denominators are exactly those employed in Eq. (2). Therefore the presence or absence of recoil during emission has no observable effect on the cross section, and the results (9) and (13) obtained for the double Mössbauer case are valid for all outgoing photons.

IV. CONCLUSION

Because this method of measuring g values depends predominantly on the early-time behavior of the γ-ray pulse which de-excites the resonance, it is sensitive to the mode of excitation of the state and hence to the bandwidth of the incoming beam. For the special case of a beam whose energy spread is Lorentzian, we find that this sensitivity is great enough to cause significant error in the extracted g values if not taken into account. This suggests that the spectral distribution of the incident beam should be known with fair accuracy, and employed in Eqs. (3) and (5), to extract reliable g values.

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Observation of the 4.12-MeV $O^{14} \rightarrow N^{14}$ Positron Spectrum Shape†*

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The spectrum shape for the 4.12-MeV $O^{14} \rightarrow N^{14}$ allowed positron transition has been measured in the positron energy range greater than 2 MeV. The observed shape deviates markedly from the statistical shape (slope about -11% per MeV at 3 MeV). The $\int \boldsymbol{\alpha}\times\mathbf{r}$ forbidden matrix element is extracted from the data and used to calculate the mean life of N^{14*}. For the latter, the value obtained is $(3.3\pm0.3)\times10^{-14}$ sec. The sign of the allowed matrix element $\int\boldsymbol{\sigma}$ is found to be positive. The ft value obtained for the 4.12-MeV transition is $(2.14\pm0.03)\times10^{7}$ sec and the branching fraction is found to be $(0.61\pm0.01)\%$.

I. INTRODUCTION

THE allowed Gamow-Teller positron transition from the 0^+ ground state of O^{14} to the 1^+ ground state of N^{14} is strongly inhibited. Its ft value ($\sim2\times10^7$ sec) is roughly 10^4 times larger than typical for favored $0^+ \rightarrow 1^+$ transitions. In this respect the $O^{14} \rightarrow N^{14}$ transition is similar to its analog $C^{14} \rightarrow N^{14}$ which also has an anomalously large ft. In both cases the inhibition is attributed[1,2] to accidental cancellation in the allowed nuclear matrix element for the transition. Because the allowed matrix elements are so small, the higher order forbidden matrix elements are expected to contribute appreciably to the decay probability. One possible result would be deviation from the allowed or statistical spectrum shape. Such effects on the spectrum shape should be particularly prominent if the decay energy is large, as in the case of $O^{14} \rightarrow N^{14}$ (end-point energy 4.12 MeV). The work reported here was undertaken to observe deviations from the statistical shape in the $O^{14} \rightarrow N^{14}$ positron spectrum.

Our experimental results for the shape factor for $O^{14} \rightarrow N^{14}$ indicate a strong energy dependence, a slope of about -11% per MeV at 3 MeV. This is the largest deviation from the statistical shape yet observed for an allowed transition. Calculations based on the wave functions proposed by Visscher and Ferrell[2] for the mass-14 nuclei indicate that this energy dependence of the shape factor is primarily attributable to interference of the allowed axial-vector term and the first-order velocity-forbidden term in the interaction Hamiltonian. An experimental value for the nuclear matrix element of the latter term was extracted from the data after eliminating the contributions of the smaller forbidden matrix elements which were calculated theoretically with the Visscher and Ferrell wave functions. According to the conserved-vector-current theory of beta decay[3] this matrix element is identical to that for the analogous 2.31 MeV gamma-ray transition $N^{14*} \rightarrow N^{14}$. From our experimental value of this matrix element the lifetime of N^{14} is calculated to be $(3.3\pm0.3)\times10^{-14}$ sec.

Beyond these primary results, our experimental data show that the sign of the allowed Gamow-Teller matrix element $\int\boldsymbol{\sigma}$ is positive. Our data also provide more precise values for the ft value and the branching fraction for $O^{14} \rightarrow N^{14}$. We find $ft=(2.14\pm0.03)\times10^7$ sec and the branching fraction to be $(0.61\pm0.01)\%$.

