Neutron Guides

The path of a neutron may be modified within certain limits by varying the reflection conditions on the guide walls. The range for reflection is, however, relatively narrow, specifically an incident angle of approx. 0,1°-1°, depending upon the energy of the neutron. It is nevertheless possible to deflect or guide the neutrons so as to improve experimental conditions, the objective being

- to achieve high neutron intensity at the experiment with low background radiation,
- to split beams in order to supply several instruments,
- to ensure optimal utilisation of the neutron source,
- to enable optimal utilisation of the available space,
- to polarise neutrons.

In addition to conventional straight neutron guides, a modern neutron guide installation also contains special systems such as neutron guide switches, curved and focussing sections as well as novel coatings known as neutron supermirrors.

Neutron guide switches split an initially relatively large cross-section beam into individual sub-beams and cause them to diverge. In this way, a larger number of terminal measurement stations is obtained, which have the advantage of a neutron beam without spectral holes. Curving the guide in the horizontal plane serves two purposes:

- Firstly, the sub-guides are spaced apart so allowing a sufficient distance from the neighbouring experiment,
- and secondly the curvature filters out background radiation from the reactor core (fast neutrons, gamma radiation).

This effect is achieved if the length of the curved section is sufficient to ensure that no particles can reach the measuring position by a direct path, i.e. without reflection. Due to its high energy, the background radiation cannot be reflected and thus exits from the guide at the point of contact, unlike the majority of the cold and thermal neutrons. Focussing guides increase the neutron flux density at the sample. Such guide elements taper in one or two dimensions. The spatial compression is accompanied by an increase in the divergence of the neutron beam, which can be tolerated in many instrument and experiments. A similar situation applies to neutron guides with the above-mentioned supermirror coating, in which a multilayer coating of variable thickness adds a range of continuous diffraction on each side of the angle

The neutron guide options outlined in the previous section are used at FRM II to create a state of the art neutron guide installation. Six large cross-section primary guides lead out from the large beam tube SR1, which is supplied by the cold source. The beam tube port itself accomodates the first neutron guide elements, which extend as far as approx. 2 metres towards the cold source. There are two guides both of which have cross-sections of 60mm x 120mm, 60mm x 170mm and 50mm x 170mm. After the portion inside the beam tube, adjoining the reactor pool, there is a common beam shutter which, if necessary, shuts off all the guides simultaneously. The beam shutter and the downstream neutron guides are located in the reactor building's neutron guide tunnel.

The first neutron guide switches for splitting the primary guide are installed in this zone. The curved section of the neutron guides also begin at this point. After 16m, they pass through the wall of the reactor building. There then follows a small casemate, in which the guides are still predominantly curved and further split. The end of the small casemate forms a solid wall protecting the actual experimental area in the neutron guide hall. At this point, with one exception, none of the neutron guides any longer has a direct line of sight to the source. In other words, theres is virtually no background radiation from the reactor in the instrumentation area. The usable experimental area in the neutron guide hall is approx. 24m wide and 50m long, and the neutron guides are continued to their respective instruments.

In addition to standard guides with a conventional nickel or supermirror coating, the installation will also have special guide systems in order to meet the very particular requirements of some instruments. The high resolution time-of-flight spectrometer requires a neutron beam with a very pure spectrum at λ>2Å containing no shorter wavelength neutrons. The beam is filtered by the upstream neutron guide, which is of an S-shaped profile for this purpose. This shape ensures that neutrons which, above a defined energy threshold, hit the outer wall of the guide too steeply after the reversal of curvature are no longer reflected are thus filtered out.

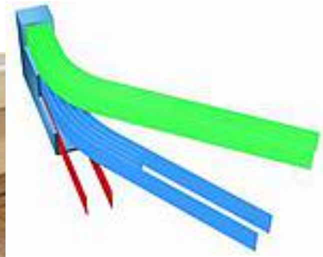
Other experiments require a polarised neutron beam: neutrons as tiny elementary magnets that may all be alligned (polarised) in one direction. At FRM II, a polarised beam is produced by a curved neutron guide with a special coating. The coating, a supermirror with appropriate coating materials, has different transmission characteristics, dependent upon spin orientation, but virtually independently of neutron energy. This method has the advantage of polarising the entire neutron spectrum.

of total reflection. This multiplies the incident angle at which the neutrons are still reflected, so meaning that more neutrons are gathered and conveyed to the experiment. The characteristics of the supermirror are advantageous in particular for focussing and curved guides. In focussing guides, the reduction in cross-section may be greater, which also increases the degree of compression of the neutron beam. Curved sections may be kept shorter as smaller radii are possible. Vertical partitions permit still sharper bends without clipping the desired spectrum at short wavelengths. These guides are known as beam bender.


