PHYSICAL REVIEW VOLUME 105, NUMBER 4 FEBRUARY 15, 1957

Positron Spectrum of O^{15}

O. C. Kistner, A. Schwarzschild, and B. M. Rustad, *Columbia University,* New York, New York, and Brookhaven National Laboratory,* Upton, New York*

and

D. E. Alburger, *Brookhaven National Laboratory,* Upton, New York*

(Received November 8, 1956)

The positron spectrum of O^{15} has been investigated with two iron-free magnetic spectrometers. One measurement, performed with an intermediate-image spectrometer and a solid source, gave an end-point energy of 1.723 ± 0.005 Mev. The other measurement, performed with a thin-lens spectrometer and a gaseous source, gave an end-point energy of 1.736 ± 0.010 Mev. These values, which are approximately 0.050 Mev higher than the only previously reported spectrometer measurement, are in good agreement with the end point predicted from $N^{15}(p,n)O^{15}$ threshold determinations. The *ft* value calculated from an average end-point energy of 1.733 ± 0.005 Mev derived from the beta spectra and the (p,n) threshold measurements is 4280 ± 100 seconds. This new value brings the O^{15} decay into good agreement with the $B-x$ analysis of the $0-0$ spin change and the "doubly closed shell plus or minus one nucleon" beta transitions.

INTRODUCTION

The decay, $O^{15}(\beta^+)N^{15}$, is one of the six interesting cases of mirror transitions occurring between nuclei with a configuration differing by one nucleon from a doubly closed shell. The measured *ft* values for these transitions and for the $0-0$ transitions have been used in a number of papers[1–3] to determine the coupling constants in the beta-decay interaction because, for these cases, the Gamow-Teller matrix elements can be approximated from a simple nuclear model.

O^{15} has been studied previously by Brown and Perez-Mendez who reported[4] that it decays by emission of a single positron group with a half-life of 118 ± 0.6 seconds and with an end-point energy of 1.683 ± 0.005 Mev determined by means of a 180 degree, iron-core spectrometer. Kline and Zaffarano have reported[5] the half-life as 123.4 ± 1.3 seconds. According to Kington *et al.*, their recent measurement[6] of the $N^{15}(p,n)O^{15}$ threshold leads to a maximum beta energy of 1.735 ± 0.008 Mev, a value which is 52 kev higher than the result of Brown and Perez-Mendez. This difference is significant because the comparative half-life varies approximately as the fifth power of the end-point energy. The present measurements of the O^{15} beta spectrum were undertaken to resolve this discrepancy and thereby better establish the comparative half-life of O^{15}.

EXPERIMENTAL PROCEDURE AND RESULTS

Two independent measurements of the beta spectrum were made, one with an iron-free intermediate-image spectrometer[7] and a solid source, the other with an iron-free thin-lens spectrometer and a gaseous source.

(a) Intermediate-Image Spectrometer

The O^{15} for the measurement with the intermediate image spectrometer was produced by the reaction $N^{14}(d,n)O^{15}$. Targets of titanium nitride, several mg/cm^2 in thickness, were deposited on 0.00005-inch nickel foil and located in the normal source position of the instrument. A tantalum aperture limited the deuteron beam from the Van de Graaff accelerator to a spot 2 mm in diameter. After passing through the foil and the nitride deposit, the beam was collected in a cup attached to the inner limiting entrance baffle.

The beta spectrum was measured with the resolution of the spectrometer set for a momentum line width of 0.8% (full width at half maximum). The procedure consisted of irradiating the target for 2 minutes, turning down the Van de Graaff voltage, and then measuring a set of four points on the spectrum. An end-window Geiger counter was used for detection. Counting periods were of 30 seconds duration spaced 30 seconds apart in order to allow time for the spectrometer current to stabilize. In each sequence of four points, the first two points overlapped the last two points of the previous set so that a normalized spectrum could be obtained after correction for decay. Data taken beyond the end point established the amount of scattered background which was to be subtracted. A deuteron current of 0.02 microampere at 3 Mev was sufficient to give an initial counting rate at the peak of the spectrum of over 10 000 counts per minute. No deterioration of the target was observed.