II. EXPERIMENTAL PROCEDURE

The special experimental problems faced in studying the 4.12-MeV $O^{14} \rightarrow N^{14}$ positron spectrum are pri-

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[1] D. R. Inglis, Rev. Mod. Phys. **25**, 390 (1953).
[2] W. M. Visscher and R. A. Ferrell, Phys. Rev. **107**, 781 (1957).
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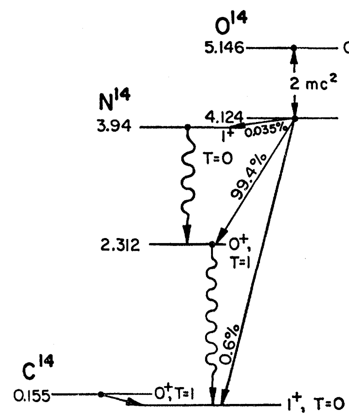

FIG. 1. Decay scheme for mass-14 nuclei.

marily the result of the small branching fraction for this transition and the relatively short half-life of O^{14} (see Fig. 1). The 71-sec half-life makes necessary the continuous production of the activity while data are collected. Because the spectrum shape is to be determined, the O^{14} source must be such that spectrum distortions arising from the source thickness and backing material are minimized and known. In addition, variations of source strength with time must be accurately monitored.

The small branching (0.6%) to the 4.12-MeV positron transition leads to additional experimental problems. First, the dominant 1.81-MeV transition to N^{14*} masks almost half of the 4.12-MeV positron spectrum. Further, the intense 2.31-MeV γ ray from the decay of N^{14*} is a potential source of large, time-dependent background. Reduction of this background to manageable levels required the use of a scintillation counter for the positron detector which was specially designed to discriminate against γ-ray background.

Finally, because this experiment was directed toward an accurate spectrum-shape determination, it was necessary to study possible instrumental distortions introduced by the β-ray spectrometer and its associated detection equipment. The measures taken to resolve these experimental problems are discussed in the following subsections.

A. O^{14} Source

O^{14} was produced by a continuous gas-flow technique developed previously in our laboratory.[4] Protons of about 9 MeV from the University of Washington 60-in. cyclotron were used to bombard nitrogen gas, producing the reaction $N^{14}(p,n)O^{14}$. Nitrogen, containing a small amount of oxygen as a carrier, was swept continuously through the cyclotron target chamber. The active gases leaving this chamber contained, in addition to O^{14}, large amounts of C^{11} produced by the reaction $N^{14}(p,\alpha)C^{11}$ and some O^{15} produced by $N^{15}(p,n)O^{15}$. The C^{11} activity was largely removed by passing the gas stream through hot CuO (to convert $C^{11}O$ to $C^{11}O_2$) and then through Ascarite to absorb $C^{11}O_2$. Then, hydrogen was added to the gas stream and the mixture passed through a hot platinum catalyst to convert all the oxygen to H_2O. The resulting mixture of N_2 and H_2O was pumped about 100 ft to the β-ray spectrometer where it was passed over a liquid-nitrogen-cooled beryllium disc located at the spectrometer source position. A fraction of the active H_2O was frozen on this source backing while the remaining gases were exhausted to the atmosphere.

Sources of O^{14} produced this way can be maintained at relatively stable strengths over long periods. As H_2O is continuously deposited, the thickness of the ice layer grows larger, but the actual source remains on the surface of the ice because of the short O^{14} life time. The shift in source position as ice accumulates is not enough to produce measurable effects on the spectrum until activity has been collected continuously for more than 1.5 h. To avoid any such effects the spectrometer source was defrosted frequently during data accumulation. Positrons entered the spectrometer vacuum through a 1-mil Mylar window that separated the vacuum from the low-pressure source gas ($\sim$20 mm Hg).

B. Spectrum Distortion by the Spectrometer

The β-ray spectrometer used to observe the O^{14} positron spectrum is an iron-free, uniform-field, solenoidal spectrometer whose design has been described by Schmidt.[5] The spectrometer is equipped with helical baffles to discriminate between positrons and electrons. For this experiment the spectrometer field coils and power supply were rebuilt to make it possible to focus β rays of up to 5-MeV kinetic energy. The spectrometer current was regulated to one part in 10^4. It was calibrated with K conversion electrons following the decay of Cs^{137} and with the F, I, and X conversion lines from a $Th(B+C+C'')$ source. The calibration is accurate to one part in 10^3. Since transmission is more important than resolution in this experiment, the spectrometer was operated with its baffles set for momentum resolution $\Delta p/p=1\%$, corresponding to transmission 3.3% of 4π.

An observed spectrum shape may reflect distortions introduced by various means such as scattering near slit edges, energy dependence of the particle detector efficiency, or pulse-height-dependent effects in electronic equipment. To discover any such effects, we studied the 4.15-MeV positron transition from Ga^{66} with the same equipment we used to observe the O^{14} spectrum. The Ga^{66} spectrum, which has almost exactly the same end-point energy as the O^{14} spectrum, was studied in great detail by Camp and Langer.[6] They

[4] J. B. Gerhart, F. H. Schmidt, H. Bichsel, and J. C. Hopkins, Phys. Rev. **114**, 1095 (1959); J. C. Hopkins, J. B. Gerhart, F. H. Schmidt, and J. E. Stroth, *ibid.* **121**, 1185 (1961).