Neutron guide: Rectangular glass tube guiding neutrons by total reflection.


The coated glass of the neutron guide allows neutron guidance for more than 100m.

A twisted neutron guide, the world's first, is being installed at FRM II. This guide converts an initially tall and narrow neutron beam into a flat, wide beam. This is achieved by rotating the cross-section continuously about a total angle of 90° over a distance of 36m. The resultant beam shape is optimised for the requirements of the REPSANS instrument, which is designed for studying horizontal, thin layers such as lipid films. An approx. 2,5 times gain in intensity is achieved with this design in comparison with a conventional neutron guide.


Vertical splitting of the neutron beam.


Horizontal splitting of the neutron beam.

print version

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concept of neutron mirror / supermirror

The concept of neutron supermirror was initially proposed by Turchin [1] and Mezei [2,3] aiming to extend the range of neutron reflection from smooth surfaces beyond the regime of total external reflection. There high reflectivity is obtained from continuous Bragg reflection from a multilayer with a depth-graded variation of the layer thickness. A proper formalism to compute the thickness profile was provided by Hayter and Mook [4]. The following paragraphs describes the concept of neutron supermirror and its extension to polarizing supermirror.

total external reflection

Neutrons (thermal, cold) can be reflected from smooth surfaces when they impinge at grazing incidence. Most materials have a refractive index, which is slightly smaller than one. Hence, neutrons are totally reflected up to a critical angle θ_c, which depends on the material and on the neutron wavelength λ, e.g. $\theta_{c,\mathrm{Ni}} \approx 0.1°/Å \cdot \lambda$ for natural Ni. The material property is generalized, i.e. independent of λ in terms of the momentum transfer q (perpendicular to the surface):

$$q = \frac{4\pi}{\lambda}\sin(\theta)$$

(eq. 1)

with θ being the angle of incidence. For example the critical momentum transfer of natural Ni is at $q_{c,\mathrm{Ni}}$ = 0.217nm^{-1}.

supermirror reflection

Beyond θ_c, q_c respectively, the neutron wave propagates in the material and is partially reflected at smooth interfaces (Figure 1) between layers of different materials having usually a different scattering length density (SLD). Multilayers represent an artificial one-dimensional lattice and Bragg reflection occurs at an appropriate momentum transfer similar to the Bragg reflection from the lattice planes of a crystal. Neutron supermirror exploit this property and provide a regime of continuous Bragg reflection from a depth-graded multilayer (Figure 2).

Neutron supermirror are essentially characterized by their reflectivity and the m value. The latter defines the range of the supermirror regime in multiples of $q_{c,\mathrm{Ni}}$. It is also common to refer to the m value as the critical edge of the supermirror according to the critical angle θ_c (in general momentum transfer) for total reflection.

