Resonant neutron reflectometry of magnetic nanoheterostructures

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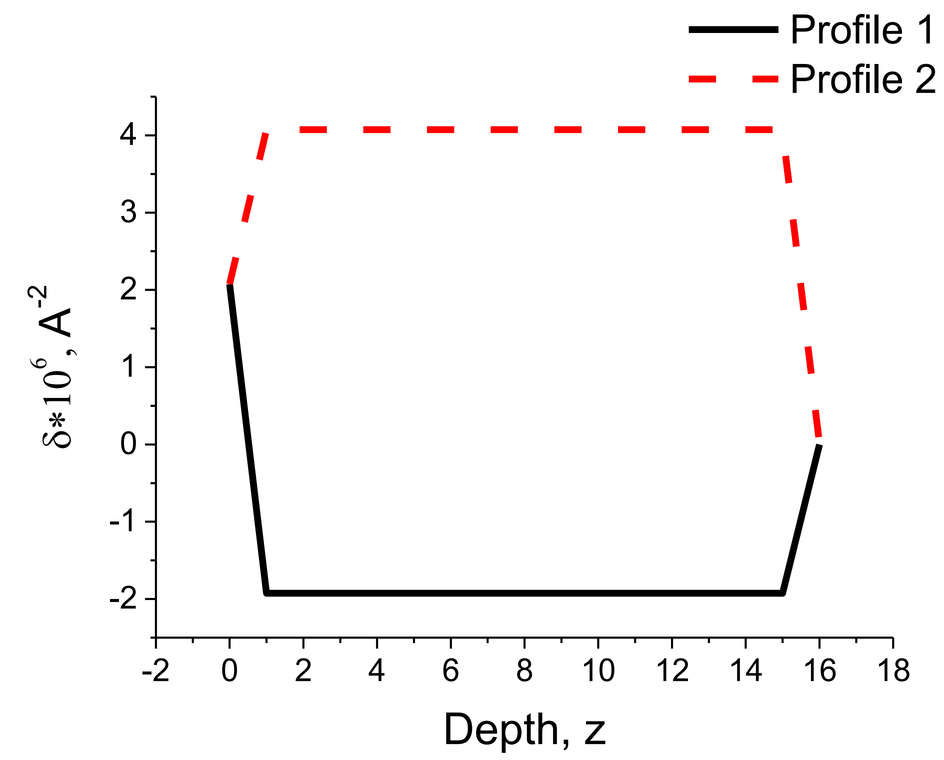
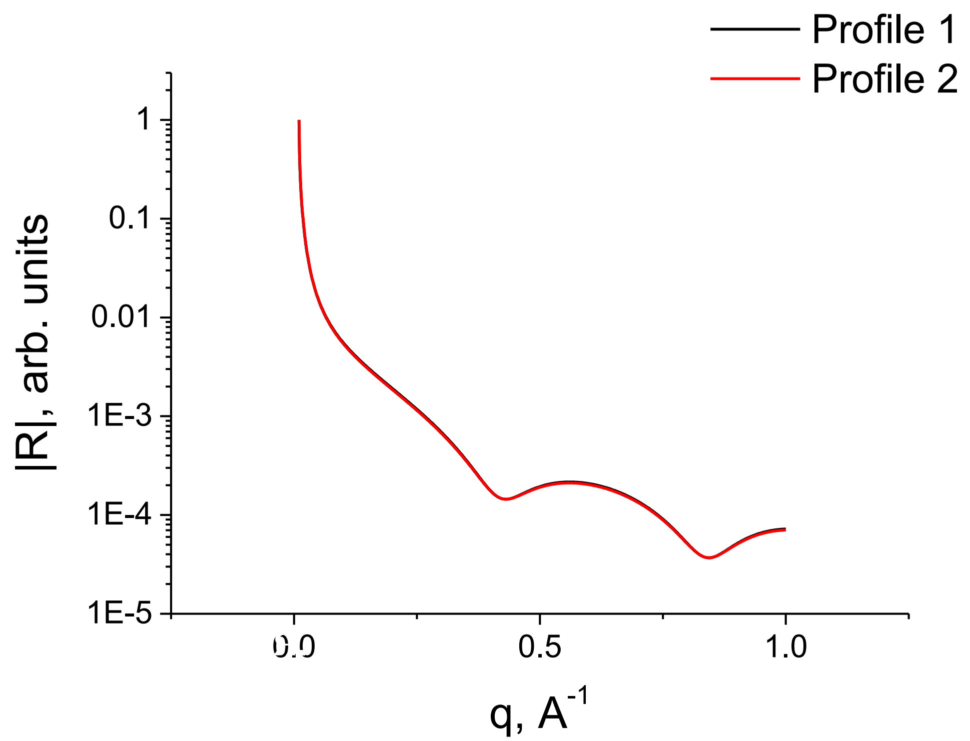
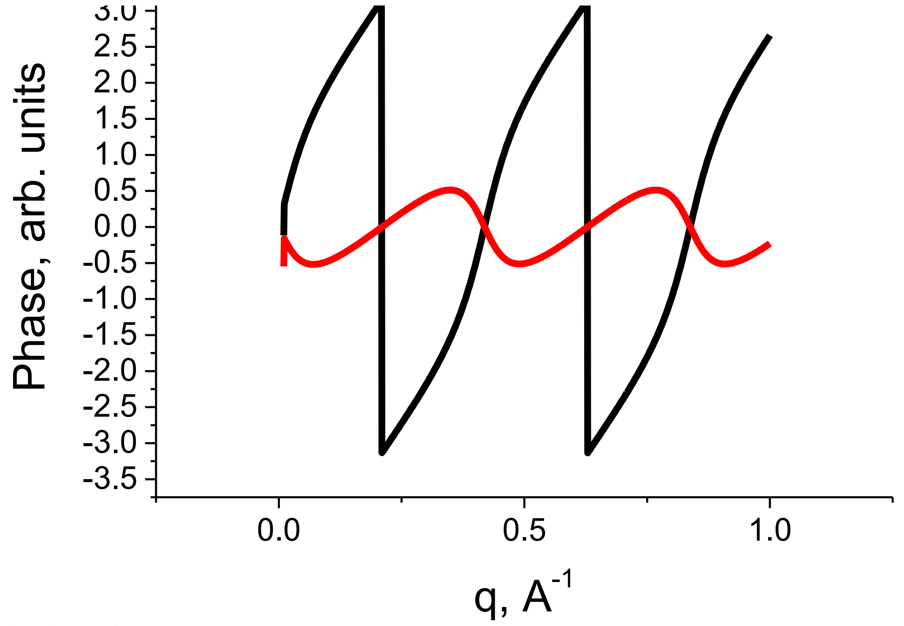