[5] F. H. Schmidt, Rev. Sci. Instr. **23**, 361 (1952).

[6] D. C. Camp and L. M. Langer, Phys. Rev. **129**, 1782 (1963).

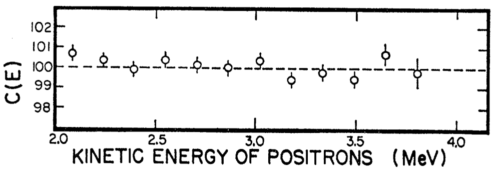

FIG. 2. Shape factor for Ga^{66} ($\frac{1}{4}$ mil Al source backing).

found a small energy dependence in its shape factor (a slope of about 1.3%/MeV in the energy range from 2 to 4 MeV).

We observed the Ga^{66} spectrum under conditions as much as possible the same as those used for observing the O^{14} spectrum except that a thin Ga^{66} source was used (to permit us to distinguish instrumental effects from those introduced by the source backing). Our experimental results (Fig. 2) yield a shape factor for the Ga^{66} spectrum that is constant within the limits of statistical uncertainty of the data. It may be assumed that the difference between this result and that of Camp and Langer provides a measure of the instrumental distortions introduced by our apparatus. However, as noted by Wu,[7] small discrepancies have been observed between shape factors observed with iron-free spectrometers (such as ours) and those determined with iron-magnet spectrometers (such as used by Camp and Langer). Because of this we will present our final results for O^{14} both with and without a correction for instrumental distortion based on Camp and Langer's Ga^{66} measurements.

C. Spectrum Distortion by the Source Backing

The O^{14} sources used in this work were formed on a thick backing, a beryllium-tipped rod connected to the liquid-nitrogen reservoir used to cool the source. As is well known, such thick backings generally result in a distorted spectrum because of scattering from the backing material. Back scattering increases with the Z of the backing material as $Z^{1/2}$. The use of a beryllium backing greatly reduces this effect but does not eliminate it.

To obtain the necessary correction to be applied to the O^{14} spectrum to remove the distortion introduced by the source backing, we studied the 4.15-MeV Ga^{66} positron spectrum from sources on the same backing as used for O^{14}. Figure 3 shows the Ga^{66} shape factor determined this way. The ratio of this shape factor to that observed for Ga^{66} on thin backings was used to correct our O^{14} data.

D. Positron Detector

Because of the intense 2.3-MeV γ rays and the annihilation radiation produced by the dominant $O^{14} \rightarrow N^{14*}$ transition, it was necessary to use a positron detector that had good discrimination against γ rays scattered by the spectrometer coils and baffles. Because the positron beam has a minimum diameter of 1.3 in. in the detector region, the detector had to be relatively large. A plastic scintillator 1.75 in. diam by $\frac{3}{8}$ in. thick was used. The scintillator was coupled to a Dumont 6292 photomultiplier by a 1.75-in.-diam by 60-in.-long Lucite light guide. The latter was used so that the photomultiplier could be in a region of relatively weak magnetic field and also so that the high-μ magnetic shielding of the multiplier could be far from the spectrometer.

The scintillator thickness was selected to be great enough to stop positrons in the lower part of the energy range of interest in this experiment, but not great enough to stop positrons with higher energies. This was done to reduce the scintillator volume and thus obtain lower efficiency for γ-ray detection. Positrons with energies near the O^{14} end point passed through the detector with a minimum energy loss of about 2 MeV. Figure 4 shows typical pulse-height spectra obtained with positrons. The pulse-height resolution for 2-MeV positrons was 20% full width at half-maximum (FWHM). The pulse heights of the full-energy peaks were proportional to energy to better than 1%, an indication that the photomultiplier gain was insensitive to the spectrometer magnetic field.

For all positron energies the pulse-height distribution included a low energy tail produced by positrons backscattered from the detector. These low pulses, however, correspond to focused positrons and must be included in the total number of counts observed at each spectrometer setting. So that positrons could be counted by scaling the detector output above a discriminator set below the main pulse-height peak but above most of the background of γ-ray produced pulses, a detailed study was made of the pulse spectra produced by various positron energies between 2 and 4 MeV. For this purpose Ga^{66} positrons were used since they are accompanied by only a very low γ-ray background. For each positron energy the fraction of all pulses that fall above a given discriminator setting (expressed as a fraction of the pulse height of the full-energy peak)

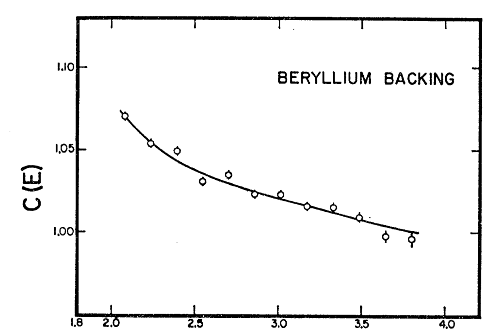

FIG. 3. Shape factor for Ga^{66} (thick beryllium backing).

