

Neutron Guides

In the following exercises we will use various types of neutron guides. Before starting with the instrument files, you might want to take a look at McStas Component manual, which you can access with the ‘Help (McDoc)’ button in the mcgui environment. Chapter 5 in general, and in particular paragraphs 5.5 and 5.6 on benders and curved guides might help you understand how those components work and behave. Also, chapter 5.1 gives a brief and useful explanation on neutron mirrors and reflectivity.

Furthermore, you might want to take a look at the brief, informative material attached at the back of this document, regarding neutron guides¹.

NOTE: You will need at least 10^8 particles in your simulations, in order to get good statistics.

1 Exercise 1.2a: Curved Guide

Instructions: First, you will build a Curved Guide, using the component *Guide_curved* from McStas’ available *optics components*. A pair of slits will also be used after the guide, in order ‘to collimate’ the out coming beam. As a second step, the curved guide should be compared to a set-up where the curved guide has been replaced by a bender (Exercise 1.2b). Last, replace the curved guide component with a sequence of 3 straight guides, each rotated with respect to the previous one, to imitate the effect of curvature (Exercise 1.2c).

¹Sources: TUM website, Swiss Neutronics website, and *Erko A, Idir M, Krist T and Michette A G (eds) 2008 Neutron Supermirror Development (Berlin-Heidelberg: Springer)*

Build the instrument file

- Source:
 - 0.12 m in diameter
 - flat spectrum in the range $1 - 9\text{\AA}$
- Curved Guide:
 - Position: 1.5 m after source
 - Length: 20 m
 - Dimensions: $0.06 \times 0.06 \text{ m}^2$
 - Curvature: 1000 m
 - Coating: $m = 1, m = 3$
- Slit 1:
 - Dimensions: $0.03 \times 0.06 \text{ m}^2$
 - Position: 0.5 m from guide's exit
- Slit 2:
 - Dimensions: $0.015 \times 0.06 \text{ m}^2$
 - Position: 1.5 m from first slit
- Monitors
 - PSD monitor, wavelength monitor (L_monitor), and divergence monitor **at the source.**
 - PSD monitor, wavelength monitor (L_monitor), and divergence monitor **after the guide.**
 - PSD monitor, wavelength monitor (L_monitor), and divergence monitor **after the slits.**

Run the instrument file

- Run the simulation with and without slits
- Increase the m value from 1 to 3 (or higher if you want. Current supermirrors can go up to $m = 7$.) What does that do to the divergence and wavelength distributions of the neutrons passing through the curved guide?

2 Exercise 1.2b: Bender

Instructions: Replace the curved guide in Exercise 1.2a with a bender (i.e., a channeled curved guide), and compare.

Build the instrument file

- Source:
 - 0.12 m in diameter
 - flat spectrum in the range $1 - 9\text{\AA}$
- Bender:
 - Position: 1.5 m after source
 - Length: 20 m
 - Dimensions: $0.06 \times 0.06 \text{ m}^2$
 - Curvature: 1000 m
 - Coating: $m = 1, m = 3$
 - Channels: 10 of 0.3 mm thickness
- Slit 1:
 - Dimensions: $0.03 \times 0.06 \text{ m}^2$
 - Position: 0.5 m from guide's exit
- Slit 2:
 - Dimensions: $0.015 \times 0.06 \text{ m}^2$
 - Position: 1.5 m from first slit
- Monitors
 - PSD monitor, wavelength monitor (L_monitor), and divergence monitor **at the source.**
 - PSD monitor, wavelength monitor (L_monitor), and divergence monitor **after the guide.**
 - PSD monitor, wavelength monitor (L_monitor), and divergence monitor **after the slits.**

3 Exercise 1.2c: Curved Guide made of Straight Parts

Instructions: Replace the curved guide of Exercise 1.2a with three straight guides, placed one after the other. The second and third guides are rotated with respect to the original neutron's path, in order to imitate a curved guide.