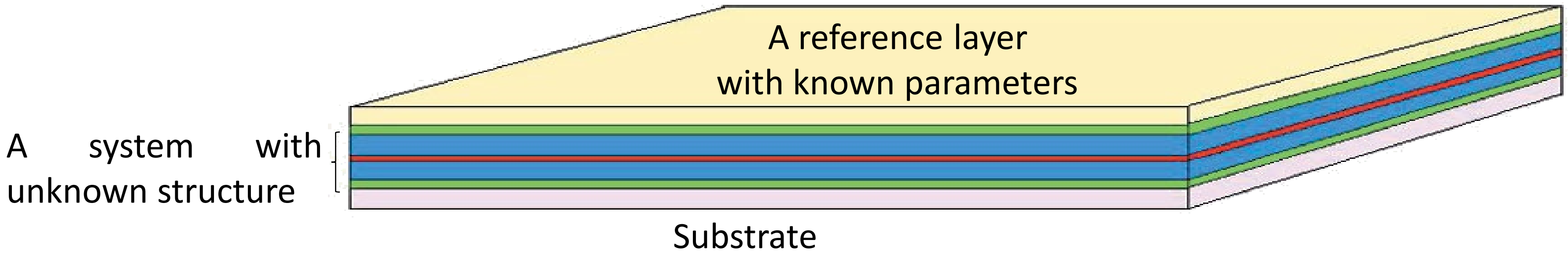


The reflection amplitude: $R = |R|e^{i\varphi}$

The modulus $|R|$ may be the same for different profiles, the phase φ always depicts the differences.

But it is impossible to obtain information about the phase in the experiment.

