2^+ $T=1$ states are almost pure $1s^{-1}1d_{3/2}$ and $1s^{-1}1d_{5/2}$ states with transition energies near 48.3 and 53.3 MeV. The energy separation of these levels reflects the $d_{3/2}$ - $d_{5/2}$ splitting of about 5 MeV.

The resonances at 45.9 and 51.6 MeV are in reasonable agreement with these calculations as well as with levels observed by Isabelle and Bishop[19] at 44.8 and 49.3 MeV in an inelastic electron scattering experiment.

The remaining resonances may be associated with $E2$ transitions to $1f_{7/2}$ levels, with the recently discussed nuclear $E1$ overtones,[20] or the $3\hbar\omega$ resonances postulated by Danos.[21] Further insight into the nature of these resonances will probably have to await higher resolution experiments and angular distribution studies of the particular resonances.

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EXPERIMENTAL TEST OF THE CONSERVED VECTOR CURRENT THEORY ON THE BETA SPECTRA OF B^{12} AND N^{12}†

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The postulated universal V-A Fermi interaction[1-3] demands not only the identical form of interaction, but also the same strength for the bare coupling constants in the various weak decay processes. However, if renormalization of the vector coupling constant due to the pionic effects is required in nuclear beta decay, as it is certainly not in muon decay, then it is very hard to understand the near equality[4,5] of the observed vector coupling constants of these two decays. To explain the lack of renormalization of the vector coupling constants in beta decay, Feynman and Gell-Mann,[2] and earlier, Gershtein and Zel'dovich,[6] proposed a simple and elegant hypothesis, conservation of vector current (C.V.C.), which attributes the beta interaction strength not only to the bare nucleons, but also to the virtual pions, and intimately associates it with the symmetry property of strong interactions; that is, the charge independence of nuclear forces. To test the C.V.C. hypothesis Gell-Mann,[7] and Gell-Mann and Berman[8] suggested investigating the decays of the $T=1, J=1^+$ multiplet B^{12}, C^{12*}(15.11-MeV state), and N^{12} into the $T=0, J=0^+$ ground state in C^{12}. According to this conservation hypothesis, the interference term between the second-order vector interaction and the allowed term of the axial vector interaction should give a predictable shape correction factor and thus provide a sensitive test for the C.V.C. theory.[9]

Several laboratories[10,11] have, in the past, experimentally investigated the beta spectra of B^{12} and N^{12}. Although the ratio of the shape factors between these two spectra was found to be of the right order of magnitude, the deviation of each individual spectrum from the allowed shape was either several times larger than what was calculated, or the sign was opposite to what was predicted, or the individual spectrum was just not investigated. Recently, another investigation,[12] utilizing slits made of different materials, has observed that not only the individual shape correction factors change with the slit composition in their experiment, but the ratio of the shape correction factors $(a^- - a^+)$ vary with it as well. Since an experimental confirmation of the C.V.C. theory is so important, it seems highly desirable to have the spectra reinvestigated.

(1) The spectrometer and its adjustments. –An iron-free intermediate-image spectrometer, similar to the one described by Alburger,[13] was used for this investigation after extensive modifications. In this type of spectrometer the beta rays are first focused into an annular image located half-way between the source and the detector and then focused once again into the detector. In effect, it focuses as if it were two spectrometers, aligned one after the other. Because of this, any beta particle which has altered its direction or been degraded in its energy, due either to slit scattering or slit penetration, will have a greatly reduced chance of being focused into the detector again.

To adjust the spectrometer, the 976-keV conversion line from a Bi^{207} source was used. First, the optimum positions for the source and detector were located. Then the two parts of the entrance baffle (i.e., the outer ring and the inner disk) were separately closed in until a symmetrical conversion line was obtained without any reduction of the peak yield. However, it was noticed that even when the magnetic conversion line was apparently symmetrical, the scintillation spectrum which was taken with the magnetic field adjusted for the low-energy tail of the conversion line was extremely sensitive to adjustments of the entrance baffle. Usually, a slight closing of the baffle opening – even a fraction of a millimeter – brought all three scintillation spectra at the low-energy (B), peak (A), and high-energy (C) regions into identical distribution shapes, as shown in Fig. 1.

