Direct Measurement of the L/K Ratio in the Electron Capture Decay of ^{7}Be with Cryogenic Micro-Calorimeters

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Abstract. Using a cryogenic micro-calorimeter originally developed for x-ray astrophysics, we have the performed the first direct investigation of the L/K capture ratio in ^{7}Be electron capture decay. The low background and excellent energy resolution clearly resolve capture from the individual shells, resulting in a direct determination of the L/K ratio.

INTRODUCTION

A good knowledge of electron capture parameters is important for certain searches for massive neutrinos [1], for radionuclide metrology[2], and for other electron capture experiments [3]. ^{7}Be is the lightest nucleus that decays via electron capture, with a maximum energy release (excluding the energy of the emitted neutrino) of 112 eV. Due to this very low energy release, the properties of the decay have always been very difficult to study and the L/K ratio has never been accurately measured. Cryogenic micro-calorimeters, thanks to their good energy resolution and equal sensitivity to different kinds of radiation, are the perfect instruments for such measurements [6]. We report here the observation of ^{7}Be electron capture made with cryogenic micro-calorimeters based on mercury telluride absorbers in which the radioactive nucleus was embedded. With an energy resolution of 8.5 eV FWHM, we have been able to separate the different features of the energy spectrum, leading to the first direct exploration of the L/K ratio in ^{7}Be.

When ^{7}Be decays [See Fig.1], an electron from either the K-or L-shell can be captured by the nucleus to either the nuclear ground state or the first excited state of the residual ^{7}Li nucleus. If the decay is to the ^{7}Li ground state, a neutrino with an energy of 862 keV is emitted and the residual nucleus recoils with a kinetic energy of 57 eV. If the decay is to the ^{7}Li excited state, the neutrino energy is 384 keV and the decay is quickly followed by the emission of a 478 keV gamma ray. In this case the nuclear recoil energy depends on the time and angle between the neutrino and gamma ray emission. If the capture is

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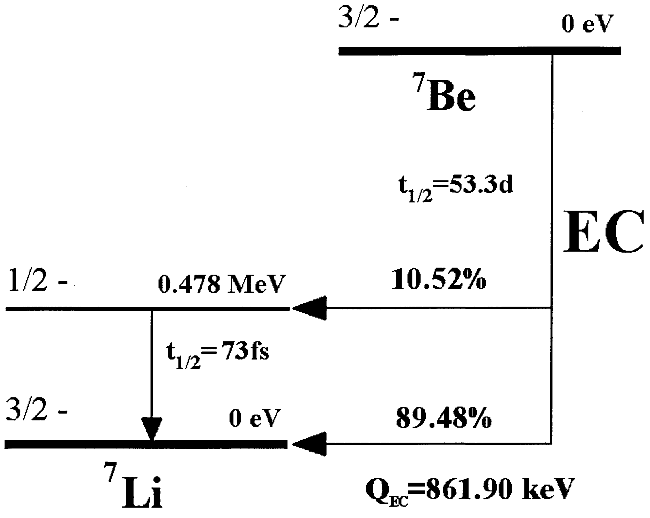

FIGURE 1. Decay scheme of ^{7}Be

from the ^{7}Be K-shell, an electron from the L-shell fills the hole and the binding energy of 55 eV is released and adds to the recoil energy.

The energy spectrum is therefore characterized by a K-capture to ground state peak at 112 eV, an L-capture to ground state peak at 57 eV, a distribution due to the K-capture to the excited state centered at about 85 eV, and a distribution due to the L-capture to the excited state centered at about 28 eV.

The ^{7}Be was produced with the TWINSOL [7] secondary radioactive beam facility [Fig.2] at the University of Notre Dame. A 100 particle-nA beam of ^{6}Li at 15 MeV was incident on a 2.54 cm long gas cell filled with one atmosphere of ^{3}He, producing ^{7}Be via the ^{3}He(^{6}Li,^{7}Be)d reaction. Recoil ^{7}Be ions at a central energy of 8.5 MeV were brought to a focus 5.5 m downstream of the ^{3}He cell by two superconducting solenoids. A targetholder with four small samples of HgTe (0.5 mm $\times$ 1 mm $\times$ 8 μm) mounted on it was placed at the focus. After implanting for 44 hours, the activity of each chip was measured to be about 10 Bq by counting the 478 keV gamma rays emitted after the decay to the ^{7}Li excited state. The HgTe chips were cleaved to a size with an activity of 2-3 Bq in order to reduce pileup effects.

