



	Experiment title: Stroboscopic SAXS by anisotropic nanoparticles	Experiment number: MA 1845
Beamline: ID13	Date of experiment: from: 22/01/2014 to: 26/01/2014	Date of report: 09/03/2015
Shifts: 12	Local contact(s): M. Burghammer	<i>Received at ESRF:</i>
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Report:

The response of magnetic nanoparticles to applied static and dynamic magnetic fields is the subject of intense research in view of its fundamental technological importance, *e.g.* for medical applications such as imaging and magnetic hyperthermia [1], or sensor applications [2]. The field-assisted self-assembly of shape-anisotropic nanoparticles in dispersions is further desired for liquid crystalline or optically anisotropic materials [3] and as a prerequisite for self-organization into long range ordered arrangements [4]. Our long term objective is to gain microscopic insight into the orientation dynamics of elongated nanoparticles in order to advance both the self-organization of shape anisotropic nanoparticles and their use as nanoprobe for viscoelastic properties of the surrounding matrices [5, 6]. Objective of this experiment was a demonstration of the capability of time-resolved small-angle X-ray scattering (SAXS) techniques for studying the reorientation of elongated magnetic nanoparticles in a dynamic magnetic field.

The weakly ferromagnetic hematite nanoparticles under study are spindle-shaped and known to orient with their principal axis perpendicular to an applied magnetic field [7,8], leaving two degrees of freedom for particle orientation. Time-resolved SAXS measurements were carried out at the ID13 beamline upon application of alternating and rotating magnetic fields with different frequencies ranging from 25 to 300 Hz, using the Maxipix detector in a stroboscopic mode. In order to enhance the weak anisotropy of the measured SAXS pattern, the isotropic SAXS measured

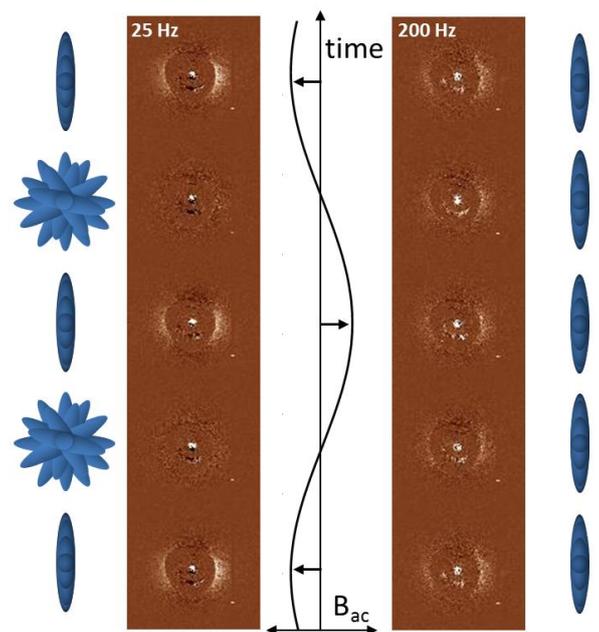


Fig. 1: Time-resolved SAXS in alternating magnetic fields. SAXS pattern measured at different states of the applied magnetic field are shown for frequencies of 25 and 200 Hz along with schematics of the nanoparticle

without magnetic field is subtracted from each pattern presented in Figure 1. For low frequencies, we clearly observe the time-resolved interplay of isotropic particle orientation and planar particle orientation perpendicular to the inducing field direction in vanishing and maximum applied field, respectively (Fig. 1, left side). With increasing frequency the particle reorientation in the inducing field is delayed, resulting in a quasi-static orientation of the anisotropic particle orientation throughout the entire period, shown exemplarily for 200 Hz in Fig. 1 (right side).

The transition in particle reorientation behavior beyond 150 Hz observed using time-resolved SAXS corresponds well to measurements of the rotational diffusion constants using dynamic light scattering and is in good agreement with theoretical estimates [9]. In addition to the planar orientation achieved using alternating magnetic fields, application of rotating fields promises a significantly higher degree of orientation. For frequencies between the characteristic rotational frequencies of the principal and equatorial axes, parallel alignment of the elongated hematite nanoparticles with their principal axis perpendicular to the rotation plane is expected. Further analysis of the obtained data is ongoing and will likely result in at least one major publication.

References

- [1] Q. A. Pankhurst, J. Connolly, S. K. Johnson, J. Dobson, *J. Phys. D: Appl. Phys.* 36, R167 (2003).
- [2] D. T. N. Chen, Q. Wen, P.A. Janmey, J.C. Crocker, A.G. Yodh, *Annual Review of Condensed Matter Physics* 1, 301 (2010).
- [3] G. M. Whitesides, B. Grzybowski, *Science* 295, 2418 (2002).
- [4] A. Ahniyaz, Y. Sakamoto, L. Bergström, *Proc. Natl. Acad. Sci. U.S.A.* 104, 17570 (2007).
- [5] S. Schrittwieser, F. Ludwig, J. Dieckhoff, A. Tschöpe, A. Guenther, M. Richter, A. Huetten, H. Brueckl, J. Schotter, *Small* 10, 407 (2014).
- [6] P. Bender, A. Tschöpe, R. Birringer, *J. Mag. Mag. Mater.* 346, 152 (2013).
- [7] L. Roeder, P. Bender, A. Tschöpe, R. Birringer, A. M. Schmidt, *J. Polymer Science Part B: Polymer Physics* 50, 1772 (2012).
- [8] C. Märkert, B. Fischer, J. Wagner, *J. Appl. Cryst.* 44, 441 (2011).
- [9] M. M. Tirado, J. G. de la Torre, *J. Chem. Phys.* 71, 2581 (1979).