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Basic features of the upgraded S18 neutron interferometer set-up at ILL

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Abstract

The perfect crystal interferometer instrument S18 at the Institute Laue-Langevin (ILL) in Grenoble has been upgraded to allow more advanced neutron optics experiments for fundamental, nuclear and condensed matter physics. The new supermirror guide together with the multipurpose monochromator provides considerably higher intensities in a wide wavelength region. The optimal use of neutrons is obtained by a nondispersive arrangement of the monochromator and the interferometer crystals. This also allows to obtain completely polarised beams using permanent magnetic prism deflection. An additional third analyzer axis permits novel postselection experiments concerning momentum distribution and polarisation analysis of the interfering beams. Several types of large perfect crystal interferometers are available for different applications. The system can be configured as an advanced high-resolution Bonse–Hart small angle scattering camera. The results of various test measurements concerning intensities, interference contrast, long-term stability, the accessible wavelength range and the basic features as a SANS camera will be presented. Various proposals for experiments will be discussed as well. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Neutron optics; Neutron interferometer; Ultra small angle neutron scattering (USANS)

1. Introduction

Perfect crystal neutron interferometry has been introduced in 1974 by test measurements at a 250 kW TRIGA reactor in Vienna [1,2]. It provides widely separated coherent beams and reasonable intensities due to the nondispersive action of the reflecting crystal plates and the possibility to use rather large beam cross sections. The perfect crystal interferometer technique has been developed before for X-rays [3] and profits from the availability of large perfect silicon crystals. In a joint undertaking between the Atominstitut in Vienna and the University of Dortmund and according to an invitation of H. Maier-Leibnitz, the director of the ILL at that time, a prototype interferometer was installed at the high flux reactor in Grenoble [4]. After its successful operation the ILL, the University Dortmund and the Atominstitut Vienna installed the S18 interferometer set-up, used afterwards for numerous experiments (e.g. Refs. [5–10]). A basic feature of that installation

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was the use of a perfect crystal monochromator in nondispersive position with the interferometer crystal, which provides highest intensity and a very narrow rocking curve but also results in a high sensitivity to vibrations and thermal drifts. On the other hand, polarised neutron experiments could be easily performed by using prism deflection between the monochromator and the interferometer crystal [11].

More recently the need for postselection experiments became obvious [12] and therefore the upgraded instrument described here has a third axis for routine momentum and polarisation postselection experiments. The mechanical and the electronic control parts have been as well renewed taking into account the progress of technology in that fields. In parallel to the interferometer set-up a perfect crystal Bonse–Hart small angle scattering camera has been installed [13], which takes advantage of a new tail suppression method [14].

2. The instrument

A schematic view of the instrument is shown in Fig. 1. The optical bench, which is isolated against vibrations by a system of springs and oil dampers, has been extended with a platform to carry the third axis. The monochromator is placed directly in front of the supermirror guide H25 which provides a large divergency of the beam and therefore considerably higher intensities than the previous set-up. A rather large range of wavelengths is accessible by variations of the Bragg angle and by using different reflecting planes of a properly cut silicon monochromator block. The fine adjustment system of the nondispersive arrangement is achieved by an advanced piezodrive which has an adjustment range of $\pm 3.2^\circ$ and an accuracy of 0.036 sec of arc. Symmetrically and skew symmetrically cut interferometer crystals with beam separations up to 5 cm, enclosed areas of 100 cm^2 and flight paths of 25 cm are available. Phase shifters and samples can be introduced and adjusted by supports on the optical bench and from a separate sample platform mounted above the interferometer. A Bonse–Hart ultra-small angle scattering camera with additional tail supression is an integral part of the instrument.

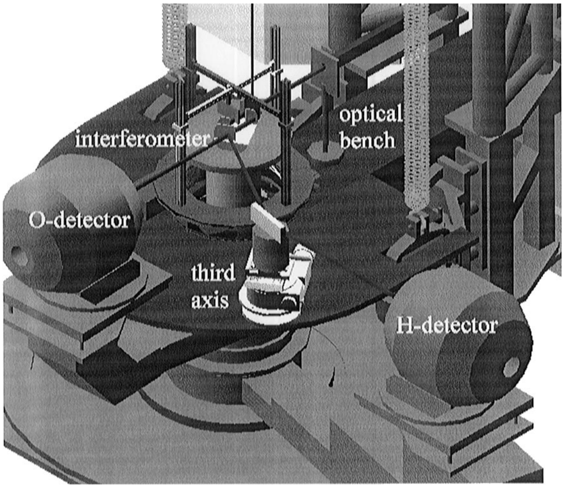

Fig. 1. Cut away drawing of the new S18 interferometer set-up.