The **reference layer** method is one of the approaches to solving the phase problem in neutron reflectometry

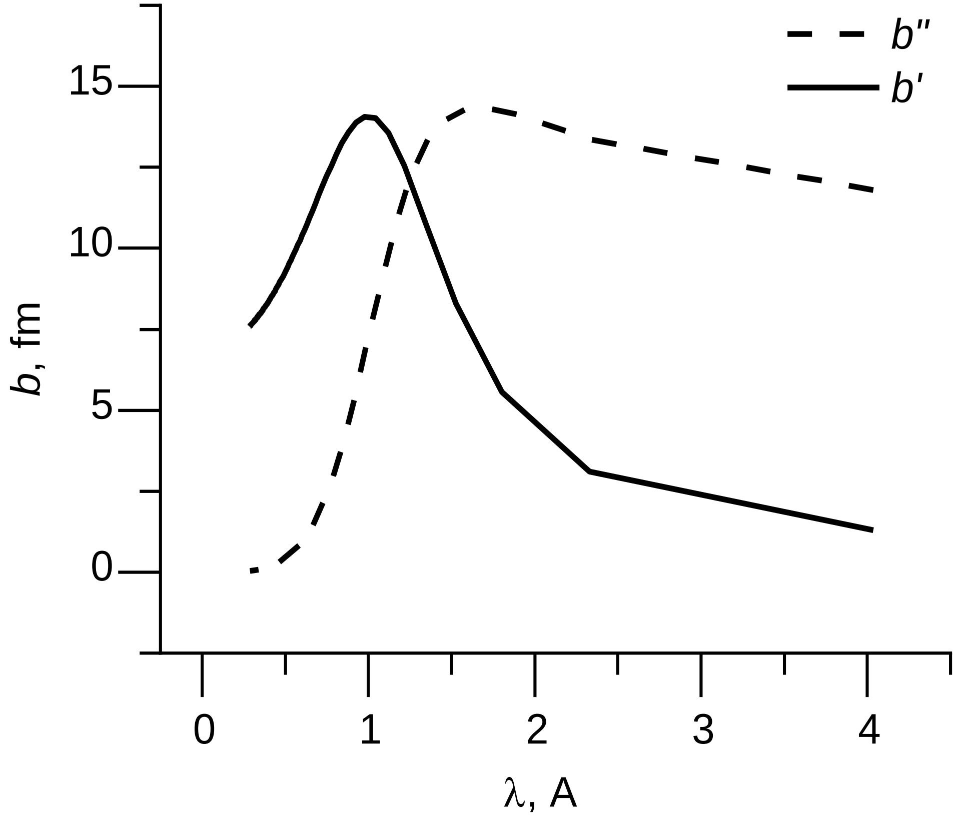


In the original works [*C. F. Majkrzak, N. F. Berk. Exact determination of the phase in neutron reflectometry. Physical Review B, V. 52 № 15, pp. 10827-10830 (1995); V. O. de Haan, A. A. van Well, P. E. Sacks et al. Toward the solution of the inverse problem in neutron reflectometry. Physica B, V. 221, pp. 524-532 (1996)*] it was proposed to use a magnetic reference layer to study non-magnetic systems.

The use of a Gd reference layer makes it possible to study magnetic systems as well, since:

