TEMPERATURE VARIATION OF SPIN- AND ORBITAL-MAGNETIC FORM FACTOR OF HOLMIUM IRON GARNET BY X-RAY MAGNETIC DIFFRACTION

X-ray magnetic diffraction with the use of elliptically polarized synchrotron radiation is a unique tool which enables us to take separate measurements of spin- and orbital-magnetic moments of ferromagnets [1]. These magnetic moments are fundamental physical quantities and give us essential knowledge regarding magnetism. To date, the white beam method [2-5] which utilizes elliptically polarized white X-rays of bending-magnet radiation, has been the most extensively employed technique. In the present experiment we have adopted an advanced method by utilizing a monochromatic beam. This method utilizes highly brilliant undulator radiation and a phase plate. One advantage of the monochromatic beam method is its capability of more precise measurements, as it is not subject to fluorescent X-rays and multiple scattering as much as the white beam method.

The monochromatic beam method was applied to a determination of the spin- and orbital-magnetic form factor of Holmium Iron Garnet, $Ho_3Fe_5O_{12}$, at various temperatures between 60 K and 300 K. This compound is a ferrimagnet with a compensation temperature (Tc) of approximately 130 K, at which the total magnetization vanishes. The total magnetization is composed of the magnetic moments of Ho and Fe atoms. The dominant component of the total magnetization, which is the Ho moment below the Tc, is believed to be switched to the Fe moment above the Tc. In this experiment, we aim to determine how the spin- and orbital-magnetic moments of this compound vary through the compensation temperature.

The experiment was performed at the undulator beamline **BL39XU**, where a phase plate made of diamond crystal is installed [6]. The phase plate is an X-ray optical device utilized to control the polarization of synchrotron radiation and to generate elliptically polarized radiation. The phase plate system has been successfully applied to MCD measurements at this beamline [7], and to the X-ray magnetic diffraction measurement [8]. The present study is the first case in which a phase plate was applied in the X-ray magnetic diffraction, together with the third-generation undulator radiation.

The prepared single crystal specimen of the compound was made by the LPE method. Elliptically polarized X-rays out of the phase plate were irradiated on the specimen and the diffraction intensity of the (880) reflection plane was measured using an APD detector [9]. The scattering angle to the specimen was set at the 90 degrees. The specimen was kept in a refrigerator to maintain the desired temperature between 60 K and 300 K. The specimen was also kept under a magnetic field of 0.6 Tesla by an electromagnet. The diffraction intensities were measured by reversing the magnetization direction (referred to as a magnetic effect or a flipping ratio). The magnetic field was applied in two ways; (i) along the incident beam and (ii) along the diffraction beam. The former measurement gives us the orbital-magnetic form factor at the 880 reciprocal lattice point, $\mu_L(880)$, and the latter measurement gives us the total magnetic form factor (orbital+spin), $\mu_{L+2S}(880)$.

In Fig. 1, the observed values of the $\mu_L(880)$ and

the $\mu_{L+2S}(880)$ are shown between 60 K and 300 K. Solid circles and solid squares represent the $\mu_L(880)$ and the $\mu_{L+2S}(880)$, respectively. Above the compensation temperature, which is 130 K, the absolute values of the $\mu_L(880)$ and the $\mu_{L+2S}(880)$, are shown by the open circles and open squares, respectively. It is noted in Fig. 1 that (i) the signs of both $\mu_L(880)$ and $\mu_{L+2S}(880)$ are reversed at the compensation temperature, (ii) the absolute values of the both $\mu_L(880)$ and $\mu_{L+2S}(880)$ decrease monotonically as the temperature increases. The estimated statistical error bars, which are not shown in the figure, are about the same as the size of data point. The solid lines and dashed lines in Fig. 1 represent the fitted cubic curves for the absolute values of the $\mu_L(880)$ and the $\mu_{L+2S}(880)$, respectively. From these fitted curves the spin-magnetic form factor $\mu_{2S}(880)$ was derived as $\mu_{2S}(880) = \mu_{L+2S}(880) - \mu_L(880)$ and is plotted in Fig. 2. We see, that the sign of the $\mu_{2S}(880)$ is opposite to that of the $\mu_L(880)$ and the absolute value of the $\mu_{2S}(880)$ decreases monotonically as the temperature increases. This is the first measurement of the temperature variation in the spin- and orbital-magnetic form factor of this compound.

