 10 kev, 275 ± 5 kev, 390 ± 10 kev, and 511 kev annihilation radiation which was used for calibration. The spectrum obtained from bombarding a 2.47 mg/cm^2 nickel foil for the same quantity of beam showed gamma-ray peaks at 60 ± 10 kev, 155 ± 10 kev, 511 kev, and a slight indication at about 340 kev. The intensity of the 155 kev and 511 kev radiations was less than from the N^{15} target. The origin of the annihilation radiation is probably from N^{14} and C^{12} contamination. The associated reactions $N^{14}(d,n)O^{15}$ and $C^{12}(d,n)N^{13}$ produce residual nuclei which decay by β^+ emission. The relative intensities of the annihilation radiation from the N^{15} target indicate that these reactions may be the source because there is certain to be some N^{14} contamination in the N^{15} target and probably none on the nickel foil. The origin of the 155 kev gamma ray has not been determined.

The peaks at 120 kev, 275 kev, and 390 kev are believed to be from N^{16} . The energy level diagram for the first four states of N^{16} (19) is shown in Figure 5. One observes that the 120 kev gamma ray is consistent with a transition from the first excited state to the ground state and the 390 kev gamma ray is consistent with a transition from the third excited state to the ground state. The 275 kev peak is believed to consist of two unresolved gamma rays of 295 kev and 272 kev energy resulting

FIG. 5

GAMMA - BRANCHING

Fig. 5. The four lowest energy levels of N^{16} . The energies are in kev and the gamma-ray percentages are for each level.

from transitions between the second excited state and the ground state and between the third and first excited states, respectively. A gamma ray having an energy of 105 kev could result from a transition between the third and second excited states but would not be resolved due to the closeness of the 120 kev gamma ray.

The yield of the 120 kev gamma ray was determined to be 4.17×10^7 gamma rays/24.96 microcoulombs and 4.55×10^7 gamma rays/24.96 microcoulombs using the 1/2 inch diameter by 1/2 inch thick NaI crystal and the 1 inch diameter by 1 inch thick NaI crystal, respectively.

ANALYSIS AND CONCLUSIONS

The 120 kev electron yield was normalized to the number of counts per 24.96 microcoulombs, the number for which the gamma-ray yields were made. The electron yield, the gamma-ray yield for each crystal size and the conversion coefficient are given in Table 2 for $E = 120$ kev.

Table 2

E (kev)	NaI Crystal	Y_γ ($\gamma/24.96 \mu\text{coul.}$)	Y_e ($e/24.96 \mu\text{coul.}$)	α_K
120	1/2" x 1/2"	4.17×10^7	8.27×10^4	1.98×10^{-3}
120	1" x 1"	4.55×10^7	8.27×10^4	1.82×10^{-3}

Table 3 gives the theoretical conversion coefficients for E_1 , M_1 , E_2 , and M_2 radiations. It also gives the ratio of the experimental coefficient to the theoretical coefficient.

Table 3

Theoretical Conversion Coefficients, 120 kev Transition				
	E_1	M_1	E_2	M_2
	6.79×10^{-4}	2.55×10^{-4}	8.10×10^{-3}	2.40×10^{-3}
NaI	$\alpha_K(\text{Experimental})/\alpha_K(\text{Theoretical})$			
1/2"	2.92	7.76	0.244	0.825
1"	2.68	7.14	0.224	0.758

The ratio is most nearly unity for M_2 radiation rather than E_2 radiation which is indicated by present spin and parity assignments. Assuming the ground state is definitely 2^- , M_2 radiation would require the first excited state to be 4^+ or 0^+ rather than the presently assigned value of 0^- . A positive parity assignment to this level is in complete disagreement with the theoretical predictions of Elliott and Flowers (6) and the experimental results of Zimmerman (3), Wilkinson (7), and Freeman (8).

Loss of internal conversion electrons would result if recoiling N^{16} nuclei escaped from the target. Calculations to determine the magnitude of this effect indicate that less than 10 percent of the recoiling N^{16} nuclei would have sufficient energy to escape from the target.

In order to confirm or reconcile this disagreement, new experiments are being planned. These include measuring some well established internal conversion coefficients as a check of the experimental procedure.

The 105 ± 2 kev electron peak falls within the limits of error of a transition between the third and second excited state in N^{16} . A gamma ray of this energy would not be resolved in a NaI crystal in the presence of the strong 120 kev gamma ray. A gamma transition between the third and second excited states would be in coincidence with the 295 kev transition of the second excited state to the ground state. Wilkinson (7) in his investigation of this reaction looked for such coincidences and actually observed no increase of coincidence counts above the accidental rate. He assigned an intensity for gamma rays resulting from a third to second excited state transition to be ≤ 2 relative to the 120 kev first excited to ground state gamma-ray intensity of 111. Freeman and Hanna (8) studied this reaction at the same deuteron energy as Wilkinson. Their gamma-gamma

coincidence results indicated the intensity of gamma rays due to transitions between the third and second excited states to be < 4 percent of the total gamma-ray transitions from the third excited state. On this basis, the intensity of 105 kev gamma rays resulting from a third to second excited state transition would be ≤ 3 relative to the 120 kev first excited to ground state gamma-ray intensity of 100. This is a slightly higher upper limit than that stated by Wilkinson.

This experiment was performed using approximately the same deuteron energy as that used by Wilkinson and Freeman, hence the gamma-ray branching ratios determined in their investigations were considered to be valid for this investigation. Assuming the intensity of the 105 kev gamma ray relative to the 120 kev gamma ray to be $3/100$, an estimated yield of 13.9×10^5 gamma rays/ 24.96 microcoulombs for the 105 kev gamma ray was obtained. The 105 kev electron yield was 1.87×10^4 electrons/ 24.96 microcoulombs. Using these values for N_e and N_γ one obtains an estimated internal conversion coefficient of 1.35×10^{-2} . The theoretical E_1 , M_1 , E_2 , and M_2 conversion coefficients for $E_\gamma = 105$ kev and the ratios of the estimated conversion coefficient to the theoretical coefficients are given in Table 4.

Table 4

Theoretical Conversion Coefficients, 100 kev Transition			
E_1	M_1	E_2	M_2
1.03×10^{-3}	4.46×10^{-4}	1.40×10^{-2}	4.53×10^{-3}
$\alpha_K(\text{Estimated})/\alpha_K(\text{Theoretical})$			
> 10.3	> 30.2	> 0.96	> 2.98

The ratios exclude E_1 , M_1 , and M_2 radiations. The ratio is most nearly unity for E_2 radiation which would be consistent with present spin and parity assignments of 1^- and 3^- for the third and second excited states, respectively. The theoretical conversion coefficients for both electric and magnetic transitions of higher multipolarity give an estimated conversion coefficient to theoretical conversion coefficient ratio less than 1. Since the estimated gamma-ray yield is an upper limit value, neither electric nor magnetic radiation of multipolarity greater than 2 can be excluded as being possible for a transition between the third and second excited state.

Although assignment of the 105 kev line to N^{16} is not definite and the conversion coefficient is only a rough approximation, this analysis does indicate some particular areas to be carefully studied in future experiments.

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