Researchers achieve almost instant magnetization of matter by light

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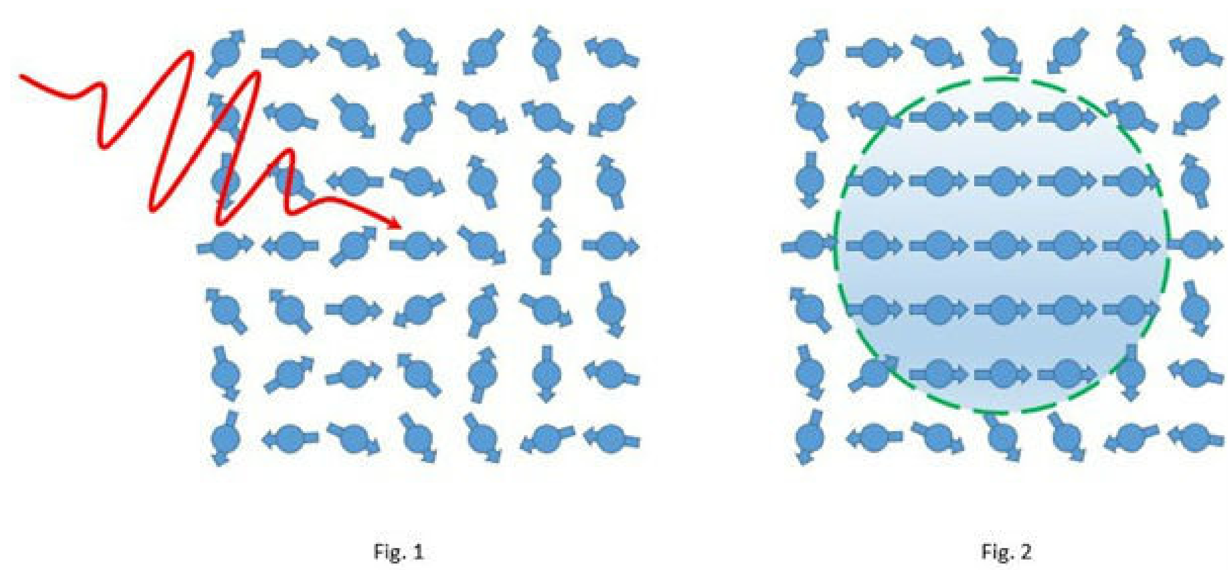

Alignment of europium atom spins by light. Credit: André Bohomoletz Henriques

The production of devices to store or transmit information is one of the most frequent technological applications of magnetism. An experimental and theoretical study conducted at the University of São Paulo's Physics Institute (IF-USP) in Brazil has discovered an ultrafast way of magnetizing matter with minimal energy consumption.

Using a technique called magnetization by light, the researchers magnetized a sample of europium selenide (EuSe) in 50 picoseconds with a 50-watt bulb located a few centimeters away. A picosecond is one trillionth of a second.

An article describing the experiment, titled "Ultrafast light switching of ferromagnetism in EuSe," was recently published in *Physical Review Letters*.

The experiment was conducted by André Bohomoletz Henriques, a full professor at IF-USP, and collaborators with support from the São Paulo Research Foundation—FAPESP.

"Our aim was to find new mechanisms to change the magnetism of materials in an ultrashort time scale using only light. The novelty of our research is that it makes very strong magnetization possible with very small amounts of light," Henriques said.

The process was experimentally derived at the University of São Paulo's Magneto-Optics Laboratory, but interpreting the phenomenon required substantial theoretical work, involving procedures such as self-consistent quantum mechanical calculations and Monte Carlo simulations, on the part of the group led by Henriques.

The magnetization of a material is associated with the spatial ordering of the spins of its constituent particles. In an unmagnetized material, the spins of its atoms (resulting from the spins of its electrons) are disordered. Because vector magnitude is involved, the spin of each atom points in an arbitrary direction. In certain situations, these spins can be ordered by light, which, as a result, can completely magnetize an initially disordered material. The image above illustrates the process of magnetization by light.

The material chosen for the experiment was the semiconductor europium selenide (EuSe), in which each photon ordered the spins of 6,000 electrons.

"This happens because when a photon interacts with an electron, it changes a state that is strongly located in the atom to a state that extends to many atoms," Henriques explained. "The result is that in an extraordinarily short time, about 50 picoseconds, all the atoms within reach of the electron's wave function switch their spins to a common direction, creating a super-gigantic magnetic moment approaching 6,000 Bohr magnetons. That is equivalent to the magnetic moment of 6,000 electrons with spins all pointing in the same direction. The result, considered unexpected and spectacular by peer reviewers for Physical Review Letters, was that with a single photon, we were able to align the spins of 6,000 electrons."

Spin is popularly understood as the rotation of a particle around an axis, but this conception does not correspond to reality and only serves as a representation of a particle associated with an electric current equivalent to a magnetic moment.

Particles not only have inertial mass and electric charge but also a third physical property called spin. This property, characterized as a vector (i.e. a physical quantity with magnitude and direction), describes the magnetic moment of the particle. Like a compass needle, which is oriented in a North-South direction by the pull of Earth's magnetic field because it has a magnetic moment, a particle's spin also tends to point in the direction of the magnetic field acting on it.

"To magnetize europium selenide, the photon must have enough energy to transfer an electron from an orbit very close to the atomic nucleus to a distant orbit in the conduction band. As a result of this transfer, the electron interacts magnetically with thousands of nearby atoms. The interaction between the electron's magnetic moment and the magnetic moments of the nearby atoms aligns all their spins," said the FAPESP-supported researcher.

Anti-ferromagnetic interaction

Europium selenide was chosen due to its high magnetic susceptibility, which results in the strong tendency of atom spins to align under the effect of a very small magnetic field.

"In addition to the magnetic interaction between the electron and the europium atoms, there is also magnetic interaction among the europium atoms themselves. Interaction between first neighbors is ferromagnetic; in other words, it favors alignment in the same direction. But interaction between second neighbors is anti-ferromagnetic and favors alignment in opposite directions," Henriques said.

"These two interactions almost cancel each other out. Actually, the anti-ferromagnetic interaction just about prevails. For this reason, under usual conditions, the material is found in the anti-ferromagnetic state, without magnetism. However, any minor disturbance, such as the presence of an electron, can upset this delicate balance of interactions and favor the ferromagnetic state, i.e. the alignment of all spins in the crystal in the same direction, magnetizing the material almost instantly."

There are different forms of magnetic interaction. The best-known form is dipolar interaction, which characterizes the attraction between two magnets, but there is also exchange interaction, which is far stronger and influences the magnetism of a compass needle or refrigerator magnet.

Exchange interaction is electrostatic in origin and constitutes a quantum phenomenon derived from the Pauli exclusion principle, which has no analogue in classical physics. This process makes ultrafast magnetization by light possible with minimal energy consumption.

Although they conducted this study strictly as basic research, Henriques and his team are aware of the potential technological applications in the context of the swiftly advancing electronics industry. According to an editorial published in March 2018 in the journal *Nature Physics*, the manipulation of magnetism in anti-ferromagnetic materials such as europium selenide is an emerging field of research with promising potential for application in electronic devices.

More information: A. B. Henriques et al, Ultrafast Light Switching of Ferromagnetism in EuSe, *Physical Review Letters* (2018). DOI: 10.1103/PhysRevLett.120.217203

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