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Short Note

A new measurement of ^{208}Tl levels

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Abstract. A new determination for the levels of the nucleus ^{208}Tl was performed by measuring the γ-rays following the β^--decay of ^{208}Hg. Twenty-six γ-rays were assigned and three new levels of ^{208}Tl at 1.728 MeV, 1.652 MeV and 1.362 MeV have been affirmed. A partial ^{208}Hg decaying γ scheme was proposed. The experimental level structure was compared with a shell model calculation.

PACS. 23.20.Lv Gamma transitions and level energies – 23.40.-s Beta decay; double beta decay; electron and muon capture

The odd-odd nucleus ^{208}Tl is one of the members of the natural-radioactivity thorium series. The earlier studies on the ^{208}Tl level structure started in the 1920s. By the end of the 1960s, the published experimental and theoretical studies on the nucleus ^{208}Tl were as much as several tens of papers. Before the present work, the level structure of ^{208}Tl was investigated on the basis of the α-decay of the nucleus ^{212}Bi which is also lying in the same thorium series as the α-decay mother nucleus of ^{208}Tl. The information relating to the nucleus ^{208}Tl, obtained from previous studies, is mainly as follows: 1) the energies and intensities have been measured for the α-particles, the α-sequential γ-rays and the internal conversion electrons, emitted during the α-decays of the ^{212}Bi source; 2) an α-decay γ scheme, comprising eight low-lying levels of ^{208}Tl and nine transition γ-rays, has been constructed, and the spins and parities of the lowest three levels have been assigned by means of various correlation experiments; 3) the β-decay half-lives of the ^{208}Tl ground state and its 39.85 keV isomer state have been determined, respectively. All the information was collected in ref. [1].

In the present work, we tried, for the first time, to study the ^{208}Tl level structure based on the measurements for the γ-rays following the β^- decay of ^{208}Hg. The neutron-rich isotope ^{208}Hg was produced with a multi-nucleon transfer reaction taking place in the bombardment of a ^{18}O projectile on a thick natural lead target. The average production cross-section is about 5 μb for a ^{18}O projectile energy range from the incident-channel Coulomb barrier to 30 MeV/u [2]. Three experiments were successively performed at RIKEN in Japan or at HIRFL (Heavy-Ion Research Facility on Lanzhou) in China, respectively. For the first experiment, a 25 MeV/u ^{18}O beam of average intensity 0.2 μA, provided by the cyclotron of RIKEN, was used. The Hg-isotope products produced in the irradiated lead target piece were separated and absorbed in a gold-foil sample by using a specific off-line gas-thermachromatographic device, which was developed for the identification of the neutron-rich nuclide ^{208}Hg [3, 4]. This device possesses a good element selectivity and a high efficiency of about 85% for the mercury element products. Each lead target piece was irradiated for 100 min, then the separation took about 20 min, and the gold-foil sample was detected for 100 min. For the first experiment, a γ-γ coincident measurement was performed. The γ-rays were detected with two HPGe γ detectors, one four-cell clever mode with a total relative efficiency of 80% and another single detector of 50%. In order to reduce the γ-ray detection background and to suppress the detection of the γ-rays from the neutron-deficient Hg isotopes absorbed simultaneously in the same gold-foil sample, the γ-rays signals from HPGe detectors were gated by the beta energy loss signals, detected with a 4π thin plastic scintillation detector [5]. The γ-γ coincidence data were recorded in the event mode. The second experiment was performed at the HIRFL. It is similar to the first experiment, but a 7.5 MeV/u ^{18}O beam was used. This time,