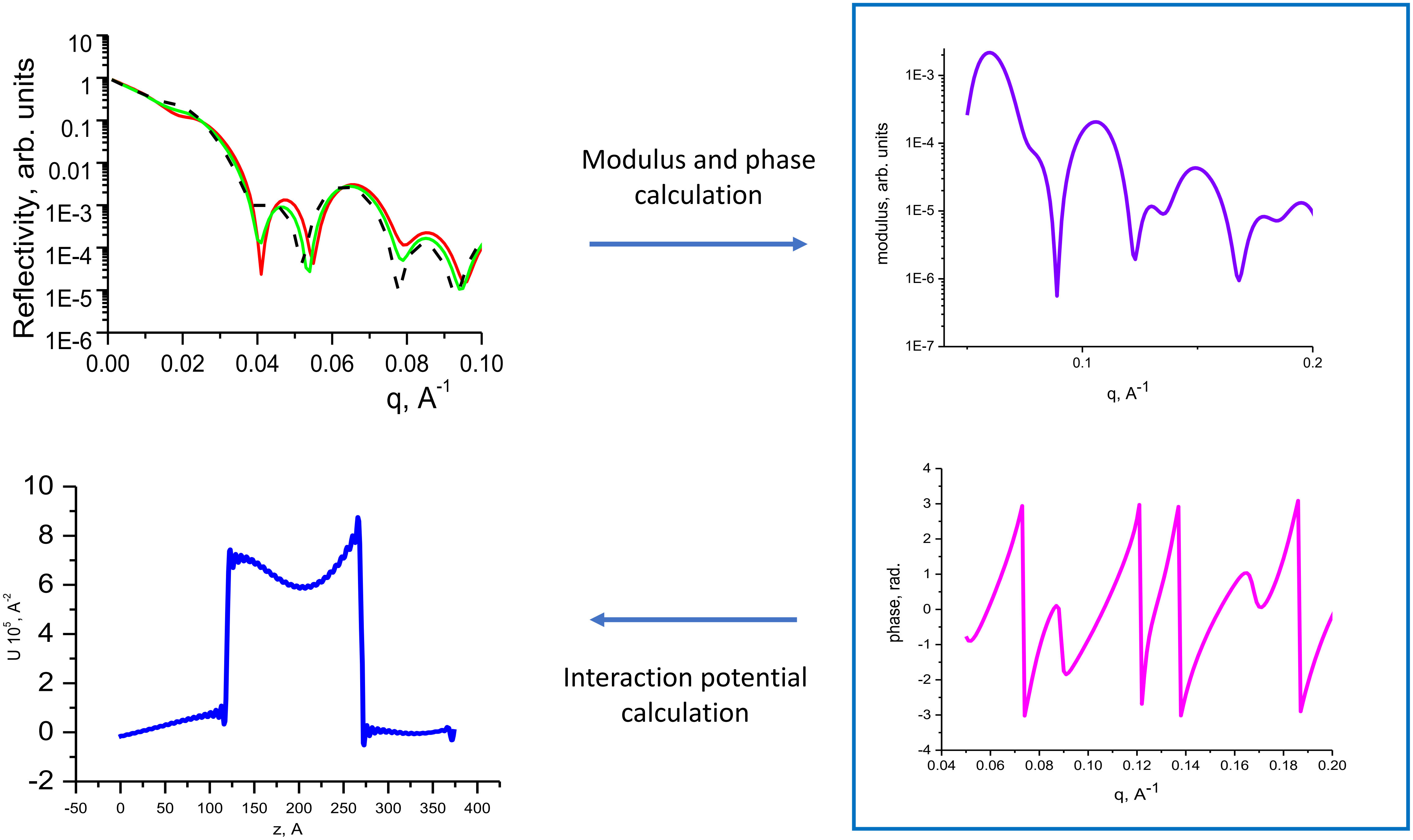
1. The change of the scattering characteristics of Gd occurs without the application of a magnetic field, by changing the wavelength of the incident neutrons.
2. At room temperature, Gd is paramagnetic and does not have magnetic interactions with neutrons.

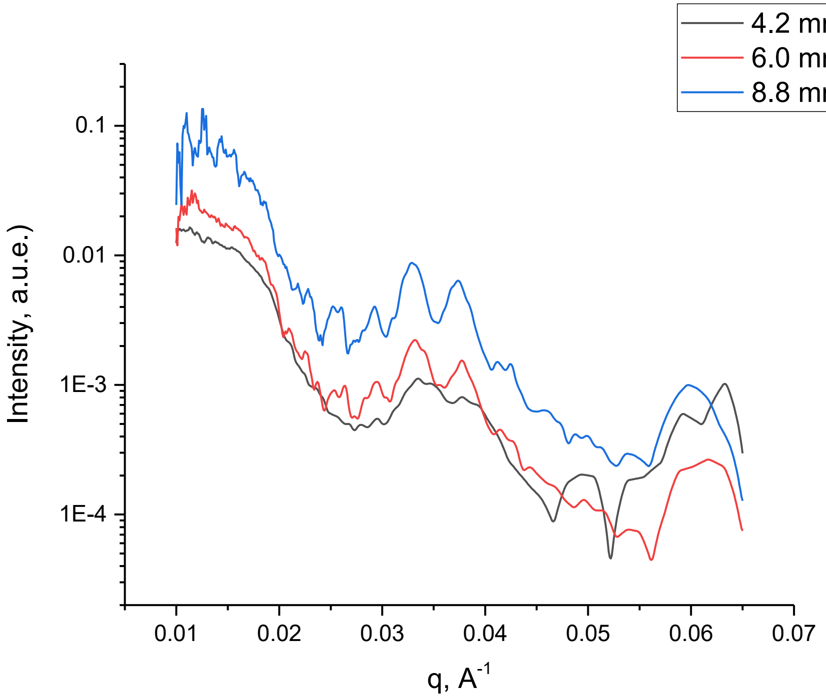
Two gadolinium isotopes, ^{155}Gd and ^{157}Gd, have a resonant interaction with thermal neutrons and a large absorption cross section. Due to their rather high content in natural gadolinium (15% and 10%, respectively), its scattering length significantly depends on the wavelength of neutrons. The method of resonant neutron reflectometry implies the application of these properties in the experiments.

