SPACE & PHYSICS

Mystery of Spinning Atomic Fragments Solved at Last

New experiments have answered the decades-old question of how pieces of splitting nuclei get their spins

By Charles Q. Choi on February 24, 2021

Credit: Getty Images

For more than 40 years, a subatomic mystery has puzzled scientists: Why do the fragments of splitting atomic nuclei emerge spinning from the wreckage? Now researchers find these perplexing gyrations might be explained by an effect akin to what happens when you snap a rubber band.

To get an idea why this whirling is baffling, imagine you have a tall stack of coins. It would be unsurprising if this unstable tower fell. However, after this stack collapsed, you likely would not expect all the coins to begin spinning as they hit the floor.

Much like a tall stack of coins, atomic nuclei rich in protons and neutrons are unstable. Instead of collapsing, such heavy nuclei are prone to splitting, a reaction known as nuclear fission. The resulting shards come out spinning, which can prove especially bewildering when the nuclei that split were not spinning themselves. Just as you would not expect an object to start moving on its own without some force acting on it, a body beginning to spin in absence of an initiating torque would seem decidedly supernatural, in apparent violation of the law of conservation of angular momentum.

This “makes it look like something was created from nothing,” says study lead author Jonathan Wilson, a nuclear physicist at Université Paris-Saclay's Irene Joliot-Curie Laboratory in Orsay, France. “Nature pulls a conjuring trick on us. We start with an object with no spin, and after splitting apart, both chunks are spinning. But, of course, angular momentum must still be conserved.”

Previous research found that fission begins when the shape of a nucleus becomes unstable as a consequence of jostling between the protons; since they are positively charged, they naturally repel each other. As the nucleus elongates, the nascent fragments form a neck between them. When the nucleus ultimately disintegrates, these pieces move apart rapidly and the neck snaps quickly, a process known as scission.

Over the decades, scientists have devised a dozen or so different theories for this spinning, Wilson says. One class of explanations suggests the spin arises before scission given the bending, wriggling, tilting and twisting of the particles making up the nucleus before the split, motions resulting from thermal excitations, quantum fluctuations or both. Another set of ideas posits that the spin occurs after scission consequent to forces such as repulsion between the protons in the fragments. However, “the results of the experiments looking into this all contradicted each other,” Wilson says.

Now Wilson and his colleagues have conclusively determined that this spinning results after the split, findings they detailed online February 24 in *Nature*. “This is wonderful new data,” says nuclear physicist George Bertsch at the University of Washington at Seattle, who did not participate in this study. “It’s really an important advance in our understanding of nuclear fission.”

In the new study, the scientists examined nuclei resulting from the fission of various unstable elemental isotopes: thorium-232, uranium-238 and californium-252. They focused on the gamma rays released after nuclear fission, which encoded information on the spin of the resulting fragments.

If the spinning resulted from effects before scission, one would expect the fragments to have equal and opposite spins. But “this is not what we observe,” Wilson says. Instead, it appears that each fragment spins in a manner independent of its partner, a result that held true across all examined batches of nuclei regardless of the respective isotopes.

The researchers suspect that when a nucleus lengthens and splits, its remnants start off somewhat resembling teardrops. These fragments each possess a quality akin to surface tension that drives them to reduce their surface area by adopting more stable spherical shapes, much as bubbles do, Wilson explains. The release of this energy causes the remnants to heat and spin, a bit like how stretching a rubber band to the point of snapping leads to a chaotic, elastic flailing of fragments.

Wilson adds this scenario is complicated by the fact that each chunk of nuclear debris is not simply a uniform piece of rubber, but rather resembles a bag of buzzing bees, given how its particles are all moving and often colliding with each other. “They’re like two miniature swarms that part ways and start doing their own things,” he says.

All in all, “these findings give big support to the idea that the shapes of nuclei at the point at which they’re coming apart is what determines their energy and the properties of the fragments,” Bertsch says. “This is important for directing the theory of fission to be more predictive and allow us to more confidently discuss how it can make elements.”

One reason Wilson suggests previous analyses of fissioning atoms did not deduce the origins of these gyrations was because they did not have the benefit of modern, ultrahigh-resolution detectors and contemporary, computationally intensive data-analysis methods. Previous work also often focused more on exploring the exotic structures of “extreme” superheavy neutron-rich nuclei to see how standard nuclear theory could account for such distinctly unusual cases. Much of that prior work deliberately avoided collecting and analyzing the huge amount of extra data needed to investigate how the nuclear fragments spun, whereas this new study explicitly focused on analyzing such details, he explains. “For me, the most surprising thing about the measurement is that it could be done at all with such clear results,” Bertsch says.

Wilson cautions more work is needed to explain how exactly spin results after scission. “Our theory is simplistic, for sure,” he notes. “It can explain about 85 percent of the variations we see in spin as a function of mass, but a more sophisticated theory could certainly be able to make more accurate predictions. It’s a starting point; we're not claiming anything more than that.” Other scientists at the European Commission’s Joint Research Center facility in Geel, Belgium, he adds, have now also confirmed the observations with a different technique, and that those independent results should be published soon.

These findings may not only solve a decades-long mystery but could help scientists design better nuclear reactors in the future. Specifically, they could help shed light on the nature of the gamma rays emitted by spinning nuclear fragments during fission, which can heat reactor cores and surrounding materials. Currently these heating effects are not fully understood, particularly how they vary between different types of nuclear-power systems.

“There’s up to a 30 percent discrepancy between the models and the actual data about these heating effects,” Wilson says. “Our findings are just a part of the full picture one would want in simulating future reactors, but a full picture is necessary.”

These studies of subatomic angular momentum could also help scientists figure out which superheavy elements and other exotic atomic nuclei they can synthesize to shed more light on the still-murky depths of nuclear structure. “About 7,000 nuclei can theoretically exist, but only 4,000 of those can be accessed in the laboratory,” Wilson says. “Understanding more about how spin gets generated in fission fragments can help us understand what nuclear states we can access.”

Future research, for instance, could explore what might happen when nuclei are driven to fission when bombarded by light or charged particles. In such cases, Wilson says, the incoming energy might potentially lead to pre-scission influences on the spinning of the resulting fragments.

“Even though fission was discovered 80 years ago, it’s so complex that we're still seeing interesting results today,” Wilson says. “The story of fission is not complete—there are more experiments to do, for sure.”

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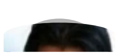

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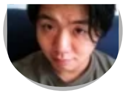

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