Completing Einstein's homework on special relativity in electromagnetism

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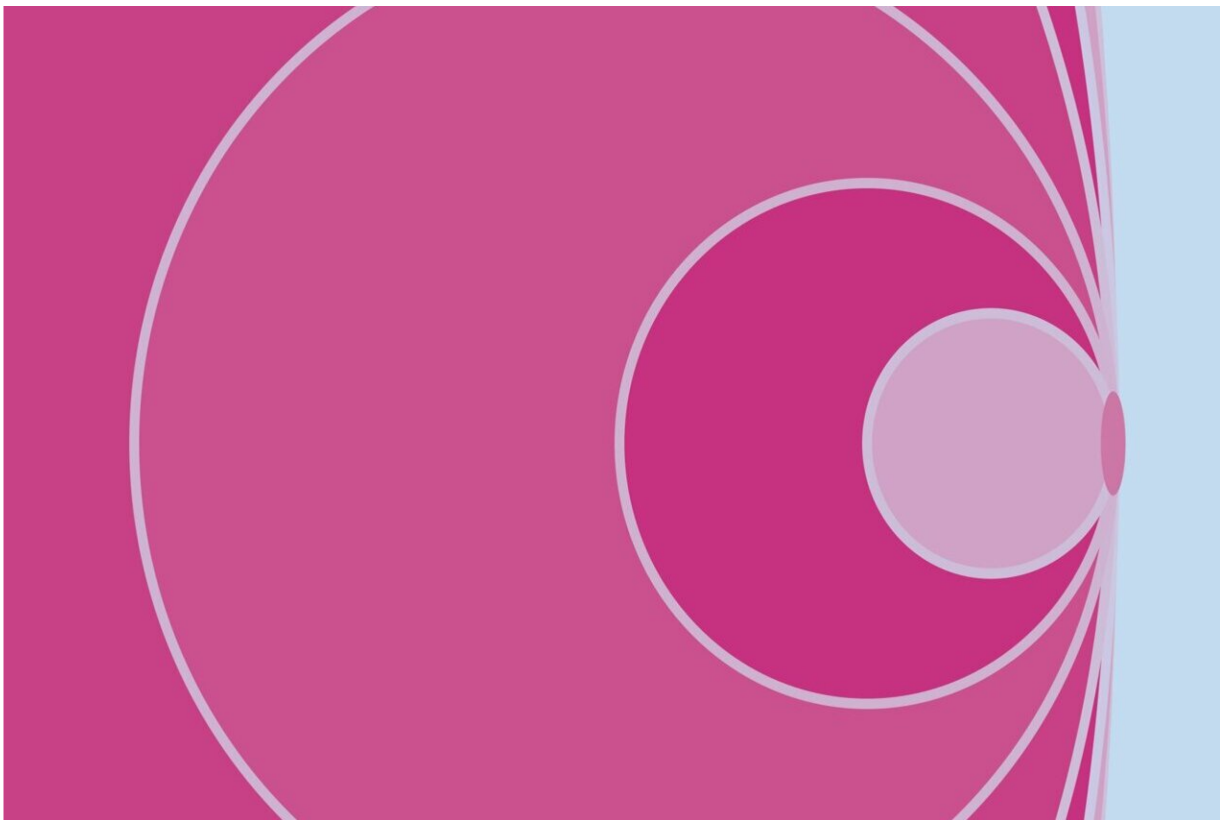

Illustration of the formation process of the planar electric field contraction that accompanies the propagation of a near-light-speed electron beam (shown as an ellipse in the figure). Credit: Masato Ota, Makoto Nakajima

Albert Einstein, one of the most celebrated modern scientists, proposed the revolutionary theory of special relativity more than a century ago.

This theory forms the basis of most of what we understand about the universe, but a part of it has not been experimentally demonstrated until now.

Scientists from the Institute of Laser Engineering at Osaka University have used ultrafast electro-optic measurements to visualize for the first time the contraction of the electric field around an electron beam moving at close to the speed of light and demonstrate the generation process.

In the theory of special relativity, Einstein proposed that in order to properly describe the motion of objects moving past an observer at close to the speed of light, one needs to employ a "Lorentz transformation" that mixes the coordinates of space and time. He was able to explain how these transformations made the equations for electric and magnetic fields self-consistent.

While various effects of relativity have been demonstrated many times to a very high degree of experimental precision, there are still aspects that remain unrevealed in experiments. Ironically, these include the contraction of the electric field represented as a phenomenon of special relativity in electromagnetism.

Now, the research team at Osaka University has demonstrated this effect experimentally for the first time. They accomplished this feat by measuring the profile of the Coulomb field in space and time around a high-energy electron beam generated by a linear particle accelerator. Using ultrafast electro-optic sampling, they were able to record the electric field with extremely high temporal resolution.

It has been reported that the Lorentz transformations of time and space as well as those of energy and momentum were demonstrated by time dilation experiments and rest mass energy experiments, respectively.

Here, the team looked at a similar relativistic effect called electric-field contraction, which corresponds to the Lorentz transformation of electromagnetic potentials.

"We visualized the contraction of electric field around an electron beam propagating close to the speed of light," says Prof. Makoto Nakajima, the project leader. In addition, the team observed the process of electric-field contraction right after the electron beam passed through a metal boundary.

When developing the theory of relativity, it is said that Einstein used thought experiments to imagine what it would be like to ride on a wave of light. "There is something poetic about demonstrating the relativistic effect of electric fields more than 100 years after Einstein predicted it," says Prof. Nakajima. "Electric fields were a crucial element in the formation of the theory of relativity in the first place."

This research, with observations matching closely to Einstein's predictions of special relativity in electromagnetism, can serve as a platform for measurements of energetic particle beams and other experiments in high-energy physics. The paper is published in *Nature Physics*.

More information: Koichi Kan, Ultrafast visualization of an electric field under the Lorentz transformation, *Nature Physics* (2022). DOI: 10.1038/s41567-022-01767-w.
www.nature.com/articles/s41567-022-01767-w

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