Persistence of the $Z = 28$ shell gap around ^{78}Ni: first spectroscopy of ^{79}Cu†

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The shell model constitutes one of the main building blocks of our understanding of nuclear structure. Its robustness is well proven for nuclei close to the valley of stability, where it successfully predicts and explains the occurrence of magic numbers. However, the magic numbers are not universal throughout the nuclear chart and their evolution far from stability, observed experimentally over the last decades, has generated much interest. With 28 protons and 50 neutrons, the ^{78}Ni nucleus is expected to be one of the most neutron-rich doubly magic nuclei. Up to now, no evidence has been found for the disappearance of the shell closures at $Z = 28$ and $N = 50$, even if recent studies hint at a possible weakening of the $N = 50$ magic number below ^{78}Ni. The half-life of ^{78}Ni was determined at 122.2(5.1) ms, rather suggesting a survival of magicity, and calculations predict a first excited state in ^{78}Ni above 2 MeV. But so far no information on the spectroscopy of ^{78}Ni is available and the behavior of the $\pi f_{7/2}$ orbital, of primary importance as one of the orbitals defining the $Z = 28$ gap, is elusive. Access to this hole state is possible through proton transfer or knock-out reactions.

In our experiment performed at the Radioactive Isotope Beam Factory (RIBF), a ^{238}U beam with an energy of 345 MeV per nucleon and an average intensity of 12 pnA was sent on a 3-mm thick ^{9}Be target. The secondary ^{80}Zn beam, with an average intensity of 260 particles per second, was selected in the BigRips separator. The isotopes before and after the secondary target placed at the end of BigRips were identified event-by-event in the BigRips and ZeroDegree spectrometers, respectively, with the tof-$B\rho$-ΔE method. The detector set-up installed between the two spectrometers was composed of the Minos device mounted inside the Dali-2 γ-ray multidetector. Minos consisted of a liquid-hydrogen target of 102 mm long surrounded by a cylindrical time-projection chamber (TPC). The ^{79}Cu nucleus was produced mainly through proton knock-out from the incoming ^{80}Zn isotopes, the $(p, 3p)$ channel contributing with 8%. The emitted protons were tracked in the TPC, while the beam trajectory was given by two parallel-plate avalanche counters before the target. The interaction vertex was reconstructed with 95% efficiency and 5-mm uncertainty FWHM along the beam axis. The Dali-2 array, comprising 186 NaI scintillator crystals, yielded a photopeak efficiency with add-back of 27% and an energy resolution of $\sigma = 45$ keV for a 1 MeV transition emitted at 250 MeV per nucleon.

We carried out the first spectroscopy of ^{79}Cu and compared the results with MCSM calculations. The calculations show the restoration of the single-particle nature of the low-lying states, which is supported by the experiment. There is no significant knock-out feeding to the excited states below 2.2 MeV, indicating that the $Z = 28$ gap remains large. The ability to describe the ^{79}Cu nucleus as a valence proton outside a ^{78}Ni core presents us with indirect evidence of the magic character of the latter.

† Condensed from Phys. Rev. Lett. **119**, 192501 (2017)
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