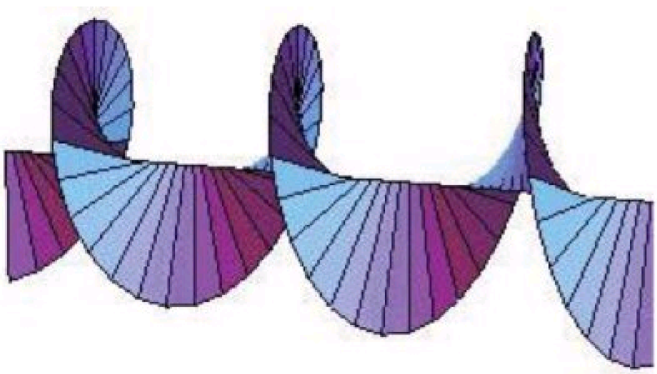
New twist to electron beams

Apr 3, 2010 5 comments

Physicists in Japan have for the first time generated beams of electrons displaying the fundamental physical property of orbital angular momentum. Like light beams before, these electron beams have had their wavefronts distorted so that they spiral through space and create a "phase singularity". They could be used to make more powerful electron microscopes.



Spiral wavefront

Beams of light possess a property known as spin angular momentum, which is associated with the direction in which the light is polarized. However, light can also carry "orbital" angular momentum. This comes about from twisting a beam's wavefront, the imaginary locus of points on a wave possessing the same phase. In contrast to the simple plane wavefront of a collimated beam, this kind of wavefront rotates around a central axis and leads to what is known as a "phase singularity" at the centre of the beam, a type of vortex where the intensity of the wave is zero and its phase is undefined. Such spiral-like waves have been used in a number of applications, including the "optical spanner" – a light beam that traps and rotates particles – and higher-dimensional encoding in quantum optics.

Spiral phase plate

Plane waves can be converted into these spiral waves by passing them through a tiny curved ramp known as a "spiral phase plate", with the height at any point on the ramp proportional to the angle at that point. Building this structure for light waves is relatively straight forward, since it can be carved out of silicon using the lithographic techniques employed by the semiconductor industry.

But doing the same for electron beams is more difficult. Quantum mechanics tells us that electrons, like any other kind of particle, have an associated wave, but their wavelength will tend to be much smaller than that of light. This means that the phase plate also needs to be smaller. Electrons with an energy of 300 keV would require a ramp made of silicon to be just 100 nm high.

Masaya Uchida and Akira Tonomura of the RIKEN institute in Wako, Japan, have used an alternative approach. Rather than attempting to build a smooth spiral they instead built a step-like structure – the equivalent of a miniature spiral staircase.

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Nature **464** 737

They crushed graphite from a pencil into fine fragments and laid them on a copper grid coated with a carbon film. The result is a graphite square made up of a number of smaller squares of varying thickness, with the top-left square being the thickest, the top-right square being the second thickest and so on in a descending clockwise spiral. The typical difference in thickness of adjacent squares, in other words the typical thickness of their graphite films, was between 10-100 nm (*Nature* **464** 737).

Screw-type phase singularity

To demonstrate their phase plate, they accelerated a beam of electrons to an energy of 300 keV (corresponding to a wavelength of about 0.002 nm) and then split the beam in an electron biprism. One half of the beam was sent through the phase plate and the other half remained as a reference plane wave. Directing the two beams to a screen and observing the interference pattern, the researchers saw the tell-tale sign of a screw-type phase singularity – a Y-shaped defect in which a new fringe started at the location of the phase singularity.

Miles Padgett of Glasgow University describes the research as "highly interesting" and says it could lead to enhanced electron microscopy. He points out that low image contrast in optical microscopy can be partly overcome by exploiting the phase rather than the intensity of the light transmitted by an object, and believes that the new work might "create new opportunities for the use of phase imaging in electron microscopy".

Uchida acknowledges that while their spiral-staircase technique has allowed them to demonstrate the reality of twisted electron waves, and therefore of electron orbital angular momentum, it is not precise enough to reproduce such waves reliably. He says that focused ion beams might be capable of producing spiral wave plates of sufficient precision.

Indeed, he looks forward to the production of a variety of differently-shaped electron wavefronts, comparing the waves generated in the current work to the corkscrew-shaped fusilli pasta. "Just as there are many types of pasta, so there are many shapes of electron wave," he says, "such as double-helix or U–shaped wavefronts."

The work is described in *Nature* **464** 737.

About the author

Edwin Cartlidge is a science writer based in Rome

5 comments

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1 **reader01**
Apr 4, 2010 2:49 PM

beams ratation

It is not long time since I heard about light rotating beams produced by laser pen, that rotates. I think that there is possible to have a source of electrons that is rotate by similar way.

Reply to this comment · Offensive? Unsuitable? Notify Editor

2 **misra.saurabh1**
Apr 4, 2010 7:00 PM

I am a student(school final-year) aspiring to be a scientist...
I want to know if there is phase singularity then what will be the wavelength of this wave? is this some kind of merging of the two spins of electrons?

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3 **reader01**
Apr 5, 2010 11:56 AM

angular and spin momentums of light and electrons

Must have photon, which make electron excitated, the same momentums as excitated electron. Because exist two different momentums there are several possibilitis of combinations. I know that I only speculate.

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4 **reader01**
Apr 6, 2010 9:16 AM

electron shape waves

Electron shape waves make by Japanees scientist remindns me electron waves changed (modulated) at TV. How would this new electron shape waves with bouth spin and angular momentums show its singnal at TV? Would be there any change at TV signal??

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5 **reader01**
Apr 6, 2010 12:27 PM

there many possibilities here

Quote:

> *Originally posted by* ***reader01***
> Electron shape waves make by Japanees scientist remindns me electron waves changed (modulated) at TV. How would this new electron shape waves with bouth spin and angular momentums show its singnal at TV? Would be there any change at TV signal??

Also what is the "shape" of electromagnetic field produced by such electron waves? I think this electric beams of verified shapes make also possibsible of special electromagnetic fields.

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