Electrons in magnetic field reveal surprises

Aug 14, 2014 11 comments

Beam out: elongated "Landau" states

The best glimpse yet of electrons moving in a magnetic field has revealed that the particles' behaviour differs strongly from what is predicted by classical physics but is consistent with quantum-mechanical theory. Instead of rotating uniformly at a particular frequency, an international team of researchers has found that electrons in a magnetic field are capable of rotating at three different frequencies, depending on their quantum properties.

Cyclonic movements

Little is known about the behaviour of electrons in a magnetic field and scientists are keen to improve our understanding of the physical processes that are involved. Free-electron Landau states are a form of quantized state adopted by electrons moving through a magnetic field. All charged particles interact with electromagnetic fields via the Lorentz force. This interaction causes electrons in a magnetic field to move in a corkscrew pattern. "Landau states can be envisaged as vortices occurring naturally in the presence of magnetic fields. The magnetic field plays the same role for electrons as the Earth's rotation plays for the creation of cyclones, but on a much smaller scale," says Peter Schattschneider of the Institute of Solid State Physics at the Vienna University of Technology, who is part of an international team that includes researchers from France, Japan and the US that has now devised a way to reconstruct these states.

According to classical physics, electrons should rotate about the magnetic-field direction with a single frequency, called the "cyclotron frequency". But in their experiments, the researchers found that, contrary to what was predicted, they were able to induce a multitude of rotation frequencies in their moving electrons, namely the cyclotron frequency, zero frequency and the Larmor frequency (which is half the cyclotron frequency).

Vortex beams

The team did not observe the electrons' Landau states directly. Rather, the researchers used a transmission electron microscope to create so-called electron vortex beams, which can be shaped so that their rotational behaviours closely resemble Landau states. "In an electron vortex beam, electrons are swirling around a common centre similar to air molecules in a tornado. Typically, this bunch of whirling electrons is also moving along its axis of rotation, thereby moving along a spiral path," says Schattschneider.

The team used the microscope's focusing lenses to reconfigure the electron vortex beams so that these matched the size of the Landau states. Schattschneider compares the task of determining the rotation of the electrons to figuring out how many times a thin wire is wound around a rod. "When looking at the wire directly, it is extremely difficult to count the number of windings. But when it is stretched along the direction of the rod, the wire takes the form of a well-spaced spiral, for which it is easy to count the revolutions," he says. "This is precisely what we did with the Landau states: we 'elongated' them to vortex beams. That way we could measure [their frequencies] with very high accuracy."

"This is a very exciting finding, and it will contribute to a better understanding of the fundamental quantum features of electrons in magnetic fields," says Franco Nori of the RIKEN Centre for Emergent Matter Science in Japan, who led the research. In addition to showing that the rotational dynamics of the electrons are more complex and intriguing than was once believed, the new findings could have practical implications for technology, according to the researchers.

Jo Verbeeck of the University of Antwerpen in Belgium believes that the quantum effects of electrons revealed in the new study are "thought-provoking". "What is interesting now is that the authors succeeded in taking these Landau states into free space, away from the material in which they normally manifest themselves, in order to better study the peculiarity of their motion," says Verbeeck, who was not involved in the study.

"We hope that this will lead to new insights and a better understanding of the delicate interaction between magnetic fields and matter, which might one day give rise to new and better technologies such as sensors and memmory devices," Schattschneider says.

The research is published in *Nature Communications*.

About the author

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11 comments

Add your comments on this article

1 **John Duffield**
Aug 14, 2014 4:33 PM
United Kingdom

Good stuff

This is promising. I was particularly struck by this: *"The magnetic field plays the same role for electrons as the Earth's rotation plays for the creation of cyclones"*. For some reason the "screw nature of electromagnetism" isn't common knowledge even though Minkowski and Maxwell spoke about it. And despite gravitomagnetism wherein "space is twisted", and rot, nobody seems to know that the electromagnetic field is "twist field", and when you move through it you perceive it to be a "turn field". Hence the electron, which is a spinor, follows the corkscrew path. It really is like a 3D cyclone. The positron is like an anticyclone. If you could place a cyclone down near an anticyclone, vorticial attraction would make them move linearly towards one another. If you throw one past the other, they swirl around each other too, as per positronium. See arxiv.org...0804.1357 and this for more.

2 **GeorgeRajna**
Aug 15, 2014 1:16 PM

Fermions' spin

The moving charges are accelerating, since only this way can self maintain the electric field causing their acceleration. The electric charge is not point like! This constant acceleration possible if there is a rotating movement changing the direction of the velocity. This way it can accelerate forever without increasing the absolute value of the velocity in the dimension of the time and not reaching the velocity of the light.
The Heisenberg uncertainty relation says that the minimum uncertainty is the value of the spin: 1/2 h = dx dp or 1/2 h = dt dE, that is the value of the basic energy status, consequently related to the mo inertial mass of the fermions.
www.academia.edu...the_Electric_current

3 **Jarek Duda**
Aug 15, 2014 3:36 PM

Electron's magnetic dipole moment

"Little is known about the behaviour of electrons" because it is usually imagined as charge only, while it has also relatively huge magnetic dipole moment - can be seen as a magnet, what e.g. adds dual analogue of Lorentz force: for magnetic dipole moving in electric field, leading to spin-orbit interaction (basic Lagrangian and sources).
Remembering about the direction of spin/magnetic dipole moment, even for classical circulating there appear additional frequencies - e.g. of trembling of this direction.

