Brief Reports

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Pair decay of the 15.1 MeV level of ^{12}C

J. M. Enagonio, F. P. Calaprice, R. W. Dunford, and M. M. Lowry
Joseph Henry Laboratories, Princeton University, Princeton, New Jersey 08544
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We have observed the e^+e^- pair line from the decay of the 15.1 MeV level of ^{12}C. Pairs were detected using an intermediate image pair spectrometer. The use of this line as a calibration point for beta spectrometers is discussed.

[RADIOACTIVITY ^{12}C; observed e^+e^- pair line from 15.1 MeV level. Intermediate image pair spectrometer.]

The 15.1 MeV $T=1$, $J^P=1^+$ state in ^{12}C decays predominantly to the ^{12}C ground state by emission of an $M1$ gamma ray, but it can also decay to the ground state by internal conversion or by emission of e^+e^- pairs. The calculated branching ratios for conversion and pair processes are approximately 4×10^{-8} and 3×10^{-3}, respectively.[1,2] We have observed the pair decay branch using an intermediate image beta ray spectrometer. A monoenergetic line was obtained by observing coincidence events which occur when the electron and positron share the transition energy equally and both are transmitted by the spectrometer. The line provides a calibration point for the spectrometer near 7.5 MeV. Part of the motivation for this work is to find useful high energy lines (5 – 15 MeV) for the calibration of beta-ray spectrometers.

Excited states of ^{12}C were produced by inelastic scattering of 22 MeV protons on a 3 mg/cm^2 carbon target. A Faraday cup located 15 cm behind the target was used to monitor the beam intensity. The intermediate image beta ray spectrometer is similar to that described by Alburger.[3] Electrons and positrons from the target traveling in an inhomogeneous axial magnetic field are focused at an annular slit halfway through the spectrometer and then refocused at the detector. The detector consisted of a plastic scintillator cylinder 2.5 cm in diameter and 3 cm long. The scintillator was coupled through a Lucite light pipe to an RCA 8575 photomultiplier tube which was enclosed in a magnetic shield. The data reported here were taken with a spectrometer geometry such that the transmission ($\Omega/4\pi$) was 1.4% and the resolution ($\Delta p/p$) was 2.5%. These parameters were measured using the internal conversion electrons from a ^{207}Bi source. This source also provided a low energy calibration for the spectrometer.

The efficiency of the spectrometer for detecting e^+e^- pairs (ϵ_l) is defined as the number of detected events after background subtraction, at the peak of the pair coincidence line per nuclear transition of multipolarity l. The efficiency factor takes into account the transmission and resolution of the spectrometer, the branching ratio for the pair transition, the angular correlation of the pairs, and the shape factor of the pair spectrum. We have calculated the efficiency of our spectrometer for detecting pairs from the 15.1 MeV level in ^{12}C following the method of Wilkinson *et al.*[4] with the result

$$\epsilon_{M1}\simeq 2.4\times10^{-8} \quad (1)$$

From the data of Berghofer *et al.*,[5] the cross section for (p,p') scattering to the 15.1 MeV state for 22 MeV protons is 6.7 mb. Thus, the expected count rate under our operating conditions of 200 nA of beam on a 3 mg/cm^2 target is about 100 coincidences per hour.

The search for the pair line was conducted by obtaining pulse height spectra from the scintilla-

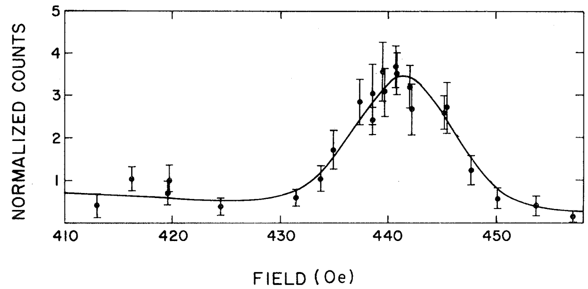

FIG. 1. The coincidence spectrum in the region of the 15.1 MeV pair transition line. The normalized rate of e^+e^- coincidences is plotted vs the magnetic field measured near the annular slit.

tion detector at a range of settings of the spectrometer near the expected energy of the line $(E_0-2mc^2)/2$, where E_0 is the transition energy. Each pulse height spectrum contains a peak which corresponds to the energy of single beta rays being transmitted by the spectrometer. At the setting corresponding to the pair line, there should be a second peak in the pulse height spectrum at an energy of about $(E_0-2\ mc^2)$, corresponding to coincidence events in which the two particles each deposit half the transition energy in the scintillator.

