ESRF	**Experiment title:** Reciprocity violation in diffuse nuclear resonant scattering?	**Experiment number:** SI-1794
Beam line: ID22N	**Date of experiment:** from: 02.12.10. to: 09.12.10.	**Date of report:** 02.03.12
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Report:

The reciprocity principle, which states that the interchange of source and detector does not change the scattering amplitude, cannot be derived from first principles and, therefore, is not necessarily fulfilled. The physical term `reciprocity' has been first mentioned by Stokes (1849) and numerous related publications cover the whole 20th century, as it is summarized in the review paper of Potton [1]. In our recent work [2] a general reciprocity theorem was formulated, which covers all cases of wave phenomena that can be represented by a Schrödinger equation.

The present study reports on an experimental investigation of reciprocity and its violation. Our aim was twofold: to demonstrate that reciprocity violation can be a remarkably strong effect, and to control easily whether reciprocity violation is present or missing.

The experimental method was nuclear resonant forward scattering (NRFS) of synchrotron radiation using two experimental arrangements of ferromagnetic scatterers. Both scatterers consist of two foils, each one being a 6 μm thick ^{57}Fe absorber uniformly magnetized in a field of 0.19 T of permanent magnets. The layers L_1, L_2 and L_3 are respectively magnetized into directions given by the polar angles (90°,0°), (90°,45°) and (135°,0°), where the coordinate system is chosen with z axis being parallel to the beam and y axis being parallel to the direction of the σ-polarization. The first scatterer S_1 was a combination of an L_1 layer and of an L_3 one, while the second scatterer S_2 was formed by an L_2 foil and an L_3 one. For each scatterer, the scattering spectrum was compared to that of the reciprocal scattering. The interchange of source and detector position was realized by a 180° rotation of the whole sample holder around the x axis of the coordinate system [2]. The four time spectra (count vs. time diagrams) shown in Figs. 1a-1b, 2a-2b were measured at the Nuclear Resonance side station ID22N using a Si(840) channel cut σ-analyzer.

The experimental results and the corresponding computer simulations made by our computer program [3] are both shown in Figs. 1, 2. The slight imperfection in the agreement between measurement and simulation is due to, and informs about, nonperfect uniformness in the foil thickness and the magnetic field inside. The experiment kept these undesired influences under control by using the high collimation and brilliance of the synchrotron beam which allows the usage of slits of as low as 0.5 mm of width selecting adequate homogeneous parts of both foils being 40 cm far from each others. The small size of the slits ensures that, after the 180° rotation of the sample holder, the same part of the foils is illuminated. The agreement of the experimental spectrum with that of the magnitude reciprocal counterpart setting–seen in Fig. 1–justifies the confidence that the recipocal situation was achieved to a high accuracy. We can see that the scatterer S_1 results in reciprocity in the measured intensities, while scatterer S_2 exhibits apparent nonreciprocity. The latter outcome is remarkable because of the large nonreciprocal effect: The ratio of intensities of direct and reciprocal scattering is almost 10^3 in certain time intervals (Fig 2).