Polarised neutrons can be adapted by magnetic prism deflection within the air gapes of two prism-shaped permanent magnets placed between the monochromator and the interferometer. Characteristical parameters are summarised in Table 1.

The instrument electronics, including the motor controller for up to 50 stepper motors, the camac readout crates, the piezo drive and the vibration damping system is controlled by five networked personal computers running LabView. Most of the stepper motors have been equipped with high-resolution absolute angle and displacement encoders.

A high-resolution position sensitive detector can be used to analyse the beam profiles or for neutron tomography and radiography experiments.

3. Test measurements

Various test measurements concerning intensity contrast and polarisation have been performed. Fig. 2 shows an interference pattern obtained with a rather large slit opening of 1×1 cm^2. The phase stability still depends on temperature gradients and the vibration level. Various improvements are under discussion. Nevertheless, for future developments vibration isolated, thermally stabilized and clean room areas are recommended to make full use of the possibilities created by neutron

Table 1
Typical parameters of the new interferometer set-up

Monochromator	
Two crystals mounted on a computer controlled support	
Type	Silicon bloc perfect crystal
Reflecting planes	[111],[220],[113],[115],[117],[331],[335],[551],[400]
Wavelength range	$0.6\ \text{Å} < \lambda < 5\ \text{Å}$
Bragg angle range	$20^\circ < \vartheta_B < 55^\circ$
Type	Silicon channel-cut perfect crystal
Reflecting planes	[220]
Wavelength range	$1.6\ \text{Å} < \lambda < 2.9\ \text{Å}$
Bragg angle range	$25^\circ < \vartheta_B < 50^\circ$
Beam area	$2 \times 4\ \text{cm}^2$
Interferometer	
Large perfect Si crystal interferometers of different designs (symmetric, skew symmetric)	
Coherent beam-separation	2–5 cm
Enclosed area	up to $100\ \text{cm}^2$
Path lengths	14–21 cm
Performance of a [220] skew symmetric interferometer at 1.84 Å with beam area *$1 \times 1\ \text{cm}^2$*	
Flux in front of interferometer	$16\,000\ \text{n cm}^{-2}\ \text{s}^{-1}$
Flux in O + H beams	$7000\ \text{n cm}^{-2}\ \text{s}^{-1}$
Contrast in O beam	$> 73\%$
Wavelength spread	$\Delta\lambda/\lambda = 2.1\%$ (FWHM)
Beam divergency	0.23°
Ultrasmall-angle scattering	
Bonse–Hart camera with two channel-cut perfect crystals	
Type	6-fold [220] Bragg reflection with tail suppression
Peak intensity	$8000\ \text{n cm}^{-2}\ \text{s}^{-1}$
Angular resolution	0.01″ (0.04″ with absolute encoder)
Momentum resolution	$1.5 \times 10^{-5}\ \text{Å}^{-1}$
Signal-to-background ratio	10^5
Polarised neutron option	
Polariser type	Double magnetic prism deflection with 116° apex angle
Beam area	$1 \times 1\ \text{cm}^2$
Polarisation	$> 98\%$
Prism polarisation separation	4.0″ (two prisms at 20° asymmetry angle and 1.9 Å)

interferometry and neutron quantum optics in general.

Fig. 3 shows a typical ultrasmall angle scattering pattern from a silicon plate having regular holes with a depth of 90 μm and a distance of 2.1 μm. Up to thirty interference orders have been observed and further improvements are anticipated. The rather low background should be mentioned.

Test measurements with the permanent magnetic prisms showed the expected separation of the two spin components by 2.2 sec of arc for 1.9 Å neutrons.

4. Forthcoming experiments

Due to the reactor refurbishment and some other delays the S18 interferometer set-up was not in operation since 1991. Therefore, many proposals for new experiments have accumulated. Some of them will be realized within the next year. Here we give some representative examples of such forthcoming experiments where preparatory work has been started.

