NEUTRONS FOR SOCIETY

INSTITUT LAUE-LANGEVIN

Annual Report 2021

Erwin Jericha. Austrian
Atominstitut, Faculty of Physics, TU Wien, Austria

'I am an assistant professor working at the Vienna University of Technology. I have been a neutron physicist for three decades, interested in neutron-induced reactions, the development of new neutron techniques and relating neutron physics to fundamental questions about nature. My first visit brought me to the ILL in 1989, and I have been a regular and enthusiastic visiting scientist to various instruments ever since.'

MONOPOL: a neutron resonator that flexibly manipulates polarised neutron beams

Ultracold neutron facility PF2

Defining the characteristics of the incoming neutron beam is an essential procedure for each neutron experiment. Here, we present a concept for polarised neutron beams that allows for remarkable flexibility. By employing spatial magnetic spin resonance using a neutron resonator whose elements are controlled individually, we have overcome all known limitations associated with pulsed, polarised neutron beam tailoring. The very cold neutrons (VCN) of the PF2 instrument proved extremely valuable for testing this new, powerful variant of an already traditional technique.

AUTHORS

E. Jericha, **J. Bosina** and **G. Badurek** (Atominstitut, TU Wien, Austria)
P. Geltenbort (ILL)
M. Masahiro and **T. Odo** (Kyoto University, Japan)

ARTICLE FROM

Sci. Rep. (2020)—doi:10.1038/s41598-020-62612-9

REFERENCES

[1] M.M. Agamalyan, G.M. Drabkin and V.I. Sbitnev, Phys. Rep. 168 (1988) 265
[2] G. Badurek, A. Kollmar, A. Seeger and W. Schalt, Nucl. Instrum. Methods A 309 (1991) 275
[3] E. Krüger, W. Nistler and W. Weirauch, Metrologia 35 (1998) 203
[4] E. Jericha *et al.*, Sci. Rep. 10 (2020) 5815

Spatial magnetic spin resonance was discovered in Gatchina, near St. Petersburg, in the 1960s. Early work concerning this technique is discussed and summarised in [1]. The technique itself entails placing a neutron resonator in a polarised neutron beam. In order to retain the neutron polarisation, typically a magnetic guide field perpendicular to the neutron propagation accompanies the neutron beam throughout the experimental set-up. For magnetic spin resonance this field acts as a selector for the neutron resonance wavelength. The resonator itself is made up of a series of elements that generate a magnetic field perpendicular to the guide field with alternating directions in each adjacent element. This configuration flips the neutron spin for a given resonance wavelength and a specific wavelength band around it, upon a resonance and amplitude condition being fulfilled. Following the resonator, the neutrons pass a broadband spin flipper that inverts the polarisation of all neutrons in the beam. The beam is eventually analysed by a neutron polariser.

In the case of the resonator being switched off, in an ideal situation of perfect neutron polarisation no neutron may pass the analyser. Switching the resonator on leads to a spectrally defined neutron beam which is allowed to pass the analyser. Thus, the complete set-up acts as a neutron monochromator, with the magnetic field configuration defining the spectral shape of the resulting neutron beam.

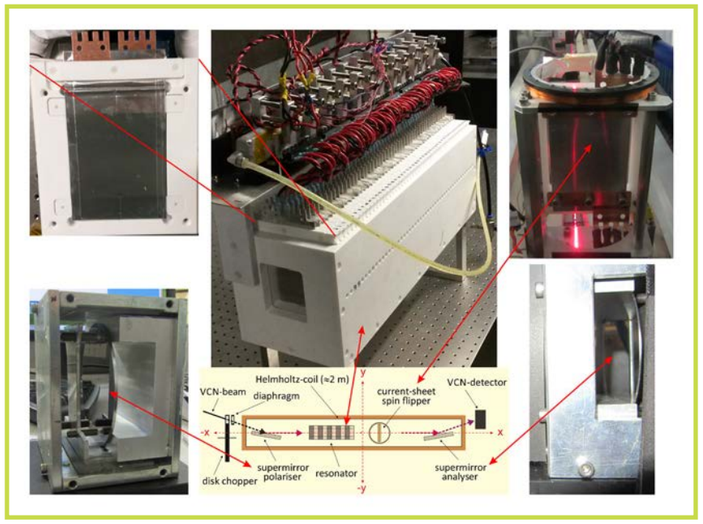

Figure 1

Essential components of the spatial magnetic spin resonance experiment. The neutron resonator (**top centre**) consists of 48 individual elements (**top left**) supplied by 48 current sources located on top of the resonator. A multilayer-coated mirror (**bottom left**) polarises the neutron beam that passes through the resonator, a broadband current-sheet spin flipper (**top right**), and is analysed by a second polariser mirror (**bottom right**). We put all these components into a large helium-filled box to reduce losses from VCN absorption in air.

