Finding the right color to control magnets with laser pulses

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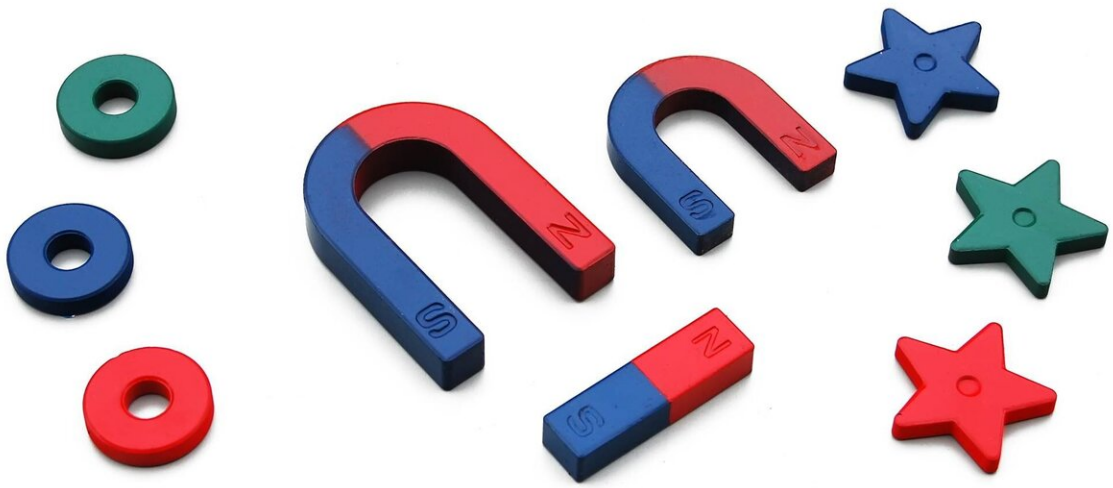

The spin can be seen as an elementary "needle of a compass", typically depicted as an arrow showing the direction from North to South poles. Credit: Lancaster University

Scientists have discovered a new way to manipulate magnets with laser light pulses shorter than a trillionth of a second.

The international team of researchers, led by Lancaster and Radboud Universities, also identified the light wavelength or color which enables the most efficient manipulation. The finding is published in *Physical Review Letters*.

Magnets have fascinated people since ancient times, but until a hundred years ago the theoretical understanding of magnetism remained very elusive. The breakthrough in understanding occurred with the development of quantum mechanics and the discovery of the fact that each electron has an intrinsic magnetic moment or spin.

The spin can be seen as an elementary "needle of a compass," typically depicted as an arrow showing the direction from North to South poles. In magnets all spins are aligned along the same direction by the force called exchange interaction. The exchange interaction is one of the strongest quantum effects which is responsible for the very existence of magnetic materials.

The strength of the exchange interaction can be appreciated from the fact that it generates magnetic fields 10,000 times stronger than the Earth's magnetic field. Another manifestation of its strength is the fact that it can drive spins to rotate with a period of one trillionth of a second and even faster.

Manipulating the exchange interaction would be the most efficient and ultimately fastest way to control magnetism. To achieve this result, the researchers used the fastest and the strongest stimulus available: ultrashort laser pulse excitation.

However, in order to detect/observe the effect of light on magnetism one would need an ultrafast magnetometer—a device which would be able to trace the dynamics of spins with less that a trillionth of a second resolution. This is much faster than the temporal resolution of modern

electronics.

But the authors have found a solution to this problem, as lead researcher Dr. Rostislav Mikhaylovskiy from Lancaster University explains: "The spins oscillate at Terahertz frequencies almost a trillion times faster than the standard power line frequency of 50 Hz. Thanks to such high frequencies of oscillations, the spins act as efficient antennas emitting electromagnetic radiation. By analyzing the properties of the emitted radiation we can extract information about the ultrafast magnetization dynamics triggered by the optical steering of the exchange forces."

By systematically varying the color of the excitation laser pulses from red to blue, the scientists were able to identify the light wavelength for which the effect of light on magnetism is the strongest.

Dr. Mikhaylovskiy said: "It was very important to see that the effect of light on the exchange interaction really exists. By tuning the wavelength or color of light we started to understand how to enhance this effect."

This exciting discovery opens a new research line at Lancaster University led by Dr. Mikhaylovskiy. The next step is to perform systematic studies of the ultrafast control of magnetism in a broad spectral range, to compare the efficiencies of the pumping in the far-, mid-infrared and visible ranges and thus to identify the most efficient as well as the fastest approach for the manipulation of spins. To this end a new laser system capable of producing laser pulses in all these frequency ranges has been commissioned.

More information: R. V. Mikhaylovskiy et al. Resonant Pumping of d−d Crystal Field Electronic Transitions as a Mechanism of Ultrafast Optical Control of the Exchange Interactions in Iron Oxides, *Physical Review Letters* (2020). DOI: 10.1103/PhysRevLett.125.157201

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