Experimental report

05/04/2019

Proposal: **3-15-90**

Council: 4/2017

Title: Precision studies of the neutron whispering gallery with a MgF2 concave mirror (continuation).

Research area: Physics

This proposal is a continuation of 3-15-85

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Samples: MgF2

Instrument	Requested days	Allocated days	From	To
D17	5	3	22/04/2018	25/04/2018

Abstract:

The neutron whispering gallery effect was observed with cold neutrons passing in the vicinity of a concave polished mirror. This phenomenon could be considered, within the quantum-mechanical equivalence principle, as an analog to gravitational quantum states of neutrons. An important motivation for precision studies of the neutron whispering gallery effect consists of its high sensitivity to extra spin-(in)dependent fundamental short-range interactions. With this (second in a series) proposal, we continue experiments aiming at measuring >100 lines in the whispering-gallery pattern with the uncertainty of <10% of the line separation. In the first experiment (3-15-85) with MgF2 mirror, we confirmed qualitatively the expected interference pattern and the estimated statistical sensitivity. Now we apply for beam time at D17 in order to calibrate the absolute wavelength scale (using two independent methods: a) with a compact ultra-precise time-of-flight device developed earlier for GRANIT, b) using Bragg reflection from mono-crystals). Also we will investigate quantitatively eventual false effects associated with residual impurities on surface. The mirror is available and characterized.

Neutron whispering gallery [1, 2] is an analog of neutron gravitational quantum states [3], where an effective centrifugal acceleration replaces gravity. An important motivation for precision studies of neutron whispering gallery consists of its high sensitivity to extra spin-(in)dependent fundamental short-range interactions [4, 5]. Fig. 1 illustrates schematically this phenomenon.

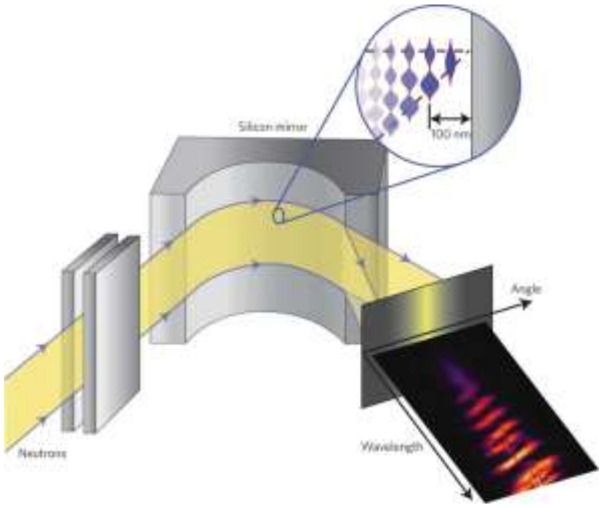

Fig. 1. Schematic demonstration of the neutron whispering gallery. This figure is copied from [H. Rauch, Nature Physics 6 (2010) 79].

In this (second in the series) experiment, we observed ~10^2 interference lines in whispering-gallery patterns in several configurations. In order to define their positions (wavelengths) with the accuracy of ~10^{-1} relative to a typical value of the lines separation (thus, with the absolute accuracy of ~10^{-3}), we performed precise calibration of the neutron wavelength scale at the D17 instrument. This precision is required for improving constraints for extra spin-independent short-range forces at distances one – a few nanometers.

As in the preceding experiment 3-15-85, whispering-gallery interference patterns were measured using a single-crystal MgF_2 cylindrical mirror. The mirror radius was equal 30.008(1) mm. The width of polished area was equal 20.40(1) mm. The total deviation angle was equal 39.7427(1) degrees. The tangential slope error (RMS) was <5 µrad. The sagittal slope error (RMS) was <25 µrad. The mean roughness of the curved surface was <8 Å (RMS). The mirror surface was exposed to air. Qualitative tests were performed to confirm that the interference pattern does not move noticeably when the mirror surface is heated to get rid of thin water/organic films on the surface. This is expected for the material used and was also confirmed in preparatory experiments done in advance. Note, however, that we will have to return to this study at a higher level of accuracy in future experiments.

The quality and parameters of this mirror allowed us to observe ~10^2 lines in whispering-gallery patterns as projected. Fig. 2 shows an example of such an interference pattern.

The accumulated statistics corresponded to the projected accuracy of ~10^{-1} of the line separation. Systematic effects associated with the uncertainties of surface potential at short distances and parasitic transitions between whispering-gallery quantum states were small enough and could not be clearly observed at the achieved level of statistical sensitivity. This conclusion follows from the fact that the experimentally observed interference pattern coincided, within the statistical accuracy, with the simulated theoretical interference pattern. However, this conclusion depends, in the general case, on the calibrations of horizontal and vertical axes in Fig. 2 and can be drawn only after performing the calibration procedures described below.

While the accuracy of measurements of the scattering angle is by far sufficient at the present level of statistical accuracy of this experiment and will not be discussed, the neutron wavelength calibration is of major importance. The absolute wavelength calibration was performed using two independent methods: 1) using mono-crystals installed instead of the mirror, 2) placing the detector at different distances and thus scaling the size of the interference pattern.