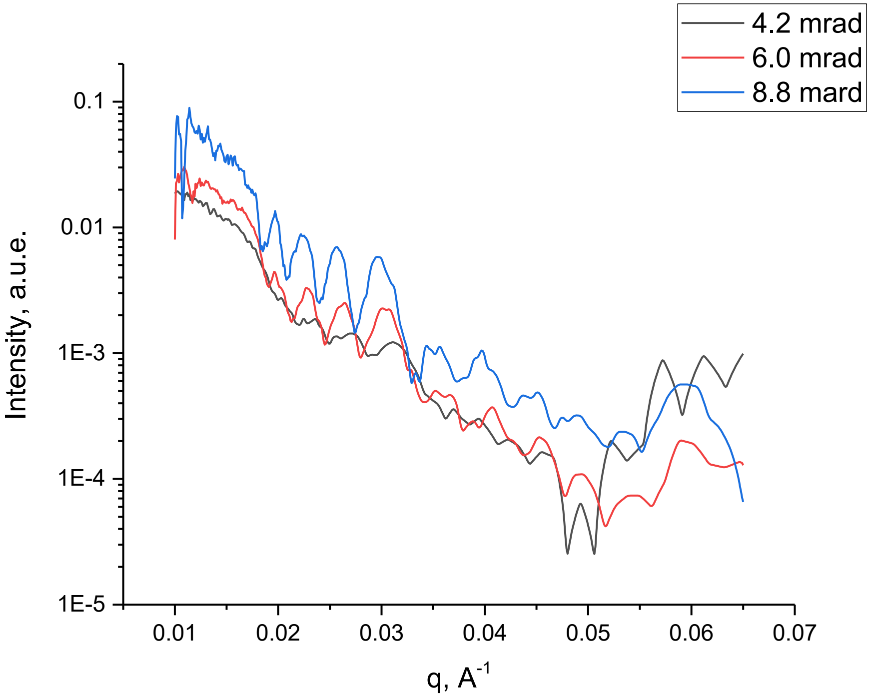


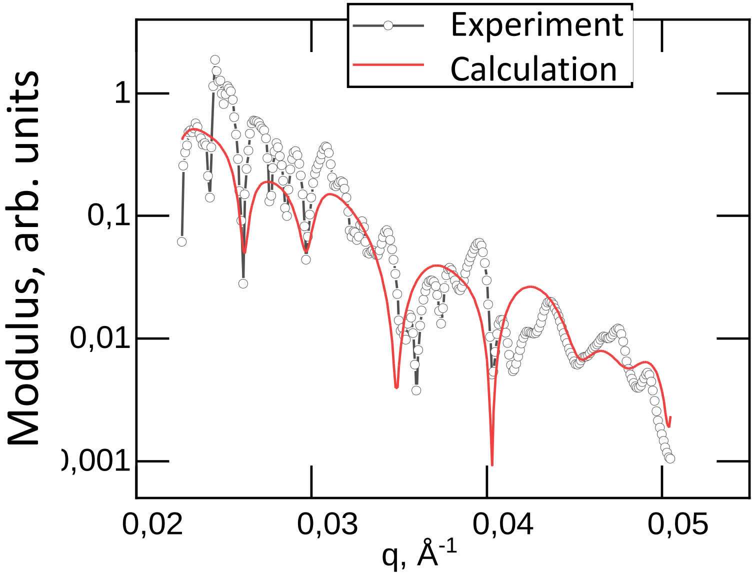
Experimental possibilities:

