INEL4— Wide-Angle Chopper Spectrometer—Reference Instrument WBS 1.7.7
Technical Note ANL/SNS/98-9
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1 Instrument Description

1.1 Overview

INEL4 is designed to be the workhorse instrument for inelastic studies requiring good resolution and extended ranges in both Q and E . Figure 1 provides a schematic representation of INEL4, and Table 1 provides the parameters for this instrument. This instrument is capable of studies involving energy transfers ranging from a few meV to more than 1 eV. The wide angular coverage and large solid angle of detectors provide relatively high data rates and an extensive Q range.

Fig. 1. Schematic plan view of the wide-angle chopper spectrometer INEL4.

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Table 1. Parameters for the wide-angle chopper spectrometer INEL4

Component	Parameter	Value
Moderator	Beam line	9BU
	Moderator	Liquid-H ₂ O decoup, pois
Geometry	Source-sample distance	18.0 m
	Sample-detector distance	4.0 m
T ₀ chopper	Type	Vertical-axis T ₀
	Chopper radius	100 mm
	Distance from moderator	7.0 m
	Frequency	≤180 Hz
	Beam width at chopper	50 mm
	Wavelength range to open or close	0.25 Å @ 180 Hz
E ₀ chopper	Type	Fermi, magnetic bearing
	Chopper radius	50 mm
	Distance from moderator	17.0 m
	Frequency	≤600 Hz
	Beam width at chopper	50 mm
Guide	Type	Straight
	Coating, sides and top and bottom	3 × θ _c supermirror
	Channel width	50 mm
	Channel height	50 mm
	Moderator-to-guide distance	8.0 m
	Guide length	8.0 m
	Moderator to end of guide	16.0 m
	Filling	Evacuated to <10 ⁻² torr
Collimation	Before E ₀ chopper	Variable aperture
	After E ₀ chopper	Soller collimator
Beam-line shielding	Steel radial thickness around beam	0.7 m
	Paraffin radial thickness around steel	0.2 m
	Channel for guide	0.2 m × 0.2 m
	Length	7.5 m
Beam stop	Steel	1.6 m × 1.6 m × 2.6 m
	Paraffin radial thickness around steel	0.2 m
	Re-entrant hole in steel	0.2 m × 0.2 m × 0.5 m
Sample	Width (maximum beam size)	50 mm
	Height (maximum beam size)	50 mm
Detector angular coverage		(-20°) to (1.5°), 1.5° to 140°

Table 6.3-9 (continued)

Component	Parameter	Value
Standard detectors	Type	^3He proportional
	Diameter	25 mm
	Length	450 mm
	Angular coverage	20° to 140°
	Number	~700
	Solid angle coverage	0.55 sr
Linear position sensitive detectors	Type	^3He proportional
	Diameter	25 mm
	Length	900 mm
	Position resolution	30 mm
	Angular coverage	(-20°) to (1.5°), 1.5° to 20°
	Number	~120
	Solid angle coverage	0.16 sr
Data acquisition		Standard system
Scattering chamber	Geometry	Vertical axis half cylinder
	Diameter, excluding shielding	8.2 m
	Height, excluding shielding	1.1 m
	Filling, direct beam portion	Evacuated to $<10^{-2}$ torr
	Filling, remainder	Helium
	Shielding, top and bottom	Fixed
	Shielding, sides	Removable
	Shielding thickness and composition	TBD
Sample chamber	Depth	~0.6 m
	Diameter	~0.3 m
	Filling	Evacuated to 10^{-6} torr
Resolution	$\delta E/E_{\text{incident}}$	~0.01 fwhm

1.2 Source

A poisoned decoupled ambient temperature water moderator provides a polychromatic beam of neutrons to the instrument. The design documented here assumes a fwhm pulse width of $\delta t \approx 25 \mu\text{s}$ at $10 \text{ \AA}$, $\delta t \approx 24 \mu\text{s}$ at $5 \text{ \AA}$, $\delta t \approx 22 \mu\text{s}$ at $3 \text{ \AA}$, and $\delta t \approx 10 \mu\text{s}$ at $1 \text{ \AA}$.¹ This moderator was selected for INEL4 because of its high intensities at short and intermediate wavelengths, coupled with adequate timing resolution. Beamline 9BU was chosen for this instrument because this beamline views the poisoned ambient temperature water moderator BU which provides these characteristics.

