NATURE | NEWS

Quantum cloud simulates magnetic monopole

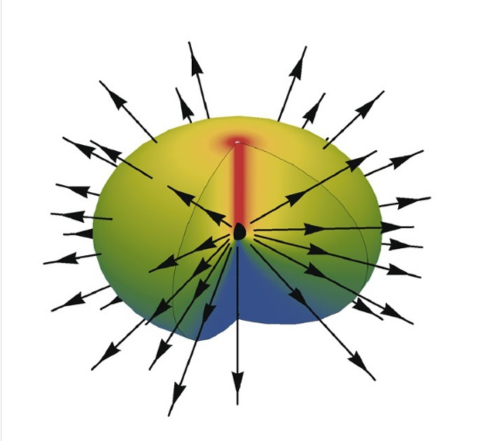
Cold atoms provide evidence for Paul Dirac's 83-year-old theory.

Elizabeth Gibney

29 January 2014

Physicists have created and photographed an isolated north pole — a monopole — in a simulated magnetic field, bringing to life a thought experiment that first predicted the existence of actual magnetic monopoles more than 80 years ago.

In nature, north and south magnetic poles always go hand in hand. Cutting a bar magnet in half just creates two magnets, each of which still has two poles, rather than creating separate north and south poles on each half. Yet their electrostatic cousins, positive and negative charges, exist independently. In 1931, British physicist Paul Dirac theorized that if magnetic monopoles did exist, it would not only address this seeming imbalance, but would also explain why charge exists in discrete packages: multiples of the charge of a single electron[1].



Ref. 2

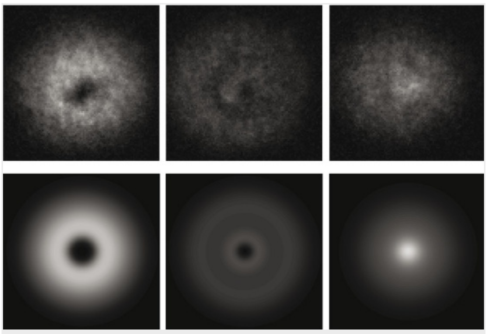
A condensate of cold atoms can be a model for a magnetic monopole, in which the magnetic field jots out of an isolated pole — except in one direction where there is no field.

Researchers have in fact suggested that the Big Bang should have forged magnetic monopoles as elementary particles, but so far no one has ever detected such things or created them in the lab. Publishing today in *Nature*[2], a team led by David Hall at Amherst College in Massachusetts has recreated Dirac's monopole by simulating one in a cloud of super-cold rubidium atoms.

Hall's team followed an idea put forward by researchers Ville Pietilä and Mikko Möttönen[3], now at Aalto University in Finland, to simulate how an electron would behave in the vicinity of a magnetic monopole using a gas of around one million rubidium atoms, cooled to less than 100-billionths of a degree above absolute zero. At that point, the atoms begin to lose their individual identities and become part of a collective quantum state of matter known as a Bose–Einstein condensate, or BEC.

Vortex view

In the comparison with Dirac's vision, the condensate in Hall and colleagues' experiment represents the single electron, and the density of atoms at each point corresponds to the probability of the electron existing in that region of space, says Hall. The atoms in the condensate each possess a magnetic spin, the quantum equivalent of a tiny compass needle, and which responds to magnetic fields applied from the outside. But in the experiment, those spins do not play the part of the magnetic field around a monopole; rather, the field is represented by a property of the way the spins are arranged, called their vorticity.



Ref. 2

Sections of the cloud (top row) show a dark region that extends out of the centre — a tell-tale sign of a Dirac monopole. A computer simulation (bottom row) is shown for comparison.

To create the monopole pattern the researchers manipulated the spins to create a 'vortex' — essentially a whirlpool — within the BEC, with the monopole at its endpoint. The team imaged the whirlpool pattern and slices through it. "We see the whirlpool as a thin dark line, an absence of material like the hole produced as water goes down the drain," Hall says.

The north pole that the team created is not magnetic in any conventional sense: a compass needle would not point to it. "The equations that govern our synthetic monopole and that govern the natural magnetic monopole are essentially the same," Hall says. The work could be seen as an example of a growing field of research called quantum simulation, which uses a quantum system to model another that is more difficult to study.

Many monopoles

This is not the first time that physicists have created monopole analogues. In 2009, physicists observed magnetic monopoles in a crystalline material called spin ice, which, when cooled to near-absolute zero, seems to fill with atom-sized, classical monopoles. These are magnetic in a true sense, but cannot be studied individually. Similar analogues have also been seen in other materials, such as in superfluid helium, but the observations were less direct than in this experiment, says Tin-Lun Ho, a physicist at Ohio State University in Columbus.

Möttönen, who is a co-author on the latest paper, says that the monopole in the new study is closest to the real deal because the structure is identical to that of a Dirac magnetic monopole. Not all physicists agree. “In some ways this is closer to what a real monopole would look like, but in some ways it’s further,” says Arttu Rajantie, a theoretical physicist at Imperial College London.

Steven Bramwell, a physicist at University College London who pioneered work on monopoles in spin ices, says that the experiment is impressive, but that what it observed is not a Dirac monopole in the way many people might understand it. “There’s a mathematical analogy here, a neat and beautiful one. But they’re not magnetic monopoles,” Bramwell says. “You have to do a sideways jump — a bit of lateral thinking in your mind — to project these onto magnetic monopoles,” he adds.

Dirac famously said that he would be "surprised" if nature had made no use of such an elegant idea as the magnetic monopole. Physicists are still looking for natural monopoles, including in rocks and lunar samples, and in experiments using particle accelerators. Simulated monopoles provide a stronger foundation for these searches, says Möttönen. “You could ask, is this structure Dirac predicted actually possible? Now we have seen that it is possible, there’s one more reason why the magnetic monopole as a fundamental particle should exist.”

Nature | doi:10.1038/nature.2014.14612

References

1. Dirac, P. A. M. *Proc. R. Soc. Lond. A* **133**, 60–72 (1931).
2. Ray, M. W., Ruokokoski, E., Kandel, S., Möttönen, M. & Hall, D. S. *Nature* **505**, 657–660 (2014).
3. Pietilä, V. & Möttönen, M. *Phys. Rev. Lett.* **103**, 030401 (2009).