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Study re-examines the decay of 185Bi using state-of-the-art technologies

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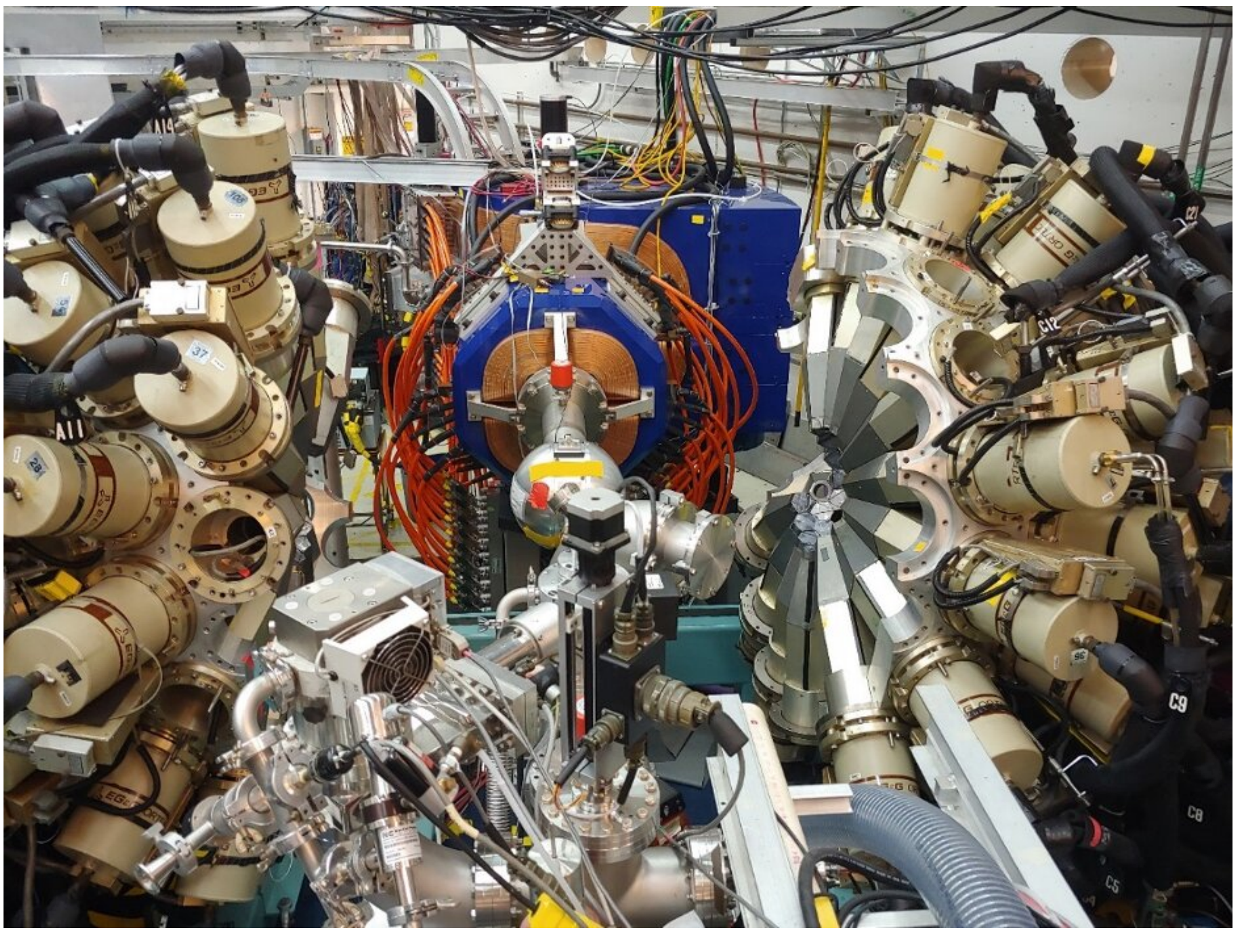

The Argonne Gas-Filled Separator (AGFA) at Argonne National Laboratory's ATLAS facility. The Gammasphere array for HPGe detectors, which is also shown, was not used in this work, but will be a key component of future studies. Credit: Doherty et al.

Researchers at University of Surrey, University of York, University of Edinburgh, and Argonne National Laboratory have recently revisited and solved some of the long-standing puzzles associated with the decay of ^{185}Bi, the heaviest known proton-emitting nucleus. Their paper, published in *Physical Review Letters*, outlines crucial new results obtained using two advanced setups at Argonne National Laboratory's ATLAS facility, namely the Fragment Mass Analyzer (FMA) and the Argonne Gas-Filled Analyzer (AGFA).