In order to observe the coincidence peak, a background suppression was performed by imposing a time of flight requirement. For each detected event, a time-to-analog converter was started by the scintillation detector and stopped by the cyclotron *rf* so that time of arrival relative to the *rf* was measured. Thus, backgrounds such as gamma rays and fast neutrons produced in the Faraday cup, and beam protons scattered through the spectrometer were eliminated. The other major background, the 11 msec β decay of ^{12}N formed in the target by the reaction $^{12}C(p,n)^{12}N$, is uncorrelated with the cyclotron *rf* and is therefore reduced by the time cut. A pileup rejection circuit with a 10 μsec window was employed to reject background due to the accidental summing of two low energy pulses.

The data for the pair line are presented in Fig. 1. Each point corresponds to approximately 0.4 mC of beam collected on the Faraday cup.[6] The solid line is a least squares fit of a Gaussian shape to the data. The centroid is located to within 0.1%. In order to use this centroid as a calibration, it is necessary to account for the fact that the excited ^{12}C nuclei are recoiling from the nuclear reaction at the time the pairs are emitted. This recoil effect

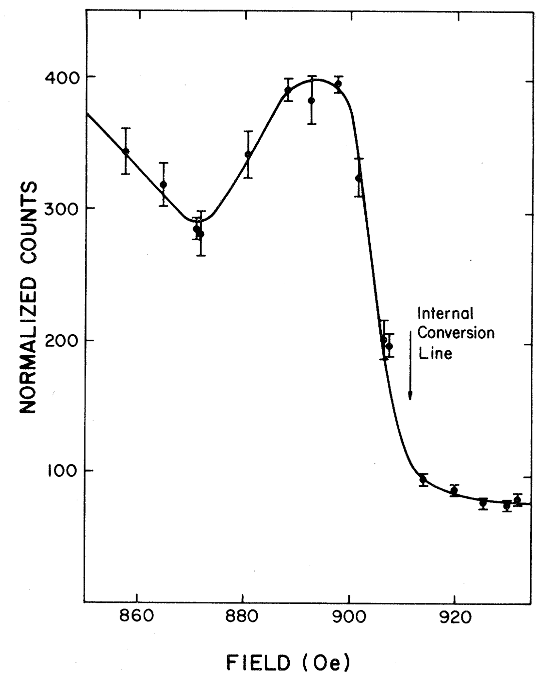

FIG. 2. The momentum spectrum of Compton electrons ejected from the target by Compton scattering of 15.1 MeV gamma rays. The expected position of the internal conversion line from the 15.1 MeV level of ^{12}C is indicated.

was calculated using a Monte Carlo simulation of the nuclear reaction and subsequent pair decay.[7] We find that the pair line occurs at a momentum 1.2% higher than that from pairs emitted from nuclei at rest. The data show a broadening of the line which is at least partially a result of nuclear recoil.

In a separate run, an attempt was made to observe the internal conversion line from the 15.1 MeV level. A thicker target (30 mg/cm^2) and a larger scintillator was used. To suppress gamma ray background, we required a coincidence with a thin gas proportional counter placed in front of the scintillation counter. During this run, the pair line was again observed but the conversion line could not be detected because of a background from Compton electrons produced in the target by 15 MeV gamma rays. The spectrum of Compton scattered electrons and the expected position of the internal conversion line are presented in Fig. 2. For each point a charge of 0.1 mC was collected on the Faraday cup. The Compton edge is broadened by multiple scattering of the electrons in the target. Background at the position of the conversion line was a factor of 20 larger than the predicted intensity of the conversion line.

In summary, we have shown that one can readily detect the pair transition line due to the decay from the 15.1 MeV state of ^{12}C to the ground state. This occurs at a spectrometer setting corresponding to the transmission of 7.5 MeV betas, and may therefore be useful as a high energy calibration point for beta spectrometers. An effort to detect the 15.1 MeV conversion electron, for a much higher calibration point, proved to be unsuccessful, due to a background of Compton scattered electrons. However, the peak structure of the spectrum of Compton scattered electrons may itself be useful for a calibration point.

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[1]I. Band, M. Tryhoskovskaya, and M. Listengarten, Bull Acad. Sci. USSR Phys. Ser. 40, 68 (1976).
[2]M. Rose, Phys. Rev. 76, 5 (1949).
[3]D. Alburger, Rev. Sci. Instrum. 27, 991 (1956).
[4]D. Wilkinson, D. E. Alburger, E. K. Warburton, and R. E. Pixley, Phys. Rev. 129, 1643 (1963).
[5]D. Berghofer, M. D. Hasinoff, R. Helmer, S. T. Lim, D. F. Measday, and K. Ebisawa, Nucl. Phys. A263, 109 (1976).
[6]The rate of coincidences was roughly consistent with the calculated rate but we are unable to report a value for the pair branching ratio of the 15.1 MeV state in ^{12}C because the relation between our normalization and the number of states produced was not measured.
[7]J. Enagonio, Senior thesis, Princeton University, 1980 (unpublished).