Team uncovers fundamental property of astatine, rarest atom on Earth

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Resonance Ionization Laser Ion Source of ISOLDE

An international team of scientists, including a University of York researcher, has carried out ground-breaking experiments to investigate the atomic structure of astatine (Z=85), the rarest naturally occurring element on Earth.

Astatine (At) is of significant interest as its decay properties make it an ideal short-range radiation source for targeted alpha therapy in cancer treatment.

The results of the project, which was conceived by Professor Andrei Andreyev, an Anniversary Professor in the Department of Physics at the University of York, and Dr Valentine Fedosseev, from CERN, the European laboratory for nuclear physics research in Geneva, are reported in *Nature Communications*.

Through experiments conducted at the radioactive isotope facility ISOLDE at CERN, scientists have accessed, for the first time, the ionization potential of the astatine atom. This represents the essential quantity defining chemical and physical properties of this exclusively radioactive element.

The successful measurement fills a long-standing gap in Mendeleev's periodic table, since astatine was the last element present in nature for which this fundamental property was unknown.

As binding energy of the outermost valence electron, the atomic ionization energy is highly relevant for the chemical reactivity of an element and, indirectly, the stability of its chemical bonds in compounds.

Professor Andreyev, who moved to York from the University of the West of Scotland last year, said: "Astatine is of particular interest because its isotopes are interesting candidates for the creation of radiopharmaceuticals for cancer treatment by targeted alpha therapy.

"The experimental value for astatine serves also for benchmarking the theories used to predict the atomic and chemical properties of super-heavy elements, in particular the recently discovered element 117, which is a homologue of astatine."

Astatine was discovered by D. Corson and co-workers in 1940 by bombarding a bismuth target with alpha particles. The most stable isotope of this element has a half-life time of only 8.1 hours. In 1964, McLaughlin studied a 70 ng sample of artificially produced radioactive isotopes of astatine and was first to observe two spectral lines in the UV region. Apart from this, no other data on astatine's atomic spectrum was known before the study launched at CERN´s ISOLDE.

At ISOLDE, short-lived isotopes created in nuclear reactions induced by a high energy proton beam release from target material and can immediately interact with laser beams inside the hot cavity of laser ion source.

Once the wavelengths of lasers are tuned in resonance with selected atomic transitions the atoms are step-wise excited and ionized due to absorption of several photons with total energy exceeding the ionization threshold. This so-called Resonance Ionization Laser Ion Source (RILIS), in combination with electromagnetic separator, supplies pure isotopic beams of different elements for many experiments performed at ISOLDE.

Among these, is a study of short-lived nuclides by in-source resonance ionization spectroscopy using a highly sensitive (below 1 isotope per second) detection of nuclear decay. Physicists from KU Leuven, Belgium developed the setup for this study. The first laser-ionized ions of astatine were observed and identified by its characteristic alpha-decay in these experiments. Also the ionization threshold of astatine was found by scanning the wavelength of ionizing UV laser.

A second phase of the study of the atomic spectrum of astatine took place at the ISAC radioactive isotope facility of the Canadian national laboratory for particle and nuclear physics TRIUMF in Vancouver, where new optical transitions in the infrared region of spectrum were found. With the newly found transitions a highly efficient three-step ionization scheme of astatine was defined and used at ISOLDE RILIS for further study of astatine spectrum.

The researchers probed the interesting region around the ionization threshold and found a series of highly excited resonances – known as Rydberg states. From this spectrum the first ionization potential of astatine was extracted with high accuracy.

Dr Fedosseev, the RILIS team leader working at CERN, said: "The in-source laser spectroscopy today is a most sensitive method to study atomic properties of exotic short-lived isotopes. For artificially produced elements, like super-heavy ones, this could be a real way to probe their spectra. The success in the study of astatine spectrum added confidence to such projects started recently at GANIL, France and at JINR, Russia."

Professor Andreyev, who joined York as one of 16 Chairs established to mark the University's 50th Anniversary in 2013, added: "This development allows several new phenomena to be investigated, such as the size (radii) of astatine nuclei, along with a very exotic type of nuclear fission. Our collaboration has recently initiated a series of experiments to reach these goals."

More information: The paper 'Measurement of the first ionization potential of astatine by laser ionization spectroscopy' will appear in *Nature Communications* on Tuesday, 14 May, 2013. DOI: 10.1038/ncomms2189

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