1.3 Choppers

A T_0 chopper is used to cut out the prompt pulse to reduce background. An E_0 Fermi chopper near the sample allows only a very narrow band of wavelengths to reach the sample, thus

effectively monochromating the incident beam as well as providing a reference starting time for time-of-flight measurement of the scattered neutron energies. The T_0 chopper is a relatively massive vertical-axis chopper designed to stop the faster neutrons as well as the slow ones. This chopper is essentially a Fermi chopper without the slit package, and it is closed most of the time to further reduce the background.

Preliminary optimization of the chopper locations and speeds was done using a spreadsheet to evaluate the wavelengths for which the chopper system is fully open and the wavelengths for which one or more of the choppers is opening or closing. Table 2 shows the parameters assumed for the choppers, and Table 3 shows the opening and closing wavelengths for each of these choppers for several different choices of chopper phases. Appendix A of Reference 2 gives the equations used for these calculations.

Table 2. Assumed chopper parameters for INEL4.

T_0 chopper diameter (mm)	200.00
T_0 chopper distance (m)	7.00
beam width at T_0 chopper (mm)	50.00
E_0 chopper diameter (mm)	100.00
E_0 chopper distance (m)	17.00
E_0 chopper blade spacing (mm)	1.00
beam width at E_0 chopper (mm)	50.00
distance to sample (m)	18.00
sample-detector distance (m)	4.00
ratio scattered/incident wavelength	0.45

Table 3a. Chopper opening and closing times for INEL4.

frame	1
$t_{\max}$ (μ s)	16667
T_0 freq (Hz)	180.0
$T_0 \Delta t$ (μ s)	442
E_0 freq (Hz)	600
$E_0 \Delta t$ (μ s)	2.7

Table 3b. Accessible wavelengths for INEL4.^a

frame	1
$t_{\max}$ (μ s)	16667
T_0 freq (Hz)	180.0
$T_0 \Delta \lambda$ ($\text{\AA}$)	0.25
E_0 freq (Hz)	600
$E_0 \Delta \lambda$ ($\text{\AA}$)	0.0006
$\lambda_{\text{inc-max}}$ ($\text{\AA}$)	2.45

^a Assumes scattered wavelength is 222% of incident wavelength.

1.4 Guide

1.4.1 Guide Gain

Appendix B of Reference 2 provides the equations used to estimate guide gain. These were used to establish the preliminary set of guide parameters shown in Table 4 for INEL4. The gains calculated using these parameters with two different sizes of guide starting 8 m from the moderator are shown respectively in Tables 5a and 5b.

Table 4. Preliminary guide parameters for INEL4.

Parameter	Meaning	Value
M_h	moderator width (mm)	100.00
M_v	moderator height (mm)	120.00
L_{inc}	moderator-guide distance (m)	8.00
g_h	guide width (mm)	50.00 75.00
g_v	guide height (mm)	50.00 75.00
m_h	horizontal supermirror "m"	3.00
m_v	vertical supermirror "m"	3.00
λ^*	characteristic wavelength (Angstroms)	straight
R	radius of curvature (m)	straight
L_{sight}	line-of sight distance (m)	straight
L	source-sample distance (m)	18.00
L_{exit-h}	horizontal guide-sample distance (m)	2.00
L_{exit-v}	vertical guide-sample distance (m)	2.00
S_h	sample width (mm)	50.00
S_v	sample height (mm)	50.00
M_h/L	no-guide collimation horizontal (rad)	0.00556
M_v/L	no-guide collimation vertical (rad)	0.00667
g_h/L_{exit-h}	exit collimation horizontal (rad)	0.02500
g_v/L_{exit-v}	exit collimation vertical (rad)	0.02500
	(M-g)/2 (horizontal) (mm)	25.00
	(M+g)/2 (horizontal) (mm)	75.00
	(M-g)/2 (vertical) (mm)	35.00
	(M+g)/2 (vertical) (mm)	85.00
	(g-S)/2 (horizontal) (mm)	0.00
	(g+S)/2 (horizontal) (mm)	50.00
	(g-S)/2 (vertical) (mm)	0.00
	(g+S)/2 (vertical) (mm)	50.00