To ascertain that the scattering from the spectrometer wall or slit edges was negligible, the magnetic and scintillation spectra of the continuous beta spectra of P^{32} (1.7 MeV) and Rh^{106} (3.5 MeV) were carefully examined. The background counts both at zero field and at fields just above the maximum energy were hardly measurable (<0.02 % of the peak value). When the scintillation spectra for the low-energy region of the beta spectrum were examined, no high-energy tail due to scattering of high-energy electrons was detected (<0.03 % of the peak value).

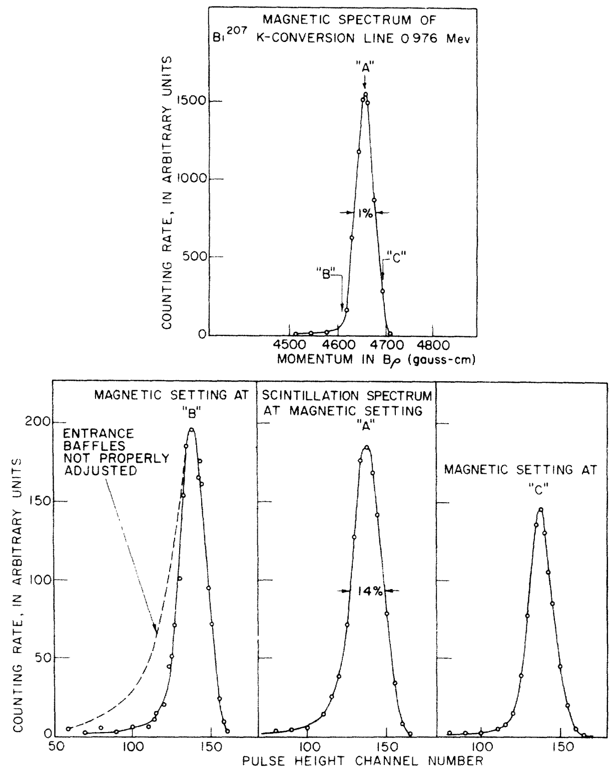

FIG. 1. Spectra of the Bi^{207} 976-keV conversion line. Scintillation spectra were taken at the peak and at the high- and low-energy sides of the magnetic spectrum. The dashed line shows the effect of the entrance baffle on the scintillation spectrum at the low-energy side.

(2) Calibration. – The calibration of the magnetic spectrometer was accomplished by using several conversion lines of known energy from Bi^{207}, Ca^{40}, and O^{16}. Its linearity was good to 1 part in 2000. For details of the calibration, please refer to the following Letter.[14]

(3) Production of B^{12} and N^{12}. – B^{12} and N^{12} are produced by $B^{11}(d,p)B^{12}$ and $B^{10}(He^3,n)N^{12}$ reactions inside the spectrometer, which is located 50 ft from the Van de Graaff accelerator. The B^{11} and B^{10} targets are prepared by evaporating a thin layer (~0.5 mg/cm^2) of boron onto Ni (1 mg/cm^2) or nickel-plated copper foils (3 mg/cm^2) by the electron-gun method. Targets were evaporated onto one side of the foil only, and the foil was always mounted with the boron facing the beam. The beam was aligned so it entered

the spectrometer along the magnetic axis and reached the target through a collimator 2 mm in diameter. There was no change in the beam's position on the target over the entire range of magnetic field used. Pulsing of the beam was accomplished by a rotary mechanical chopper (3000 rpm) which also provided a photoelectric signal to mark the end of beam duration. Conventional univibrator and delayed pulse circuitry precisely controlled the time sequence of the measurements (Fig. 2).

(4) Detectors and monitors. – The detector consisted of an anthracene crystal $\frac{2}{5}$ in. thick and 1 in. in diameter, permanently cemented on a 2-ft long light pipe which was connected to a DuMont-6292 photomultiplier shielded by conetic and soft iron. A scintillation spectrum with the 976-keV conversion line from Bi^{207} gave a resolution of 14% and a peak-to-valley ratio better than 100 to 1. With electrons from B^{12}, the scintillation spectra gave similar shapes above 6 MeV, while the peak-to-valley ratio kept improving up to 7 MeV where it became better than 100 to 1. With positrons from N^{12}, the scintillation spectra showed a small tail due to the annihilation radiation of positrons, so that the peak-to-valley ratio was only 30 to 1 above 7 MeV. Another anthracene crystal, $\frac{2}{5}$ in. thick and $1\frac{3}{4}$ in. in diameter, was used in connection with the wide-slit investigation, as described later.