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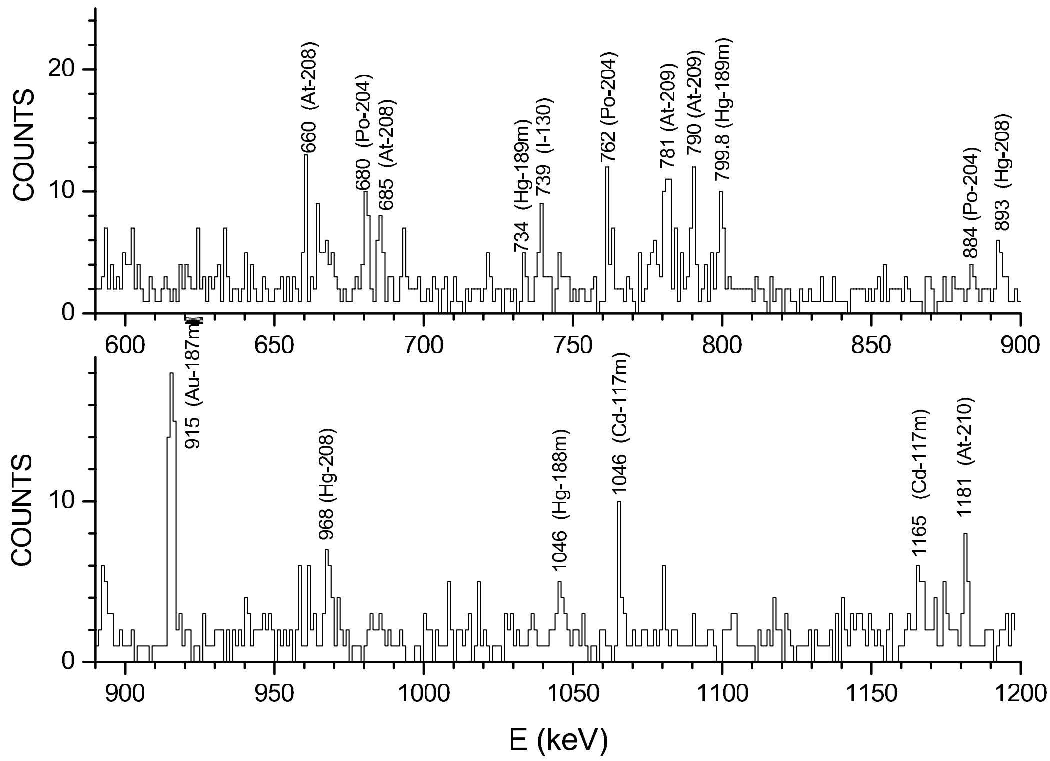

Fig. 1. A typical correlation spectrum obtained by summing three spectra, gated by the 266.9 keV, 142.0 keV, and 285.4 keV γ-rays, respectively.

the time-successive singles γ-ray spectra were simultaneously measured with coincidence spectrum, according to 10×10 min arrangement. The third experiment was done on the isotope separator on-line (ISOLan) [6] located at the HIRFL. A 30 MeV/u ^{18}O beam bombarded on a molten lead target, the volatilizable reaction products escaped from the surface of the molten lead target at a work temperature of 700 °C, then passed though a transfer tube into a FEBIAD ion source [7]. The ISOLan has a mass resolution better than 500 and an overall efficiency of 3.8% for the Hg products [6]. We collected the mass-separated ($m = 208$) products, then the time-successive singles γ-ray spectra were measured at off-line conditions. A P-type HPGe gamma ray detector with a 1.9 keV FWHM (Full Width at Half Maximum) and a mini-plane HPGe detector were used. The later has a higher detecting sensitivity for the γ-rays below 200 keV.

The γ-rays following the β^--decay of ^{208}Hg were assigned on the basis of the gamma correlation, the γ-ray energy fits, and the decaying half-lives of the γ-ray counts, determined with time-successive singles γ-ray spectral analyses. The production cross-sections of ^{208}Hg in the reaction $^{18}\mathrm{O} + {}^{\mathrm{nat}}\mathrm{Pb}$ is only a few microbarns, but other radioactive Hg isotopes may be produced with an overall cross-section of several-ten millibarns. In the present work, therefore, the experimental condition was very critical to obtain a fine gamma scheme.

Because some low-lying levels of ^{208}Tl were known [1], we searched for the new γ-rays corresponding to the gamma transition between the energy levels of ^{208}Tl according to four practical steps as follows:

1) Searching for the probable γ-rays corresponding to the gamma transition from the known 759 keV or 803 keV levels to other known low-lying levels. The experimental γ-γ coincident spectra were gated with the known seven γ-rays, and some such new γ-rays were found.
2) The γ-γ coincident spectra were gated with the new γ-rays found in the first step, so that probable new levels of ^{208}Tl above 803 keV may be found. In this step we found many new γ-rays which result in the confirmation of ^{208}Tl new levels above 1 MeV.
3) The various correlation relations of all the γ-rays to be assigned to the level transition of ^{208}Tl were checked up by means of a γ-gated technique. So that a decay scheme may be constructed.
4) The relative intensities and the decaying half-lives of all the γ-rays were determined by using the time-successive single γ-ray spectra.

