β-Decay half-lives of ^{76,77}Co, ^{79,80}Ni and ^{81}Cu: experimental indication of doubly magic ^{78}Ni[†]

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In order to study the nuclear shell evolution around ^{78}Ni, the β-decay half-lives of neutron-rich nuclei, i.e., ^{76,77}Co, ^{79,80}Ni and ^{81}Cu were measured for the first time. The experiment was performed as part of an EURICA campaign at the RIBF facility, RIKEN in 2012. A high-intensity ^{238}U beam was accelerated up to an energy of 345 A MeV by the RIKEN cyclotron accelerator complex before hitting a 3-mm-thick beryllium target to produce secondary beams via in-flight fission. The ^{238}U^{86+} beam was delivered at an average current of 5 pnA to the production target position. During the 13 days of the experiment, about 1.2×10^4 ^{78}Ni nuclei were identified and delivered to the experimental decay station at the end of the ZeroDegree spectrometer.

Figure 1 shows the experimental results (solid symbols) and the values in the literature (open symbols) as a function of the neutron number. Due to the fifth power relation between the half-life and its Q_β value, a linear relationship between $\log_{10} T_{1/2}$ and the neutron number of the parent nucleus is expected phenomenologically when Q_β evolves smoothly in an isotopic chain. In Fig. 1 this linearity is clearly visible below $N = 50$. Beyond that, a sudden reduction is seen in the $Z = 28$ isotopic chain due to the shorter half-lives of ^{79,80}Ni with reference to the systematics at $N \leq 50$. The fast β-decay processes in ^{79,80}Ni could be attributed to the neutrons outside the $N = 50$ shell, which result in higher Q_β values and β-decay rates of ^{79,80}Ni compared to that of ^{78}Ni.

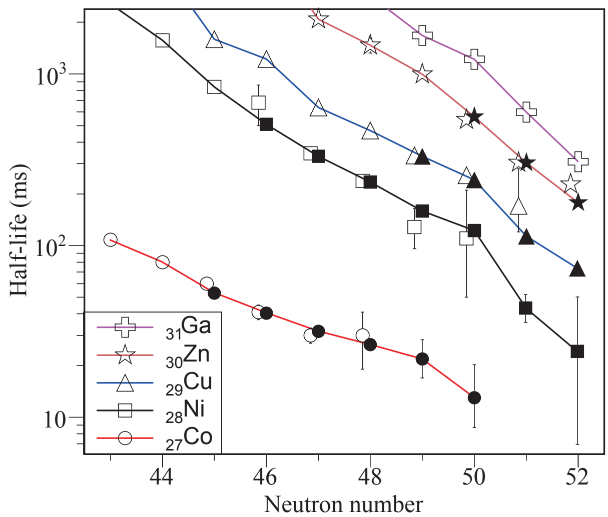

Fig. 1. Experimental half-lives as a function of neutron number for isotopes with $Z = 27 - 31$. All the solid symbols represent the half-lives determined in this work while the open symbols are the half-lives taken from the literature[1–4)]. The systematic trends in the different isotopic chains are highlighted by lines connecting the data points with a smaller uncertainty.

In addition, a large gap can be noticed in Fig. 1 between the half-lives of the Co and Ni isotopes from $N = 44$ to $N = 50$. According to shell model calculations, this can be explained by the filled proton $f_{7/2}$ single particle orbit (SPO) in Ni isotopes. In this case, the proton produced in the β decay of Ni isotopes fills the $\pi f_{5/2}$ SPO above $\pi f_{7/2}$, leading to a reduction of the Q_β value and longer half-lives of Ni isotopes than those of Co isotopes. The newly measured half-lives of ^{76,77}Co follow the decreasing trend with considerable gaps relative to those of the corresponding Ni isotones, indicating an almost constant $Z = 28$ shell gap without significant quenching up to $N = 50$.

References
1) NNDC database (2013), http://www.nndc.bnl.gov/;
2) C. Mazzocchi *et* al.: Phys. Lett. B **622**, 45 (2005);
3) P. Hosmer *et* al.: Phys. Rev. C **82**, 025806 (2010);
4) M. Madurga *et* al.: Phys. Rev. Lett. **109**, 112501 (2012);

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