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Atom-trap trace analysis of ^{41}Ca/Ca down to the 10^{-17} level

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Calcium is a major element in the biosphere and lithosphere. Its cosmogenic isotope ^{41}Ca, with a half-life of 99 thousand years, can trace environmental processes at an age scale beyond the reach of ^{14}C. A wide range of potential applications, including burial dating of bones and exposure dating of rocks, pose an analytical challenge as they require measuring ^{41}Ca/Ca values in the range of 10^{-16} – 10^{-15}. Accelerator Mass Spectrometry (AMS) has been used to measure ^{41}Ca/Ca down to the 10^{-15} level in natural samples[1], where it was limited by isobar interferences. Here we show an Atom Trap Trace Analysis (ATTA)[2] method for ^{41}Ca/Ca analysis, in which individual ^{41}Ca atoms are selectively captured into a magneto-optical trap and counted by detecting their fluorescence. ATTA is immune to contamination from other isotopes, elements, or molecules. We realize a precision of 12% at the level of 10^{-16} and a detection limit at 10^{-17}, well below the distribution of natural abundances, and analyzed samples of bones, rocks, and seawater. The accuracy of the ^{41}Ca/Ca results is verified by measuring a series of reference samples in the range of 5×10^{-16} – 4×10^{-13}. This table-top method has met the requirements to explore the proposed ^{41}Ca tracer applications, and is poised for studies of calcium-containing samples of Middle- and Late-Pleistocene in geoscience and archeology[3].

[1] Wallner, A. *et al.* Accelerator mass spectrometry with ANU's 14 million volt accelerator. *Nucl. Instrum. Methods Phys. Res. B* **534**, 48-53 (2023).

[2] To be published in Nature Physics (2023)

[3] Henning, W. *et al.* Calcium-41 concentration in terrestrial materials: prospects for dating of Pleistocene samples. *Science* **236**, 725-727 (1987)