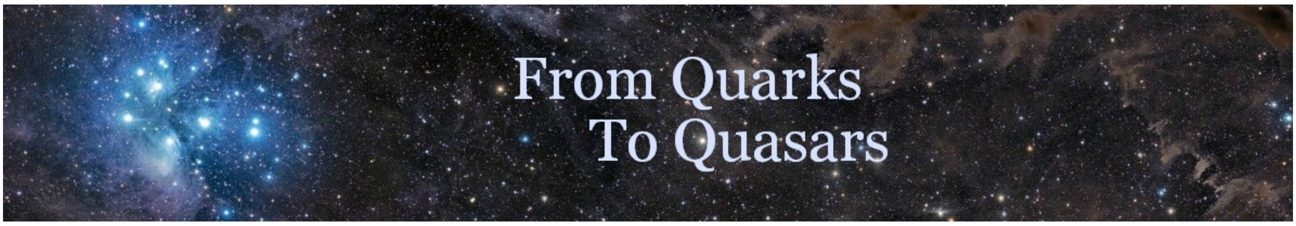

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GERDA's Victory in the Neutrinoless Double Beta Decay Failure

Often times with science, progress is built on failure- – not on "eureka!" moments of pivotal insight (which propel scientists to legendary status), but on abysmal moments of failure (which propel scientists to the blackened pages of history books). Ultimately, science, a slow and painstaking field of study governed by the scientific method, insists on both logical hypotheses AND proving the validity of these hypotheses through careful testing. However, sometimes, failures are not what they seem.

As many of you may already know, the Nobel prize was recently awarded for the confirmation of the detection of the Higgs Boson, verifying its corresponding Higg field this October. Researchers made the official announcement of the discovery last year. After a culmination of many years of hard work from thousands of physicists and collisions from particle accelerators, Peter Higgs and Francois Englert shared this prestigious award. It is fantastic that we now know that the Higgs is responsible for imparting mass to subatomic particles; however, there are still a number of problems that physicists need to solve. You see, according to the triumphant edifice known as the Standard Model, the universe should be empty. This is called the matter/antimatter asymmetry problem, and is rather embarrassing.

Ultimately, neutrinos are speculated to hold the key to solving this problem because their mass is meager, even when compared to the tiny electron (neutrinos are almost massless). This could mean that the Higgs field might not play a role in accruing this tiny portion of mass. This is a interesting prospect which has led to exciting new tests (especially as it is a very pressing problem that is directly related to the question of why matter exists and didn't annihilate itself). Physicists planned to use a process called "double beta decay" in an expensive detector in Italy, called the GERmanium Detector Array (or GERDA, for short), to conduct their tests.

Double beta decay is a rare type of decay. It is when two neutrons inside an atomic nucleus get transformed into two protons, which subsequently ejects two neutrinos and two electrons. Now, neutrinoless double beta decay is exactly how it sounds, two neutrons turn into protons, eject the electrons but lack the neutrinos. Scientists hypothesized that, if this rare type of decay could happen, the neutrinos absorbed each other because the neutrino particle pair emitted are completely identical (thus, they are their own antiparticle). This idea was first proposed in 1937 by the Italian physicist Ettore Majorana, and a particle that exhibited this behavior would be known as a "Majorana particle."

To sum the theory: in a certain beta decay, a neutron in a nucleus randomly turns into a proton, electron, and an antineutrino. And in an inverse beta decay, the neutron absorbs a neutrino and transforms into a proton and an electron. In this hypothetical neutrinoless double beta decay, these two processes happen simultaneously. Neutrinos are electrically neutral, so they can fit the bill for being Majorana particles. If this neutrinoless decay exists, it would prove neutrinos are Majorana particles, which could explain the matter-antimatter asymmetry.
How exactly does this fit with our model of the universe?

In the physics community, there is a widely supported hypothesis called the "seesaw mechanism". It posits there are actually two kinds of Majorana particles, light weight ones and heavy ones. The light weight ones are the ones we observe today. The heavy ones were only able to exist is the extremely high energies of the primordial universe. Their mass is intrinsic to one another via a seesaw mechanism, a relationship that is inverse to the other one (essentially, one is high and the other is low).

These hypothetical heavy neutrinos, that can only exist at high energies that were present in the ephemeral fraction of a second after the big bang, decayed asymmetrically (called Leptogenesis). This created slightly fewer leptons (electrons, muons and tau particles) than antileptons. By a well known Standard Model process, calculations derived the antilepton surplus that would have then led to a one-part-per-billion excess of baryons (protons and neutrons) over antibaryons. A process called Baryogenesis. This, of course, would allow things like stars, black holes, galaxies, and eventually life to emerge. If neutrinos are their own antiparticle, Leptogenesis would be given a tremendous amount of credence.

If your head has not exploded yet, let us proceed to how GERDA fits in to all of this.

Deep in a mountain in Italy, highly protected Germanium discs are suspended in tanks of water and liquid argon. 15 kilograms of pure Germanium crystals are being used to (hopefully) detect this ultra rare neutrinoless double beta decay. The GERDA team await the electrical signal of Germanium-76
transforming into Selenium-76. However, spotting this electrical activity is challenging because other false signals such as detector 'noise', rogue radiation (like that from cosmic rays), and possibly other types of decays. Among this chaos, physicists still planned on seeing 2 to 3 spikes, or hits," from this neutrinoless decay. But that is simply not good enough in the physics community. 8 to 10 spikes are what was needed to be certain they were on path for a profound discovery.

After a decade of painstaking work, 60 physicists crowded into a conference room at the Joint Institute for Nuclear Research in Dubna, Russia. They eagerly awaited to see the results. The conclusion: 3 spikes showed up on the conference screens- the experiment failed to detect this desired result conclusively—and cheers erupted, congratulatory hugs and high fives were rife in the room. The physicist's cameras furiously snapped away at the results. Perplexed? You would think this lack of signal is a failure. But this negative signal is STILL a victory for the community.

The results of the GERDA experiment support the idea that neutrinos are Dirac particles, not Majorana particles, and our idea of neutrinos being the source of the matter/antimatter asymmetry may be wrong. This experiment showed us that the half life of this ultra rare decay in this sample size would occur perhaps once in 30 trillion trillion years, if it exists at all. That is two thousand trillion times the age of the universe. If the half life was shorter, GERDA would have detected it. The nature of the precision of these experiments have never been before achieved. Previous experimental results were repudiated by the community because of uncontrolled backround noise.

For all senses and purposes, GERDA was a success by the fact their experiment worked with the sample they had to start with (Germanium-76 is not exactly inexpensive either). The longer the half life of a sample , the more atoms must be used to observe it. The scientists know for sure that now they need a larger sample to possibly observe this decay to see the desired 8-10 electrical spikes: and 40 kg of Germanium 76 will be used in the upgraded GERDA Phase II experiment.

With that sample size, the neutrinoless double beta decay should be observed in 3 years if its half-life is less than 100 trillion trillion years (which they now know it should be). Ultimately, neutrino scientists fully expect to see these results to confirm their argument that neutrinos are Majorana particles. Confirming this will support our current cosmological model. Ruling neutrinos out as being Majorana particles will send the community back to the drawing board. For physicists, this is always exciting, regardless of the results.

Additional reading here, at Quanta Magazine.

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