The spectrometer was calibrated with the *K*-conversion line[8] of the 1.0639-Mev transition in the Bi^{207} decay by using a source 1.5 mm in diameter; the line was taken at the beginning and end of each day of

---

* Under contract with the U. S. Atomic Energy Commission.

[1] G. L. Trigg, Phys. Rev. **86**, 506 (1952).

[2] A. Winther and O. Kofoed-Hansen, Kgl. Danske Videnskab. Selskab, Mat.-fys. Medd. **27**, No. 14 (1953); O. Kofoed-Hansen and A. Winther, Phys. Rev. **86**, 428 (1952).

[3] J. M. Blatt, Phys. Rev. **89**, 83 (1953).

[4] H. Brown and V. Perez-Mendez, Phys. Rev. **78**, 649 (1950).

[5] R. B. Kline and B. J. Zaffarano, Phys. Rev. **96**, 1620 (1954).

[6] Kington, Bair, Cohn, and Willard, Phys. Rev. **99**, 1393 (1955).

[7] D. E. Alburger, Rev. Sci. Instr. (to be published).

[8] D. E. Alburger, Phys. Rev. **92**, 1257 (1953).

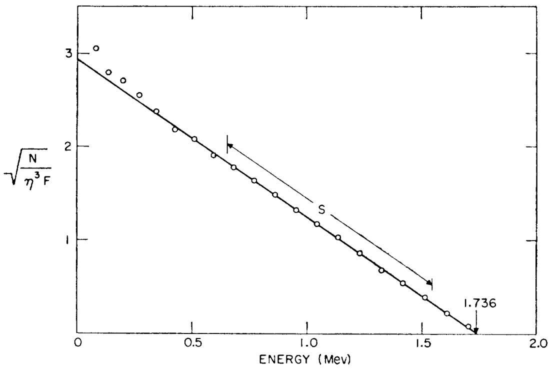

FIG. 1. Kurie plot of the positron spectrum from gaseous O^{15} measured with the thin-lens spectrometer. The curve is a weighted least-squares fit to the points in region *S*.

runs on the O^{15} spectrum. The greatest variation in the peak position was less than 0.1%. In addition the overall linearity of the current regulating system, which uses a 0.025% linearity Helipot as a reference potentiometer, was checked by means of a Leeds and Northrup type *K* potentiometer. A correction in the calibration constant was made for a slight difference between the axial positions of the target and the Bi^{207} test source.

In measurements of the complete positron spectrum, the Kurie plot was linear above 0.7 Mev. Deviations below that energy are undoubtedly caused by source thickness and backing effects. At the peak of the spectrum the counting rate was observed to decay with a half-life of 122±5 seconds.

Because the principal interest centers on the end-point energy, data were thereafter restricted to the region above 1.2 Mev in one group of runs and above 1.5 Mev in another group. In each case a number of sets of points was averaged together after correction for counter dead-time, natural background, source decay, normalization, and subtraction of scattered background. The weighted average end-point energy of the various groups of runs is 1.723±0.005 Mev, where the estimated error includes the uncertainties of calibration, current regulation linearity, background subtraction, and Kurie plot extrapolation.