To provide a measure of activity produced, a p-n junction solid-state detector with a 130-mg/cm^2 aluminum absorber was used to monitor the $B^{10}(d,p)B^{11}$ reaction leading to the ground state with the natural boron target. A lithium-drifted solid-state detector with a 389-mg/cm^2 aluminum absorber was used to monitor the $B^{10}(He^3,p)C^{12}$ reaction leading to the ground state with the B^{10}-enriched target. A 128-channel display of the proton spectrum showed no drifts over 24 h, and the peak-to-valley ratio was better than 100 to 1.

(5) Measurements. – The beta counts were stored in a multichannel analyzer which was turned on 0.7 msec after the signal indicating the end of the

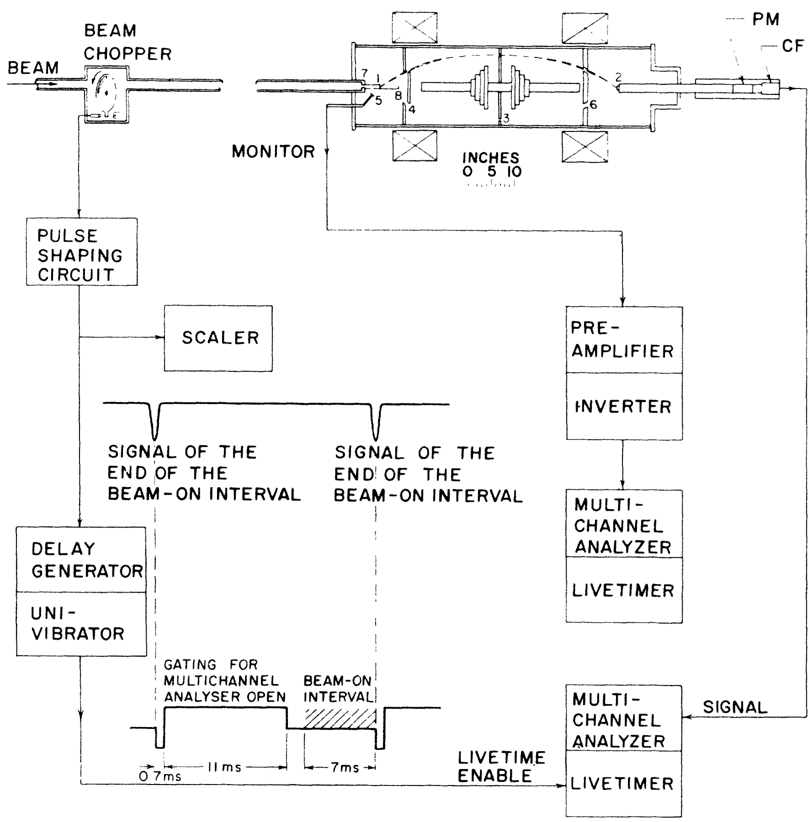

FIG. 2. Schematic diagram of the spectrometer and electronics block diagram. The sequence of gating of the multichannel analyzer by pulses derived from the mechanical chopper is also shown. Numbered details are: (1) source or target; (2) detector; (3) annular slit; (4) entrance baffle; (5) solid-state monitor; (6) exit baffle; (7) collimator.

"beam-on" cycle to allow any spurious counts due to slowed-down neutrons to subside, and again gated off 1 msec before the start of the next "beam-on" cycle. The monitor counts were also stored in a multichannel analyzer. The total beta counts divided by the live time of the beta channel was normalized by the proton monitor counts divided by the live time of the proton channel. The background counts were about the same at both zero field and high field ($>E_{max}$), less than 0.1% of the peak counting rate for B^{12} and around 1% for N^{12}. The increase of background for N^{12} was mainly due to the increase in beam energy and flux, and the decrease in yield compared to that of B^{12}. However, in both cases the background was sufficiently low as not to affect the interpretation of the results.

