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Nanomagnets levitate thanks to quantum physics

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Cosimo Rusconi (l.) and Oriol Romero-Isart (r.) play with a levitron to illustrate their work on nano magnets. Credit: IQOQI Innsbruck/M.R.Knabl

Quantum physicists in Oriol Romero-Isart's research group in Innsbruck show in two current publications that, despite Earnshaw's theorem, nanomagnets can be stably levitated in an external static magnetic field owing to quantum mechanical principles. The quantum angular momentum of electrons, which also causes magnetism, is accountable for this mechanism.

Already in 1842, British mathematician Samuel Earnshaw proved that there is no stable configuration of levitating permanent magnets. If one magnet is levitated above another, the smallest disturbance will cause the system to crash. The magnetic top, a popular toy, circumvents the Earnshaw theorem: When it is disturbed, the gyrating motion of the top causes a system correction and stability is maintained. In collaboration with researchers from the Max Planck Institute for Quantum Optics, Munich, physicists in Oriol Romero-Isart's research group at the Institute for Theoretical Physics, Innsbruck University, and the Institute for Quantum Optics and Quantum Information, Austrian Academy of Sciences, have now shown that: "In the quantum world, tiny non-gyrating nanoparticles can stably levitate in a magnetic field." "Quantum mechanical properties that are not noticeable in the macroscopic world but strongly influence nano objects are accountable for this phenomenon," says Oriol Romero-Isart.

Stability caused by gyromagnetic effect

Albert Einstein and Dutch physicist Wander Johannes de Haas discovered in 1915 that magnetism is the result of quantum mechanical principles: the quantum angular momentum of electrons, or so-called electron spin. Physicists in Oriol Romero-Isart's research group have now shown that electron spin allows the stable levitation of a single nanomagnet in a static magnetic field, which should be impossible according to the classic Earnshaw theorem. The theoretical physicists carried out comprehensive stability analyses depending on the object's radius and the strength of the external magnetic field. The results showed that, in the absence of dissipation, a state of equilibrium appears. This mechanism relies on the gyromagnetic effect: Upon a change in direction of the magnetic field, an angular momentum occurs because the magnetic moment couples with the spin of the electrons. "This stabilizes the magnetic levitation of the nanomagnet," explains first author Cosimo Rusconi. In addition, the researchers showed that the equilibrium state of magnetically levitated nanomagnets exhibits entanglement of its degrees of freedom.

New field of research

Oriol Romero-Isart and his team are optimistic that these levitated nanomagnets can soon be observed experimentally. They have made suggestions on how this could be achieved under realistic conditions. Levitated nanomagnets are a new experimental research field for physicists. Studies of nanomagnets under unstable condition could lead to the discovery of exotic quantum phenomena. In addition, after coupling several nanomagnets, quantum nano magnetism could be simulated and studied experimentally. Levitated nanomagnets are also of high interest for technical applications, for example for developing high precision sensors.

More information: C. C. Rusconi et al. Quantum Spin Stabilized Magnetic Levitation, *Physical Review Letters* (2017). DOI: 10.1103/PhysRevLett.119.167202

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