(b) Thin-Lens Spectrometer

The experimental arrangement for the measurement with the thin-lens spectrometer was essentially the same as that used previously for the measurement of the A^{35} beta spectrum.[9] The O^{15} was made by the reaction, $C^{12}(\alpha,n)O^{15}$, using a liquid target of carbon tetrachloride and 40-Mev alpha particles from the Brookhaven 60-inch cyclotron. O^{15} was produced continuously during the measurements; vapor evolving from the target liquid swept the activity from the target chamber and carried it through $\frac{1}{4}$-inch copper tubing to the experimental area. The vapor and any condensable contaminants were removed from the stream of radioactive gas by means of a series of liquid nitrogen traps, and the remaining gas was concentrated by a diffusion pump and passed through the source volume of the spectrometer at a pressure of about 10 microns. The activity was monitored with a Geiger counter which detected the annihilation radiation emanating from a blind tube leading out of the source volume. The spectrometer was calibrated with an extended Bi^{207} source placed in the median plane of the source volume. The validity of this method of calibration has been verified by measurements[9] on other gaseous and solid sources. The resolution of the instrument was 2.5%.

The decay of the O^{15} was observed by isolating the source volume with toggle valves and recording the output of the monitor scaler with a fast pen oscillograph. The logarithmic decay curves of the activity were linear for more than four half-lives, giving a value of 120±2 seconds. Analysis of the decay curves showed that at most only insignificant amounts of active contaminants were present.

The field-dependent background of the beta spectrometer was approximated by linear interpolation between the background at zero field and that at several points taken past the end of the spectrum, and amounted to less than 3% of the intensity at the peak of the spectrum. The Kurie plot of the beta spectrum is linear down to less than 0.4 Mev as is shown in Fig. 1. An end point of 1.736±0.010 Mev was obtained from a weighted least-squares fit to the points indicated in the figure. The assigned error is a conservative estimate based on the accuracy of the calibration and the statistical deviations of the background and the Kurie plot.

DISCUSSION

The values of the O^{15} end-point energy of 1.723 ±0.005 Mev and 1.736±0.010 Mev, obtained from the present spectrometer measurements, are in good agreement with the value[6] of 1.735±0.008 Mev predicted by the (p,n) threshold measurement of Kington *et al.* In addition, the $N^{15}(p,n)O^{15}$ threshold has just recently been remeasured by the Van de Graaff accelerator group at Columbia University with a resulting O^{15} end-point energy[10] of 1.738±0.007 Mev. The above agreement is evidence that the earlier spectrometer measurement by Brown and Perez-Mendez is probably in error.

To obtain a best value of the end point for the calculation of the comparative half-life, it was considered most reasonable to weight each of the four independent measurements equally. The average value is 1.733 ±0.005 Mev, where the error is twice the probable error computed from the deviations from the mean. The average value of the half-life, computed in a similar manner from the two previously reported values

---

[9] Kistner, Schwarzschild, and Rustad, Phys. Rev. **104**, 154 (1956).

[10] L. Lidofsky (private communication).

of 118 seconds and 123.4 seconds together with the gaseous source measurement of 120 seconds from the present experiment, is 120.5±2.2 seconds. From the tables[11] of Moszkowski and Jantzen, which are accurate to 0.5%, the *ft* value for the $O^{15}(\beta^+)N^{15}$ transition was calculated as 4280±100 seconds. This new *ft* value brings the O^{15} decay into excellent agreement on the $B-x$ diagram[2,12] with the $0-0$ transitions and the "doubly closed shell±one nucleon" mirror transitions of n, H^3, and F^{17}.

ACKNOWLEDGMENT

We are indebted to Professor C. S. Wu, Dr. D. H. Wilkinson, and Professor W. W. Havens, Jr., for their helpful discussions in this problem and to Mr. Henry Brinton for performing some of the calculations. We thank Dr. L. Lidofsky for communicating the results of his (p,n) threshold measurement before publication.

---

[11] S. A. Moszkowski and K. M. Jantzen, University of California Technical Report No. 10-26-55 (unpublished).

[12] O. Kofoed-Hansen and A. Winther (to be published). In this paper the *ft* value for O^{15} on the $B-x$ diagram was calculated on the basis of the end point predicted by the (p,n) threshold measurement of reference 6 and the half-life of reference 5.