(6) Results.–The Kurie plots of B^{12} and N^{12} are shown in Fig. 3. The end point of B^{12}, calculated by the least squares method, is 13.373 ± 0.04 MeV, which is in excellent agreement with the value given by the reaction data of 13.369 ± 0.001 MeV. In making the Kurie plot, no radiative correction was applied. However, since the shape factor correction due to the C.V.C. theory is about equal and opposite in sign to that of the radiative correction, no resultant effect was expected on the end point on the Kurie plot of B^{12}. In the case of N^{12}, the end point on the Kurie plot was 16.43 ± 0.10 MeV. However, in this case, the radiative correction and the C.V.C. shape-factor correction were in the same direction. Their combined effect should therefore have been to shift the end point by 0.6% to an energy higher on the axis than is shown on the Kurie plot.

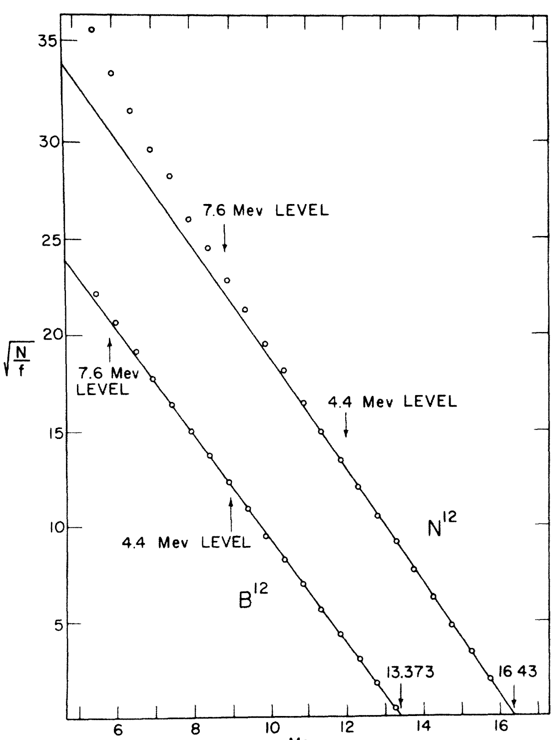

FIG. 3. Kurie plots of β rays from B^{12} and N^{12}. The end-point energies obtained from the Kurie plots are 13.373 ± 0.04 MeV and 16.43 ± 0.10 MeV for B^{12} and N^{12}, respectively. The arrows indicate the end points of branching transitions.

The shape correction factor $(1+aE)$ is defined by the relation

$$S_{\rm exp} = S_{\rm allowed} f(1+aE),$$

where $S_{\rm exp}$ is the experimental spectrum shape; $S_{\rm allowed}$, the shape of the allowed spectrum; f, the radiative correction[16-18]; and E, the beta energy. $S_{\rm exp}$ was also corrected for the branching transitions to the 4.4- and 7.6-MeV levels in C^{12}. Measured branching ratios of 1.3 ± 0.1 and 1.3 ± 0.4%, respectively, were used for the case of B^{12}.[19-20] In the case of N^{12}, the measured value of 2.4 ± 0.2% for the transition to the 4.4-MeV level[20] was used, but only the estimated value of 4.0 ± 1.3% was available for the branching ratio to the 7.6-MeV level. However, in analyzing our data, emphasis was put on the region where the uncertainty due to the branching to the 7.6-MeV level gave negligible effect. Effects due to the uncertainty in the measured branching ratios are also negligible. According to Morita[21] the shape correction factor $1+aE$ vs energy E may have a very slight curvature, but the determination of the curvature is beyond the statistical accuracy of our experimental points. Since only a portion of the experimental spectrum can be used for comparison with the theoretical one, what one obtains from the data is the coefficient of the slope a in percent per MeV. For display purposes, we have shifted both curves of $1+aE$ for B^{12} and N^{12} to meet at a convenient energy, as shown in Fig. 4(a). The results give $a^- = +0.57 \pm 0.11$% per MeV for B^{12} and $a^+ = -0.62 \pm 0.06$% per MeV for N^{12}. The uncertainty of the B^{12} end point (13.369 ± 0.001 MeV) from the reaction data quoted above gives a negligible effect, while the uncertainty in the N^{12} end point (16.43 ± 0.06 MeV) from reaction data[22] gives an uncertainty of 0.2% in the N^{12} shape factor. Exactly as was predicted, the correction term due to weak magnetism changes sign as one goes from β^- to β^+ decay. In addition,