[7] C. S. Wu, *Alpha-, Beta-, and Gamma-Ray Spectroscopy*, edited by K. Siegbahn (North-Holland Publishing Company, Amsterdam, 1965), Vol. II, p. 1388.

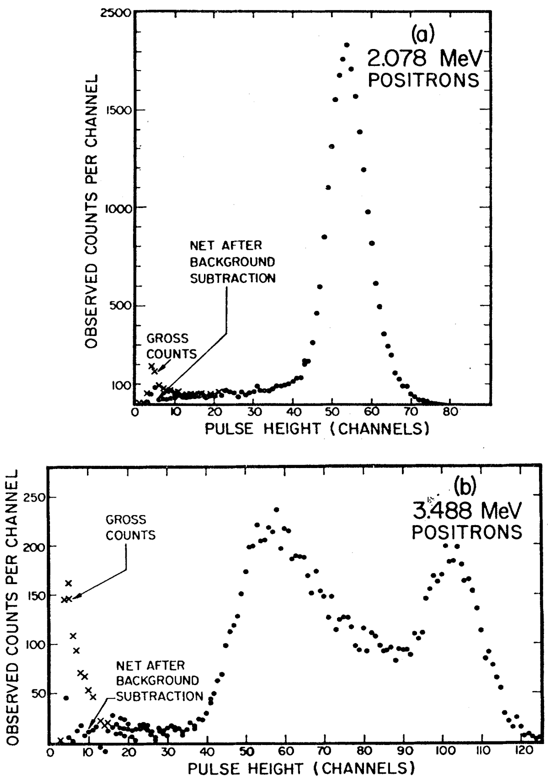

FIG. 4. Pulse-height spectra for positrons.

was determined. Two such determinations are shown in Fig. 5. In observing the O^{14} spectrum, the discriminator level, the pulse height of the full-energy peak, and the total number of counts above the discriminator level were measured. The true count was then determined using curves such as those of Fig. 5. This method had the advantage that γ-ray backgrounds in the O^{14} measurements were reduced to only 8 to 15% at most energies, and to only about 30% close to the O^{14} end point. In addition, it eliminates any dependence of the data taken at different times on the discriminator level or the positron detector gain.

E. Source Monitor

To monitor variations of the O^{14} source strength during data collection the 2.31-MeV γ ray which follows $O^{14} \rightarrow N^{14*}$ was detected with a NaI(Tl) scintillation counter. The scintillator was placed outside the spectrometer vacuum and shielded so that gamma rays could reach it only from a small region near the source. To make this monitor insensitive to changes in the spectrometer magnetic field, the scintillator was coupled to its photomultiplier with a 48-in. Lucite light guide. In this configuration the monitor resolution for the gamma ray from Cs^{137} was 12% FWHM and its gain shift was less than 0.25% for a change in the spectrometer current from 0 to its maximum value.

During data collection the monitor pulse spectrum was recorded along with the positron pulse spectrum. The 2.31-MeV photopeak was considerably attenuated and broadened because the scintillator was separated from the O^{14} source by the spectrometer's vacuum chamber walls and field windings. To obtain very accurate monitor counts, a fixed fraction of this pulse spectrum was used rather than the number of pulses above a fixed discriminator setting. (A discriminator was used, however, to limit the counting rate to the pulse-height analyzer.) The fraction of the pulse spectrum was determined in each case by using the internal-energy calibration provided by the known zero of the pulse-height scale and the observed positron of the 2.31-MeV photopeak.

This method of monitoring eliminates all effects of shifts in discriminator settings from one time to another. It also has the advantage of eliminating all dependence on monitor gain changes whether they be produced by magnetic field changes or electronic gain shifts.

