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Cold Neutron Focusing Multiple Biconcave Lenses and Anti-Gravity Prisms for 40m Small Angle Neutron Scattering Instrument

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1. Introduction

Small angle neutron scattering (SANS) instrument with long flight path is a very powerful tool to investigate the structures of various nanoscale materials. Currently, a new 40m SANS instrument is under development to be installed at HANARO, which will be one of the key facilities for nano-characterization in Korea. To enhance the measurement capability of the 40m SANS, especially in the low Q region, cold neutron focusing and cancellation of gravity effects using multiple biconcave lenses and prisms are suggested. In this paper, we present recent Monte Carlo simulation studies on the refractive focusing and anti-gravity optics.

2. Simulations and Results

To investigate effects of lenses and prisms, we have done the MC simulations with the condition of 40m SANS instrument. As shown as Figure 1, the neutron beams pass through and focused by lenses, and canceled the effects of gravity effect by prism.

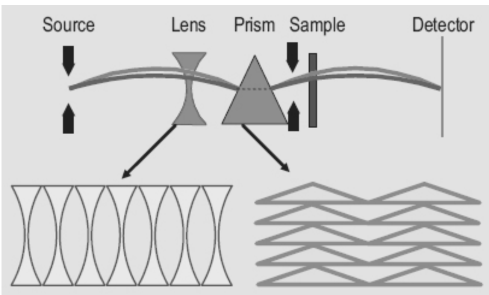


Figure 1. Cold neutrons collimation by multiple biconcave lenses and anti-gravity prism

2.1 Lens Focusing Geometry

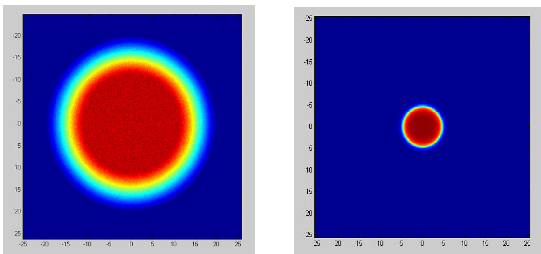
Since the neutron refractive index, n, is less than unity for most materials, a concave lens is convergent while a convex lens is divergent. The focal length, f, for a biconcave lens is given by [1],

$$f_o = \frac{R}{2(1-n)} = \frac{R}{\xi} = (\frac{R}{\rho b_c})(\frac{\pi}{\lambda^2}) \quad (1)$$

where, R is the radius of curvature of the lens, b_c is the bound coherent scattering length of an atom, and λ is the wavelength of incident neutrons. In this equation, we can notice that focal length of lens is in inverse proportion to λ^2 [1]. So neutrons with well-defined wavelength is needed for good focusing (In most SANS instruments, steady states neutrons source utilize neutrons with wavelength spread 10~15%). According to Gaussian optics (Born & Wolf, 1975), the focal length obeys $1/f = 1/L_1 + 1/L_2$ where, L_1 is the distance between source and lenses and L_2 is the distance between lenses and detector. For N multiple biconcave lenses located in series, the focal length is expressed by $f = f_0 / N$.

In 40m SANS instrument, $L_1 = L_2 = 20m$, R=25mm, $\xi = 1.024\times10^{-4}$ for 8Å cold neutrons. Therefore, $f_0 = 244m$ and 24 MgF_2 lenses are needed to focus 8Å neutrons.

To check the improvement of collimation, we studied MC simulation on the condition of 40m SANS instrument at HANARO. The simulation assumed triangular wavelength distribution and included gravity effect. Here we present a case where λ =8.15Å, $\Delta\lambda/\lambda$ =0.1 L_1=20m, L_2=20m, A_1=0.95cm, A_2=1.59, 24 MgF_2 biconcave lenses with 2.5cm radius of curvature and 1mm center thickness were used.



a) b)

Figure 2. 2D images of unfocused and focused beams: MC simulation a) unfocused beam b) focused beam

In Figure2, it is clear that area of focused beam is much smaller and has more intense at the center. In this simulation, gravity effect was not considered, so spread caused by gravity does not appear.

2.2 Prism Correction Geometry

Similarly biconcave lens case, since the neutron refractive index, n, is less than unity for most materials, a prism shift up the neutron beam.

The spreading length of neutrons by gravity effect is given by [3],

$$Z_d = \frac{gm^2}{2h^2} L_2 (L_1 + L_2)\lambda^2 \quad (4)$$

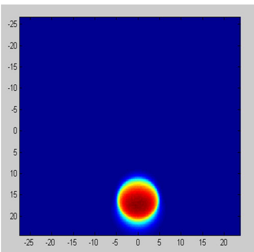
where, Z_d is the vertical spread length , g is the gravity constant, and h is the height of prism. And the apex angle of prism is calculated by,

$$\tan(\frac{A}{2}) = \frac{\pi g m^2}{2\rho h^2}(L_1 + L_2) \quad (5)$$

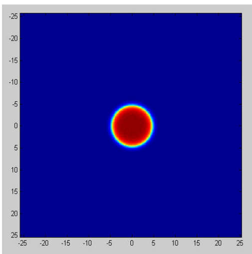
where, ρ is the scattering length density of prism.

In 40m SANS instrument, $L_1 = L_2 = 20m$, h=25mm, $\rho = 5.0186 \times 10^{14}$ for 8.15 Å cold neutrons. Therefore, the apex angle of prism is 177° and base length of prism is 2.72m. In practical measurements, such a long base length could have problem to intercept the full beam. To avoid this problem, stack two sets of prisms can be the solution which gives us same anti-gravity effect [3]. At this case, the bottoms of prisms are coated to eliminate surface reflections.

Here we present the results of MC simulation on the condition of 40m SANS instrument to check the correction of gravity effect and the improvement of collimation together. The conditions of simulation are same as simulation of lenses. We assumed triangular wavelength distribution and included gravity effect and λ =8.15 Å, $\Delta \lambda / \lambda$ =0.1 L_1 =20m, L_2 =20m, A_1 =0.95cm, A_2 =1.59, 24 MgF_2 biconcave lenses with 2.5cm radius of curvature and 1mm center thickness were used. Neutrons beams pass through 24 MgF_2 biconcave lenses and focused first. After pass lenses, neutron beams pass through the prism.



a)



b)

Figure 3. 2D images of uncorrected and corrected beams: MC simulation, magnified image by twice a) focused and uncorrected beam b) focused and corrected beam

Two figures in Figure 3 shows a effects of prism. These two figures are magnified images by twice to see the difference better. In figure 3 a) there are vertical spreads due to gravity. But in Figure 4 b) it is clear that vertical spread is disappeared and looks just like focused beam without gravity effect.

3. Conclusion

The properties of focusing neutrons by multiple MgF_2 biconcave lenses are well works and improve the intensity. Compared with conventional pinhole collimation, the intensity gain at $Q_{\min}$ is greater than 1 order of magnitude. And Correction of gravity effect by prism also suited and cancel the beam spreading due to gravity for all wavelengths. It is expected that these properties could enhance the performance of 40m SANS instrument which is under development to be installed at HANARO.

REFERENCES

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