Both Ho and Fe atoms contribute to the total magnetic form factor of this compound. Assuming that the orbital moment of Fe is quenched, as is almost the case for 3*d* transition-metal atoms, the total magnetic form factor is composed of the following three components; (a) the orbital moment of Ho, (b) the spin moment of Ho, and (c) the spin moment of Fe. The $\mu_L(880)$ would come from the orbital-magnetic form factor of Ho. The change in the sign of the $\mu_L(880)$ at the compensation temperature directly indicates the direction reversal of the magnetic moment of Ho. The $\mu_{2S}(880)$ is composed of the spin moments of Ho and Fe. In

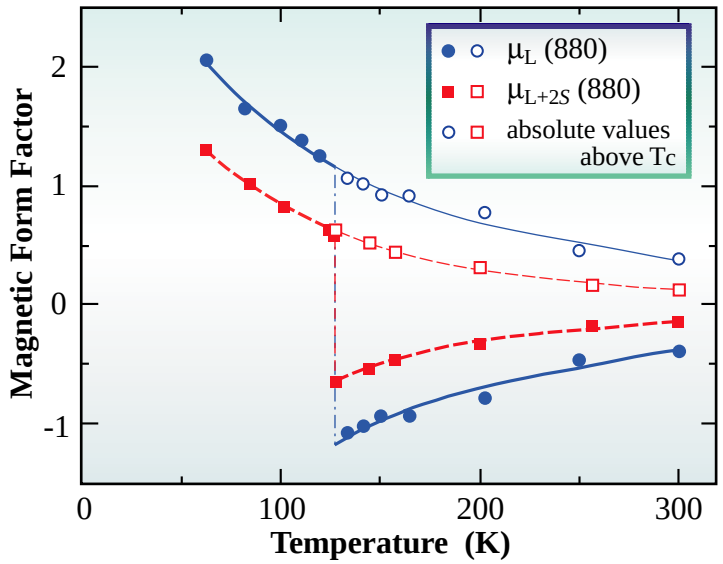

Fig. 1. Temperature variation of orbital-magnetic form factors (solid circles) and total magnetic form factors (solid squares) of Holmium Iron Garnet at the 880 reciprocal lattice point, $\mu_L(880)$ and $\mu_{L+2S}(880)$, respectively. Open circles and open squares represent absolute values of the form factors above the compensation temperature Tc (130 K). Solid lines and dashed lines represent the fitted cubic curves for the absolute values of $\mu_L(880)$ and $\mu_{L+2S}(880)$, respectively. Thicker lines are drawn for the data represented by solid circles and squares.

order to separate Ho and Fe contribution in the spin-magnetic form factor, further experiments and/or analyses are needed. Therefore we plan to obtain the spatial distribution of the spin and orbital moments of Ho and Fe in the compound.

In conclusion, (i) the spin- and orbital-magnetic form factors of the Holmium Iron Garnet at the 880 reciprocal lattice point were measured between 60 K and 300 K for the first time; (ii) both the magnetic form factors show the change in the sign at the compensation temperature which is the direct observation of the reversal of the magnetic moment direction; and (iii) the absolute values of both magnetic form factors indicate a monotonic decrease as the temperature increases.

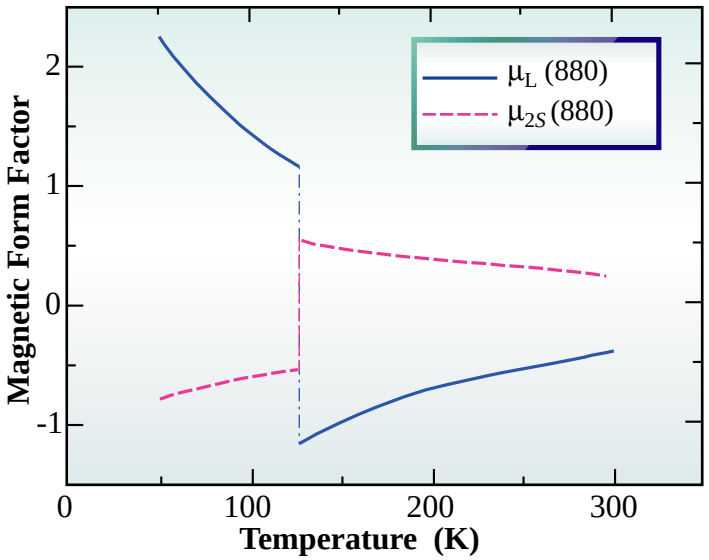

Fig. 2. Orbital-magnetic form factor $\mu_L(880)$ (solid lines) and spin-magnetic form factor $\mu_{2S}(880)$ (dashed lines). $\mu_{2S}(880)$ are derived from the fitted curves of $\mu_L(880)$ and $\mu_{L+2S}(880)$, as $\mu_{2S}(880) = \mu_{L+2S}(880) - \mu_L(880)$.

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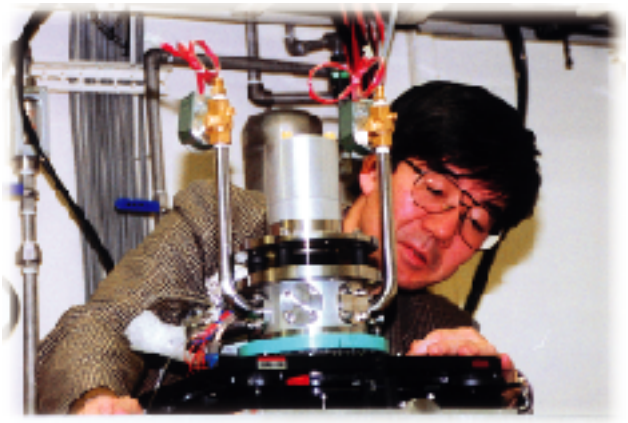

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