

High Resolution Laser Resonance Ionization Mass Spectrometry

The rare, long-lived radioactive isotope ^{41}Ca can be used as a tracer in a variety of applications. However, the low natural abundance of the order of 10^{-14} requires an extremely efficient detection system. A team of researchers at the University of Mainz, Germany, combined diode laser spectroscopy and quadrupole mass separation techniques to detect the ultratrace isotope with unparalleled selectivity.

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Key Words

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Related Products

TOPTICA Photonics AG DL 100 System

1 Description

What do environmental studies, cosmochemistry, bio-medical investigations and geo-historical examinations have in common? Not much, one might be inclined to think. Not so to an elemental trace analyst: All of these fields of application deal with detecting minute amounts of rare isotopes amongst a wealth of other substances. More particularly, they all benefit from a new sensitive technique to determine the concentration of the ultra trace isotope Calcium-41 (^{41}Ca).

^{41}Ca is a radioactive tracer with a half-life of $1.03 \cdot 10^5$ years. Its relative terrestrial abundance is of the order of 10^{-14} . This value can be a thousand times higher in extraterrestrial material, e.g. meteorites, but the isotope remains, at any rate, a rare and hard-to-detect species. Yet ^{41}Ca can be used as a versatile marker: The long half-life makes the isotope an ideal candidate for radiodating, for medical assessments involving permanent labelling of the skeleton below any radiation hazard, and for studying production mechanisms of elements in stellar matter. On the other hand, ^{41}Ca is produced in the shielding concrete of nuclear facilities and is the highest long-lived contamination of this material. Thus, the interest in ultratrace determination of ^{41}Ca is manifold. However, the only established technique providing the necessary selectivity and efficiency has been accelerator mass spectrometry, a sophisticated and expensive procedure which requires a large experimental set-up.

Researchers at the University of Mainz, Germany, have now developed an ultra-sensitive trace analysis method using only table-top equipment. The LARISSA project (LAsER Resonance Ionization Spectroscopy for Selective trace Analysis) led by Priv.-Doz. Dr. K. Wendt combines optical techniques (laser-induced optical excitation and ionization of atoms) and quadrupole mass spectrometry to measure and quantify the rare calcium isotope with unprecedented precision. The set-up uses an electrothermally heated furnace which evaporates the sample to be analyzed.

The resulting atomic beam is then overlapped with beams of three narrow-bandwidth diode-lasers from TOPTICA Photonics AG. The lasers are tuned to selected atomic transition wavelengths, exciting the atoms in a sequential multi-step process. Exploiting the uniqueness of the optical transitions, an unparalleled elemental (“isobaric”) and isotopic discrimination is achieved. In order to increase the isotopic selectivity even further, the atoms are ionized by a powerful far-infrared laser, and the resulting ions are mass-selected by a commercial quadrupole spectrometer.

To-date, the team achieved an overall selectivity of their system of $5 \cdot 10^{13}$ at an efficiency of $2 \cdot 10^{-5}$. According to Dr. Wendt, modern diode laser technology was key in the development of the new high-precision technique. “The increasing availability of new diode lasers was a crucial step in miniaturizing the detection system, making it more powerful and reliable at the same time”, Wendt said.

The researchers have successfully analyzed bio-medical samples, meteorite material and irradiated concrete from a nuclear reactor. Wendt hopes to increase the measurement accuracy still further to be able to detect ^{41}Ca in geo-archaeological probes. The technique would be similar to radiocarbon-dating via ^{14}C , but access the range of 10^5 to 10^6 years before present. These measurements require an overall selectivity of 10^{15} to resolve the low natural abundance of ^{41}Ca . “This value has not been reached with any technique so far”, Wendt said. “The realization of this extreme specification with a table-top set-up is a true challenge for the experimentalist.”

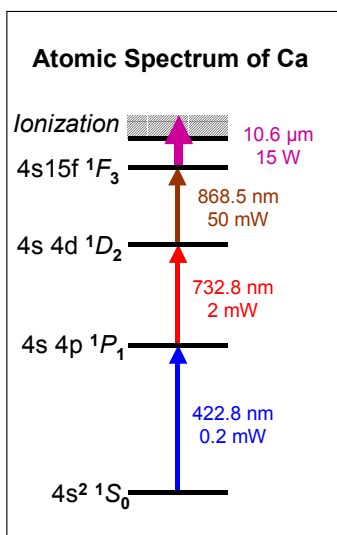


Figure 1 Excerpt from the level scheme of Calcium. Three diode lasers (wavelengths of 422.8 nm, 732.8 nm and 868.5 nm) are used for successive excitation of the atoms, which are finally ionized by a powerful CO_2 laser.

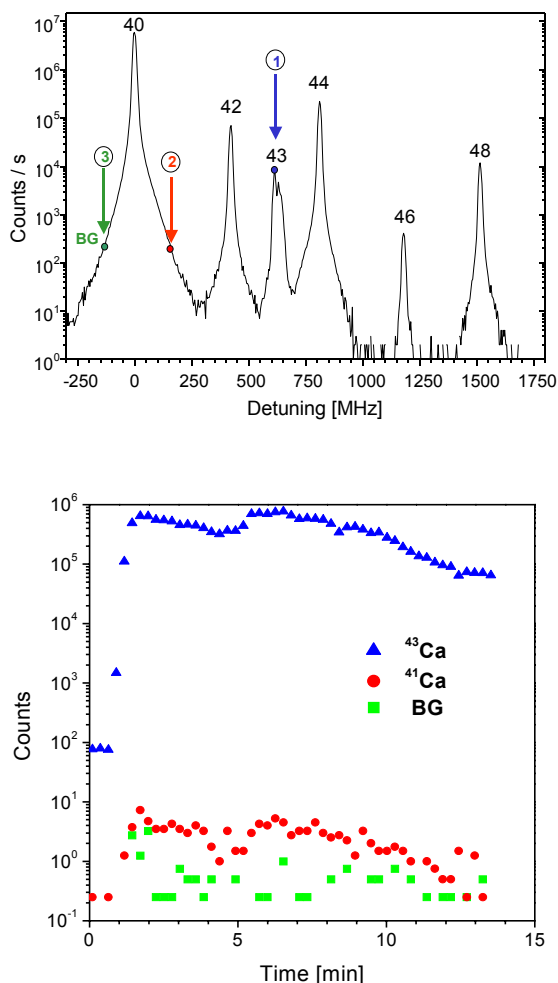


Figure 2 **Top:** A measurement of the ^{41}Ca concentration is performed by adjusting the laser frequency and quadrupole mass acceptance in an alternating manner to
 (1) ^{43}Ca for reference,
 (2) ^{41}Ca and
 (3) the background signal (BG) of ^{40}Ca .

Below: In this sample, a relative ^{41}Ca abundance of 7×10^{-9} is quantified. The signal decreases over time as the sample is evaporated.

2 References

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