Build the instrument file

- Source:
 - 0.12 m in diameter
 - flat spectrum in the range $1 - 9\text{\AA}$
- Straight Guide 1:
 - Position: 1.5 m after source
 - Length: 5 m
 - Dimensions: $0.06 \times 0.06 \text{ m}^2$
 - Coating: $m = 1, m = 3$
- Straight Guide 2:
 - Position: after straight guide 1
 - Length: 10 m
 - Dimensions: $0.06 \times 0.06 \text{ m}^2$
 - Rotation: 0.5° around Y-axis with respect to straight guide 1
 - Coating: $m = 1, m = 3$
- Straight Guide 3:
 - Position: after straight guide 2
 - Length: 5 m
 - Dimensions: $0.06 \times 0.06 \text{ m}^2$
 - Rotation: 0.5° around Y-axis with respect to straight guide 2
 - Coating: $m = 1, m = 3$

- Slit 1:
 - Dimensions: $0.03 \times 0.06 \text{ m}^2$
 - Position: 0.5 m from guide's exit
- Slit 2:
 - Dimensions: $0.015 \times 0.06 \text{ m}^2$
 - Position: 1.5 m from first slit
- Monitors
 - PSD monitor, wavelength monitor (L_monitor), and divergence monitor **at the source**.
 - PSD monitor, wavelength monitor (L_monitor), and divergence monitor **after the guide**.
 - PSD monitor, wavelength monitor (L_monitor), and divergence monitor **after the slits**.

Run the simulation Compare with the two previous exercises. What is the effect of such a 'curved' guide on the divergence of the outgoing beam?

4 Exercise 1.3a: Ballistic Guide

Instructions: You will create a ballistic guide consisting of 3 separate pieces (guides).

Build the instrument file

- Source:
 - 0.12 m in diameter
 - flat spectrum in the range $1 - 9\text{\AA}$
- Guide:
 - First Guide Part:
 - * Position: 1.5 m after source
 - * Length: 5 m
 - * Dimensions: **Entrance** of $0.06 \times 0.06 \text{ m}^2$ and **Exit** of $0.12 \times 0.12 \text{ m}^2$
 - Second Guide Part:
 - * Position: right after part 1
 - * Length: 15 m
 - * Dimensions: **Entrance** of $0.12 \times 0.12 \text{ m}^2$ and **Exit** of $0.12 \times 0.12 \text{ m}^2$
 - Third Guide Part:
 - * Position: right after part 2
 - * Length: 5 m
 - * Dimensions: **Entrance** of $0.12 \times 0.12 \text{ m}^2$ and **Exit** of $0.06 \times 0.06 \text{ m}^2$
 - Coating: $m = 1, m = 3$
- Monitors
 - PSD monitor, wavelength monitor (L_monitor), and divergence monitor **at the source**.
 - PSD monitor, PSD linear monitor (X and Y directions), wavelength monitor (L_monitor), and divergence monitor 1.5 m **after the guide**.

Run the instrument file:

- Compare the intensity and divergence distribution before and after the guide.
- Vary the position of the monitors after the guide.
- Compare the intensity and divergence distributions 1.5m after the ballistic guide with those of a straight guide (Exercise 1.3b) and an elliptic guide (Exercise 1.4).
- Experiment with the coating m of the guide (increase it). Does that alter the intensity and divergence of the outgoing neutrons?

5 Exercise 1.3b: Straight Guide

Instructions: Replace the ballistic guide in Exercise 1.3a with a straight guide. The rest of the instrument file should stay as is.