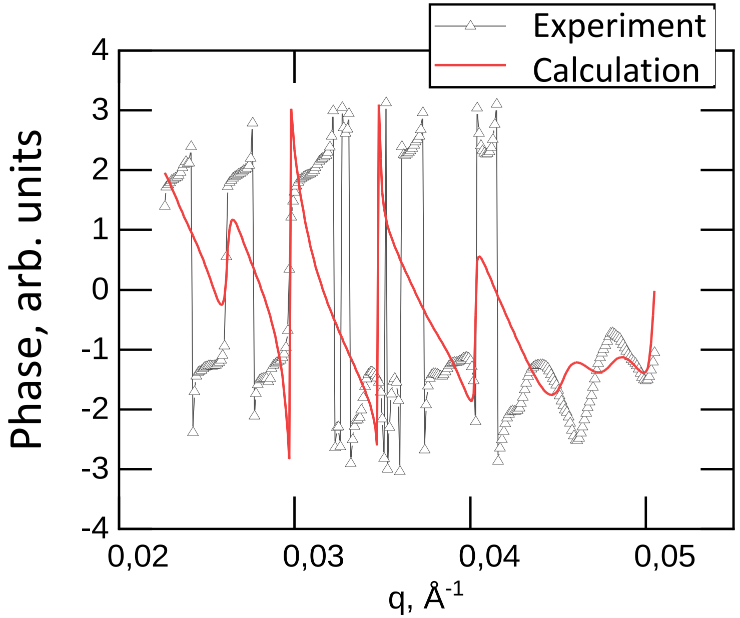
1. It is possible to change the scattering properties of a sample, containing gadolinium, by carrying out experiments at different neutron wavelengths.
2. Gadolinium can be used as a neutron absorber with a very high absorption coefficient.
3. Since the resonant neutron absorption in gadolinium caused secondary gamma radiation, this effect can be used for additional analysis of the sample.


Reflectivity, arb. units
q, A-1
Modulus and phase calculation
modulus, arb. units
q, A-1
phase, rad.
q, A-1
Interaction potential calculation
U 10^5, A^-2
z, A









Experimental approbation

Al_2O_3//Cr(100 Å)/[Fe(90 Å)
/Cr(11 Å)]$_{x12}$/Gd(50 Å)
/Cr(50 Å)

«--» scattering channel

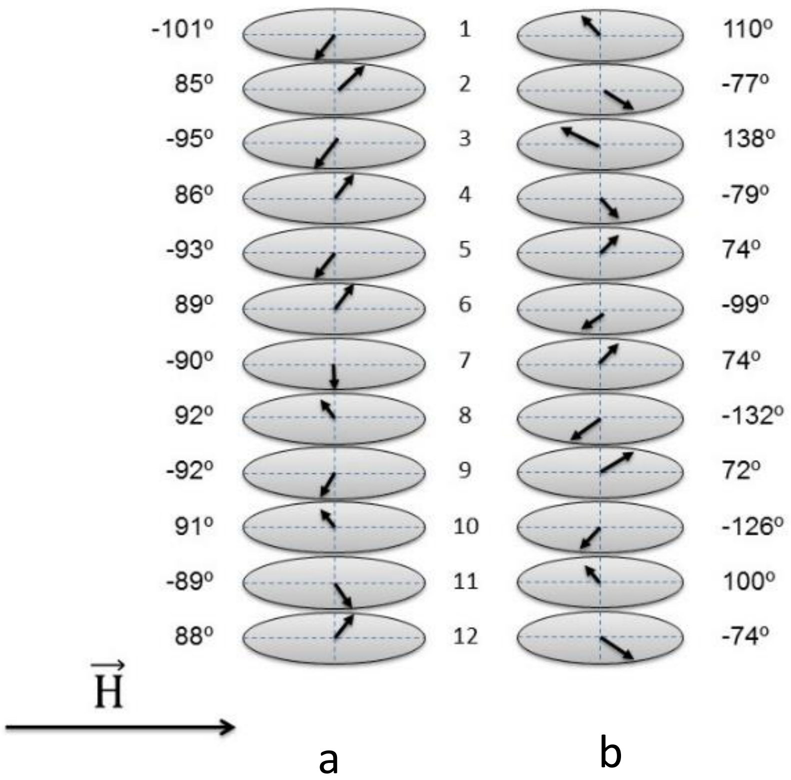
RESULTS:

Al_2O_3//Cr(133 Å)/[Fe(94 Å)/Cr(10 Å)]$_{x12}$/Gd(53 Å)/Cr(25 Å)/Cr_2O_3(24 Å) – standard fitting procedure

