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Atomic structure investigation of curium by laser mass spectroscopy

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As a transuranium element with proton number $Z = 96$, curium is considered as one of the “minor actinides” in spent nuclear fuel. It is produced during burn-up by a series of nuclear reactions from ^{238}U ; spent nuclear fuel contains about 20 g/tonne. Nineteen curium isotopes from ^{233}Cm to ^{251}Cm are known [1], with some exhibiting long half-lives between a few days and 10^7 years. As these include strong α -emitters as well as fissionable isotopes with large fission cross section, it is considered for transmutation as a highly radiotoxic contaminant. Targeted production of curium isotopes is achieved by neutron-irradiation of plutonium isotopes in high flux research reactors. As a mid-range actinide element within the Periodic Table, Cm has an electronic odd-parity ground state configuration $5f^7 6d 7s^2 {}^9D_{2,3,4,5,6}^\circ$ and a second nearby located even-parity configuration $5f^8 7s^2 {}^7F_{0,1,2,3,4,5,6}$. Accordingly, its atomic structure is very rich, highly complex and so far only known to some degree.

Resonance ionization mass spectroscopy (RIMS) at the RISIKO mass separator of Mainz University has been applied for off-line studies of the Cm atomic structure within a series of investigations on long-lived actinides [2,3]. Due to its high ionization efficiency and outstanding elemental selectivity the technique is an excellent tool for high precision optical spectroscopy of atoms, especially regarding minuscule and rare samples, for the selective production of ions of a given element and, finally, for selective and sensitive ultra-trace determination [4]. A sequence of carefully selected optical transitions is used as resonant laser excitation ladder up to ionization. The combination with high transmission mass separation permits for quantitative low background detection of individual ions within an isotopically pure ion beam [5]. The laser system and the layout of the laser ion source unit are the central aspects of RIMS and determine the quality and significance of the spectroscopic data [5,6,7]. In Cm, three first excitation steps from the $5f^7 6d 7s^2 {}^9D_2^\circ$ atomic ground state to the $5f^7 6d 7s 7p {}^9D_3$, $5f^8 6d 7s {}^9D_3$, and $5f^7 6d 7s 7p {}^7D_2$ levels were studied for ^{248}Cm . Based on all these steps, Rydberg levels were identified and their convergences were analyzed to deliver a precise value of the first ionization potential (IP). The Rydberg analysis was complicated due to the high spectral line density and strong configuration interactions. The IP value was independently confirmed by involving the field ionization approach with varying external electric field and applying the saddle point model. An IP value of $48330.73(18) \text{ cm}^{-1}$ was obtained from the weighted mean of the results from both methods; which certifies a slight underestimation of the former literature IP value of $48324(2) \text{ cm}^{-1}$ by Köhler et al., measured in 1996 [8].

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Primary author: KNEIP, Nina (Johannes Gutenberg University Mainz)

Co-authors: Mr WEBER, Felix (Institute of Physics, Johannes Gutenberg University Mainz); Mrs KAJA, Magdalen A. (Institute of Physics, Johannes Gutenberg University Mainz); Prof. DÜLLMANN, Christoph E. (Department of Chemistry –TRIGA Site, Johannes Gutenberg University Mainz, GSI Helmholtzzentrum für Schwerionenforschung GmbH Darmstadt, Helmholtz Institute Mainz); Mr MOKRY, Christoph (Department of Chemistry –TRIGA Site, Johannes Gutenberg University Mainz, Helmholtz Institute Mainz); Dr RAEDER, Sebastian (GSI Helmholtzzentrum für Schwerionenforschung GmbH Darmstadt, Helmholtz Institute Mainz); Mr RUNKE, Jörg (Department of Chemistry –TRIGA Site, Johannes Gutenberg University Mainz, GSI Helmholtzzentrum für Schwerionenforschung GmbH Darmstadt); Dr STUDER, Dominik (Institute of Physics, Johannes Gutenberg University Mainz); Dr TRAUTMANN, Norbert (Department of Chemistry –TRIGA Site, Johannes Gutenberg University Mainz); Prof. WENDT, Klaus (Institute of Physics, Johannes Gutenberg University Mainz)

Presenter: KNEIP, Nina (Johannes Gutenberg University Mainz)

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