- Straight Guide
 - Position: 1.5 m after source
 - Length: 20 m
 - Dimensions: **Entrance** of $0.06 \times 0.06 \text{ m}^2$ and **Exit** of $0.06 \times 0.06 \text{ m}^2$
 - Coating: $m = 1$, $m = 3$

6 Exercise 1.4: Elliptic Guide

Instructions:

Build the instrument file

- Source:
 - 0.12 m in diameter
 - flat spectrum in the range $1 - 9\text{\AA}$
- Elliptic Guide:
 - Position: 1.5 m after source
 - Length: 20 m
 - Dimensions: **Entrance** of $0.06 \times 0.06 \text{ m}^2$ and **Exit** of $0.06 \times 0.06 \text{ m}^2$
 - focal points: 1.5 m before and after guide
 - Coating: $m = 1$, $m = 3$
- Monitors
 - PSD monitor, wavelength monitor (L_monitor), and divergence monitor **at the source**.
 - PSD monitor, PSD linear monitor (X and Y directions), wavelength monitor (L_monitor), and divergence monitor 1.5 m **after the guide**.

Run the instrument file:

- Compare the intensity and divergence profiles of the elliptic guide with those of the ballistic one. Is there an increase in intensity? How about the intensity's profile? Can you notice the focusing properties of the elliptic guide?
- Replace the source with one of 2 cm diameter. Do the same for the source of the ballistic guide. Compare.

of 70% as compared to the tapered guide. The parabolic guide would be most efficient with a point source. The elliptical guide offers the highest flexibility. The performance could be slightly improved if a closer position of the sample was possible: 51% at 400 mm, 71% at 100 mm. This gain is negligible compared to the accompanying constraints.

The previous situation applies to the case of a facility where the main guides are already in place and where one wants to maximize the flux at the sample position. However, in the case of the design of new spectrometers, the entire beam delivery system should be optimized, including the primary guide.

7.5.6 Ballistic Guides: Neutron Beam Delivery over Large Distances

In general, one wants to transfer as much neutron intensity from the cold (or thermal) source to the sample position. Until recently, this was achieved by using neutron guides (with a square section of the order of $100 \times 50 \text{ mm}^2$) which were bringing the neutrons outside the reactor into an experimental hall where the spectrometers are located. In the previous decade, the spectrometers were optimized to make the best use of the flux in these guides. The trend in the design of new spectrometers is to optimize the setup from the source to the sample and specifically to optimize the guide geometry for the specific need of the spectrometer. This assumes that each spectrometer has its own dedicated guide. The space between the cold source and the spectrometer position is very large (from 10 m to several tens of meters). This makes possible the implementation of complex optical systems.

The first optimization consists in increasing the amount of neutrons effectively brought to the spectrometer. With the implementation of neutron supermirror guides (with $m=2$ or $m=3$), the flux at short wavelengths has been significantly increased (Fig. 7.10). However, the problem is that, contrary to nickel coatings, the reflectivity of supermirrors is of the order of 0.8. Thus