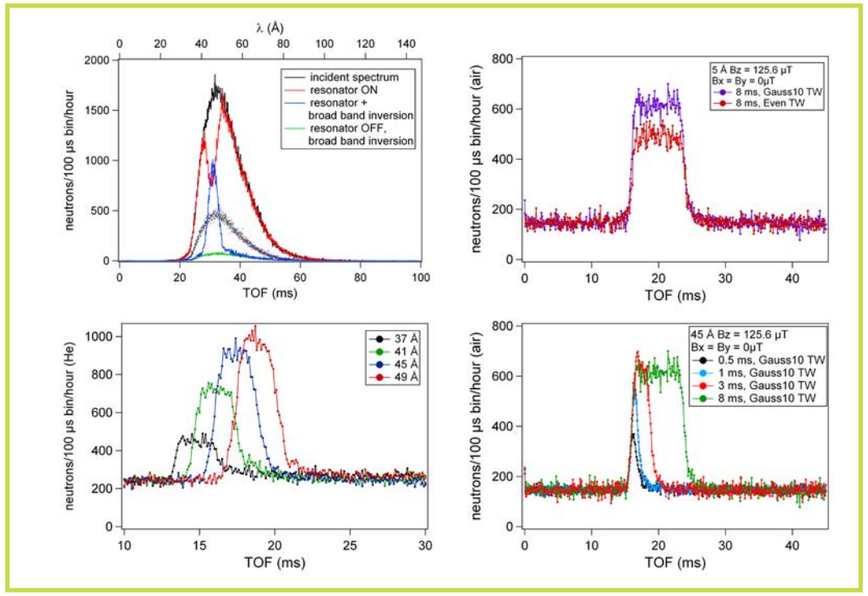

Figure 2

Time-of-flight spectra of the VCN beam, as measured by means of a mechanical single-disk chopper (**top left**) and by the resonator itself (**three other graphs**). The various spectra illustrate the high flexibility gained using this resonance technique.

Such monochromators were designed to replace analyser crystals in inverted geometry neutron spectrometers [2] or to precisely define the velocity of neutrons used to determine the fine structure constant by neutron resonance and perfect crystal reflection in a high-precision experiment [3]. Development of the new type of resonator was also motivated by high-precision studies, at that time investigating the beta decay of neutrons. In the traditional configuration [1], the resonator took the form of a single metal foil in meander shape, supplied by a common electrical current. To shape the corresponding magnetic field configuration it was necessary to tailor the resonator geometrically [1], which limited the neutron spectrum to a specific shape. In addition, the pulsing of this type of resonator relies on a timing that relates to the overall length of the resonator. In neutron instruments that rely on a sharp neutron pulse structure, the timing of a conventional resonator may be insufficient.

By creating a resonator with individually controllable elements, we have overcome all these limitations associated with pulsed, polarised neutron beam tailoring [4]. **Figure 1** shows the essential components of the experimental set-up that demonstrated this technique for the first time with a polychromatic white neutron beam. **Figure 2** displays a few aspects of the flexibility of this method. In the **top left** graph, we follow the action of the various components. A disk chopper offers appropriate timing for displaying the total incoming spectrum, the spectrum that misses the resonantly flipped neutrons, the spectrum of the resonantly flipped neutrons and the background as a result of non-perfect neutron polarisation. Also in **figure 2**, various neutron pulses obtained from different settings of the resonator can be seen. The **top right** plot compares different magnetic field distributions. The **bottom left** plot illustrates the importance of the selector field with respect to the resonance wavelength. The height of the pulses corresponds to the intensity of the incoming neutron spectrum. And finally, the **bottom right** plot shows estimates of the possible length of neutron pulses. For VCN, the minimum pulse lengths are of the order of 1 ms, from which we may extrapolate pulses in the order of 100 µs for cold neutrons and even shorter ones for thermal neutron beams. All this has been achieved simply by changing the currents in the individual resonator elements.

Corresponding developments may turn out to be attractive for polarised neutron diffractometers and spectrometers at the ILL, as well as for tailoring the long pulses at the European Spallation Source. A special place exists for the MEPHISTO beamline at the FRM II in Garching and its neutron decay facility PERC, which motivated this new development.