Inquiro, the UAB undergraduate science research journal

Volume 2015 | Number 9 Article 12

2015

# The Neutrino: A Particle Ahead of Its Time

Emily Jennings

# The Neutrino: A Particle Ahead of Its Time

Emily Jennings

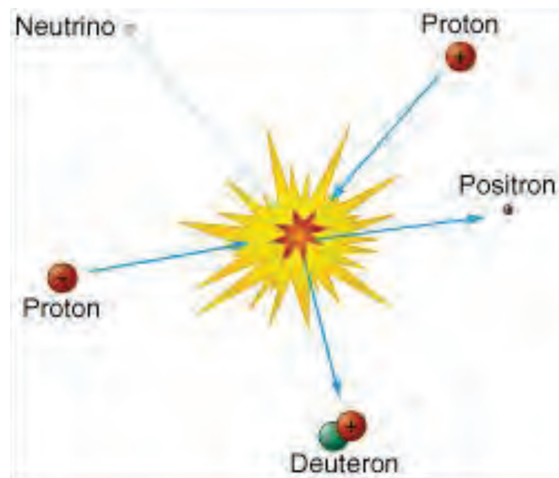
Throughout school and in any physics class, students are told that nothing travels faster than the speed of light. However, that statement might no longer be true because of the neutrino—the particle that may be able to transcend dimensions that light cannot. The concept of the neutrino is significant to our understanding of the universe because the neutrino can be used to determine how fast the universe is expanding, as well as its ultimate destiny[1].

Everyone has heard of electrons, protons, and neutrons, but what exactly is a neutrino? A neutrino is an exponentially small particle with no electrical charge. To put the remarkably small size of a neutrino into perspective, consider that neutrinos are thought to be a million times smaller than electrons, which have a mass of $9.11 \times 10^{-31}$ kilograms[2]. Neutrinos are likely the most abundant particles in the universe and may be more common than photons, the basic unit of light. Because neutrinos are so common, their mass, which remains unknown, is thought to have an effect on the gravity of the universe[1]. Neutrinos can pass through almost anything, and they do so constantly. In fact, about 400 billion neutrinos from the sun alone pass through each person on Earth each second. According to physicist Frank Close, "One neutrino can fly through a light year of lead without hitting anything"[1]. Physicists also suspect that neutrinos can move through dimensions forbidden to light[2].

If neutrinos are so small and pass through almost everything known to us, as well as through potential dimensions unknown to us, how do we know that neutrinos exist? Where do neutrinos come from? These questions are best answered through a consideration of the history of the neutrino's discovery. In 1930, Wolfgang Pauli (the father of the Pauli Exclusion Principle) proposed the existence of the neutrino to explain the conservation of energy in beta radioactive decay. Beta radioactive decay occurs when protons change into neutrons, such as when protons fuse near the center of the sun. In 1930, Pauli speculated that when neutrons form from the fusion of protons, the extra energy is carried away by light-weight, electrically neutral particles. At the time, Pauli did not believe what he had proposed was true; he said, "I have done a terrible thing, I have postulated a particle that cannot be detected"[3].

In 1933, an Italian physicist named Enrico Fermi named Pauli's mystery particle the "neutrino" and created a quantitative theory for weak particle interactions involving the neutrino. About 20 years later, in 1956, two American physicists, Frederick Reines and Clyde Cowan, reported that they had detected neutrinos using a fission reactor as a neutrino source and a well-shielded scintillator detector[4]. Neutrinos had finally been detected, but much remains to be discovered about these tiny particles. The next piece to the long-standing neutrino puzzle came from Takaaki Kajita and Arthur McDonald, who were awarded last year's Nobel Prize in Physics for their discovery of neutrino oscillations[3].

One question about neutrinos that has puzzled scientists is why the Earth receives so few neutrinos. Scientists have calculated the theoretical number of neutrinos produced by the fusion reactions that power the sun, but when the number of neutrinos Earth actually receives was measured, almost two-thirds of the calculated amount were missing[3]. The idea of neutrino oscillations was proposed in 1998 by Kajita at the Super-Kamiokande neutrino detector in Japan to explain the discrepancy in the number of neutrinos measured on Earth.




