A Nine-Second Mystery in *Scientific American*

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How a neutron's life ends is not a mystery to physicists. Exactly *when* that happens, however, is a much trickier puzzle to solve. Pinpointing this timeline not only means a deeper understanding of the weak force—one of the four fundamental forces governing the natural world—but also a more accurate picture of the Big Bang that created the universe we live in.

Working on opposite sides of the Atlantic and using two different methods, scientists have conducted the most precise experiments in the world to figure out when neutrons will meet their demise. Even with repeated attempts, they arrive at results that differ by nine seconds. The editors of *Scientific American* took notice and invited UT Physics Professor Geoff Greene and his colleague Peter Geltenbort to write about this riddle for their magazine. Their take on these studies is laid out in "The Neutron Enigma," published in the **April 2016 issue (http://www.scientificamerican.com/magazine/sa/2016/04-01/)**.

Bottles and Beams

Greene explained that while a typical neutron lifetime is 880 seconds, these particles aren't necessarily predestined to live short lives. If they stay nestled inside an atomic nucleus, neutrons might actually live indefinitely. Yet on their own, they break down into a proton, an electron, and an antineutrino in a process called beta decay.

Quantum Cuteness: Neutron Beta Decay
A video from Scientific American about neutron beta decay, involving a gift from Geoff Greene.

http://www.scientificamerican.com/video/quantum-cuteness-neutron-beta-decay (http://www.scientificamerican.com/video/quantum-cuteness-neutron-beta-decay)/.

"At any given time, any neutron, no matter how long it's been there, has an equal probability of decaying in the next one second," Greene said. "And that's what we believe describes radioactive decay; it's totally random. A neutron that's been around for an hour is just as likely to decay in the next second as one that's been around for a microsecond."

In 2005 two research teams—one a Russian-led group in France (Geltenbort's group) and Greene's group in the U.S.—set out to precisely measure the neutron lifetime. They used two different methods: the bottle and beam approaches.

In the bottle method, scientists confine neutrons in a container for an hour or so and then count how many are left after a certain time. In the beam method, they count the decays by letting neutrons fly through a detector and looking for the particles into which they transform.

"One is you count the survivors; the other is you count the 'dead,'" Greene said. "Counting the survivors is the bottle method; counting the 'dead,' or the number of decays, is the beam method."

The bottle group in France and the beam group in the U.S. published results about the same time and found there was a nine-second difference in their measurements; much greater than would be expected given the uncertainties in the measurements. Greene said that about two years ago his group published a new result for the neutron lifetime that included a significant improvement in the understanding of the most important systematic effect in the experiment. They hoped this would resolve the discrepancy.

“I fully expected it would sort things out,” he said. “It made things slightly worse.”

Both the French and American experiments were replicated, and while they confirmed earlier findings, the nine-second gap remained. This created some interest in the popular science press, prompting a *Scientific American* editor to contact Greene and ask him to write a feature article.

“I thought it would be a better article if it were co-written by me and a member of the other group,” he said. “Peter is an old friend. I’ve known him for 30 years. He worked on the competitive experiment. We were invited to submit a joint article, which I thought would make a nicer story since it’s being presented by both teams.”

“Johnny Appleseed,” Neutron Version

As for the nine seconds difference, Greene said there are a number of possibilities; attributable to statistical or systematic errors. The statistical errors are easily defined.

“If we count a thousand decays, the mathematics tells me exactly what the uncertainty is,” he said.

The systematic errors are another story.

“There’s no exact prescription that says how you determine the uncertainties due to imperfections in your measurement,” he said. “That we have to estimate. We do as careful a job as we can; explain everything that we do. But it’s always possible that we miss something.”

Along with UT Assistant Physics Professor Nadia Fomin and their colleagues, Greene’s goal is to start a new version of the beam experiment late this year to address any systematic problems. In the longer term, he’d like to capitalize on new detector developments to improve anticipated uncertainties by a factor of five.

He is nothing if not patient, however. Greene has worked in the field for 40 years and the beam experiments he conducts at the National Institute of Standards and Technology (NIST) are done on the beamlines he built in the 1980s.

“I helped start the program at NIST,” he said, “and then a similar program at Los Alamos (National Laboratory). I’m afraid I’ve become a sort of Johnny Appleseed for neutron nuclear physics. I seem to go from neutron facility to neutron facility.”

Greene also led the team that built a beamline at the Spallation Neutron Source in Oak Ridge, though instead of neutron lifetime measurements those studies are directed toward other features of neutron decay as well as the study of neutron nuclear interactions.

After 40 years of studying neutron decay Greene say that he feels an obligation to finally get the beam experiments as refined and error-free as possible.

“I feel a responsibility to that as best can be done,” he said, “and then, perhaps, I can retire happily, though I don’t know when that would actually happen.”