4 **John Duffield**
Aug 15, 2014 4:00 PM
United Kingdom
Zitterbewegung, see for example arxiv.org...0802.2728 and geocalc.clas.asu.edu...ZBW_I_QM.pdf along with

www.cybsoc.org…electron.pdf and arxiv.org…0512265 and On Vortex Particles by David St John. You can trace it back to Thomson and Tait, who coined the phrase spherical harmonics.

5 **ernstein**
Aug 16, 2014 10:18 AM

rotating electrons in a magnetic field

Does this rotating electrons creates magnetic flux lines ? Lets say one flux line per electron or what ?

6 **M. Asghar**
Aug 16, 2014 11:20 AM

Landau levels and others

Although the Landau levels per se are limited to the so-called classical cyclotron frequencies for electrons, it is normal that in the presence of the magnetic field, one also excites the quantum spin-dépendent(via the magnetic moment) Larmor frequency and zero ferquency. The problem is to find a method to observe them separately at once. Moreover, the "quantum cyclotron" based on the Landau levels has been used to study the fine-stucture constant with a very high precision.

7 **M. Asghar**
Aug 16, 2014 12:20 PM

Positronium atom - also cyclone and cyclone

The positronium, the atom with the electron and positron, exists in a singlet state (S=0) with their spins spinning in the opposite directions just like a cyclone and anti-cyclone. However, it also existes in the triplet state (S=1), where both of them are cyclones and understandnably, it has a longer life than for the singlet state. The rotational nature of the EM comes from the rotational property of the magnetic field, and this also strongly opposes the existence of the magnetic monopoles.

Quote:

> *Originally posted by* ***John Duffield***
> This is promising. I was particularly struck by this: *"The magnetic field plays the same role for electrons as the Earth's rotation plays for the creation of cyclones"*. For some reason the "screw nature of electromagnetism" isn't common knowledge even though Minkowski and Maxwell spoke about it. And despite gravitomagnetism wherein "space is twisted", and rot, nobody seems to know that the electromagnetic field is "twist field", and when you move through it you perceive it to be a "turn field". Hence the electron, which is a spinor, follows the corkscrew path. It really is like a 3D cyclone. The positron is like an anticyclone. If you could place a cyclone down near an anticyclone, vorticial attraction would make them move linearly towards one another. If you throw one past the other, they swirl around each other too, as per positronium. See arxiv.org…0804.1357 and this for more.

8 **John Duffield**
Aug 17, 2014 6:14 AM
United Kingdom
You're getting confused, M. See this picture. The electron is like the 3D cyclone, the positron is like the 3D anticyclone. That's why they corkscrew different ways in a magnetic field. The different states of positronium are just different picosecond/nanosecond gyrations prior to annihilation. Annihilate a cyclone with an anticyclone and all you've got is wind. Annihilate an electron with a positron and all you've got is light.

9 **M. Asghar**
Aug 17, 2014 7:59 AM

Charges and spin

Well, the electron and positron curl in an opposite manner in a magnetic field, because of their negative and positive electric charges. Their spinning relative to each other, their self-annihilation in a medium and the conservation of the initial and final (photon with spin S=1) angular momentum brings in its own constraint.

Quote:

> *Originally posted by* ***John Duffield***
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10 **John Duffield**
Aug 17, 2014 11:23 AM
United Kingdom

Charge is topological

And their opposite charges are because of their opposite chiralities. Remember Dirac's belt: *"In this sense a Möbius strip is reminiscent of spin-½ particles in quantum mechanics, since such particles must be rotated through two complete rotations in order to be restored to their original state"*. Draw arrowheads on strips of paper and make some Möbius strips. The orthogonal twist can go clockwise or anticlockwise. Check out TQFT and chiral knots and optical vortex.

11 **M. Asghar**
Aug 17, 2014 11:57 AM

Rotation and charge

The different types of rotations of the spin to restore the original state is the intrinsic property that distinguises the fermions from the bosons. However, here one is dealing with the direction of spinning (cyclone-anticyclone or cyclone-cyclone) of the electron and the positron at the moment of annihilation in a material space (no magnetic field) that ends up in a photon of spin S=1. The opposite charges of the pair just help it to come closer (determined by the Compton wavelength) for annihilation and nothing more. In the case of a neutron and anti-neutron pair, these charges do no existe yet it does self-annihilate.

Quote:

> *Originally posted by **John Duffield***
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