keV γ rays are newly added into the level scheme compared with that in Ref. [5]. Accepting the $(17/2^+)$ state as the fully-aligned state in the valence space $\pi(p_{1/2}, g_{9/2})^1$ and $\nu(d_{5/2})^2$, one can deduce that the higher-spin states involve the competition of the proton $p_{3/2}(f_{5/2}) \rightarrow p_{1/2}$ and neutron $d_{5/2} \rightarrow g_{7/2}$ particle-hole excitation, which is related to crossing the $Z = 38$ and $N = 56$ sub-shell closures respectively. Analogous to the analysis for ^{92}Zr[6], we propose that based on the $(17/2^+)$ state, the 3 528.4 keV $(21/2^+)$ level is attributed to neutron $(d_{5/2} \rightarrow g_{7/2})$ particle-hole excitation, while the other $(21/2^+)$ state at 3 734.4 keV is naturally ascribable to the proton $(p_{3/2} \rightarrow p_{1/2})$ particle-hole excitation. Therefore the 4 148.4 keV $(25/2^+)$ state is assigned to the $\pi(p_{3/2}^{-1} p_{1/2} g_{9/2}) \otimes \nu(d_{5/2} g_{7/2}^{-1})$ configuration, which involves both neutron and proton particle-hole excitation from the $(17/2^+)$ state. Comparing the 619.6 keV (415.3 keV) transition with 1 577.0 keV (1 371.0 keV) transition, one can find that there is a reduction of energy for Z=38 (N=56) as one neutron (proton) is added to the $g_{7/2}$ $(p_{1/2})$ orbital, which is also found in ^{92}Zr[6]. In addition, the $N = 52$ isotones ^{93}Tc and ^{95}Tc are anticipated having the similar property and the detailed analysis is in progress.

References

[1] L. Funke, G. Winter, J. Döring, et al., Nucl. Phys. A, 541(1992)241.
[2] N. S. Pattabiraman, S. N. Chintalapudi, S. S. Ghugre, et al., Phys. Rev. C, 65(2002)044324.
[3] M. Hausmann, A. Jungclaus, E. Galindo, et al., Phys. Rev. C, 68(2003)024309.
[4] A. Jungclaus, D. Kast, K. P. Lieb, et al., Phys. Rev. C, 60(1999)014309.
[5] D. Bucurescu, Zs. Podolyak, C. Rusu, et al., Phys. Rev. C, 71(2005)034315.
[6] Z. G. Wang, et al., Phys. Rev. C, 71(2014)044308.

2 - 4 First Isochronous Mass Measurement in Neutron-rich Region at CSRe*

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Mass is one of the fundamental properties of atomic nuclei. Isochronous mass spectrometry (IMS), using a storage ring combined with an in-flight separator, has been shown to be a powerful tool for mass measurement of exotic nuclei[1]. Recently, masses of many proton-rich nuclides were accurately determined at the HIRFL-CSR facility[2]. In this paper, we described the first isochronous mass measurement of neutron-rich nuclides at CSRe.

This experiment was performed at the end of 2011. In the experiment, the primary beam of ^{86}Kr^{28+} ions was accumulated and accelerated to an energy of 460.65 MeV/u in the synchrotron CSRm. The ^{86}Kr^{28+} ions were fast extracted and focused on a $\sim$15 mm thick beryllium target which was placed at the entrance of the RIBLL2 (an in-flight fragment separator). The hot fragments, produced via projectile fragmentation of ^{86}Kr^{28+}, were separated by the RIBLL2 and then injected and stored in the experimental cooler storage ring CSRe. Both RIBLL2 and CSRe were set to a fixed magnetic rigidity of $B\rho = 7.6755$ Tm for optimum transmission of the target ions ^{61}Cr^{24+}. The CSRe was tuned in isochronous mode for the target ions. The energy of the primary beam was chosen such that the isochronous condition $\gamma \approx \gamma_t$ is fulfilled for the target ions, where γ is the Lorentz factor of the ions and γ_t is the so-called transition point of the ring. Other fragments within a $B\rho$-acceptance of about $\pm$0.2% of the RIBLL2-CSRe system were also transmitted and stored. The revolution times of the stored ions were measured by a dedicated time-of-flight detector.

