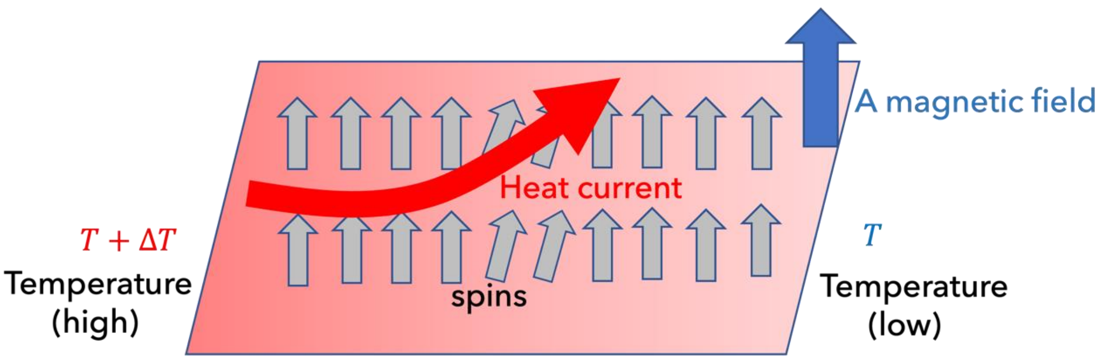
Can magnon be a platform for new technologies and the new topological physics?

Nanse Esaki

I believe that observation of the thermal Hall effect of magnons in a magnetic insulator $Lu_2V_2O_7$ [1] is a hidden gem of basic science.

Originally, the Hall effect was discovered by Edwin Hall in 1879 and have been used in various industrial usages such as semiconductor device. The Hall effect is the production of a voltage difference across an electrical conductor that is transverse to an electric current when a magnetic field is applied perpendicular to the current. When a charged particle like an electron moves under a magnetic field that is perpendicular to the direction of its velocity, they feel the force called the Lorentz force and the force bends the direction of a charged particle to the direction perpendicular to both its original one and the magnetic field. So, the Lorentz force bends an electric current and electrons accumulate in the direction perpendicular to its original direction. This causes a difference in the population of the electrons in the direction perpendicular to both its original direction and the magnetic field, and therefore there is a voltage difference to reduce the difference in the population. That is how the Hall effect occurs in an electrical conductor.

However, as mentioned above, this effect is usually driven by Lorentz force acts on a charge current in a conductor in the presence of an applied perpendicular magnetic field the current of uncharged particles was believed not to show it. But in the experiment [1], the thermal analog to this effect could be caused by uncharged particles magnons in a magnetic insulator was confirmed. Before explaining it in detail, one must understand the concept of spin and a magnon. Intuitively, spin is a kind of arrow that represents the rotational motion of an electron, with upward spin representing counterclockwise motion and downward spin representing clockwise motion. In truth, this explanation is incorrect and requires quantum mechanics for a correct understanding. In a magnet, there are lots of spins of electrons. To explain the concept of magnon, we consider the following situation: When all spins are oriented in the same direction, spins with different orientations appear, and such spins gradually propagate in a magnet. When one sees the propagation, he or she feels there is a "wave" of spins in a magnet. Also, physicists interpret the wave motion as a kind of particle (quasiparticle) that moves around a magnet and call this quasiparticle a "magnon". One of the important questions for the physics of magnons was whether the magnons exhibit the Hall effect or the analog to it like the electric current carried by electrons. The answer is that magnons show the thermal analog of this effect (the thermal Hall effect). If there is a temperature gradient, a heat current appears from the high-temperature region to the low-temperature region. However, the heat current carried by magnons can be bent under a magnetic field like the usual Hall effect and there appears a heat current perpendicular to the original direction.



This is how the thermal Hall effect occurs in a magnet. As mentioned already, the Hall effect of magnons cannot be caused by Lorentz force since a magnon is a charge-neutral particle. However, magnons can carry heat instead of charge and the mechanism of the thermal Hall effect can be understood in terms of the concept of topology [2]. Topology is a mathematical concept that focuses on the properties that are preserved by successive transformations of some form and classifies forms from this viewpoint. For example, a torus and a coffee cup are regarded as the same in terms of topology. At first glance, this seems not to be related to physics, but physics related to the concept of topology is one of the most important and the hottest topics in modern physics.

However, why it can be a hidden gem of basic science? There are two reasons for this. First, it is important for a deeper understanding of physics in terms of topology. As mentioned above, the thermal Hall effect of magnons can be understood from the topological point of view, and therefore it can be said that it is one of the examples of topological effects. There have already been numerous studies about the topological properties of the systems of electrons, and therefore our understanding of them has advanced considerably. However, studies on topological properties of the systems of the other particles are much fewer than on electronic systems, and therefore studies about the thermal Hall effect of magnons [1, 2] are one of the clues to understanding the topological properties of the other systems. In fact, various studies have been conducted about them later [3,4]. So, observation of the thermal Hall effect of magnons is important in the sense of promoting basic science.

Second, it is important for applications in future technologies and can be beneficial to society. Silicon semiconductors which are widely used in electronic products such as computers, smartphones, IC cards, and so on are said to be approaching the limit of miniaturization and integration due to the problems such as heat generation by Joule heat. To avoid loss of Joule heat due to electrical conduction, the possibility of technological innovation through electronics using the spin (spintronics) degree of freedom is being investigated [5]. It can enable electronic circuits with less energy loss. However, in conductors and semiconductors where conduction electrons exist, energy loss due to the interaction between spins and electrons is inevitable. So, controlling the current carried by magnons in magnetic insulators is very important in terms of the realization of future power-saving electronic technologies since there are no conduction electrons in insulators. Observation of the thermal Hall effect of magnons in a magnetic insulator might be the first step toward it.

Then, what is the impact it could have on the future of science and society? One is a better understanding of topological phenomena. Realization of the thermal Hall effect of magnons in real magnets means that we can think of the topological phenomena in the systems of other particles than electrons as a reality, not an impracticable theory. This can motivate us to investigate various topological phenomena for other systems than electronic systems, and therefore can lead to a better understanding of the physical world in terms of topology.

Another is that it helps to develop a new device beyond the current one. As mentioned already, the magnon current is virtually dissipationless since it is barely affected by energy loss unlike the electronic current, and therefore it can enable us to realize new information processing methods beyond current electronics. This kind of research field is now often called ‘magnonics’. Controlling the transport phenomena of magnons such as the thermal Hall effect is essential for realizing these methods, and therefore observation of the thermal Hall effect of magnons in a magnetic insulator might be a clue to it.

References

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