INEL2— 100-Microvolt Spectrometer —Reference Instrument WBS 1.7.4
Technical Note ANL/SNS/98-8
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1 Instrument Description

1.1 Overview

INEL2 is a crystal-analyzer spectrometer optimized for quasielastic scattering and low-energy inelastic scattering and designed to provide energy resolution of ~ 70 to $100 \mu\text{eV}$. Figure 1 provides a schematic representation of INEL2, and Table 1 gives the parameters for this instrument. The large solid angle subtended by the analyzer arrays leads to high data rates, making this an excellent instrument for real-time spectroscopic studies of chemical reactions, phase changes, and so forth.

Fig. 1. Schematic plan view of the 100-microvolt spectrometer INEL2.

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Table 1. Parameters for the 100-microvolt spectrometer INEL2

Component	Parameter	Value
Moderator	Beam line	3TU
	Moderator	Liquid-H ₂ , decoup, pois
Geometry	Source-sample distance	12.0 m
	Crystal analyzer	
	Sample-analyzer distance	0.6 m
	Analyzer-detector distance	0.6 m
T ₀ chopper	Type	Horizontal-axis T ₀
	Radius to beam center	250 mm
	Length	300 mm
	Distance from moderator	7.0 m
	Frequency	30 Hz
	Beam width at chopper	40 mm
	Wavelength range to open or close	0.48 Å @ 30 Hz
Bandwidth chopper #1	Type	Eisk
	Radius to beam center	250 mm
	Length	10 mm
	Distance from moderator	5.0 m
	Frequency	60 Hz
	Beam width at chopper	40 mm
	Wavelength range to open or close	0.34 Å @ 60 Hz
Bandwidth chopper #2	Type	Disk
	Radius to beam center	250 mm
	Length	10 mm
	Distance from moderator	7.5 m
	Frequency	60Hz
	Beam width at chopper	40 mm
	Wavelength range to open or close	0.22 Å @ 60 Hz
Guide	Type	Straight
	Coating, sides and top and bottom	2 × θ_c supermirror
	Channel width	40 mm
	Channel height	80 mm
	Moderator-to-guide distance	2.50 m
	Guide length	7.0 m
	Moderator to end of guide	9.5 m
	Gap for T ₀ chopper	0.4 m
	Filling	Evacuated to <10 ⁻² torr
Guide funnel	Coating, sides and top and bottom	3 × θ_c supermirror
	Width at exit	20 mm
	Height at exit	60 mm
	Funnel length	2.0 m
	Moderator to end of funnel	11.5 m
	Filling	Evacuated to <10 ⁻² Torr

Table 1 (continued)

Component	Parameter	Value
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 $\times$ 0.2 m
	Length	3.0 m
Beam stop	Steel	1.6 m $\times$ 1.6 m $\times$ 2.6 m
	Paraffin radial thickness around steel	0.2 m
	Re-entrant hole in steel	0.2 m $\times$ 0.2 m $\times$ 0.5 m
Sample	Width	6 mm
	Height	50 mm
Analyzer crystals	Material and plane	Graphite 002
	Bragg angle	$\sim 45^\circ$
	Wavelength selected	$\sim 4.7 \text{ \AA}$
	Analyzer area	$\sim 4,000 \text{ cm}^2$
	Distance from sample	$\sim 0.6 \text{ m}$
	Angular coverage	$\sim 20^\circ$ - 160°
	Number of independent angle groups	~ 16
	Solid angle coverage	$\sim 1 \text{ sr}$
	Cooling	TBD
Standard detectors	Filter	Cooled beryllium
	Type	^3He proportional
	Diameter	6 mm
	Length	50 mm
Data acquisition	Number	~ 80
Scattering chamber	Geometry	Vertical axis cylinder
	Diameter, excluding shielding	$\sim 2 \text{ m}$
	Height, excluding shielding	0.5 m
	Filling, direct beam portion	Evacuated to $<10^{-2}$ torr
	Filling, remainder	Helium
	Shielding, top and bottom	Top removable
	Shielding, sides	Removable
	Shielding thickness and composition	TBD
Sample chamber	Depth	$\sim 0.6 \text{ m}$
	Diameter	$\sim 0.3 \text{ m}$
	Filling	Evacuated to 10^{-6} torr
Resolution	Elastic	70 μeV

1.2 Source

A poisoned decoupled supercritical hydrogen moderator at ~22K provides a polychromatic beam of cold neutrons to the instrument. The design documented here assumes a fwhm pulse width of $\delta t \approx 58 \mu\text{s}$ at $10 \text{ \AA}$, $\delta t \approx 48 \mu\text{s}$ at $5 \text{ \AA}$, $\delta t \approx 35 \mu\text{s}$ at $3 \text{ \AA}$, and $\delta t \approx 11 \mu\text{s}$ at $1 \text{ \AA}$.¹ This moderator was selected for INEL2 because it provides a relatively high intensity of long-wavelength neutrons and the poisoning provides better resolution with these cold neutrons.