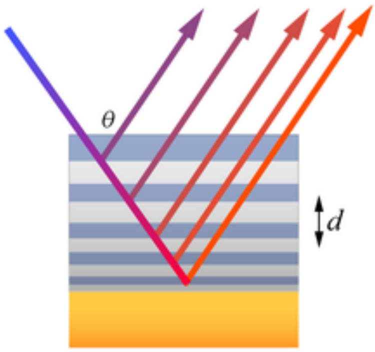

Figure 1

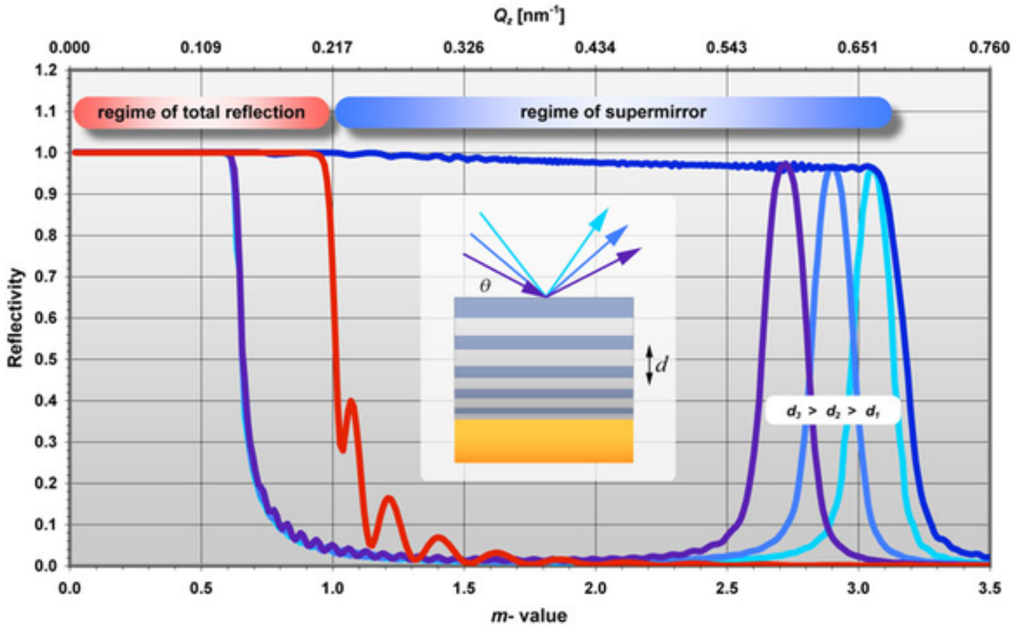

Figure 2: Theoretical supermirror reflectivity

polarizing supermirror

So far the nuclear interaction is concerned but for magnetic materials the magnetic interaction contributes in addition to the neutron scattering properties. In the following, the discussion about nuclear and magnetic interactions is rather simplified, addressing only those aspects, which are most relevant for the discussion on polarizing supermirror.

The magnetic interaction adds in terms of the magnetic scattering length p to the nuclear b, dependent on the relative orientation of the neutron spin to the magnetization, i.e. $(b \pm p)$ with (+) for spins parallel to the magnetization and (-) for vice versa. As the critical momentum transfer depends on the total scattering length, the regime of total reflection depends on the relative orientation between neutron spin and magnetization: $(b + p)$ has an enhanced critical momentum transfer, whereas it is reduced for $(b - p)$.

Considering a supermirror with one type of the layers being magnetic and their magnetization commonly aligned, neutrons with spins either parallel or antiparallel to the layer magnetization have a different reflectivity in the supermirror regime. For the state of the neutron spin parallel to the magnetization the total SLD of the magnetic layers is enhanced, thus having high reflectivity. For the antiparallel configuration the total SLD is reduced, ideally it matches the SLD of the non-magnetic layers. In the latter case the SLD is constant throughout the supermirror and the neutrons do not see the interfaces. The supermirror is transparent. These properties are illustrated in Figure 3.

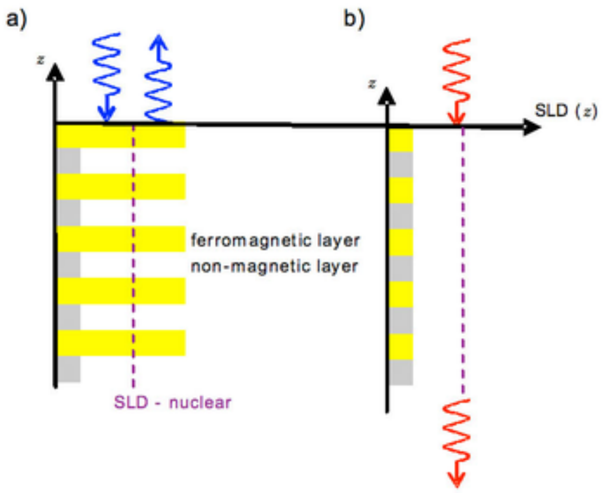

Figure 3: Illustration of the spin dependent depth profile of the SLD of a multilayer comprising magnetic and non-magnetic layers: a) neutron spin parallel to layer magnetization, b) neutron spin antiparallel to layer magnetization

measurement of the reflectivity of supermirror

The reflectivity of a supermirror is a function of the momentum transfer q (eq. 1). Hence it can be either measured in a wavelength or an angular dispersive mode. Besides specific features the information is the same obtained from the different techniques. However, most of the instruments used for reflectivity measurements operate in the angular dispersive mode i.e. using a neutron beam at a constant wavelength and scan the reflectivity by varying the angle of incidence. This mode is also applied at the instrument NARZISS (PSI, SINQ), which is available for SwissNeutronics.

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