Experimental report

07/10/2019

Proposal: **3-15-92**

Council: 10/2018

Title: Measurement of neutron whispering galley at monochromatic neutron beam

Research area: Nuclear and Particle Physics

This proposal is a new proposal

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Samples: MgF2 cylindrical mirror

Instrument	Requested days	Allocated days	From	To
SUPERADAM	7	5	10/07/2019	15/07/2019

Abstract:

We continue a series of precision measurements of neutron whispering gallery motivated by the possibility to provide competitive constraints for fundamental short-range forces. On the other hand, this phenomenon can serve at certain conditions to study surface. Currently, the precision is limited by the neutron wavelength calibration, which is of the order of 10^(-3) in the time-of-flight mode of measurement at D17 instrument. We are going to use a monochromatic neutron beam at SuperADAM to further improve the precision of this calibration. Preliminary measurement showed that the count rate in the monochromatic mode at SuperADAM is sufficiently high, the mean wavelength of 5.2A corresponds nicely to our range of interest and the spectrum band width of 0.5% should allow to resolve the interference lines on one hand and provide high statistics on the other hand. The proposed experiment consists of a few measurements of the neutron whispering gallery at different parameters also a dedicated calibration of the neutron wavelength with the precision 10^(-4) using a new compact time-of-flight device developed for GRANIT.

This experiment, performed with SuperAdam instrument, continues a series of precision neutron whispering gallery measurements [1-2], performed previously using D17 and PF1B instruments. A detailed description of the neutron whispering gallery phenomenon can be found in the textbook [3], and the motivation for its precise study is the same in many cases as for the precision study of gravitational quantum states of neutrons [4-7].

Fig. 1 illustrates this phenomenon. If the energy of the radial motion of a cold neutron near the surface of a concave mirror is smaller than the optical potential of the mirror material, then, in the classical approximation, the neutron is totally reflected from the surface and slide along the surface of the mirror on a Garland trajectory. Centrifugal acceleration acts on such a neutron and, under certain conditions for the radial motion, this neutron is in quasi-stationary quantum states formed in the potential well formed by centrifugal and mirror optical potentials. A pattern resulting from the interference of such quantum states is shown in Fig. 2.

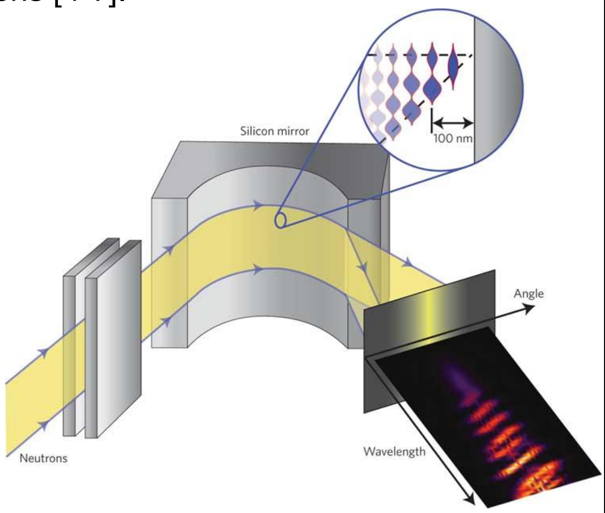
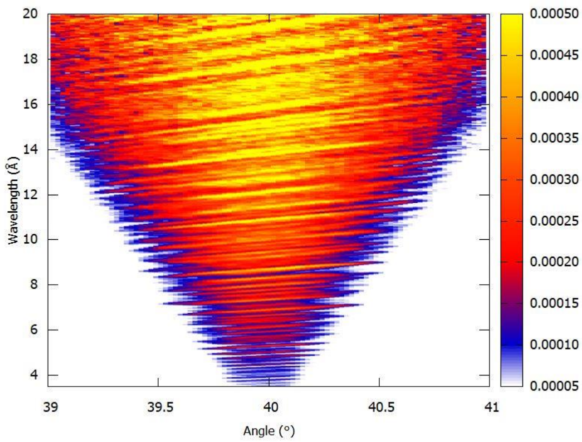


Fig. 1. The design of experiment in which the neutron whispering gallery was observed. This figure is copied from the publication [H. Rauch, Nature Physics 6 (2010) 79].

