Gyroscopic g-factor of rare earth metals

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1) : Spin-energy transformation Science Gr., JAEA

We have developed an apparatus for observing the Barnett effect. The apparatus is composed of a fluxgate sensor, a high speed rotor, and a magnetic shield at room temperature. The effective magnetic field (Barnett field) in a sample arising from its rotation is proportional to the rotational frequency. The gyroscopic *g*-factors, *g'*, of Gd, Tb, and Dy were estimated to be 2.00 ± 0.08, 1.53 ± 0.17, 1.15 ± 0.32, respectively, from the slope of the rotational dependence of the Barnett field. This study provides a technique to determine the *g'*-factor even in samples where the spectroscopic method may not be available.

A magnetic moment is composed of spin and orbital magnetic moments. Extracting the spin and orbital contribution by measuring the *g'*-factor is fundamental research subject. The *g'*-factor is the ratio between the angular momentum and magnetic moment and is determined by the gyromagnetic effects known as the Barnett effect [1] (a body is magnetized due to the rotation of the body) and Einstein-de Haas effect [2] (a body is rotated due to the magnetization of the body). On the other hand, the contributions can be extracted by the ESR method. However, the short relaxation time of electron prevents from ESR measurements. Using the 4*f* rare earth metals, both measurements have not been experimentally reported.

Figure 1 shows the apparatus we developed in this study. A sample is introduced into the rotation system and is rotated by the bearing air and the driving air. The direction of the rotation can be switched by the direction of the driving air. To measure the stray field ΔB from the rotating sample, the fluxgate sensor is mounted next to the rotation system. To suppress the magnetic fluctuation, the fluxgate sensor and the rotation system are enclosed in a static magnetic shield made of permalloy. The whole apparatus is placed inside a thermal isolation chamber, and the experimental temperature is controlled within ±0.1K using a high precision air controller. We checked the performance of the apparatus by applying an electric current to a solenoid coil, which is replaced with the sample. We confirmed that our apparatus works well down to a few pT

Figure 2(a) shows the stray field from the rotating Gd sample at various rotational frequencies. By switching the rotational direction, the stray field rapidly changes. Figure 2(b) shows the rotational frequency dependence of the stray field for samples. The stray field of samples linearly depends on the rotational frequency indicating the stray field arises from the rotating sample. From the stray field, we estimate the magnetization of the rotating sample using dipole model. The Barnett field was estimated from the magnetization and the magnetic susceptibility of sample. The rotational frequency dependence of the Barnett fields is shown in Figure 2(c). From slopes of the lines, we estimated the *g'*-factors to be 2.00±0.08, 1.53±0.17, 1.15±0.32, for Gd, Tb, and Dy, respectively [3].

When the strength of the spin-orbit coupling is less than that of the Coulomb interaction between *f*-electrons, the magnetic moment is described using Lande g_J-factor. Our experimental results indicate that the 4*f*-electron states in Tb and Dy are well described by the *LS* coupling scheme.

The present technique allows us to experimentally extract the orbital contributions to the magnetism in the 5*f*-electron state of actinide compounds, which are described as the intermediate state between the *LS* coupling and *j-j* coupling schemes.

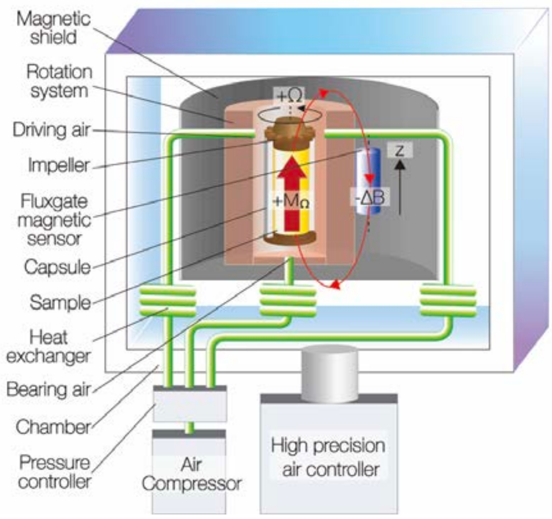

Fig. 1 Schematic illustration of the experimental apparatus for measuring the Barnett effect. The direction of rotation, magnetization, and the stray field are shown by arrows.

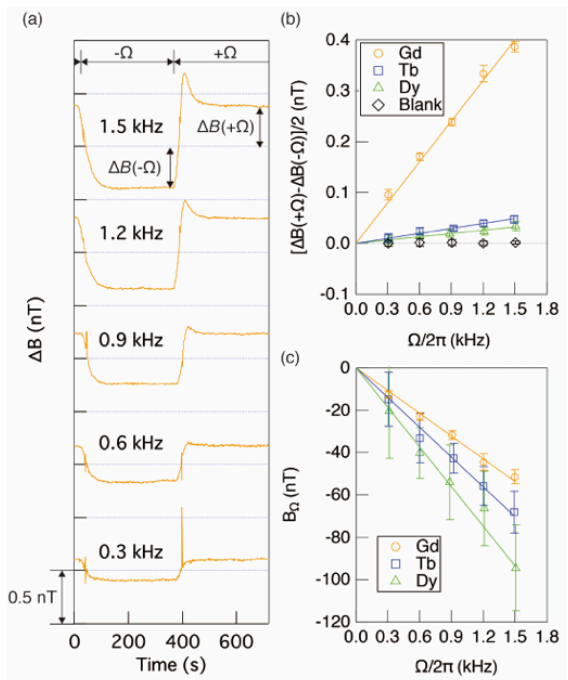

Fig. 2 (a) Stray field changes because of the change in the rotational direction for the Gd sample at various angular velocities. $\Delta B(+\Omega)$ and $\Delta B(-\Omega)$ represent the stray field of the forward and backward rotation. Rotational frequency dependence of (b) the stray field and (c) the Barnett field B_Ω.

References

[1] S. J. Barnett, Phys. Rev. **6**, 239 (1915).
[2] A. Einstein *et al.*, Verh. Dtsch. Phys. Ges. **17**, 152 (1915).
[3] Y. Ogata *et al.*, Appl. Phys. Lett. **110**, 072409 (2017).