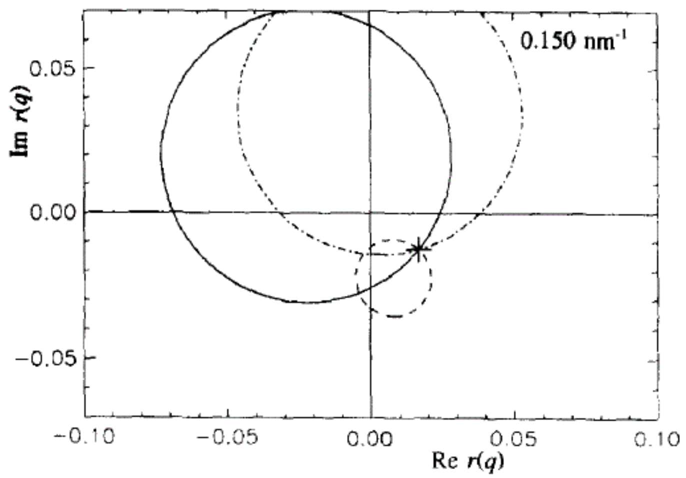
Al_2O_3//Cr(86 Å)/[Fe(94 Å)/Cr(13 Å)]$_{x12}$Gd(50 Å)/Cr(25 Å)/Cr_2O_3(25 Å) – reference layer method

The angles between the moments of neighboring layers Fe, deg

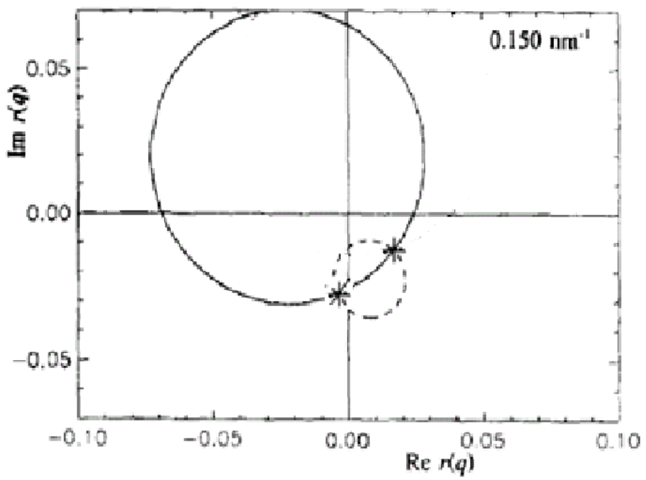
Neighboring Fe layers	Reference layer method	Standard fitting
1-2	174	173
2-3	180	145
3-4	179	143
4-5	179	153
5-6	178	173
6-7	179	173
7-8	178	154
8-9	177	156
9-10	178	162
10-11	180	134
11-12	177	174



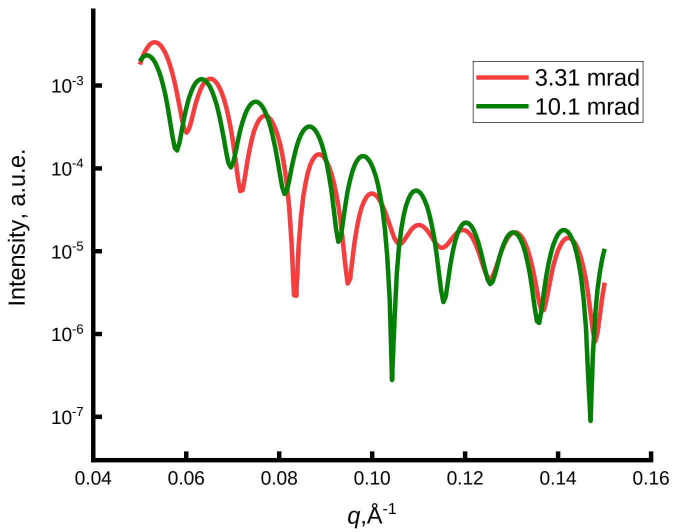
Orientation of the Fe layers magnetic moments: a – reference layer method; b – standard fitting procedure.