THE EXPERIMENT:

Four of the HgTe chips implanted with ^{7}Be were mounted on micro-calorimeters using Stycast 2850FT epoxy. The micro-calorimeters were part of a 36 pixel array based on ion-implanted silicon Si:P:B thermistors. The array was built as a test device for the X-Ray Quantum Calorimetry sounding rocket program[8, 9, 10]. The array was

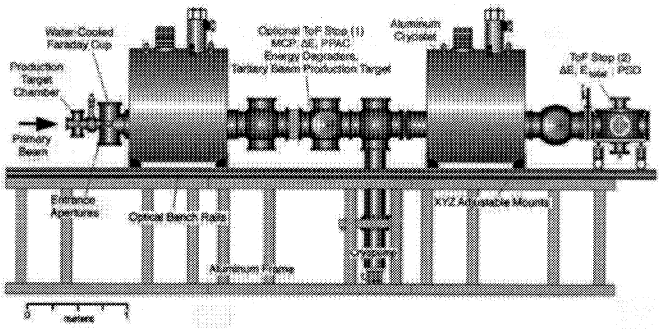

FIGURE 2. Schematic layout of TWINSOL secondary radioactive beam facility

installed on the cold plate of an adiabatic demagnetization refrigerator and maintained at a temperature of 60 millikelvin. The voltages across the thermistors are amplified using silicon JFET source followers operating at about 120 Kelvin. The signals then pass out of the cryostat and are further amplified by low noise amplifiers. The output is sampled continuously by a 12 bit digitizer at 50 microsecond intervals, and for each event above a threshold of approximately 20 eV, a 4096 channel sample containing the pulse is written to tape for later off-line analysis.

The calorimeter detectors were calibrated using an external, α-excited fluorescence source with a Teflon target which provided carbon and fluorine K x-rays at 277 eV and 677 eV respectively. The monoenergetic events at 112 eV from the ^{7}Be K-shell capture to the ^{7}Li nuclear ground state provided information on gain drifts when the fluorescence source was removed. To check that residual pileup does not affect the results of the analysis, the data have been acquired into different runs, separated by 80 days. Since the half-life of ^{7}Be is 53.29(7) days, the activity of the samples was lower by about a factor of three in the second run.

RESULTS AND CONCLUSIONS:

Figure 3 indicates the low backgrounds (approximately one count per eV all the way down to 20 eV) and the excellent energy resolution (8.5 eV FWHM) we obtained. This allows fairly clean deconvolution of the components of the decay.

The non-zero slowing time of the recoils and the lifetime of the nuclear excited state give rise to a broad distribution of energies for decays to the first nuclear excited state of ^{7}Li. Three models for the recoil slowing process were considered, corresponding to a linear decrease in velocity over time, an exponential decrease in velocity over time, or a quadratic, concave down velocity vs. time dependence. None of the models is completely realistic; however, their different curvatures cover a wide range of possible behaviors. Each of the two runs was fit separately, and each run was fit with each model twice: once with the branching ratio for the decay to the first excited state of the ^{7}Li nucleus fixed at the accepted value (0.1052) and once with the ratio free to vary.

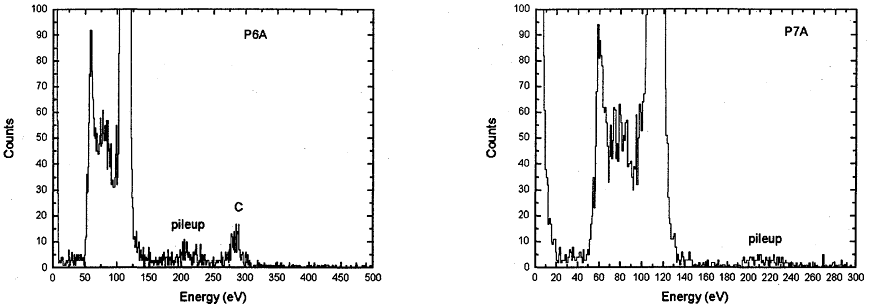

FIGURE 3. Energy spectra from both data runs showing low background and excellent energy resolution.

Averaging both treatments of the branching ratio yields an L/K ratio of 0.040(5) [[11] where the uncertainty represents the spread in the values.

Our experimental value for the L/K ratio is a factor of about 2 lower than the average existing theoretical predictions [12] for free beryllium, and much closer to the naive model which ignores exchange and overlap effects in the outer electron orbits. This disagreement is perhaps not unexpected due to the environment of the beryllium atoms when they undergo electron capture. The theoretical calculations mentioned above apply to free beryllium atoms. However in our experiment, as in most, the ^{7}Be is in a solid host, so considerable distortion of the outer electron wave functions is to be expected.

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