*Neutrinos are emitted when protons are converted into neutrons during beta radioactive decay[6].*

In quantum mechanics, particles exhibit properties of both point particles and waves, and neutrinos are no exception. When three different neutrinos (each with a different mass) are traveling through space with waves of different frequencies, they are thought to each be a different type of neutrino, and are thus each a different "flavor." These three different flavors are the three different types of neutrinos: muon neutrinos, electron neutrinos, and tau neutrinos[5]. Physicists describe waves in terms of both amplitudes and phase, and when multiple waves add together, their phases are altered. When the waves that make a neutrino add together, the phases do not cancel to zero. Since the flavor of a neutrino depends on its phase, the flavor can change over time. This phenomenon is called a neutrino oscillation, the metamorphosis of a neutrino of one flavor to a neutrino of a different flavor.

Kajita and McDonald proved that neutrino oscillations are not just theoretical. Kajita, working at the Super-Kamiokande neutrino detector just outside of Tokyo, Japan, discovered that the detector caught some muon neutrinos coming from the atmosphere above and some from the other side of the planet after the particles had traveled through the Earth. Because the Earth does not present any considerable obstacle to neutrinos, equal numbers of neutrinos should have come through the Earth and directly from the sun. However, Kajita found that the muon neutrinos that came straight down to Super-Kamiokande were more numerous than those first passing through the globe. The only way to explain this observation is if the muon neutrinos traveling through the earth morphed into another type of neutrino, in this case, the tau neutrino. At the Sudbury Neutrino Observatory in Ontario, Canada, McDonald encountered a similar oddity. The lab was measuring the electron neutrinos that come directly from the sun, but the captured number of electron neutrinos was only one-third of the expected number. When the labs pieced together their numbers, they discovered that the theoretically calculated number of neutrinos had in fact reached Earth, confirming that neutrinos do morph into other types of neutrinos. Thus, neutrino oscillations are real!

This discovery and conclusion have led to another ground-breaking conclusion in particle physics: the Standard Model, the theory of how the universe is fundamentally organized and works, is not actually fully developed because it requires that neutrinos be massless[3,5]. However, in order for neutrino oscillations to be possible, neutrinos must have mass[3]! These conclusions have posed many other questions for particle physicists. What is the mass of a neutrino? Why are neutrinos so light-weight? Finally, what do these conclusions suggest about the potential dimensions alluded to earlier?

The existence of a neutrino with mass could suggest that those other dimensions forbidden to light are real and are waiting to be discovered. If it can be demonstrated that a neutrino can travel faster than the speed of light by taking a shortcut through one of the forbidden dimensions, then we can extend Einstein's theory of relativity to those dimensions light is forbidden from entering. The implications of such an application could radically alter our understanding of time and space relative to life as we know it.

## References

1. Close, F. *Particle physics a very short introduction*, Oxford: Oxford University Press (2004).
2. Weiler, T. Neutrinos, Einstein, time and paradox: Tom Weiler at TEDxNashville [Presentation], Nashville, TN (2012).
3. The chameleons of space. *Nobelprize.org*. Retrieved from https://www.nobelprize.org/nobel_prizes/physics/laureates/2015/popular-physicsprize2015.pdf (2015, October 6).
4. The story of the neutrino. Fermi National Accelerator Laboratory. Retrieved from http://www-numi.fnal.gov/public/story.html (2015).
5. What is a neutrino? Neutrinos and neutrino oscillations. Super-Kamiokande Official Website. Retrieved from http://www-sk.icrr.u-tokyo.ac.jp/sk/sk/neutrino-e.html (2015).
6. Chaisson, E. & McMillan, S. Chapter 16: The Sun: Our Parent Star. In *Astronomy Today* (7th ed.), Addison-Wesley (2010).