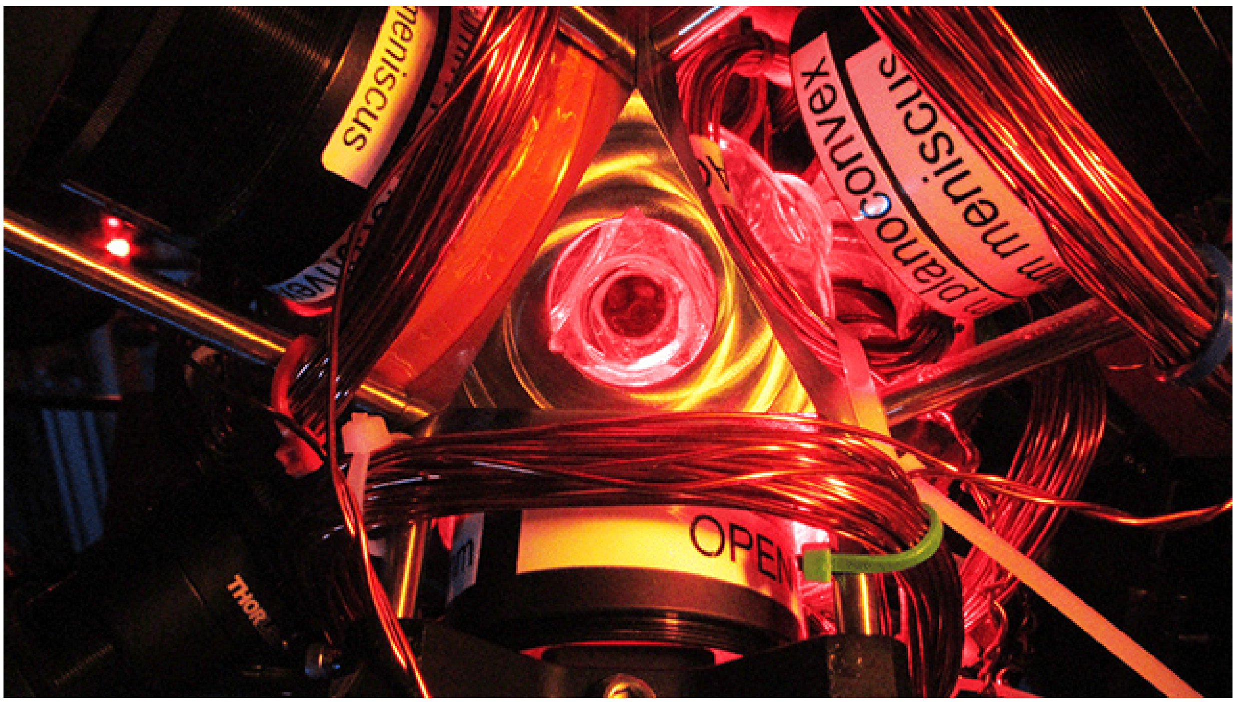
PHYS.ORG

Using an electron to probe the tiny magnetic core of an atom

August 12 2015



A view of the apparatus that is used to capture francium. Credit: P. Schewe/JQI

Precise information about the magnetic properties of nuclei is critical for studies of what's known as the 'weak force.' While people do not feel this force in the same way they feel electricity or gravity, its effects are universal. The weak force allows stuff to become unglued and form new elements through decay—the sun, for example, is powered through deuterium fuel, which is generated via weak force mediated interactions.

The weak force is elusive as it operates between objects that are separated by miniscule distances deep within atomic nuclei. To study its properties physicists must be able to extract the weak interactions out of a jumbled sea of other, more dominant phenomena that, alongside the weak force, work to govern particle behavior. Physicists from the Francium Parity Non-Conservation (FrPNC) collaboration, which includes researchers from JQI Fellow Luis Orozco's group, believe that the radioactive element francium is the perfect "laboratory" for uncovering the secrets of the weak force.

To understand this force, physicists must carefully characterize many intricate aspects of francium. Recently, the team carried out precision measurements of the magnetic properties of the francium nucleus. They have succeeded in determining important, yet nearly imperceptible deviations from the point-like behavior in the francium (Fr) nucleus—the so-called hyperfine anomaly. Their results were recently published in the journal *Physical Review Letters*. This research took place at TRIUMF in Vancouver BC, the Canadian national accelerator laboratory for nuclear and particle physics.