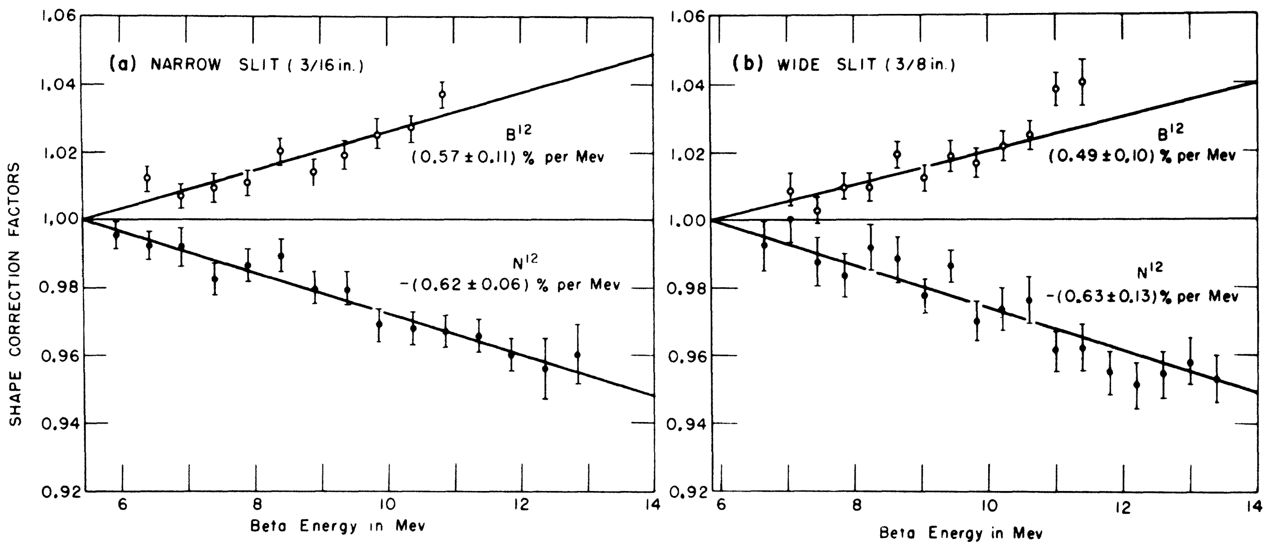

FIG. 4. (a) Shape correction factor of β spectra from B^{12} and N^{12}. $S_{\text{exp}}(S_0 f)^{-1} = 1 + aE$ measured with the narrow annular slit ($\frac{3}{16}$ in.). The points are normalized to the value at 5.45 MeV. (b) Shape correction factor measured with the wide slit ($\frac{3}{8}$ in.). The points are normalized to the value at 5.85 MeV. Numbers are the slopes of the least squares fit. Uncertainties quoted are based on the scatter of the experimental points only.

the ratio of these two spectra yields $a^- - a^+ = 0.57 + 0.62 = 1.19 \pm 0.24\%$ per MeV, which is also in good agreement with the calculated value of $1.10 \pm 0.17\%$ per MeV.

(7) Wide-slit investigation.—To ensure that neither slit scattering nor slit penetration caused any detectable distortion on the spectrum, a new baffle with an annular slit twice as wide ($\frac{3}{8}$ in.) as the narrow one ($\frac{3}{16}$ in.) described above was installed and adjusted. The wide-slit system gave nearly twice the transmission (2%) and resolution (2%) of the narrow slit, which had 1% transmission and 1% resolution. Any distortion effect from the edge of the wide slit should therefore have been proportionately reduced because of its larger transmission. The shape factor curves obtained from the wide slit are displayed together with those obtained from the narrow slit [Fig. 4(b)]. They are in good agreement within the experimental uncertainty, and therefore the slit effect on the shape factors must be negligible.