Fig. 2. An example of an unpublished high-resolution interference pattern that was measured with D17 reflectometer in experiment 3-15-85 with a high-quality MgF_2 single-crystal concave cylindrical mirror. Scattering probability is measured as a function of neutron wavelength (in Å, vertical axis, using the time-of-flight method) and deviation angle (in degrees, horizontal axis, using a position-sensitive detector). Neutrons enter through the entrance edge of the mirror and escape through its exit edge. Parameters of the mirror are as follows: the radius is 30.008(1)mm, the angular size is 39.7427(1)^0, the tangential slope error is <5μrad, the sagittal slope error <25μrad, and the mean roughness of the curved surface is <8Å.



The neutron wavelength and angular resolution achieved in the previous experiment 3-15-85, were very high. However, its overall accuracy was limited by the uncertainty of knowledge of the off-set for the neutron wavelength scale, which, in turn, was limited by the uncertainty of measuring the absolute distance between the chopper and the position-sensitive detector of D17 instrument.

The most precise neutron wavelength calibration method we have been able to find is to perform an additional measurement of the neutron whispering gallery using a monochromatic neutron beam with a precisely measured wavelength. It should be noted that such an experiment alone allows one to obtain very sensitive constraints on extra short-range interactions. However, it also allows one to precisely calibrate the neutron wavelength scale in experiments performed using D17 instrument, and use these results as well for constraining short-range interaction.

This calibration measurement has been performed using SuperAdam instrument. The neutron beam of SuperAdam instrument is monochromatized using the reflection of neutrons from inter-collated graphite crystals. As our preliminary measurements showed, both the mean wavelength of this neutron beam and its width were suitable for performing such a calibration. For these spectral measurements, we used a new time-of-flight device that we developed earlier for measuring the neutron spectrum in the GRANIT instrument neutron beam. A detailed description of this device can be found in ref. [8]. In the present experiment, we modified the experimental design in order to achieve a maximum accuracy. In particular, we increased the neutron flight path, as far as possible in the experimental zone of SuperAdam instrument. In addition, we carefully studied and took into account several systematic effects that could affect the result of this experiment, in particular refraction and spectral modifications in air as well as position and angular dependencies of the neutron spectrum. In air, the wavelength of the first order diffraction peak was measured to be $\lambda_n = 5.2255(4)$ Å. A time-of-flight spectrum measured in the center of gravity of the neutron beam is shown in Fig. 3.

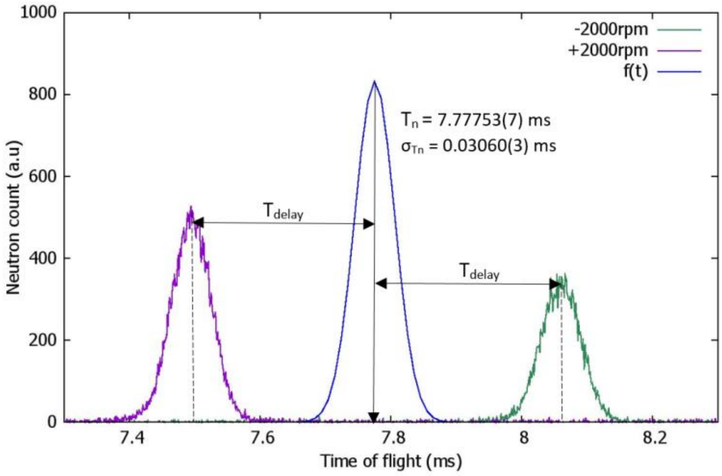


Fig. 3. A time-of-flight spectrum. The two spectra shown with violet and green colors correspond to opposite directions of the chopper rotation. Opposite, but equal in size, time delays between the optical signal and the moment of opening the chopper, are shown with arrows. The spectrum with subtracted delays is shown in the middle with the blue color. The chopper rotation frequency is 2000 rpm.