Table 5a. Approximate guide gains for INEL4 (5 cm x 5 cm guide).

[illegible]

Table 5b. Approximate guide gains for INEL4 (7.5 cm x 7.5 cm guide).

[illegible]

1.4.2 Guide Curvature

This guide is not curved.

1.4.3 Monte Carlo Simulations

Monte Carlo simulations were used to obtain a more accurate estimate of the performance of the INEL4 guide system. Parameters were the same as in Tables 1 and 4 except as noted. For the simulations, neutrons were assumed to be emitted with equal probability from the entire moderator surface, and with equal probability within the angular range ± 0.06 radians about the nominal beam direction. Since the critical angle for natural Ni at 3 Å is only 0.005 radians, this range of angular divergence was more than enough to include all neutrons that could be accepted by the INEL4 $m=3$ guides. The same number of randomly generated initial neutron paths (1,000,000) was used for each 1-dimensional simulation, and total guide performance was obtained by comparing neutrons on sample with and without the guide for the corresponding simulations for the horizontal and vertical direction. For these simulations, the guides were assumed to have reflectivity of 1.0 up to the critical angle θ_c for natural Ni, and a reflectivity of 0.95 from θ_c to $m\theta_c$, where $m=3$ for these particular guide surfaces. Table 6 shows the results of these simulations.

Table 6a. Simulated guide gains for INEL4 (7.5x7.5 cm² guide, $L_{inc} = 2.5$ m with 0.5 m gap).

λ	0.3	1	3
$G_{actual-h}$	0.89	1.75	4.04
$G_{actual-v}$	0.75	1.47	3.59
G_{actual}	0.66	2.57	14.5

Table 6b. Simulated guide gains for INEL4 (7.5x7.5 cm² guide, $L_{inc} = 8.0$ m with no gap).

λ	0.3	1	3
$G_{actual-h}$	1.00	1.51	2.15
$G_{actual-v}$	0.97	1.39	2.15
G_{actual}	0.97	2.10	4.62

Table 6c. Simulated guide gains for INEL4 (5x5 cm² guide, $L_{inc} = 8.0$ m with no gap).

λ	0.3	1	3
$G_{actual-h}$	0.91	1.55	1.92
$G_{actual-v}$	0.80	1.34	1.87
G_{actual}	0.73	2.08	3.59

The simulation for the guide specified in Table 1 is shown in Table 6c. This guide gives a gain of 0.7 at 0.3 Å, rising to 2.1 at 1 Å and 3.6 at 3 Å. Increasing the cross-section of the guide to 7.5x7.5 cm² increases the gains to 1.0, 2.1, and 4.6 respectively. Extending this 7.5x7.5 cm² guide to 2.5 m from the moderator while introducing a gap for the T₀ chopper would increase the gain at 3 Å by a factor of 3, but would reduce the gain at 0.3 Å because it would obscure more of the moderator. These simulations indicate that the guide for INEL4 is far from optimized, and that this guide should probably be about 10x10 cm² and should start at no more than 2.5 m from the moderator.

The values from the simulation (Tables 6b and 6c) agree very well with those from the analytical calculation (Table 5). The small differences can be ascribed statistical variations and to the fact that the simulation used an average reflectivity of 0.95 for the supermirror while the analytical calculation assumed a reflectivity of 1.00.

