

Observation of angular momentum compensation by using the Barnett effect

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Ferrimagnets contain some kinds of magnetic ions, the magnetic moments of which are antiferromagnetically coupled with each other as shown in Fig. 1(a). Their spontaneous magnetization originates from the difference of magnetic moments of sublattices. In some ferrimagnets, the size of the sublattice magnetic moments is balanced at a temperature called the magnetization compensation temperature T_M , resulting that net magnetization vanishes. In addition, when the gyromagnetic ratio differs depending on the kind of ions, the net angular momentum becomes zero at a temperature called the angular momentum compensation temperature T_A , which is considered as a key characteristic of spintronics from the viewpoint of high-speed magnetic response. While T_M can be easily measured by magnetization measurements, T_A has not been able to be measured directly as the temperature that the net angular momentum is zero. In order to detect T_A , the Barnett effect was used in this work. We constructed a variable temperature apparatus for measuring the Barnett effect, and determined T_A of the ferrimagnetic insulator $\text{Ho}_3\text{Fe}_5\text{O}_{12}$.

The Barnett effect is a phenomenon in which matter is magnetized by mechanical rotation Ω [1], resulting from angular momentum \mathbf{J} of electrons in material aligns with the rotation axis through the spin-rotation coupling ($-\mathbf{J}\cdot\boldsymbol{\Omega}$). The Barnett effect does not apply when the net angular momentum $\langle \mathbf{J}_{\text{net}} \rangle = 0$, which is the definition of the angular momentum compensation.

Figure 1(b) shows a schematic illustration of our experimental setup [2]. The powder sample of $\text{Ho}_3\text{Fe}_5\text{O}_{12}$ packed in a capsule was floated by bearing air and rotated by blowing driving air on the impeller. The magnetization M_Ω induced by mechanical rotation was detected with a fluxgate magnetic sensor through the stray magnetic field from the sample. To realize the measurement under low temperatures, the system

was placed into a cryostat, and the rotor was driven by nitrogen gas cooled through a heat exchanger.

Figure 2 shows that M_Ω becomes zero at 135 and 240 K. The former corresponds to T_M determined by conventional magnetization measurements. At T_M , the angular momentum in the sample aligns with $\boldsymbol{\Omega}$, but magnetization M is zero, resulting in $M_\Omega = 0$. The latter is T_A . The bottom of Fig. 2 shows $\langle \mathbf{J}_{\text{net}} \rangle$ obtained from M_Ω and M . At $T_A = 240$ K, $\langle \mathbf{J}_{\text{net}} \rangle$ becomes zero. We succeeded in observation of the temperature dependent net angular momentum and determination of T_A of $\text{Ho}_3\text{Fe}_5\text{O}_{12}$ [2]. Furthermore, the gyromagnetic reversal state, where the angular momentum and the magnetization are coupling inversely in ordinary electrons, was realized at the temperatures between T_M and T_A .

The Barnett effect enables us to measure the net angular momentum in materials and to determine T_A , supporting to exploration of candidate materials for the high-speed magnetic devices utilizing fast-magnetization reversal at T_A .

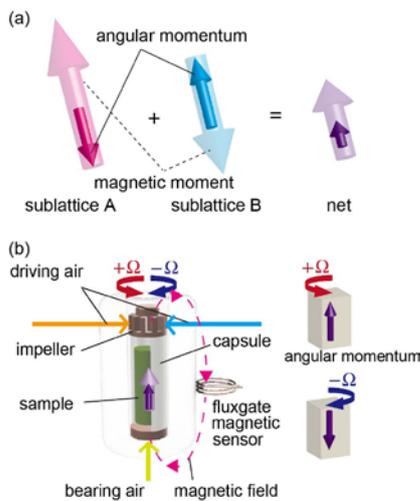


Fig.1 Schematic illustration of ferrimagnet and experimental setup. (a). Relationship between angular momentum and magnetic moment. (b) The apparatus for the Barnett effect measurement using an air-driven rotor system.

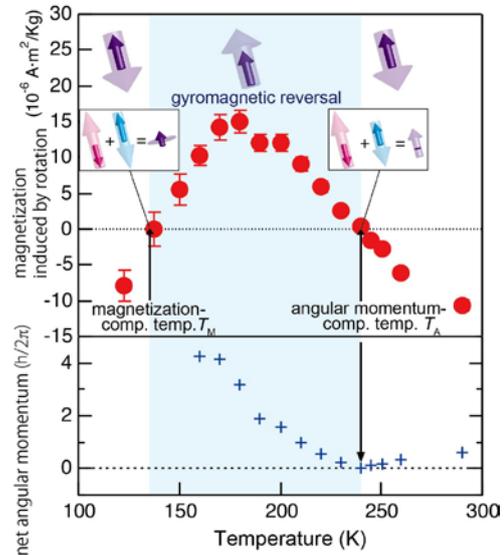


Fig.2 Temperature dependence of magnetization induced by mechanical rotation (top) and the net angular momentum of $\text{Ho}_3\text{Fe}_5\text{O}_{12}$ (bottom).

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References

- [1] [S. J. Barnett, Phys. Rev. **6**, 239 \(1915\).](#)
- [2] [M. Imai et al., Appl. Phys. Lett. **113**, 052402 \(2018\).](#)