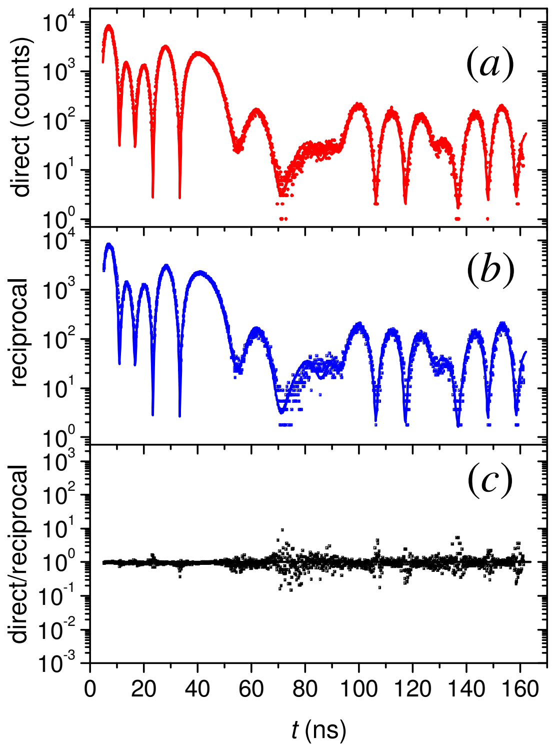

Fig. 1. (a) Measured and simulated NRFS of synchrotron radiation time spectra (count vs. time diagrams, dotted and solid lines, resp.) on scatterer S_1 considering σ→σ scattering. **(b)** Results for the reciprocal (source-detector exchanged) situation realized by the 180° rotation of the sample holder. **(c)** The amount of non-reciprocity, displayed as the ratio of the counts for the direct process (a) and of the reciprocal process (b). The ratio is found to be near the constant 1, which is the value when the intensities exhibit reciprocity. Slight deviations of the ratio from 1 can be seen in the regions of the minima of the beatings, where the count rates are low and statistical errors are significant.

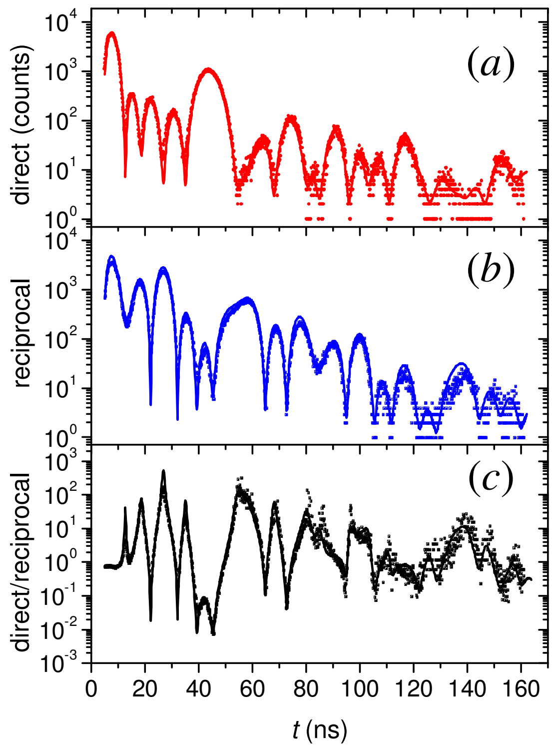

Fig. 2. (a) Measured and simulated NRFS of synchrotron radiation time spectra (count vs. time diagrams, dotted and solid lines, resp.) on scatterer S_2 considering σ→σ scattering. **(b)** Results for the reciprocal (source-detector exchanged) situation realized by the 180° rotation of the sample holder. **(c)** The amount of non-reciprocity, displayed as the ratio of the counts for the direct process (a) and of the reciprocal process (b). Almost three order of magnitude non-reciprocity in certain time intervals is found.

In summary, we have realized a (magnitude) reciprocal and a nonreciprocal experimental arrangement of magnetized α–^{57}Fe foils, which had neither time reversal invariance nor 180°–rotational symmetry. Using nuclear resonant scattering of synchrotron radiation, depending on the easily adjustable experimental geometry, reciprocity, and also three orders of magnitude large nonreciprocity, was experimentally observed in the intensities, in full agreement with the theoretical expectations. The presence of magneto-optic Faraday effect does not automatically lead to nonreciprocity. Further applications in the field of γ -optics are expected, as nonreciprocal devices belong to an important class of optical components.

References

[1] R.J. Potton, Rep. Prog. Phys **67** (2004) 717.
[2] L. Deák and T. Fülöp, Ann. Phys. (N.Y.) (2012)
[3] H. Spiering et al., Hyp. Int. **125** (2000) 197.