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Using heat to make magnets

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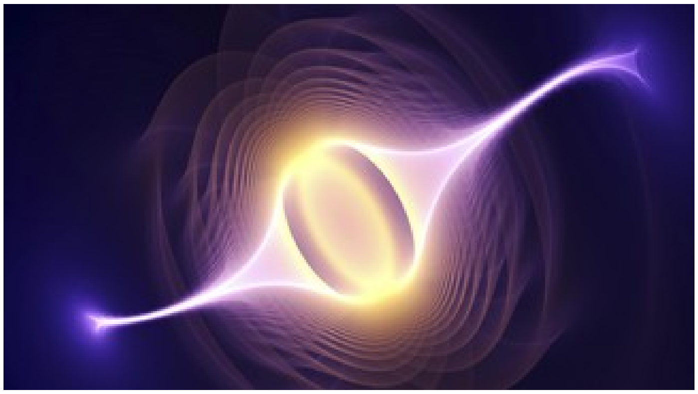

Credit: 2013 EPFL

EPFL scientists have provided the first evidence ever that it is possible to generate a magnetic field by using heat instead of electricity. The phenomenon is referred to as the Magnetic Seebeck effect or 'thermomagnetism'.

A temperature difference across an electric conductor can generate an electric field. This phenomenon, called the Seebeck effect, lies at the root of thermoelectricity (heat turned into electricity), and is used to drive space probes and power thermoelectric generators, and could be implemented for heat-harvesting in power plants, wrist-watches and microelectronics. In theory, it is also possible to generate a magnetic field by using a temperature difference across an electrical insulator ('thermomagnetism'). This has been referred to as the Magnetic Seebeck effect, and has enormous applications for future electronics such as solidstate devices and magnetic-tunnel transistors. In a breakthrough *Physical Review Letters* publication that has been promoted to "Editors' Suggestion", EPFL scientists have for the first time predicted and experimentally verified the existence of the Magnetic Seebeck effect.

Thermoelectricity and 'thermomagnetism'

The Seebeck effect (thermoelectricity) – named after Thomas Johann Seebeck who first observed it in 1821 – is generated when electrons in an electric conductor move as a response to a temperature gradient. On average, the electrons on the hot side of the conductor have more kinetic energy and subsequently move at higher speeds than the electrons on the cold side. This causes them to diffuse from the hot to the cold side, generating an electric field that is directly proportional to the temperature gradient along the conductor.

Using an electrical insulator rather than a conductor, researchers led by Jean-Philippe Ansermet at EPFL have shown that a Magnetic Seebeck effect also exists. Because an insulator does not allow electrons to flow, a temperature gradient does not cause electrons to diffuse. Instead, it affects another property of electrons that forms the basis of magnetism and is referred to as 'spin'.

In an insulator, a temperature gradient alters the orientation of electrons' spin. Under certain conditions, this generates a magnetic field that is perpendicular to the direction of the temperature gradient. Similar to thermoelectricity described above, the intensity of the thermomagnetic field is directly proportional to the temperature gradient along the insulator.

First evidence for the Magnetic Seebeck effect

Using an insulating material called YIG (yttrium iron garnet), co-author Antonio Vetrò examined the propagation of magnetization waves along it. What he found was that the direction the magnetic waves propagated along the insulator affected the degree of magnetization loss – a phenomenon called magnetic damping. When the direction of the waves matched the orientation of the temperature gradient along the YIG, then the magnetization damping was reduced; when they propagated to the opposite direction, magnetic damping increased.

The Magentic Seebeck effect combines three distinct fields of physics: thermodynamics, continuum mechanics and electromagnetism. The difficulty lies in that, until now, no-one had ever found a way to consistently unify them. Pursuing this, first author Sylvain Bréchet built upon the work of Ernst Stückelberg (1905-1984), a renowned Swiss physicist who had previously developed a thermodynamical formalism for his teaching. Out of the hundreds of equations that Bréchet produced, one of them predicted that a temperature gradient should generate a magnetic field.

Although at an early stage, this discovery opens new approaches for addressing magnetization damping. This could have a tremendous impact on future devices based on spintronics (Nobel Prize 2007), an emergent technological field that offers an alternative to traditional electronics. In spintronic devices, signal transmission relies on the spin of electrons rather than their charge and movement. For example, the spintronics field is now considering harvesting heat waste coming from microprocessors like those used in personal computers.

More information: Brechet, S. et al. 2013 Evidence for a Magnetic Seebeck Effect, *Phys. Rev. Lett*. 111, 087205 (2013). prl.aps.org/abstract/PRL/v111/i8/e087205

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