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Precise Radioactivity Measurements: A Controversy Settled

Simultaneous measurements of x-rays and gamma rays emitted in radioactive nuclear decays probe how frequently excited nuclei release energy by ejecting an atomic electron

THE SCIENCE
Radioactivity takes several different forms. One is when atomic nuclei in an excited state release their excess energy (i.e., they decay) by emitting a type of electromagnetic radiation, called gamma rays. Sometimes, rather than a gamma ray being emitted, the nucleus conveys its energy electromagnetically to an atomic electron, causing it to be ejected at high speed instead. The latter process is called internal conversion and, for a particular radioactive decay, the probability of electron emission relative to that of gamma-ray emission is called the internal conversion coefficient (ICC). Theoretically, for almost all transitions, the ICC is expected to depend on the quantum numbers of the participating nuclear excited states and on the amount of energy released, but not on the sometimes obscure details of how the nucleus is structured. For the first time, scientists have been able to test the theory to percent precision, verifying its independence from nuclear structure. At the same time, the new results have guided theorists to make improvements in their ICC calculations.

THE IMPACT
For the decays of most known excited states in nuclei, only the gamma rays have been observed, so scientists have had to combine measured gamma-ray intensities with calculated ICCs in order to put together a complete picture known as a decay scheme, which includes the contribution of electron as well as gamma-ray emission, for every radioactive decay. These decay schemes play a key role in nuclear applications, including the characterization of radioisotopes for nuclear medicine. The new measurements have already led the U.S. National Nuclear Data Center to change the way it calculates ICCs for the nuclear decay schemes it makes available to users.

SUMMARY
The new ICC measurements exploit the fact that whenever an electron is ejected from its atomic orbit, the vacancy created is soon filled by another atomic electron dropping into that orbit, a process that leads to the emission of an x-ray. This x-ray acts as a signal that an electron has been ejected. So when scientists study the radioactive decay of a prepared sample that contains many identical atoms, they can compare the number of x-rays observed with the number of gamma rays to deduce the ICC, the relative numbers of electrons to gamma rays. Unlike the electrons themselves, the x-rays can be recorded in the same detector as the gamma rays, making it possible to measure their relative intensity much more precisely than if two different detectors had to be employed. The detector used was a uniquely well calibrated high-purity germanium (HPGe) detector. So far, ICC measurements have been made on decays of eight nuclei, covering a wide range of the Periodic Table. In all cases, the results agree with one set of theoretical predictions to within a fraction of a percent, thus confirming the ICC's independence from nuclear structure. Before these results became available, there was controversy between two sets of predictions, one that included the effects of the atomic vacancy on the departing electron and one that ignored it. The new results have convincingly settled that controversy in favor of including the vacancy effects.

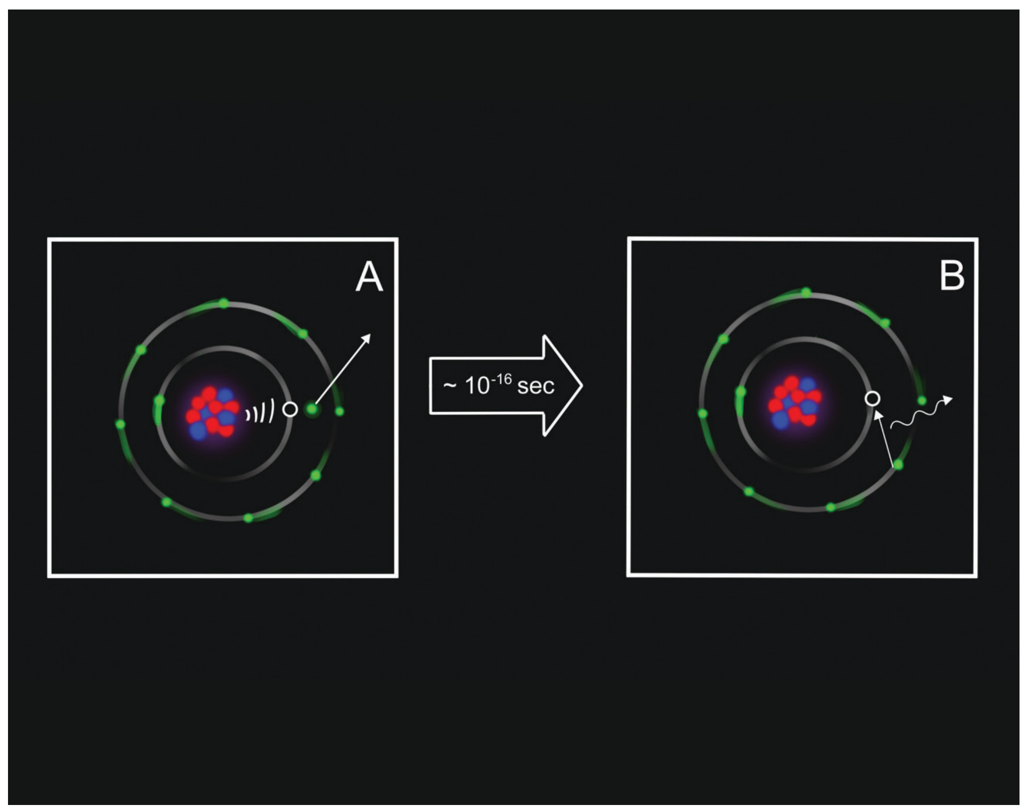
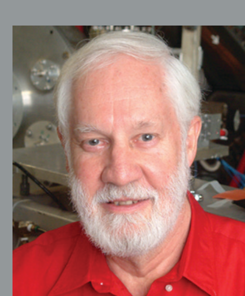


Illustration of an electron being emitted by internal conversion, then the subsequent filling of the vacancy and the associated emission of an x-ray. The electron is shown exiting from the inner atomic orbital, the K shell. Depending on circumstances, conversion electrons can be ejected from other shells as well, but the measurements described here were specifically focused on K shell conversion.



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PUBLICATIONS
N. Nica, J.C. Hardy, V.E. Iacob, H.I. Park, K. Brandenburg and M.B. Trzhaskovskaya, "Precise measurement of α_k for the 88.2-keV M4 transition in 127Te: test of internal-conversion theory," Phys. Rev. C 95, 034325 (2017).

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ABOUT THE CYCLOTRON INSTITUTE: *Dedicated in 1967, the Cyclotron Institute serves as the core of Texas A&M University's accelerator-based nuclear science and technology program. Affiliated faculty members from the Department of Chemistry and Department of Physics and Astronomy conduct nuclear physics- and chemistry-based research and radiation testing within a broad-based, globally recognized interdisciplinary platform supported by the United States Department of Energy (DOE) in conjunction with the State of Texas and the Welch Foundation. The facility is one of five DOE-designated Centers of Excellence and is home to one of only five K500 or larger superconducting cyclotrons worldwide.*