PHYSICAL REVIEW VOLUME 105, NUMBER 4 FEBRUARY 15, 1957

Deformations of Heavy Nuclei

Osamu Miyatake, *Institute of Polytechnics, Osaka City University, Osaka, Japan*
Yasukazu Yoshizawa, *Department of Physics, Osaka University, Osaka, Japan*

and

Masao Toyama, *Osaka Joshigakuen Junior College, Osaka, Japan*

(Received March 5, 1956)

The value of the distortion parameter of an even-even nucleus which is derived by using the experimental values of the energy of the first excited state, is much greater than that determined from the lifetime of the first excited state of the same nucleus. This discrepancy is explained by assuming that there is a sort of rotational character of the nuclear matter and that the protons are distributed in a region slightly smaller than the whole nucleus. The mechanism of large deformations of eleven even nuclei is explained by applying the strong-coupling theory. The coupling constants between the extra particles and the nuclear surface are much smaller than those which have been used previously. The energies of the first excited states are calculated.

I. INTRODUCTION

THE measure of nuclear distortion is given by the distortion parameter[1] β in the collective model theory. Let β_τ be the values of β determined from the lifetimes of the first excited states of even-even nuclei, and β_Q be the values of β determined from the observed quadrupole moments[2] of odd nuclei. Then β_τ of an even nucleus is nearly equal to β_Q of the neighboring odd nuclei. The value of β determined from the Coulomb excitation coincides roughly with the value β_τ. The value of β_1 determined from the energy spacing between the ground and first excited states is roughly twice that of β_τ for atoms in the vicinity of the rare earths.

β_1 is a quantity related to the moment of inertia of the nucleus, so that its value is determined by the mass distribution, and β_τ is considered to be related to the charge distribution. Recently, Ross *et al.*[3] concluded theoretically that the radii of the charge and mass distributions are given by $R_c=r_c\times A^{\frac{1}{3}}$ ($r_c=1.16\times10^{-13}$ cm) and $R_0=r_0\times A^{\frac{1}{3}}$ ($r_0=1.2\times10^{-13}$ cm), respectively. As shown below, the inequality $R_c<R_0$ is convenient for the explanation of the discrepancy between β_1 and β_τ. Though the value of r_c differs slightly from the recent experimental values,[4] the above values of R_c and R_0 are used in the present paper. We shall call the region in which the protons are densely distributed, the proton core. β_τ, measuring the distortion of the proton core, is determined experimentally from the intrinsic quadrupole moment, its value being considered to be sufficiently definite. The values of β_1, however, are debatable. The first excited energy E and the moment of inertia $\mathcal{J}$ in the direction perpendicular to the nuclear symmetry axis are related by equation $E=3\hbar^2/\mathcal{J}$. The assumption of the irrotational character gives the relation $\mathcal{J}=3B_0\beta^2$, where $B_0=(1/2)\rho R_0^5$ and ρ is the mass density. The irrotational character, however, has been criticized recently by several authors,[5] who made it clear that the nuclear matter is not completely rigid, nor is it completely irrotational. It is, therefore, not clear whether or

---

[1] A. Bohr, Kgl. Danske Videnskab. Selskab, Mat.-fys. Medd. **26**, No. 14 (1952).

[2] J. E. Mack, Revs. Modern Phys. **22**, 64 (1950); E. Segrè, *Experimental Nuclear Physics* (John Wiley and Sons. Inc., New York, 1953), Vol. 1.

[3] Ross, Mark, and Lawson, Phys. Rev. **102**, 1613 (1956).

[4] L. Fitch and J. Rainwater, Phys. Rev. **92**, 789 (1953); Hahn, Ravenhall, and Hofstadter, Phys. Rev. **101**, 1131 (1956).

[5] D. R. Inglis, Phys. Rev. **96**, 1059 (1954); **97**, 701 (1955); A. Bohr and B. R. Mottelson, Kgl. Danske Videnskab. Selskab, Mat.-fys. Medd. **30**, No. 24 (1955).