This investigation confirms that the deviations from the allowed shape of the observed beta spectra for B^{12} and N^{12} have the correct magnitude and sign due to the weak magnetism term. This unique relation between the beta interaction and electrodynamics strongly supports the conserved vector-current theory.

We wish to thank the Van de Graaff staff of our laboratories for their valuable cooperation; particularly Dr. L. Lidofsky for his close association at the early stage of the planning of this investigation, and Dr. A. Sayres, Dr. C. Engelke, and Dr. S. Harris for their constant interest throughout this experiment. To previous investigators[10-12] on this experiment, we wish to express our appreciation for the benefit of their valuable experience.

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OBSERVATION OF THE INTERNAL CONVERSION LINE FROM THE 6.052-MeV LEVEL IN O^{16}†

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For a $0^+ \to 0^+$ nuclear monopole transition, a gamma emission is absolutely forbidden. However, the excited state can be de-excited by either internal pair creation or internal electron conversion. The spectra of the emitted positrons and electrons from this transition have been theoretically calculated[1,2]; in the case of O^{16},[3-5] the agreement with experiments is excellent.[6] The ratio of internal conversion to pair creation in $0^+ \to 0^+$ transition is the most significant quantity for the understanding of nuclear structure. It is roughly proportional to $(Z/E)^3$ for the case of low Z and high energy. Thus, the weak internal conversion line of the 6.052-MeV $0^+ \to 0^+$ transition[7] in O^{16} is almost overwhelmed by the intense pair creation, and it has never been observed before.

Recently, in connection with our investigation of the conserved vector current theory by comparing the B^{12} and N^{12} beta spectra,[8] we first investigated the spectra of the electrons and positrons from this pair creation. This serves two important purposes. One is to compare the experimental results with the theoretical distribution to ascertain the absence of any pronounced distorting effects in our magnetic spectrometer. The other purpose is to use the end-point energy of the pair electrons as an additional energy calibration point.

We also made an effort to search for the conversion line, and it was observed.[9] The line was found to be sharp enough to have its energy determined and its intensity estimated. Thus it gives us not only one more calibration point on the energy scale, but also a check on the theoretically predicted ratio of internal conversion to internal pair creation of the 6.052-MeV $0^+ \to 0^+$ transition in O^{16}.

The intermediate-image type iron-free spectrometer was set at 1% resolution and approximately 1% transmission. A pair of helical baffles were installed on both sides of the central focusing slit and used to discriminate electrons from positrons, or vice versa. The helical baffle consists of an 18-in. o.d. brass ring of $\frac{3}{4}$- $\times \frac{3}{4}$-in. cross section, with attached plates $2\frac{1}{2}$- $\times 2\frac{1}{2}$- $\times \frac{1}{16}$-in. spaced 1 in. apart. The plates are turned 17° with respect to the axis of the spectrometer so that the electrons can pass between the plates while the positrons spiraling in the opposite sense are stopped by the plates. On reversing the current in the magnetic coils, the opposite is true. A 0.5-mg target of BaF_2 on 0.05-mil Ni target was bombarded with approximately 1.8-MeV protons which gives the resonance peak for the pairs.[10] The beam was collimated to less than 1-mm radius. Each point was taken with a definite amount of integrated proton current. The regulation of the magnet current was better than 3×10^{-5}.

(1) The measured points of the e^- spectrum and e^+ spectrum of the pair are shown in Figs. 1(a) and 1(b), respectively. The solid curves are the theoretical ones.[1,4,6] It can be seen that the agreement between the experimental points and the theoretical curves is very satisfactory. The end points determined from the calibration with Bi^{207} (0.976 MeV) and Ca^{40} (3.347 MeV) gave 5.030 ± 0.004 MeV in agreement with the accepted value of 5.030 MeV.[7]

(2) The internal conversion line is shown in Fig. 2. By the calibration constant derived from Bi^{207} and Ca^{40}, we obtained the line energy equal to 6.052 ± 0.004 MeV again, in agreement with the