III. EXPERIMENTAL RESULTS

For each point observed in the O^{14} positron spectrum the data collected consisted of positron and γ-ray pulse spectra simultaneously recorded in a 512-channel pulse analyzer and the total number of positron pulses above a preset discriminator level. To determine background the same measurements were repeated just before or just after each gross count but with the ring-focus baffle of the spectrometer closed by a shutter. The γ-ray monitor count was determined in each case by the method described in Sec. IIE. Because the monitor counting rates were relatively large and varying (2000

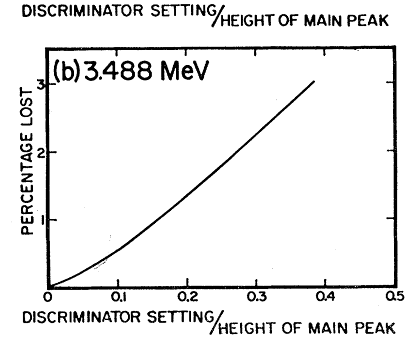

FIG. 5. Fractional loss of positron pulses as a function of discriminator setting.

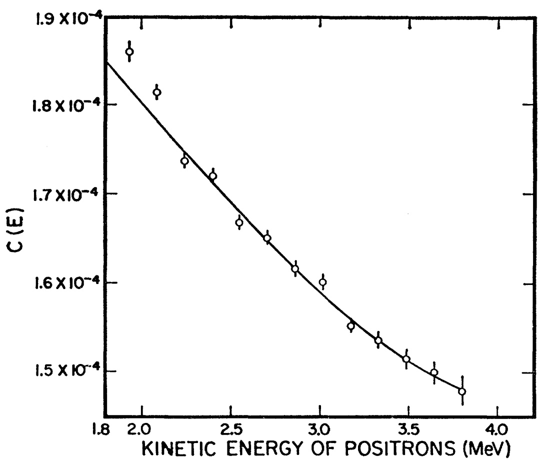

FIG. 6. Shape factor $C(E)$ for $O^{14} \rightarrow N^{14}$.

to 8000 $\sec^{-1}$), the monitor counts were corrected for dead-time counting losses using the method described by Schmidt *et al.*[8] Then the direct positron count and a corrected background count (see below) were divided by their corresponding monitor counts and their difference taken to obtain the normalized positron count. The correction described in Sec. IID for loss of positron counts below the discriminator level was applied next. Then the shape factor $N/[p^3(E-E_0)^2F(p,Z)]$ was calculated. Data for different runs at the same positron momentum p were combined. Finally the correction described in Sec. IIC for distortion because of the source backing was applied to the composite data.

Figure 6 shows our result for the shape factor of the $O^{14} \rightarrow N^{14}$ 4.12 MeV transition. The data are a composite of the results of 10 different determinations made over a period of more than a year. The 10 individual determinations are indistinguishable within the limits of statistical uncertainty of the data. The two points at the low-energy end of the data were not used in our analysis of the data. Their deviation from the trend of the remaining data may be the result of scattering of positrons from the intense 1.8-MeV $O^{14} \rightarrow N^{14*}$ transition.

The positron detector background may not be correctly determined by measurements made with the spectrometer ring-focus baffle shut because a portion of the background may be produced by positrons scattered by the baffles or by Compton electrons produced in the baffles. Such background particles would be stopped by the shutter. In order to estimate this effect we observed the positron spectrum in the energy range from 4.3 to 4.5 MeV (beyond the O^{14} end point) with the ring-focus baffle both open and shut. Throughout this range the counting rate was found to be about 3% larger with the baffle open. In both cases the positron counter pulse spectrum showed no evidence of pulse-height peaks, an observation which is consistent with the interpretation that the excess background was not produced by the positron spectrum of a source impurity. To take this effect into account we increased the background count for each spectrum observation by 3%. The extrapolation of this correction down to 3.5 MeV is probably accurate. For lower energies this correction altered the values of the shape factor by less than 0.3%, an amount small compared to other experimental uncertainties.

The various corrections to the data discussed above were relatively small. The positron-counter background ranged from 8% at 2 MeV to about 30% in the worst cases (nearest to the O^{14} end point). For most cases it was less than 15%. The corrections for loss of positron counts below the discriminator level did not exceed 2%. The dead-time correction to the monitor count ranged from 3% to 18% in the worst cases. The correction for distortion because of source backing ranged from zero near the O^{14} end point to about 6% at 2 MeV.

IV. THEORY AND INTERPRETATION

The theoretical form for the shape factor $C(E)$ for the $O^{14} \rightarrow N^{14}$ spectrum has been calculated by Goldman.[9] His results, aside from an over-all constant of proportionality, can be expressed as follows:

$$\begin{aligned} C(E) = \frac{N}{p^3(E-E_0)^2F(p,Z)} &\sim 1 + \frac{2}{3}\frac{C_V}{C_A}\frac{\langle V^+\rangle}{\langle\sigma^+\rangle} \\ &\times\left(\frac{p^2}{E}-\frac{q^2}{E_\nu}\right) - \frac{2}{3}\frac{\langle\gamma_5 r^+\rangle}{\langle\sigma^+\rangle}\left(\frac{p^2}{E}+\frac{q^2}{E_\nu}\right) \\ &-\frac{1}{3}\frac{\langle A^+\rangle}{\langle\sigma^+\rangle}\left(p^2+q^2-\frac{2}{3}\frac{p^2q^2}{EE_\nu}\right) \\ &-\frac{4}{9}\frac{\langle F^+\rangle}{\langle\sigma^+\rangle}\frac{p^2q^2}{EE_\nu}+\cdots. \end{aligned} \quad (1)$$