The effects of magnetic instability were carefully corrected by applying the method described in Ref. [3], and the revolution time spectrum was obtained (Fig. 1(a)). Masses of nuclides were calibrated from this spectrum. In particular, the mass excesses of ^{52}Sc, ^{53}Sc and ^{54}Sc were -40492(82), -38928(114) and -34654(540) keV. These values were smaller by 1.8 σ, 2.8 σ, and 1.6 σ than the adjusted values in AME12[4] respectively.

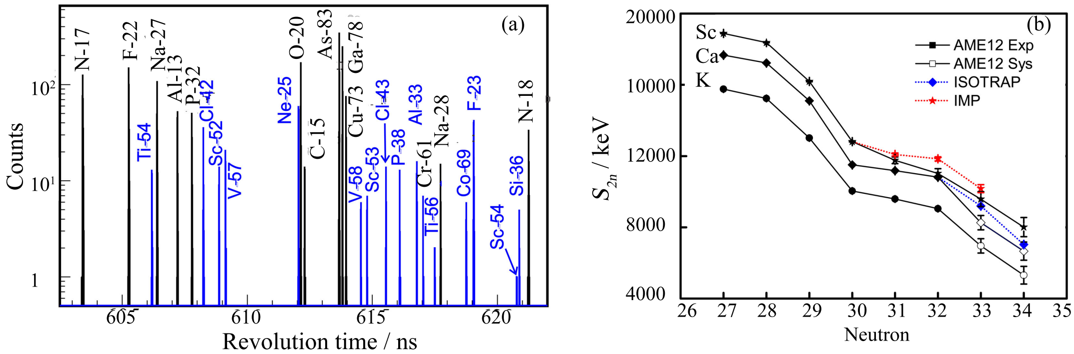

Fig. 1 (color online) (a): Corrected revolution time spectrum of ^{86}Kr fragments. Nuclei with masses determined in this experiment and those used as references are indicated with bold and italic letters, respectively. (b): Two-neutron separation energy S_{2n} as a function of neutron number N for the K, Ca and Sc isotopic chains. Solid symbols connected by solid lines represent values based completely on experimental data while hollow ones were extended values in AME12. Red solid circles connected by red dashed lines are derived from mass values from our work, and blue solid triangles are derived from ^{53,54}Ca mass values from the ISOTRAP experiment[5].

Using the mass excess values from this work, new two neutron separation energies S_{2n} of these nuclides were obtained. As can be seen in Fig. 1(b), our results show the decrease in mass excess which leads to a distinct variation of the two neutron separation energy S_{2n} in the vicinity of $N = 32$ and $Z = 20$. From $N = 32$ to $N = 33$, the drop in S_{2n} for both Ca and Sc isotopic chains is as steep as the drop from $N = 28$ to $N = 29$. The latter manifests the effect of the traditional neutron magic number 28. Hence, the former is substantial evidence of the persistence of $N = 32$ magicity in Sc isotopes. Although this magicity has been well established in the Ca isotopic chain by many experiments[5−7], it is proven in an odd isotopic chain for the first time. The physics behind this phenomena is still under exploration.

References

[1] Yu. A. Litvinov, K. Blaum, H. Geissel, et al., Nucl. Instrum. Meth. B, 317(2013)603.

[2] H. S. Xu, et al., Int. J. Mass. Spectrom., 349-250(2013)162.

[3] P. Shuai, H. S. Xu, Y. H. Zhang, et al., arXiv:1407.3459

[4] M. Wang, et al., Chin. Phys. C, 36(2012)1603.

[5] A. Gade, R. V. F. Janssens, D. Bazin, et al., Phys. Rev. C, 74(2006)021302(R).

[6] F. Wienholtz, D Beck, K Blaum, et al., Nature,498(2013)346.

[7] A. T. Gallant, J. C. Bale, T. Brunner, et al., Phys. Rev. Lett, 109(2012)032206.

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