To measure interference patterns resulting from the neutron whispering gallery, we used exactly the same single-crystal MgF_2 cylindrical mirror as that in our previous experiment 3-15-85. However, unlike the interference patterns measured using the time-of-flight instrument D17 (an example is shown in Fig. 2), interference patterns measured using the single-wavelength instrument SuperAdam contain information about only one neutron wavelength. A typical result is shown in Fig. 4.

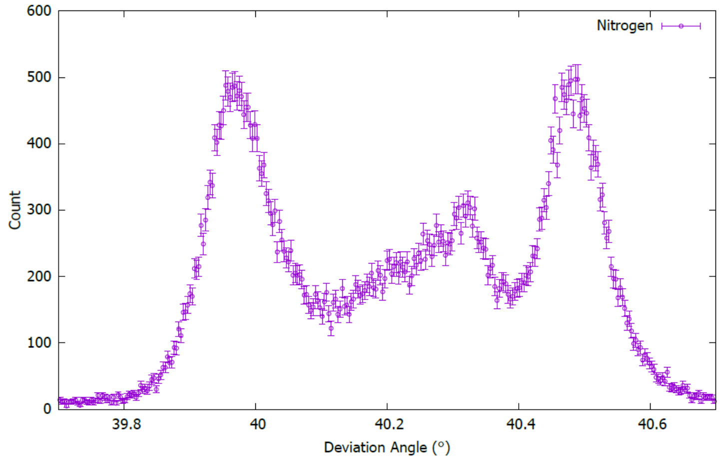


Fig. 4. A typical interference pattern measured with the single-crystal MgF_2 cylindrical mirror using SuperAdam instrument. Detector count is shown as a function of neutron beam deflection angle (in degrees). The mirror is placed inside a chamber filled with pure nitrogen at atmospheric pressure.

The data shown in Fig. 4, are, in fact, a horizontal “slice” of the data, shown in Fig. 2. The neutron wavelength corresponding to this slice was measured by the time-of-flight method at the beginning of this experiment and is given above. Angles are measured with precision higher than the horizontal size of data points. Vertical uncertainties correspond to statistical measurement accuracy. Similar interference patterns were measured for several different angles of incidence of the neutron beam on the mirror surface. Moreover, the mirror was placed in different gases (helium, air) in different measurements. Since the neutron-optical potential depends on the type of gas and its pressure, we changed the interference pattern in a controlled way.

All this set of experimental data is sufficient to unambiguously interpret the obtained experimental results, as well as to perform an accurate calibration of the neutron wavelength in the earlier experimental data obtained at D17 instrument. Analysis of the experimental data from this experiment at SuperAdam has been completed at the time of writing this report. Analysis of the entire set of available experimental data, including the results obtained previously using D17 instrument, is in progress.

References

1. **Nesvizhevsky, V.V., Voronin, A.Yu., Cubitt, R. *et al***, *Neutron whispering gallery*, **Nature Phys. 6** (2010) 114
2. **Nesvizhevsky, V.V., Cubitt, R., Protasov, K.V. *et al***, *The whispering gallery effect in neutron scattering*, **New J. Phys. 12** (2010) 113050
3. **Nesvizhevsky, V.V., and Voronin, A.Yu., *Surprising quantum bouncing*** (Imperial College Press, London, 2015)
4. **Nesvizhevsky, V.V., Boerner, H.G., Petukhov, A.K. *et al***, *Quantum states of neutrons in the Earth's gravitational field*, **Nature 415** (2002) 297
5. **Baessler, S., Nesvizhevsky, V.V., Protasov, K.V. *et al***, *Constraint on the coupling of axionlike particles to matter via an ultracold neutron gravitational experiment*, **Phys. Rev. D 75** (2007) 075006
6. **Nesvizhevsky, V.V., Pignol, G., and Protasov, K.V.** *Neutron scattering and extra-short-range interactions*, **Phys. Rev. D 77** (2008) 03402
7. **Antoniadis, I., Baessler, S., Buechner, M. *et al***, *Short-range fundamental forces*, **Compt. Rend. Phys. 12** (2011) 755
8. **Roulier, D., Nesvizhevsky, V.V., Benoit, C. *et al***, Design and test of a compact and high-resolution time-of-flight measurement device for cold neutron beams, **Phys. Rev. Accel. Beams 22** (2019) 032801