This expression includes the products of the allowed matrix element with all nonzero first and second forbidden matrix elements of the interaction Hamiltonian but neglects all higher order terms. (p,E) and (q,E_ν) are the positron and neutrino momentum and total energy, respectively. Equation (1) is expressed in units for which $\hbar=c=m=1$. It has been assumed that the β-decay interaction is $(V-A)$ and that time-reversal invariance holds. The five nuclear matrix elements correspond to the $m_f=+1$ substate of the final nucleus. They are defined in Table I.

Visscher and Ferrell[2] have obtained nuclear wave functions for the ground states of N^{14} and O^{14} (or C^{14}) which, in L-S representation, can be expressed as

$$\begin{aligned} \Psi(N^{14}) &= [C_S\,{}^3S_1 + C_P\,{}^1P_1 + C_D\,{}^3D_1]T_0{}^0, \\ \Psi(O^{14}) &= [C_S'\,{}^1S_0 + C_P'\,{}^3P_0]T_1{}^1, \end{aligned} \quad (2)$$

[8] F. H. Schmidt, R. E. Brown, J. B. Gerhart, and W. A. Kolasinski, Nucl. Phys. **52**, 353 (1964).

[9] D. T. Goldman, Ph.D. thesis, University of Maryland, 1958 (unpublished).

TABLE I. Nuclear matrix elements[a] for $O^{14}\rightarrow N^{14}$.

$$\langle\sigma^+\rangle = 2^{-1/2}\langle\sigma_1+i\sigma_2\rangle = (2/3)^{1/2}(C_PC_P'-3^{1/2}C_SC_S')\approx 0$$

$$\langle V^+\rangle = 2^{-1/2}\langle(\boldsymbol{\alpha}\times\mathbf{r})_1+i(\boldsymbol{\alpha}\times\mathbf{r})_2\rangle \approx (3M)^{-1}[5^{1/2}C_DC_P'-2C_SC_P'+2(3^{1/2})C_PC_S'] = 0.682/M$$

$$\langle\gamma_5 r^+\rangle = 2^{-1/2}\langle -\gamma_5(r_1+ir_2)\rangle = -(6M)^{-1}[5^{1/2}C_DC_P'+4C_SC_P'-3(2^{1/2})C_SC_S'] = -0.202/M$$

$$\langle A^+\rangle = \langle r^2\sigma^+\rangle = (5/2\gamma)\langle\sigma^+\rangle\approx 0$$

$$\langle F^+\rangle = \langle(\boldsymbol{\sigma}\cdot\mathbf{r})r^+\rangle = -(5^{1/2}/6\gamma)[2(2^{1/2})C_DC_S'+3C_DC_P'+10^{1/2}C_SC_S'] = -1.56/\gamma$$

[a] $\boldsymbol{\sigma}$ and $\boldsymbol{\alpha}$ are the Dirac operators with components $(\sigma_1,\sigma_2,\sigma_3)$ and $(\alpha_1,\alpha_2,\alpha_3)$. M is the proton mass. $\gamma^{1/2}$ is the nuclear scale parameter, taken to be 1.68 F for O^{14}. The ordinary allowed matrix element is $\int\boldsymbol{\sigma} = 3^{1/2}\langle\sigma^+\rangle$.

where $T_0{}^0$ and $T_1{}^1$ are the singlet and triplet isospin functions, respectively. The coefficients were determined by Visscher and Ferrell to be $(C_S,C_P,C_D) = (0.173, 0.355, 0.920)$ and $(C_S',C_P') = (0.764, 0.646)$. These values yield $\langle\sigma^+\rangle = 0$ exactly. Goldman[9] has calculated the higher order matrix elements for $O^{14}\rightarrow N^{14}$ in terms of these coefficients with the results shown in Table I. The shape factor $C(E)$ can be evaluated by substituting in Eq. (1) the nonzero experimental value of $\langle\sigma^+\rangle$ obtained from our data (see Sec. V) and the values of the other matrix elements as calculated by Goldman. The result, aside from a constant factor, is

$$C(E)\sim 1-0.0261(2E-E_0-E^{-1}) + 0.00924(E_0-E^{-1})+0.00165 \times(E_0-E)(E-E^{-1}). \quad (3)$$

