Fe$_3$O$_4$ Nanoparticles and their Magnetic Properties using X-Ray Magnetic Circular Dichroism

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1 Introduction
Nano-sized materials show superior physical and chemical properties due to their mesoscopic effect, small object effect, quantum size effect and surface effect compared to atomic or bulk [1-4]. Literature suggest that Fe$_3$O$_4$ magnetic nanoparticles (MNPs) are non-toxic and biocompatible and also show superparamagnetic behaviour, high coercivity and low Curie temperature, so due to this nature it have intensively studied. Recently, Fe$_3$O$_4$ MNPs have brought out some new kinds of biomedical applications such as dynamic sealing [5], biosensors [6], and extraction of DNA/RNA from blood samples [7].

2 Experiment
The MNPs studied here are Fe$_3$O$_4$ with an approximate diameter 5 to 20 nm. The Fe$_3$O$_4$ MNPs were prepared by co-precipitation method due to its efficient and robust performance and the fact that it does not require any specialised equipment. For this a solution of FeCl$_2$ and FeCl$_3$ in a 1:2 molar ratio is prepared and slowly dripped into a pre heated NaOH solution. This forms a black precipice consisting of Fe$_3$O$_4$ particles. The sample is annealed in controlled oxygen to obtain a clean surface. The XAS and XMCD measurements were done at BL-16 of KEK-Photon Factory (PF), Japan. The XAS spectra were taken in the total electron yield (TEY) mode.

3 Results and Discussion
The XAS spectra obtained with applied magnetic fields of +3.0 and -3.0 T are denoted by m$^+$ and m$^-$ which represent left and right circularly polarized light, respectively as shown in Fig 1. The XMCD spectrum was recorded by taking a difference between the XAS spectra with negative and positive helicity of the circularly polarized light. Figures 1 show the Fe 2p-3d XAS and the XMCD spectra, respectively. The main two groups of the peaks shown in the XAS spectra are due to the 2p3/2 (L3 edge) and 2p1/2 (L2 edge) spin-orbit components. Sharp negative, positive and negative peaks (denoted by Oh (Fe$^2+$), Td (Fe$^3+$), and Oh (Fe$^3+$)) occur in the 2p3/2 edge of the XMCD spectra, respectively, around $h\nu$= 708.5, 709.7, and 710.4 eV.

The Fe ions were in the mixed state 3+ and 2+ states, and both sublattices at Oh sites (Fe$^3+$ and Fe$^2+$) were found to be antiferromagnetically coupled to Fe$^3+$ (Td sites), finding from the opposite signs of the XMCD signals. From the sum rule analysis, the orbital and spin magnetic moments of Fe ions are found to be 0.22 and 2.1 $\mu_B$/Fe, respectively. The observed m$^b$ and m$^s$ of Fe ions are found to be 0.74 and 1.2 $\mu_B$/Fe, respectively at 0.5 T. XMCD peak intensity remains high down to an applied field of 0.5 T indicating that ferromagnetism exists in this sample. The XMCD line shape (not shown here) is independent of the magnetic field. The slope of the XMCD intensity vs H curve indicates the paramagnetic part of the Fe magnetic moment.

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References

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Fig. 1. Fe L2,3-edge of anatase Fe3O4 magnetic nanoparticles (MNPs) taken in the TEY mode at T = 300 K and H = ± 3 T. (a) XAS. (b) XMCD spectra (c) integrated XAS and (d) integrated XMCD of Fe3O4 MNPs.