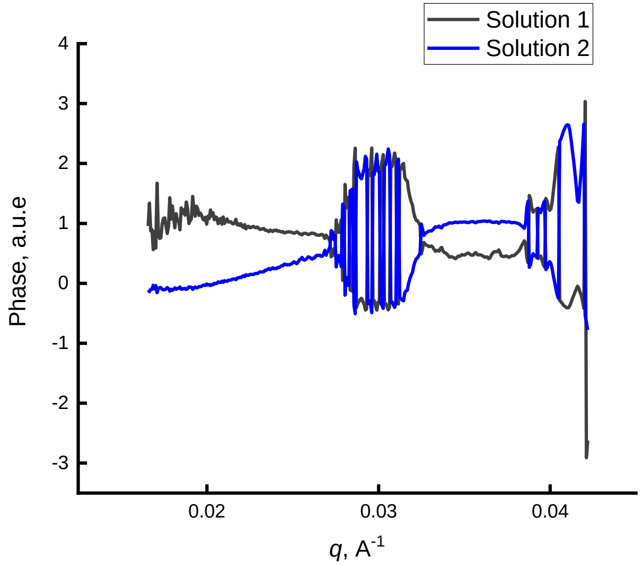


Case of three experiments – unique solution

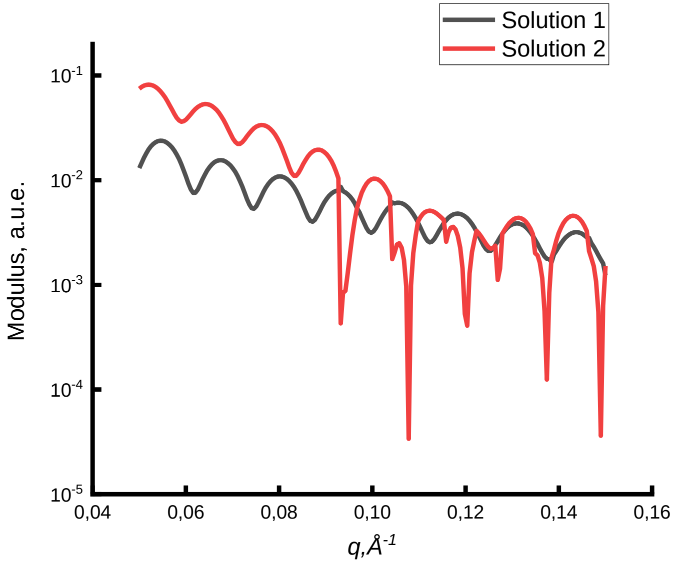


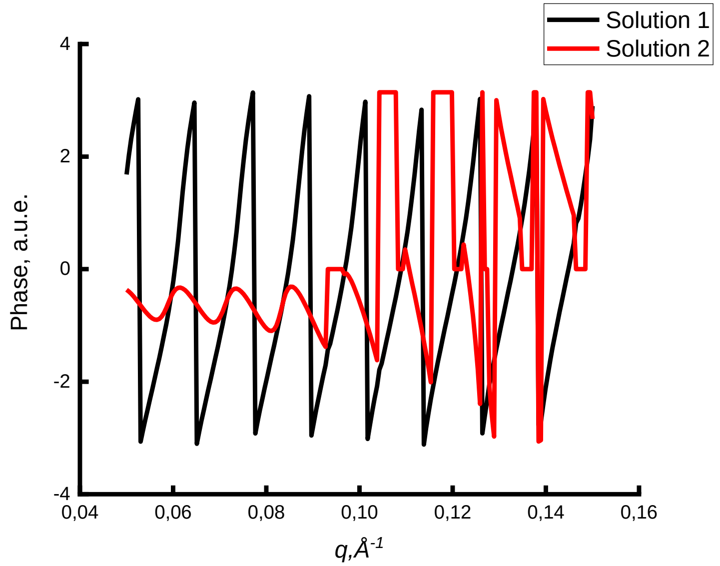
Case of two experiments – two different solutions





Example of mixed solutions (phases)





Conclusions

- A method of resonant neutron reflectometry is proposed to determine the complex reflection amplitude.
- It is shown that it is enough to conduct two experiments.
- The method has been successfully tested on samples of metal superlattices.
- Currently, it is of great interest to conduct an experiment on a wide range of wavevector transfer q, which requires a high intensity of the primary beam. This will improve the results quality and give possibility to apply model-independent methods to calculate the interaction potential. Such an experiment can be carried out on a multipurpose reflectometer at CSNS.