Time reversal: A simple particle could reveal new physics

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UA theoretical physicist Bira van Kolck has found that experimenting with a deuteron, a simple atomic nucleus, could lead to understanding a mysterious phenomenon of subatomic physics known as time reversal violation. (Photo by Daniel Stolte/UANews)

(PhysOrg.com) -- A simple atomic nucleus could reveal properties associated with the mysterious phenomenon known as time reversal and lead to an explanation for one of the greatest mysteries of physics: the imbalance of matter and antimatter in the universe.

The physics world was rocked recently by the news that a class of subatomic particles known as neutrinos may have broken the speed of light.

Adding to the rash of new ideas, University of Arizona theoretical physicist Bira van Kolck recently proposed that experiments with another small particle called a deuteron could lead to an explanation for one of the most daunting puzzles physicists face: the imbalance of matter and antimatter in the universe.

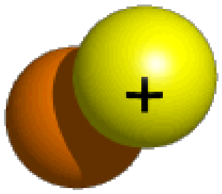
A deuteron is a simple atomic nucleus, or the core of an atom. Its simplicity makes it one of the best objects for experiments in nuclear physics.

A property of the deuteron known as a magnetic quadrupole moment could reveal sources of a phenomenon known as time reversal violation, Van Kolck and his collaborators, including recently graduated UA doctoral student Emanuele Mereghetti, show in a recent paper published in Physical Review Letters.

Most of what physicists know about the universe can be described by what is called the standard model of particle physics. Developed by Van Kolck's former doctoral advisor, Nobel Laureate Steven Weinberg, the standard model describes everything from Newton's laws of motion to the behavior of subatomic particles with what is known as quantum mechanics.

"This theory explains almost everything we know about the universe up to this point," said Van Kolck. "However," he added, "there is one problem that the standard model does not explain."

"Like the protons and neutrons – the particles making up the nucleus of an atom – every particle has what's called an antiparticle, things like antiprotons or antineutrons. The universe seems to have many more particles than antiparticles," said Van Kolck. "So there is a question of why the universe seems to have such an asymmetry between particles and antiparticles."



Because a deuteron consists of two subatomic particles, it is not considered to be a particle by nuclear physicists. A deuteron technically is an atomic nucleus, or the core of an atom, but unlike more complex nuclei, the deuteron consists of just one positively charged particle called a proton and one neutral particle called a neutron. (Image courtesy of Thomas Jefferson National Accelerator Facility)

"The current indication is that the universe started from a very concentrated state, which some people call the Big Bang, and evolved from that. It would be appealing if we could show that the universe started with a balanced number of particles and antiparticles and that the fact that we observe more particles now can be explained in the process of evolution of the universe."

When things don't look balanced, physicists ask why. The explanation may lie in a rare violation of the phenomenon of time reversal.

Time reversal?

"Let's suppose you're playing billiards," said Van Kolck. "You have two balls and you knock them against each other on the table. Suppose you film this, but you play the movie in reverse. If you don't tell the person who is watching which version is forward and which is backward, the person wouldn't be able to tell."

Just as in the movie, time can be reversed in the equations that describe our world and the equations still balance.

For example, the maximum speed of your car is the miles it can cover per hour, or to a physicist, distance divided by time. If time is reversed so that it becomes a negative number, the equation still balances because the magnitudes of the speed and distance stay the same.

But wait a minute, you say. Time only goes one way: People get older, not younger.

"This is an apparent direction of time," said Van Kolck. "It has to do with the initial conditions. We can have laws of physics that work both ways and still give rise to phenomena that have a direction of time."

"Let me continue with this example of the billiard balls," said Van Kolck. "When you start a game there is a triangle of balls in the middle, and someone shoots a ball into this cluster causing all the balls to scatter. If you play that movie in reverse, most people would say that there was a direction of the original movie, because it would be very unlikely that you could start all the balls with the right velocity so that they collide, all of them stop in a triangle and one comes out."

"The reason why we perceive a preferred direction has to do with the fact that it is much easier to go from a simple initial state then from a very complicated state," said Van Kolck. So time can be reversed in physics equations without affecting the result, but the effects of time reversal remain unperceivable in our everyday lives.

"Until the 1960s, physicists thought that the laws of physics were exactly invariant in the transformation of time going to minus time," said Van Kolck. "Then it was discovered that there are some phenomena involving subatomic particles where there seems to be a very tiny violation of this symmetry."

In other words, if you made a movie of the billiard balls and played it in reverse, the backward version actually would be a little bit different from the forward version – like a "glitch in the matrix."

"It's like the process of some things happening in one direction versus the opposite one doesn't happen at the same rate," said Van Kolck. This phenomenon is known as time reversal violation.

When time reversal is violated, the equation doesn't balance out; your car doesn't go as fast on the way back. It is this imbalance that physicists believe may explain the unequal amounts of matter and antimatter in the universe.

Since physicists first started looking for sources of time reversal violation in subatomic particles, they have been measuring properties of particles known as electric dipole moments, or EDMs.

An EDM is generated by a property of subatomic particles known as spin. Spin can be visualized as a particle spinning around its center rather like the Earth rotates around its axis.

With time reversal, the spin would appear to reverse, like a movie of the particle played backward. But for the equations to balance, the EDM would have to equal zero. Any non-zero value would generate a different outcome of the equations – the backward version of the movie actually would be different from the forward version.

"Physicists have looked for EDMs of particles because if you measure one, you know that time reversal is violated," said Van Kolck. "We know that there is a tiny bit of time reversal violation in the standard model. But it doesn't seem sufficient to explain the matter-antimatter asymmetry, because that violation of time reversal is very small. So we are looking for sources that would make other processes where we would see this phenomenon."

However: "Measuring the EDMs alone doesn't tell you a whole lot," said Van Kolck. "It tells you some, but what we show is that if you can measure another property of the deuteron, called the magnetic quadrupole moment, then you can tell a whole lot more about the mechanism."

"Like the electric dipole, the magnetic quadrupole violates time-reversal symmetry," said Van Kolck. He and his collaborators identified mechanisms of time reversal violation that correspond to different measurements of magnetic quadrupole moments for the deuteron.

"Nobody had pointed out before that this would be such an effective way to separate these mechanisms," said Van Kolck. "We are proposing that people try to measure the magnetic quadrupole moment to understand the source of time reversal violation."

Unveiling previously unknown sources of t-violation could lead to an explanation for one of the greatest questions physicists face: the reason for the imbalance of matter and antimatter in the universe.

Experiments with the deuteron would probe the same scales of energy as the Large Hadron Collider at CERN, the European Organization for Nuclear Research, and could lead to completely new discoveries in physics, Van Kolck said: "It's a different way to look for physics beyond the standard model."

Provided by University of Arizona