1.5 Collimation

The massive variable aperture collimator before the E₀ chopper is used to define the beam to the approximate size of the sample. The Soller collimator after the E₀ chopper eliminates background from neutrons scattered by that chopper.

1.6 Detectors

The linear position sensitive detectors are needed at the low scattering angles to provide good Q resolution there.

2 Performance

2.1 Resolution

For INEL4 the resolution in both Q and E are of interest.

$$Q = 2\pi \left\{ \frac{1}{\lambda_{\text{inc}}^2} + \frac{1}{\lambda_{\text{scat}}^2} - \frac{2}{\lambda_{\text{inc}} \lambda_{\text{scat}}} \cos 2\theta \right\}^{1/2} \quad (1)$$

$$\frac{\delta Q}{Q} = \left\{ \frac{\left(\frac{2}{\lambda_{inc}^2} - \frac{2 \cos 2\theta}{\lambda_{inc} \lambda_{scat}} \right)^2 \left[\left(\frac{\delta t_{inc}}{t_{inc}} \right)^2 + \left(\frac{\delta L_{inc}}{L_{inc}} \right)^2 \right] + \left(\frac{2}{\lambda_{scat}^2} - \frac{2 \cos 2\theta}{\lambda_{inc} \lambda_{scat}} \right)^2 \left[\left(\frac{\delta t_{scat}}{t_{scat}} \right)^2 + \left(\frac{\delta L_{scat}}{L_{scat}} \right)^2 \right]}{\left[\frac{1}{\lambda_{inc}^2} + \frac{1}{\lambda_{scat}^2} - \frac{2}{\lambda_{inc} \lambda_{scat}} \cos 2\theta \right]^2} + \frac{\left[\frac{2 \sin 2\theta}{\lambda_{inc} \lambda_{scat}} \delta 2\theta \right]^2}{\left[\frac{1}{\lambda_{inc}^2} + \frac{1}{\lambda_{scat}^2} - \frac{2}{\lambda_{inc} \lambda_{scat}} \cos 2\theta \right]^2} \right\}^{1/2} \quad (2)$$

$$E = \frac{81.787}{\lambda_{inc}^2} - \frac{81.787}{\lambda_{scat}^2} \quad (3)$$

$$\frac{\delta E}{E_{inc}} = 2 \left\{ \left[\frac{\delta t_{inc}}{t_{inc}} \right]^2 + \left[\frac{\delta L_{inc}}{L_{inc}} \right]^2 + \left[\frac{\lambda_{inc}^2}{\lambda_{scat}^2} \frac{\delta t_{scat}}{t_{scat}} \right]^2 + \left[\frac{\lambda_{inc}^2}{\lambda_{scat}^2} \frac{\delta L_{scat}}{L_{scat}} \right]^2 \right\}^{1/2} \quad (4)$$

Table 7 shows the resolution calculated at different scattering angles for this instrument.

Table 7. Resolution and dynamic range for INEL4.^a

2θ	$\delta Q/Q$	$\delta E/E_{inc}$	$Q (\text{\AA}^{-1})$
2°	0.36	0.015	0.28
30°	0.025	0.015	4.16
140°	0.0047	0.015	15.10

^a Calculated for $E_{inc}=E_{scat}=50$ meV, and $\delta L_{inc}=\delta L_{scat}=1$ cm.

2.2 Bandwidth and Dynamic Range

Only the first frame is needed. This provides access to incident wavelengths up to 2.45 Å with the scattered wavelength equal to 222% of the incident wavelength (incident energies down to 13.6 meV with the scattered energy equal to 20% of the incident energy).

Table 7 shows the dynamic range at different scattering angles with these wavelength ranges.

2.3 Data Rates

Data rate estimates for this instrument will be provided in a later Technical Note.

References

1. SNS Conceptual Design Report values for poisoned decoupled ambient water moderator.
2. Technical Note ANL/SNS/98-1