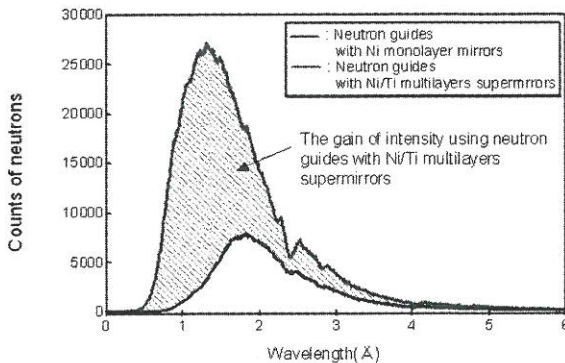


Fig. 7.10. Flux in a nickel guide and in a supermirror guide

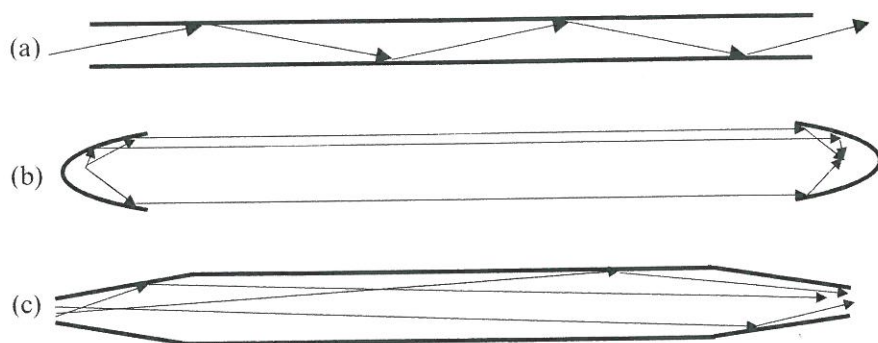


Fig. 7.11. Principle of a ballistic guide: (a) straight guide, (b) perfect ballistic guide, (c) approximation of the ballistic guide

after five reflections, the transmission is reduced to 30%. This means that long supermirror guides are inefficient, besides being expensive. For guides longer than 30 m, the losses outweigh the gains.

Recently, it has been proposed to implement so-called "ballistic guides" [20]. The principle consists in first expanding the neutron beam so as to reduce its divergence, let it travel a long distance, and eventually refocus it onto the sample at the end of the free flight travel. This makes it possible to reduce the number of reflections by getting closer to a parallel beam. Figure 7.11 illustrates this principle. If the source is small, the beam could be made parallel with a parabolic beam expander. In real life, the source is not so small. The first implementation of such a ballistic guide was approximated by using first a "tapered" section which mimics the parabolic expansion of the beam. A straight nickel guide avoids losing the neutrons which are too divergent. This section is quite efficient since the divergence of the beam is small. The beam is then refocused onto the sample with a second tapered section. The cost of such a guide is moderate since a simple nickel coating can be used over most of the guide length.

The first implementation of such a system was done on the guide H113 at the ILL [21]. The initial section is 6 cm and is increased to 9 cm. The gain in flux at the sample position was a factor of 4 for a guide length of 72 m. A detailed description of the characteristics of this guide has been published in [22].

More recently, more complex shapes have been considered for neutron guides. A detailed comparison of the different geometries (tapered, elliptic, and parabolic) has been made [23]. It appears that an ellipse is by far the best geometry which provides the highest neutron flux as well as the best flux homogeneity at the exit. A thorough comparison with other systems has been published [24].

Small scale parabolic guides consisting of four bent supermirrors have recently been made and tested [25]. The entrance was $16 \times 16 \text{ mm}^2$, the exit was $3.2 \times 3.2 \text{ mm}^2$. The focal spot achieved was 1 mm^2 . Better result, in terms

of the beam homogeneity and focal length, have since then been obtained by using elliptical shapes.

7.5.7 Reflective Lenses

A large number of solutions have been devised to fabricate lenses based on reflection.

Focusing Bender

Silicon is a very transparent material for neutrons. Thus by coating silicon wafers with neutron supermirrors and stacking the substrates, it is possible to build neutron channels with a large angular acceptance. By properly bending the stack, it is possible to focus the neutrons at a given position (see Fig. 7.12). The principle is very similar to polycapillary systems except that (a) it is possible to coat the inner part of the channel walls with supermirrors (possibly polarizing) and thus to have a large angular acceptance and (b) the transmission is close to 90% since Si is transparent. The drawbacks are (a) the focalization is only one dimensional and (b) the focal spot increases quickly in size because of the intrinsic divergence of the beam at the exit of the channel.

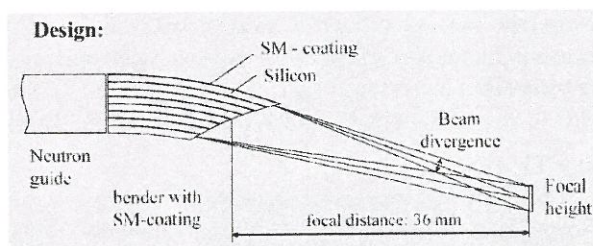


Fig. 7.12. Focusing bender (T. Krist, HMI)