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Special Article – Scientific Note

Discovery of a new long-lived isomeric state in ^{125}Ce

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Abstract. A new long-lived isomeric state in the near proton dripline nucleus ^{125}Ce has been identified with Schottky mass spectrometry at GSI. The excitation energy $E^* = 103(12)$ keV and the decay time of 193(1) s have been obtained from a single stored fully ionized $^{125m}Ce^{58+}$ ion. The data implies an $E3$ transition and a $1/2^+$ assignment for the spin of the isomer.

PACS. 21.10.Dr Binding energies and masses – 21.10.Tg Lifetimes – 23.20.Lv γ transitions and level energies

Excited states in ^{125}Ce have been extensively studied up to very high spins in recent years [1–3]. These studies, however, vary in the assignments for the spins, parities and relative excitation energies of the single-quasiparticle intrinsic states. In this paper we report on the discovery of a long-lived isomeric state in ^{125}Ce, which has been used to constrain the γ-ray spectroscopic data.

The present experiment was devoted to mass measurements of neutron-deficient medium-heavy nuclei. The exotic nuclei have been produced via fragmentation of 615 MeV/u ^{152}Sm projectiles in a thick 4 g/cm^2 ^{9}Be production target. The fragments were separated in-flight with the fragment separator FRS [4] and injected into the storage-cooler ring ESR [5]. The ions stored in the ESR were electron cooled [6] and their revolution frequencies, which directly reflect the mass-to-charge ratios, have been measured with time-resolved Schottky mass spectrometry (SMS) [7]. More than 350 neutron-deficient nuclei have been unambiguously identified in the measured frequency spectra in this experiment. A mass resolving power of $2 \cdot 10^6$ was reached by recording single stored ions. The electron cooling lasts for a few seconds, restricting the nuclei that can be investigated with this technique. Thus, isomeric states with half-lives longer than a few seconds can be studied with SMS, which is complementary to that accessible with γ-spectroscopy [8]. The area of a frequency peak is directly proportional to the number of stored ions,

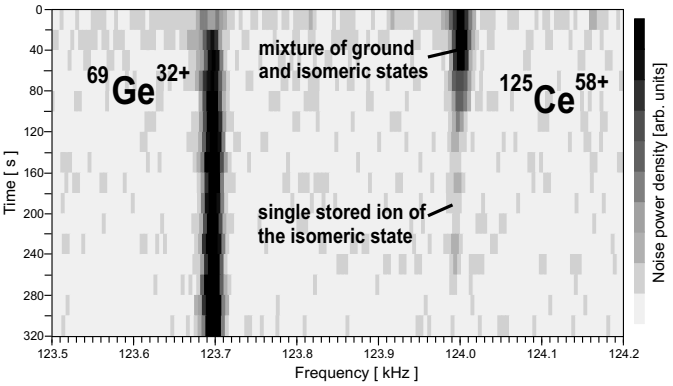

Fig. 1. Sixteen sequential Schottky frequency spectra. At first, the frequency of $^{125}Ce^{58+}$ ions corresponds to an unresolved mixture of the ground and isomeric states. After about 100 s, only one ion of ^{125}Ce in the isomeric state is left.

which is the basis for lifetime measurements [9,10]. The details on the experimental setup, data acquisition, and data analysis can be found in refs. [7,11,12] and references therein.

The ^{125}Ce ions have been observed in the spectra in two charge states, namely 14 times as fully ionized $^{125}Ce^{58+}$ and 7 times having one bound electron $^{125}Ce^{57+}$. In all these cases, several ions of ^{125}Ce were injected into the ESR, which have been assigned to an unresolved mixture of the ground and isomeric states. An obvious advantage of measuring single ions is that a single ion can belong

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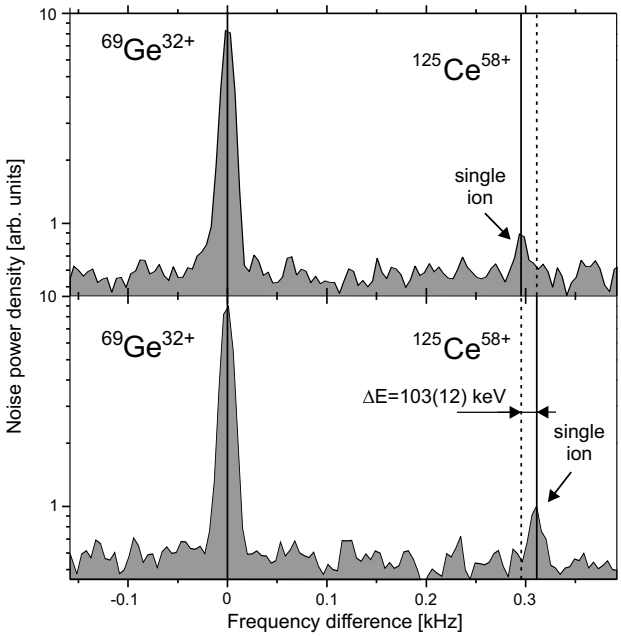

Fig. 2. Frequency spectra of single stored ^{125}Ce ions in the isomeric state (upper panel) and ground state (lower panel). The peak of $^{69}Ge^{32+}$ can be used as a reference. The frequency difference corresponds to the isomeric excitation energy of $E^* = 103 \pm 12$ keV.

to one state only. In this way ground or isomeric states can be assigned even for very small excitation energies, which cannot be resolved when both states are present simultaneously [13]. A single stored ^{125}Ce ion in the isomeric state is shown in fig. 1. In the beginning of the measurement also ions in the ground state are present, thus making a common frequency peak. After about 100 s most of the ions in the ground state have decayed. The last single ion can be identified as being in the isomeric state since its frequency has shifted, reflecting a slightly higher mass-to-charge ratio. No other fragments in different charge states can account for this frequency line. In another measurement, after about 60 s a single stored ion in the ground state has been observed. The frequency difference between the ground and isomeric states can clearly be seen in fig. 2, by comparing with the frequency of $^{69}Ge^{32+}$.