Figure 1 shows an example of the correlation spectra. Based on the data analyses, twenty-six γ-rays were identified to the level transitions of the nucleus ^{208}Tl and three nuclear-energy levels at 1362 keV, 1652 keV, 1728 keV have been confirmed. A partial γ scheme as shown in fig. 2 has been constructed. The relative branching ratios were determined by using the singles spectra data from the third experiment, and those γ-rays with branching ratio below 10% have not been identified. The experimental results indicate that the β^--decay of ^{208}Hg mainly feeds into the two high-lying energy levels at 1652 keV and 1728 keV.

The experimental result was compared with the shell model calculations in ref. [8], in which the large-basis shell

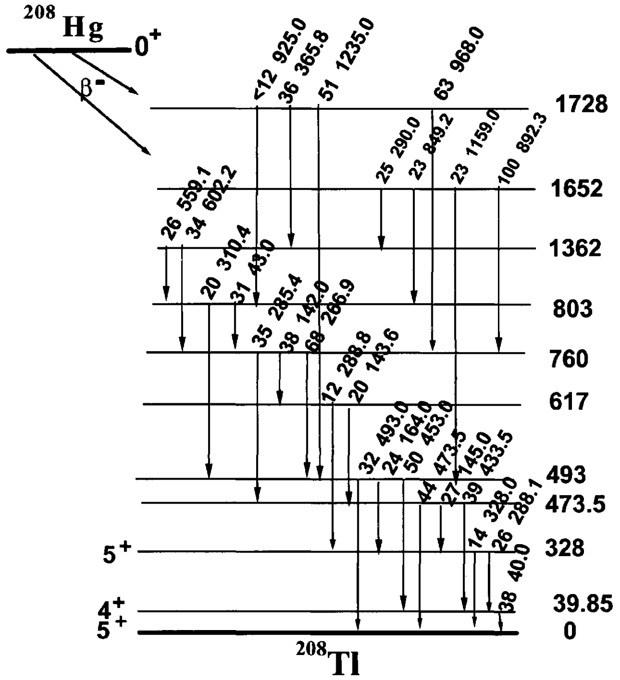

Fig. 2. A partial γ scheme of the ^{208}Hg β^--decay.

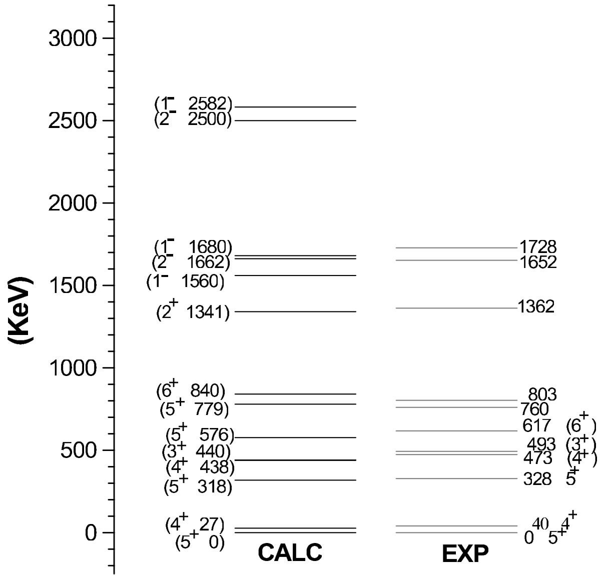

Fig. 3. A comparison between the experimental ^{208}Tl nuclear-energy levels and a shell model calculation [8].

model code OXBASH [9] was utilized and several different interactions were examined. The calculated ^{208}Tl energy levels with different interactions are very similar with each other for the low-lying levels below 1 MeV, but very different above 1 MeV. In fig. 3 the experimental ^{208}Tl levels suggested by the present work was compared with one of the calculations (see ref. [8] and the references therein). The energy positions of the three new levels, confirmed in the present work, are surprisingly in agreement with the shell model calculation shown in fig. 3. This calculation predicted that there would be 4 unknown levels within 1 to 2 MeV, in which two (1^-, 2^-) are near 1.7 MeV, one (1^-) is near 1.6 MeV, and another (2^+) near 1.3 MeV. If this calculation prediction were correct, the beta-decay of ^{208}Hg should be first-order forbidden, and the experiment 42 min half-life of ^{208}Hg [2] might be interpreted based on the first-order forbidden beta transition. However, the electromagnetic gamma transitions determined in the present work cannot be explained based on the calculation, future theoretical study should be expected.

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