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Theoretical physics breakthrough: Generating matter and antimatter from the vacuum

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Under just the right conditions -- which involve an ultra-high-intensity laser beam and a two-mile-long particle accelerator -- it could be possible to create something out of nothing, according to University of Michigan researchers.

The scientists and engineers have developed new equations that show how a high-energy electron beam combined with an intense laser pulse could rip apart a vacuum into its fundamental matter and antimatter components, and set off a cascade of events that generates additional pairs of particles and antiparticles.

"We can now calculate how, from a single electron, several hundred particles can be produced. We believe this happens in nature near pulsars and neutron stars," said Igor Sokolov, an engineering research scientist who conducted this research along with associate research scientist John Nees, emeritus electrical engineering professor Gerard Mourou and their colleagues in France.

At the heart of this work is the idea that a vacuum is not exactly nothing.

"It is better to say, following theoretical physicist Paul Dirac, that a vacuum, or nothing, is the combination of matter and antimatter -- particles and antiparticles. Their density is tremendous, but we cannot perceive any of them because their observable effects entirely cancel each other out," Sokolov said.

Matter and antimatter destroy each other when they come into contact under normal conditions.

"But in a strong electromagnetic field, this annihilation, which is typically a sink mechanism, can be the source of new particles," Nees said, "In the course of the annihilation, gamma photons appear, which can produce additional electrons and positrons."

A gamma photon is a high-energy particle of light. A positron is an anti-electron, a mirror-image particle with the same properties as an electron, but an opposite, positive charge.

The researchers describe this work as a theoretical breakthrough, and a "qualitative jump in theory."

An experiment in the late '90s managed to generate from a vacuum gamma photons and an occasional electron-positron pair. These new equations take this work a step farther to model how a strong laser field could promote the creation of more particles than were initially injected into an experiment through a particle accelerator.

"If the electron has a capability to become three particles within a very short time, this means it's not an electron any longer," Sokolov said. "The theory of the electron is based on the fact that it will be an electron forever. But in our calculations, each of the charged particles becomes a combination of three particles plus some number of photons."

The researchers have developed a tool to put their equations into practice in the future on a very small scale using the HERCULES laser at U-M. To test their theory's full potential, a HERCULES-type laser would have to be built at a particle accelerator such as the SLAC National

Accelerator Laboratory at Stanford University. Such infrastructure is not currently planned.

This work could potentially have applications in inertial confinement fusion, which could produce cleaner energy from nuclear fusion reactions, the researchers say.

To Sokolov, it's fascinating from a philosophical perspective.

"The basic question what is a vacuum, and what is nothing, goes beyond science," he said. "It's embedded deeply in the base not only of theoretical physics, but of our philosophical perception of everything---of reality, of life, even the religious question of could the world have come from nothing."

More information: A paper on this work, "Pair Creation in QED-Strong Pulsed Laser Fields Interacting with Electron Beams" is published in *Physical Review Letters.*

Provided by University of Michigan

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