- Test of Fourier reflectometry and Fourier small angle scattering

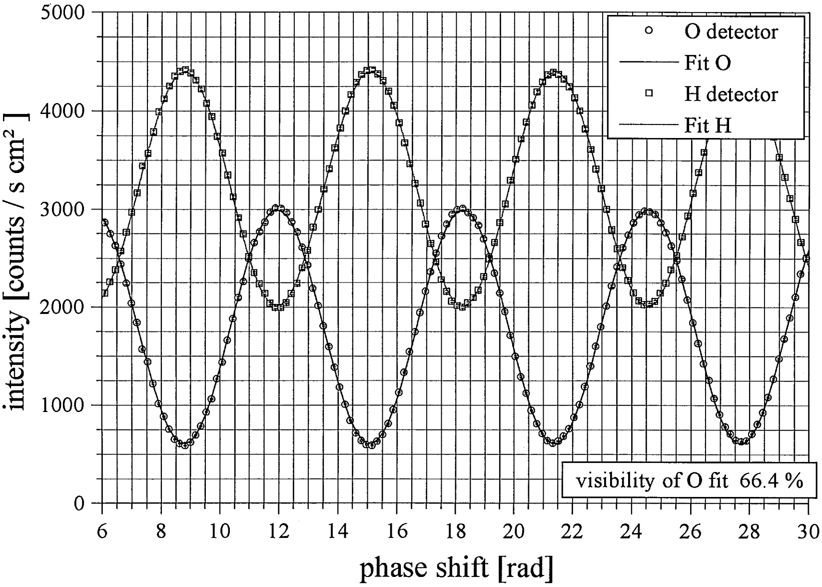

Fig. 2. Typical interference pattern obtained with a wide incident beam.

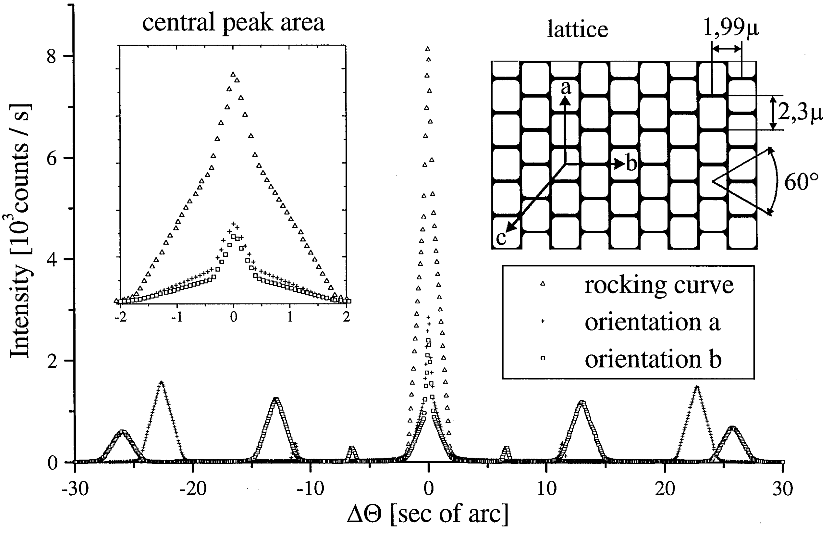

Fig. 3. Ultrasmall angle scattering pattern from a structured silicon plate.

- Scattering length measurement of polarised ^{3}He
- Dephasing effects on Schrödinger cat-like states
- Hydrogen and deuterium detection in metals
- Phase tomography and topography
- Phase shift due to narrow channels
- Gravity quantization of neutrons
- Triple Schrödinger cat-like states in four plate interferometry
- Polarised neutron delayed choice experiments
- Absorber fluctuations in highly absorbing phase shifters

5. Summary

The upgraded S18 interferometer set-up is now ready for operation and it shows considerable improvements compared to the previous instrument. Intensity is increased by a factor of five, a third axis for postselection experiments is available and a state-of-the-art electronic control system has been integrated. The instrument is operated as a CRG-C instrument, which means that it is owned by the Atominstitut in Vienna and access has to be arranged through these channels. We are convinced that neutron quantum optics will become an even more important field of research, stimulated also by the advent and progress of atom quantum optics [15]. Perfect crystal neutron optics has shown that energy resolutions up to 10^{-19} eV can be achieved by coupling coherent beams to resonance flippers [9] and momentum resolutions can be achieved up to 10^{-7} A^{-1} by using the central peak of multiple Laue–Laue reflections [16]. Quantum optics using artificially produced lattices and optical components will become another interesting field of research (e.g. Refs. [17,18]).

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