Beamline 3TU was chosen for this instrument because this beamline views the poisoned cold TU moderator and provides adequate space for this instrument.

1.3 Choppers

A T_0 chopper is used to cut out the prompt pulse to reduce background, and a series of bandwidth-limiting choppers is required to limit the incident bandwidth to prevent frame overlap and order contamination. Since larger-wavelength bands can be used if it is known that there is no neutron-energy-gain spectrum from the higher-order plane, this series of choppers must be able to select different bandwidths as well as to vary the wavelength at which the incident bandwidth is centered. The requirement to vary the selected bandwidth means that at least two choppers must be used. This bandwidth can be centered at any wavelength simply by adjusting the phase of the bandwidth choppers.

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 INEL2.

t0 chopper diameter (mm)	500.00
t0 chopper distance (m)	7.00
beam width at t0 chopper (mm)	40.00
bandwidth chopper #1 diameter (mm)	500.00
bandwidth chopper #1 distance (m)	5.00
beam width at bandwidth chopper #1 (mm)	40.00
bandwidth chopper #2 diameter (mm)	500.00
bandwidth chopper #2 distance (m)	7.50
beam width at bandwidth chopper #2 (mm)	40.00
distance to sample (m)	12.00
distance sample to detectors (m)	1.20
analyzer wavelength ($\text{\AA}$)	4.73

Table 3a. Opening and closing times for different chopper settings for INEL2.*

frame	1	2	3	4	5	6	1-2	1-3	1-4	1-5	1-6	4-6
$t_{\max}$ (μ s)	16667	33333	50000	66667	83333	100000	33333	50000	66667	83333	100000	100000
T0 freq (Hz)	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
T0 Δt_{T0} (μ s)	849	849	849	849	849	849	849	849	849	849	849	849
BW1 freq (Hz)	60.0	60.0	60.0	60.0	60.0	60.0	30.0	20.0	15.0	12.0	10.0	20.0
BW1 Δt_{BW1} (μ s)	424	424	424	424	424	424	849	1273	1698	2122	2546	1273
BW2 freq (Hz)	60.0	60.0	60.0	60.0	60.0	60.0	30.0	20.0	15.0	12.0	10.0	20.0
BW2 Δt_{BW2} (μ s)	424	424	424	424	424	424	849	1273	1698	2122	2546	1273
$t_{\min}$ (μ s)	1455	15911	32577	49244	65911	82577	1455	1455	1455	1455	1455	50602
T0 $t_{c-(N)}$ (μ s)	0	16667	33333	50000	66667	83333						
T0 $t_{eo-(N)}$ (μ s)	849	17515	34182	50849	67515	84182						
T0 $t_{sc-(N)}$ (μ s)	15818	32485	49151	65818	82485							
BW1 $t_{so-(N)}$ (μ s)	182	6205	13150	20094	27038	33983	-243	-667	-1091	-1515	-1940	19811
BW1 $t_{eo-(N)}$ (μ s)	606	6629	13574	20518	27463	34407	606	606	606	606	606	21084
BW1 $t_{sc-(N)}$ (μ s)	6347	13291	20235	27180	34124	41069	13291	20235	27180	34124	41069	41069
BW1 $t_{ec-(N)}$ (μ s)	6771	13715	20660	27604	34549	41493	14140	21509	28878	36246	43615	42342
BW2 $t_{so-(N)}$ (μ s)	485	9520	19936	30353	40770	51186	61	-364	-788	-1213	-1637	30353
BW2 $t_{eo-(N)}$ (μ s)	909	9944	20361	30778	41194	51611	909	909	909	909	909	31626
BW2 $t_{sc-(N)}$ (μ s)	9520	19936	30353	40770	51186	61603	19936	30353	40770	51186	61603	61603
BW2 $t_{ec-(N)}$ (μ s)	9944	20361	30778	41194	51611	62028	20785	31626	42467	53309	64150	62876

T0 = t-zero chopper, BW1 = first bandwidth chopper, BW2 = second bandwidth chopper

f = frequency, Δt = time for chopper edge to sweep thru beam

so = start open; eo = end open; c = fully closed; sc = start close; ec = end close

This table assumes $\Delta t_{c1}=0$ for the T₀ chopper.