For the lifetime determination, Schottky frequency spectra averaged over 2 s periods have been produced. The time of decay measured for the ion in the isomeric state in the laboratory frame is 269 ± 1 s, which in the rest frame of the ion corresponds to $t = 193 \pm 1$ s (Lorentz factor $\gamma = 1.39$). Following table 1 of ref. [14] we estimate the mean lifetime of the isomer to be $\tau = t^{+4.79t}_{-0.457t} = 193^{+924}_{-88}$ s.

The excitation energy $E^* = 103 \pm 12$ keV has been determined by calibrating the frequency spectra with neighboring $^{41}K^{19+}$, $^{82}Sr^{38+}$, $^{69}Ge^{32+}$, and $^{56}Fe^{26+}$ ions which have well-known mass values [15]. According to the Weisskopf estimate, a hindered $E3$ ($\tau_W(E3) = 14$ s) or $M3$ ($\tau_W(M3) = 115$ s) transition can be assigned for the de-excitation of this isomeric state.

There are no experimental single-particle states that seem likely to give rise to an $M3$ transition. However, the deduced energy and multipolarity $E3$ are in good accord with a "missing" transition, that would complete the low-energy part of the level structure deduced in ref. [2] using γ-ray spectroscopic data. They identify a $1/2^+$ bandhead, 92 keV above the $(7/2^-)$ ground state, but their technique was not sensitive to the associated ($E3$) transition. Allowing for an $E3$, 92 keV electron conversion coefficient of $\alpha = 43$ [16], the present lifetime of 193 s for bare ions corresponds to 4.4 s for neutral ions.

However, subsequently, ref. [3] reassigned parts of the level structure. Here, we comment on some difficulties with these reassignments. Firstly, ref. [3] assigns no $1/2^+$ state, but this is needed for the interpretation of the storage ring data. It seems to be possible that there were unobserved transitions below their "band 3" $3/2^+$ and $5/2^+$ members, *i.e.* that there is a lower-energy $1/2^+$ bandhead. If a smooth extrapolation of the band-3 energies is made, then this $1/2^+$ bandhead would be 75 ± 10 keV below the $5/2^+$ member of band 3, and 42 ± 10 keV above the assigned $5/2^+$ member of band 2. This opens up the possibility of $E2$ decay from the $1/2^+$ state, which is inconsistent with the long half-life observed in the storage ring. Secondly, inspection of the γ-ray intensities of ref. [3] reveals another potential problem with their reassignments. This involves looking at the transition intensity balance at their $7/2^+$, 135 keV level. By accounting for electron conversion intensities, and assuming no additional side feeding at the $5/2^+$, 135 keV level, the total conversion coefficient of the 135 keV transition is determined to be 0.09 ± 0.05, compared with theoretical values [16] of 0.11 for the $E1$ decay, and 0.52 for the $M1$ decay. This favours the $E1$ character for the 135 keV transition, conflicting with the assignment of ref. [3], but agreeing with that of ref. [2]. Furthermore, while ref. [3] uses the 283 keV angular-correlation ratio ($R_\theta = 1.4$) to indicate the $E2$ character, hence their $9/2^+$ to $5/2^+$ assignment, it should be noted that this angular-correlation ratio is also compatible with the $7/2^+$ to $7/2^-$, $E1$ assignment of ref. [2].

In summary, the storage ring isomer data are interpreted as arising from an $E3$, $1/2^+$ to $7/2^-$ transition, in agreement with the γ-ray data of ref. [2].

References

1. E.S. Paul *et al.*, Phys. Rev. C **58**, 801 (1998).
2. C.M. Petrache *et al.*, Eur. Phys. J. A **14**, 439 (2002).
3. J.F. Smith *et al.*, Phys. Rev. C **69**, 034339 (2004).
4. H. Geissel *et al.*, Nucl. Instrum. Methods B **70**, 286 (1992).
5. B. Franzke, Nucl. Instrum. Methods B **24/25**, 18 (1987).
6. M. Steck *et al.*, Nucl. Instrum. Methods A **532**, 357 (2004).
7. Yu.A. Litvinov *et al.*, Nucl. Phys. A **756**, 3 (2005).
8. P.M. Walker, G.D. Dracoulis, Hyperfine Interact. **135**, 83 (2001).
9. Yu.A. Litvinov *et al.*, Phys. Lett. B **573**, 80 (2003).
10. T. Ohtsubo *et al.*, Phys. Rev. Lett. **95**, 052501 (2005).
11. T. Radon *et al.*, Nucl. Phys. A **677**, 75 (2000).
12. Yu.A. Litvinov *et al.*, arXiv:/nucl-ex/0509019.
13. H. Geissel, Yu.A. Litvinov, J. Phys. G **31**, 1779 (2005).
14. K.-H. Schmidt *et al.*, Z. Phys. A **316**, 19 (1984).
15. G. Audi *et al.*, Nucl. Phys. A **729**, 3 (2003).
16. F. Rösel *et al.*, At. Data Nucl. Data Tables **21**, 91 (1978).