The energy dependence of $C(E)$ in Eq. (3) arises largely from the second term, which represents the interference of the allowed matrix element $\langle\sigma^+\rangle$ and the first-order velocity-forbidden vector matrix element $\langle V^+\rangle$. In the range of positron kinetic energy from 2 to 4 MeV, this term ranges from about -0.02 to about -0.20 while the sum of the remaining energy-dependent terms varies only from about 0.11 to about 0.09. Because of this we have eliminated the smaller energy dependence corresponding to the latter terms from our data by using their theoretical values. This was accomplished by dividing the experimental shape factor by

$$1+F(E) = 1+0.00924(E_0-E^{-1}) + 0.00165(E_0-E)(E-E^{-1}).$$

The result of this reduction of the data is shown in Fig. 7.

Dividing Eq. (1) by $1+F(E)$ gives the "reduced" shape factor

$$\frac{C(E)}{1+F(E)} = 1+\frac{2}{3}\frac{C_V}{C_A}\frac{\langle V^+\rangle}{\langle\sigma^+\rangle}(1-\bar{F})(2E-E_0-E^{-1}), \quad (4)$$

where $\bar{F}$ is the average value of $F(E)$ in the energy range of the data. In this energy range the term E^{-1} in Eq. (4) is negligible, and consequently we expect the reduced shape factor $C(E)/[1+F(E)]$ to be linearly dependent on E. Thus the value of $\langle V^+\rangle$ can be calculated from the slope of the reduced data (Fig. 7) inasmuch as C_V/C_A and $\langle\sigma^+\rangle$ are known independently.

Our experimental result is $\langle V^+\rangle = (0.625\pm 0.032)/M$. This can be compared with Goldman's theoretical result $\langle V^+\rangle = 0.682/M$. In calculating $\langle V^+\rangle$ from our data we used the value of $\langle\sigma^+\rangle$ obtained in Sec. VB, and $C_A/C_V = -(1.19\pm 0.02)$ as determined by Daniel and Schmitt.[10]

According to the conserved-vector-current theory of β decay the matrix element $\langle V^+\rangle$ of the $O^{14}\rightarrow N^{14}$ positron transition is identical (aside from a known constant factor) to the matrix element for the analogous $M1$ γ-ray transition $N^{14*}\rightarrow N^{14}$. Consequently, we can use our experimental value of $\langle V^+\rangle$ to determine the mean life of the 2.31 MeV state of N^{14}. The mean life τ is given by[11]

$$\tau = 2(137M^2/\langle V^+\rangle^2 E_\gamma{}^3) = (3.3\pm 0.3)\times 10^{-14}\ \text{sec},$$

where our experimental value of $\langle V^+\rangle$ has been used to evaluate τ. This value of τ should be compared to direct experimental values. Swann *et al.*,[12] by a resonant scattering technique, found $\tau = (7.3\pm 1.8)\times 10^{-14}$ sec, while

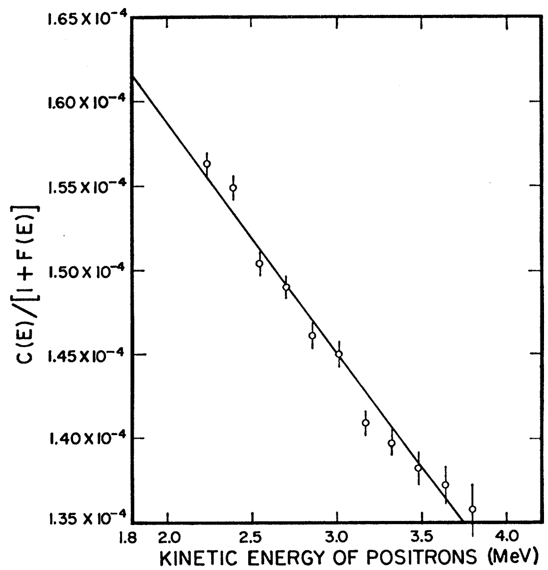

FIG. 7. Reduced shape factor $C(E)/[1+F(E)]$ for $O^{14}\rightarrow N^{14}$.

[10] H. Daniel and H. Schmitt, Nucl. Phys. **65**, 481 (1965).
[11] M. Gell-Mann, Phys. Rev. **111**, 362 (1958).
[12] C. P. Swann, V. K. Rasmussen, and F. R. Metzger, Phys. Rev. **121**, 242 (1961).

Lonergan and Donahue,[13] by a Doppler-shift technique, found $\tau=(8.3\pm3)\times10^{-14}$ sec.