* See Appendix A of Ref. 2 for definitions and equations.

Table 3b. Accessible wavelengths for different chopper settings for INEL2.*

frame	1	2	3	4	5	6	1-2	1-3	1-4	15	1-6	4-6
$t_{\max}$ (μ s)	16667	33333	50000	66667	83333	100000	33333	50000	66667	83333	100000	100000
T0 freq (Hz)	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
T0 $\Delta\lambda_{T0}$ ($\text{\AA}$)	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48
BW1 freq (Hz)	60.0	60.0	60.0	60.0	60.0	60.0	30.0	20.0	15.0	12.0	10.0	20.0
BW1 $\Delta\lambda_{BW1}$ ($\text{\AA}$)	0.34	0.34	0.34	0.34	0.34	0.34	0.67	1.01	1.34	1.68	2.01	1.01
BW2 freq (Hz)	60.0	60.0	60.0	60.0	60.0	60.0	30.0	20.0	15.0	12.0	10.0	20.0
BW2 $\Delta\lambda_{BW2}$ ($\text{\AA}$)	0.22	0.22	0.22	0.22	0.22	0.22	0.45	0.67	0.90	1.12	1.34	0.67
$\lambda_{inc-max}$ ($\text{\AA}$)	5.02	10.51	16.01	21.50	27.00	32.49	10.51	16.01	21.50	27.00	32.49	32.49
$\lambda_{inc-min}$ ($\text{\AA}$)	0.48	5.24	10.74	16.23	21.73	27.22	0.48	0.48	0.48	0.48	0.48	16.68
T0 $\lambda_{c-(N)}$ ($\text{\AA}$)	0.00	9.42	18.84	28.25	37.67	47.09						
T0 $\lambda_{eo-(N)}$ ($\text{\AA}$)	0.48	9.90	19.31	28.73	38.15	47.57						
T0 $\lambda_{sc-(N)}$ ($\text{\AA}$)	8.94	18.36	27.77	37.19	46.61							
BW1 $\lambda_{so-(N)}$ ($\text{\AA}$)	0.14	4.91	10.40	15.90	21.39	26.88	-0.19	-0.53	-0.86	-1.20	-1.53	15.67
BW1 $\lambda_{eo-(N)}$ ($\text{\AA}$)	0.48	5.24	10.74	16.23	21.73	27.22	0.48	0.48	0.48	0.48	0.48	16.68
BW1 $\lambda_{sc-(N)}$ ($\text{\AA}$)	5.02	10.51	16.01	21.50	27.00	32.49	10.51	16.01	21.50	27.00	32.49	32.49
BW1 $\lambda_{ec-(N)}$ ($\text{\AA}$)	5.36	10.85	16.34	21.84	27.33	32.82	11.19	17.02	22.84	28.67	34.50	33.50
BW2 $\lambda_{so-(N)}$ ($\text{\AA}$)	0.26	5.02	10.51	16.01	21.50	27.00	0.03	-0.19	-0.42	-0.64	-0.86	16.01
BW2 $\lambda_{eo-(N)}$ ($\text{\AA}$)	0.48	5.24	10.74	16.23	21.73	27.22	0.48	0.48	0.48	0.48	0.48	16.68
BW2 $\lambda_{sc-(N)}$ ($\text{\AA}$)	5.02	10.51	16.01	21.50	27.00	32.49	10.51	16.01	21.50	27.00	32.49	32.49
BW2 $\lambda_{ec-(N)}$ ($\text{\AA}$)	5.24	10.74	16.23	21.73	27.22	32.71	10.96	16.68	22.40	28.11	33.83	33.16

T0 = t-zero chopper, BW1 = first bandwidth chopper, BW2 = second bandwidth chopper

f = frequency, $\Delta\lambda$ = wavelength range for chopper edge to sweep thru beam

so = start open; eo = end open; c = fully closed; sc = start close; ec = end close

This table assumes $\Delta t_{c1}=0$ for the T₀ chopper.

* See Appendix A of Ref. 2 for definitions and equations.

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 INEL2. The gains calculated using these parameters with the guide starting 2.5 m from the moderator and 1.5 m from the moderator are shown respectively in Tables 5a and 5b.

Table 4. Preliminary guide parameters for INEL2.