"There has been special interest in this region of the nuclear chart for a long time, from both experiment and theory, due to instances of shape coexistence (where different configurations coexist at energies close to each other) and shape changes," Daniel Doherty, one of the researchers who carried out the study, told Phys.org. "The exotic ^{185}Bi nucleus has attracted special interest as it is a ground-state proton emitter (i.e., can decay by emitting protons from its ground state) and there are a number of features of its decay that were not understood."

The main features of ^{185}Bi decay that are under investigation are the nucleus' half-life, which is considerably longer than theories of proton emission would predict, and its 'hindered' alpha decay branch. Getting a better grasp of these features would have several important implications for this particular region of the nuclear chart, while also enhancing physicists' overall understanding of proton-emitting nuclei.

"We decided that it was time to revisit this problem due to the new and improved experimental possibilities at Argonne National Laboratory, U.S.," Doherty explained. "In the first experiment, at the FMA, led by (Andrei) Andreyev from the University of York, we detected some interesting signals (see below) but weren't yet fully convinced that we had solved the problem. We thus proposed a complementary experiment with AGFA, at the same lab, to confirm (or refute) our findings."

The recent study by Doherty and his colleagues is one of the rare nuclear physics research collaborations involving three different teams based in the UK. The important results attained by the researchers were ultimately a product of this collaboration and of the advanced equipment provided by their collaborators at Argonne National Laboratory, led by Darek Seweryniak.

"Nuclei of ^{185}Bi were produced in fusion reactions, but ^{185}Bi only represents a very small fraction of the total number of reactions (we would talk of it having a small cross section in nuclear physics)," Doherty said. "The separator is set such that the ^{185}Bi makes it to the focal plane (so that we can study its decay properties) but the background channels are suppressed. We then implanted the nuclei into custom-made silicon strip detector which has a total of 160x160 = 25600 'pixels' which enables us to measure its decay."

In their first experiment, Doherty and his colleagues also placed an array of germanium detectors around the point where they implanted the nuclei. This allowed them to measure electromagnetic decays (i.e., g-ray and X-ray photons).

In the data they collected, the researchers found evidence that the previously observed proton-emitting ground state was preceded by the electromagnetic decay of a new long-lived excited state. This level, dubbed as an 'isomer," appeared to be responsible for the unusually long half-life of ^{185}Bi nuclei determined in earlier experimental work, which were unable to observe this isomer. This in turn implied that the ground-state half-life is a factor of ~20 shorter than claimed in earlier work.

"To confirm this, what we wanted to do was to observe decays where this isomer was bypassed and by this time the new AGFA had just come online so we chose to use that to maximize our efficiency," Doherty said. "However, the implied shorter half-life was too short to be measured directly with conventional techniques. The trick we used was to record the 'waveforms' of the signals so that they could be analyzed carefully offline."

After conducting extensive analyses, the researchers finally identified several waveforms that could only be explained by very rapid proton decays. These observations confirmed the findings they had gathered in the first experiment, a few years before.

"In addition to being the heaviest proton-emitting nucleus, ^{185}Bi is special because it is also the only example of a decay to a daughter nucleus with a major shell closure (a simpler and more stable configuration)," Doherty said. "With the previously determined half-life, its hindered decay was not understood and the new, shorter half-life determined in our work, which fits theory much better, demonstrates that proton decay is in fact a relatively simple process. This agrees with expectations as, unlike alpha decay which is also a quantum-tunneling phenomenon, we don't need to consider the formation of a new particle close to the nuclear surface, as protons exist within the atomic nucleus."

The findings gathered by this team of researchers offer new insights about the dynamics behind ^{185}Bi decay. In the future, they could serve as an important benchmark for the theory of proton-emitting nuclei. This will most likely play a crucial role in broadening existing knowledge of nuclear physics, by describing the properties of exotic proton-rich nuclei and explaining phenomena such as the nucleosynthesis associated with some astrophysical scenarios (i.e., X-ray bursts).

"There's a lot still to do to understand this nucleus," Doherty added. "Further 'decay spectroscopy' (i.e., what we did) measurements are needed, especially if we are able to make use of germanium detectors that are very sensitive at low energies. In addition, we would like to perform in-beam spectroscopy measurements using the recoil-decay tagging technique. This will be important for confirming the specific assignments of the states that we present in the paper."

In addition to enhancing the understanding of ^{185}Bi decay, the recent work by Doherty and his colleagues could open new possibilities in the search for heavier proton-emitting nuclei. While these searches might be difficult to carry out and will involve challenging measurements, the tools at Argonne National Laboratory's ATLAS facility could be used to search for potential proton emitters, such as ^{188,189}At, ^{194,195}Fr and ^{200,201}Ac. If successful, such research efforts would unveil new regions of proton radioactivity.

More information: Solving the puzzles of the decay of the heaviest known proton-emitting nucleus 185Bi. *Physical Review Letters*(2021). DOI: 10.1103/PhysRevLett.127.202501