The uncertainty in the value of τ obtained from our data reflects only the statistical uncertainty of our data. Additional uncertainty is introduced by our use of theoretical corrections for the smaller energy-dependent terms in the shape factor, though these corrections were relatively small. The experimental value of $\langle V^+\rangle$ would have been about 7% larger had these corrections not been made, and this, in turn, would lead to a value of τ about 14% smaller. We believe that the various corrections made to our data for known experimental effects should have reduced possible systematic errors from these sources to a level small compared with the statistical uncertainty of the data. It must be borne in mind that we have not included any correction to our data for instrumental distortion of the O^{14} spectrum by the spectrometer. If we attribute the discrepancy between the shape factor we observed for Ga^{66} and that observed by Camp and Langer[6] to distortion by our spectrometer and apply a compensating correction to our O^{14} data, our experimental value for $\langle V^+\rangle$ would be about 15% smaller. The corresponding value of τ would be $(4.3\pm0.4)\times10^{-14}$ sec, or about 30% larger. This value is still not in good agreement with the other experimental values cited above.

V. OTHER EXPERIMENTAL RESULTS

A. *ft* Value

For any single β-ray transition

$$(ft)^{-1}=K\frac{N(p)}{p^3(E-E_0)^2F(p,Z)}\frac{\langle C(E)\rangle}{C(E)},\qquad(5)$$

where $N(p)$ is the observed spectrum and K depends only on instrumental factors and source strength. $\langle C(E)\rangle$ is the average of $C(E)$ over the spectrum. To determine ft for $O^{14}\to N^{14}$, we observed $N(p)$ for the $O^{14}\to N^{14*}$ spectrum at $E-mc^2=1.69$ MeV where the contribution to the observed counting rate from the $O^{14}\to N^{14}$ spectrum is negligible. Then, by using the known[14] ft value for $O^{14}\to N^{14*}$ and the fact that for the 1.81-MeV transition, $\langle C(E)\rangle/C(E)=1$, we found K for our experimental arrangement. Since the same apparatus and normalization were used to observe the $O^{14}\to N^{14}$ spectrum, the same value of K is appropriate for our measurements of the latter spectrum.

Since $C(E)$ is approximately linear in E we took $\langle C(E)\rangle$ to be the value of $C(E)$ at 2 MeV, which we obtained by extrapolating our data from higher energies. Then, with the value of K determined as described above and from our measurements of $N(p)$ and $C(E)$ for $O^{14}\to N^{14}$ we obtain, from Eq. (5),

$$ft(O^{14}\to N^{14})=(2.14\pm0.03)\times10^7\text{ sec}.$$

The uncertainty represents only statistical uncertainty in our data. This result is in good agreement with earlier determinations.[15]

B. The Allowed Matrix Element $\langle\sigma^+\rangle$

The ft value for $O^{14}\to N^{14}$ is given by

$$(ft)^{-1}=\frac{3C_A{}^2\langle\sigma^+\rangle^2}{2\pi\ln2}\frac{\int C(E)p^2(E-E_0)^2F(p,Z)dp}{\int p^2(E-E_0)^2F(p,Z)dp}.\qquad(6)$$

To evaluate $\langle\sigma^+\rangle$ from the ft value the integral of the shape factor over the spectrum that occurs in this equation must be carried out. In doing so, the term in $C(E)$ containing $\langle V^+\rangle$ can be neglected because its specific dependence on E is such that it contributes negligibly to the integral. The result of substituting the theoretical values of all other matrix element except $\langle\sigma^+\rangle$ in Eq. (6) along with our experimental value for ft is

$$\langle\sigma^+\rangle^2+(8.98\times10^{-4})\langle\sigma^+\rangle=7.02\times10^{-5}.$$

This equation has the two solutions $\langle\sigma^+\rangle=(7.95\pm0.20)\times10^{-3}$ and $\langle\sigma^+\rangle=-(8.84\pm0.21)\times10^{-3}$. Only the positive value is consistent with the observed negative slope of $C(E)$.

C. Branching Fraction

To obtain $f(E_0,Z)$ for $O^{14}\to N^{14}$ we calculated the statistical integral $f(E_0)$ for $E_0=9.07\ mc^2=4.12$ MeV and applied to it the same over-all correction (for finite-nuclear-size effects, screening, etc.) as was used by Bardin *et al.*[14] to obtain the f value for the $O^{14}\to N^{14*}$ transition. The partial half-life we obtain from this value of f and our experimental value of ft is $(1.15\pm0.01)\times10^4$ sec. This, combined with the total half-life[14] of O^{14} of (71.36 ± 0.09) sec, gives for the branching fraction for the 4.12-MeV transition (0.61 ± 0.01)%.

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