For large magnets, say the size of a coin, measuring the shape and strength of a magnet is straightforward. Complications arise when that magnet is excruciatingly small, like the nucleus of an atom. Its diameter is less than ten-thousandth of the size of the atom, which itself is around 100 million times smaller than a coin. For another visualization scale, imagine an ant (1 mm) in a room (10 m) compared to the surface of the earth (40,000 km in circumference). In fact, due in large part to the difficulty in making a magnetic dipole moment measurement, the nucleus is often assumed to be an infinitesimally small point – the simplest characterization for a magnet. This approximation begins to breakdown for the more massive species found in the periodic table. Practically, deviations from the ideal presents a problem: Physicists know that heavy elements are the best candidates for atomic studies of the weak force; yet the less idealized the nucleus is, the harder it will be to study the underlying weak interactions.

Luckily, francium comes in different forms called isotopes and these researchers set out to determine which ones would work best for proceeding with weak force studies. Francium itself does not exist off-the-shelf or even in a stable form, with the longest-lived type of this material having a half-life of only 23 minutes. Concentrated quantities are only available at a few accelerators in the world, such as the Isotope Selection and Acceleration facility (ISAC) at TRIUMF, which is utilized in this work. The FrPNC collaboration uses a combination of magnetic and laser fields to trap and cool francium down to millikelvin temperatures (the photo shown here is an image of the vacuum chamber used in this experiment).

By employing novel precision spectroscopic techniques, which make the most out of the scarcely available Fr, they show the relative strength of the hyperfine anomaly for a chain of five isotopes. Only a few electronic states out of the many available allow the electrons a small chance of being near the Fr nucleus, according to quantum mechanical probabilities. Lasers interrogated the electrons as they buzzed around the nucleus in two of these special states – the 7P1/2 excited state and the 7S1/2 ground state. By comparing the hyperfine splitting ratio for different isotopes the researchers can extract the hyperfine anomaly, i.e. the Bohr-Weisspkof effect, named after the two pioneers who pointed this out first in the element rubidium.

These precision measurements (errors are only 100 parts-per-million) have enabled the direct observation of the subtle effects due to the internal neutron magnetization distribution. The results indeed reveal ways in which the shape of the nucleus deviates from a uniform sphere. The researchers were able to use the data to identify a group of isotopes—the ones with the least amount of deformation— where their planned weak interaction studies could proceed. Author Jiehang Zhang, who recently completed his graduate work in Orozco's group, explains the implications of future studies, "Parity violation experiments in francium may give information about physics beyond the standard model and even limit possible explanations for dark matter, a completely open question in present day physics."

The force behind the FrPNC collaboration:

The four known physical forces can be depicted as carried from place to place by special particles: (1) the electromagnetic force is carried by photons (the particle manifestation of light); the strong nuclear force is carried by gluons; the weak nuclear force is carried by a fleet of three heavy particles called W+, W-, and Z; and gravity is carried by gravitons, which have not yet been detected.

Parity symmetry—the proposition that nature cannot tell left from right—is upheld by the strong and electromagnetic forces but not by the weak force. That is, for parity to be "conserved," then it would make no difference in our measurements whether we were observing an interaction among particles directly or by viewing them in a mirror. For the strong and electromagnetic forces this is true but not for the weak force. The weak force, although not weaker than gravity, is the least palpable of the forces in our ordinary experience. It operates only within the nuclei inside atoms and is therefore hard to probe. For many years parity violation was observed only in the decay of certain nuclei. Insofar as the electromagnetic and weak forces are considered as being two aspects of one combined "electroweak" force, the electron can interact with the nucleus, at least part of the time, via the (parity-conserving) electromagnetic force and part of the time via the (parity-non-conserving) weak force—making it also possible and perhaps even desirable to study parity-non-conservation in atoms, such as francium. Studying this fundamental weak interaction is what the FrPNC experiment is pursuing at TRIUMF.

More information: "Hyperfine Anomalies in Fr: Boundaries of the Spherical Single Particle Model," *Phys. Rev. Lett.*, 115, 042501 (2015). DOI: 10.1103/PhysRevLett.115.042501

Provided by Joint Quantum Institute

Citation: Using an electron to probe the tiny magnetic core of an atom (2015, August 12) retrieved 19 April 2024 from https://phys.org/news/2015-08-electron-probe-tiny-magnetic-core.html

This document is subject to copyright. Apart from any fair dealing for the purpose of private study or research, no part may be reproduced without the written permission. The content is provided for information purposes only.