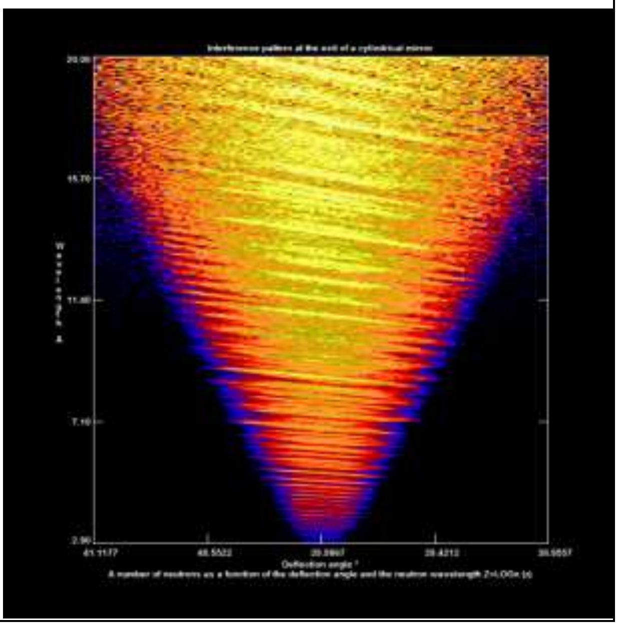

Fig. 2. An example of interference whispering-gallery pattern.

The first method of calibration of the neutron wavelength scale used Bragg scattering of neutrons in crystals installed in the sample holder instead of the cylindrical mirror. As it is standard and used in many experiments, we do not describe it here in detail.

The second method of calibration of the neutron wavelength scale is specific for this experiment and based on measurements of the same whispering-gallery interference pattern with the D17 position-sensitive detector placed at different distances from the sample. While the time-of-flight distances can be measured experimentally with a limited accuracy, the precision of translations of the detector are extremely high (of the order of 10 μm). Also, the plane of the position-sensitive detector is poorly defined, as most probable depth of neutron detection depends on the detector parameters and the neutron velocity. On the other hand, this effect is the same for different positions of the detector.

We performed measurements at 4 different detector positions (3.0 m, 2.5 m, 2.1 m and 1.5 m from the center of the cylindrical mirror). Although the total time-of-flight distance changes only by a limited fraction (taking into account the distance from the chopper to the cylindrical mirror in front of the mirror), the absolute accuracy of such calibration is very high. The reason consists of the fine interference structure of the pattern. We assume linear scaling of the interference pattern and fit the scaling parameter from the data. In order to use full statistics in the interference pattern, we calculate Xi-2 for the comparison of scaled interference patterns and search for the global minima. Fig. 3 presents 4 interference patterns measured at different detector distances.

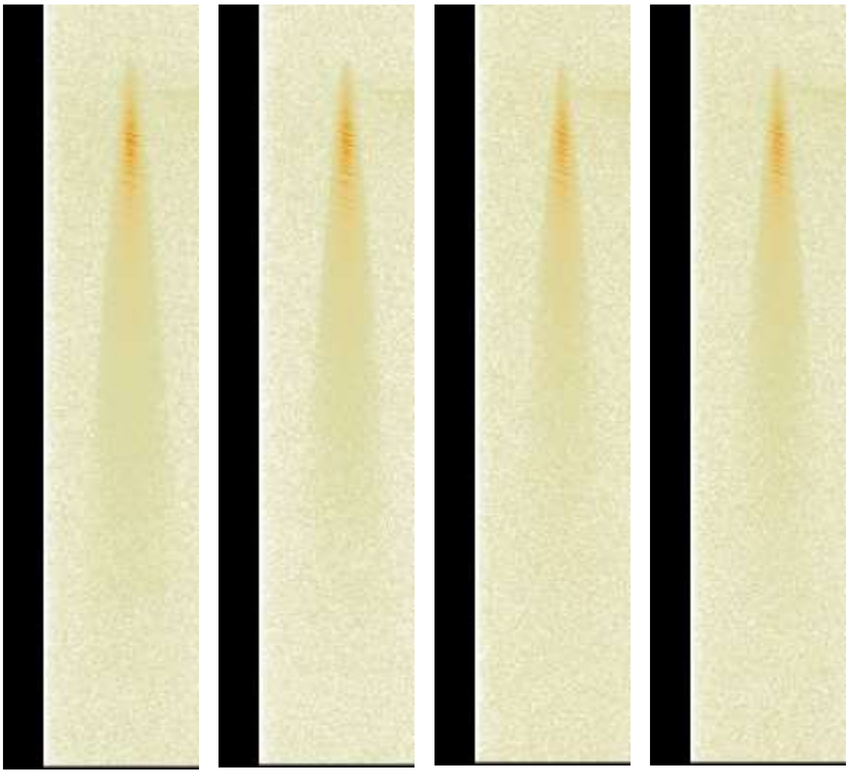

Fig. 3. Whispering-gallery interference patterns measured in the D17 position-sensitive detector installed at different distances between the detector and the cylindrical mirror: 3.0 m, 2.5 m, 2.1 m and 1.5 m.

For both methods, the absolute accuracy of the performed calibrations was higher than 10^{-3}. The results of the two independent methods were consistent within the statistical accuracy.

The next step in this experimental program will consist of performing even more precise measurements at a selected neutron energy monoline at SuperAdam instrument. The wavelength of this monoline will be calibrated using a compact time-of-flight device developed for the GRANIT instrument. This measurement will provide a “slice” of the interference pattern measured at D17. Results of this measurement will be used for even better calibration of data at D17.

References

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