Parameter	Meaning	Value
M_h	moderator width (mm)	100.00
M_v	moderator height (mm)	120.00
L_{inc}	moderator-guide distance (m)	2.50
		1.5
g_h	guide width (mm)	30.00
g_v	guide height (mm)	80.00
m_h	horizontal supermirror "m"	2.00
m_v	vertical supermirror "m"	2.00
λ^*	characteristic wavelength (Angstroms)	straight
R	radius of curvature (m)	straight
L_{sight}	line-of sight distance (m)	straight
L	source-sample distance (m)	12.00
L_{exit-h}	horizontal guide-sample distance (m)	1.00
L_{exit-v}	vertical guide-sample distance (m)	1.00
S_h	sample width (mm)	10.00
S_v	sample height (mm)	50.00
M_h/L	no-guide collimation horizontal (rad)	0.00833
M_v/L	no-guide collimation vertical (rad)	0.01000
g_h/L_{exit-h}	exit collimation horizontal (rad)	0.03000
g_v/L_{exit-v}	exit collimation vertical (rad)	0.08000
	(M-g)/2 (horizontal) (mm)	35.00
	(M+g)/2 (horizontal) (mm)	65.00
	(M-g)/2 (vertical) (mm)	20.00
	(M+g)/2 (vertical) (mm)	100.00
	(g-S)/2 (horizontal) (mm)	10.00
	(g+S)/2 (horizontal) (mm)	20.00
	(g-S)/2 (vertical) (mm)	15.00
	(g+S)/2 (vertical) (mm)	65.00

Table 5a. Approximate guide gains for INEL2 ($L_{inc} = 2.5$ m).

λ	0.5	1	2	3	4	5	6	7	8	9	10
$2\theta_{c-eff-h}$ (rad)	0.00340	0.00680	0.01360	0.02040	0.02720	0.03400	0.04080	0.04760	0.05440	0.06120	0.06800
$2\theta_{c-eff-v}$ (rad)	0.00340	0.00680	0.01360	0.02040	0.02720	0.03400	0.04080	0.04760	0.05440	0.06120	0.06800
$L_{inc-fall-h}$ (m)	20.59	10.29	5.15	3.43	2.57	2.06	1.72	1.47	1.29	1.14	1.03
$L_{inc-fall-v}$ (m)	11.76	5.88	2.94	1.96	1.47	1.18	0.98	0.84	0.74	0.65	0.59
F_{inc-h}	1.00	1.00	1.00	1.00	1.00	0.98	0.92	0.83	0.74	0.65	0.59
F_{inc-v}	1.00	1.00	1.00	0.99	0.96	0.93	0.88	0.84	0.79	0.74	0.69
F_{exit-h}	1.00	1.00	1.00	1.00	0.95	0.87	0.80	0.76	0.75	0.75	0.75
F_{exit-v}	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.98	0.97	0.97
$G_{ideal-h}$	0.41	0.82	1.63	2.45	3.26	4.08	4.90	5.71	6.53	7.34	8.16
$G_{ideal-v}$	0.71	0.76	1.36	2.04	2.72	3.40	4.08	4.76	5.44	6.12	6.80
$G_{actual-h}$	0.41	0.82	1.63	2.45	3.11	3.46	3.58	3.60	3.60	3.60	3.60
$G_{actual-v}$	0.71	0.76	1.36	2.02	2.62	3.15	3.58	3.93	4.21	4.41	4.55
G_{ideal}	0.29	0.62	2.22	4.99	8.88	13.87	19.98	27.19	35.51	44.95	55.49
G_{actual}	0.29	0.62	2.22	4.96	8.15	10.89	12.82	14.15	15.14	15.87	16.36

Table 5b. Approximate guide gains for INEL2 ($L_{inc} = 1.5$ m).

λ	0.5	1	2	3	4	5	6	7	8	9	10
$2\theta_{c-eff-h}$ (rad)	0.00340	0.00680	0.01360	0.02040	0.02720	0.03400	0.04080	0.04760	0.05440	0.06120	0.06800
$2\theta_{c-eff-v}$ (rad)	0.00340	0.00680	0.01360	0.02040	0.02720	0.03400	0.04080	0.04760	0.05440	0.06120	0.06800
$L_{inc-fall-h}$ (m)	20.59	10.29	5.15	3.43	2.57	2.06	1.72	1.47	1.29	1.14	1.03
$L_{inc-fall-v}$ (m)	11.76	5.88	2.94	1.96	1.47	1.18	0.98	0.84	0.74	0.65	0.59
F_{inc-h}	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.96	0.92
F_{inc-v}	1.00	1.00	1.00	1.00	1.00	0.99	0.98	0.96	0.93	0.91	0.88
F_{exit-h}	1.00	1.00	1.00	1.00	0.95	0.86	0.74	0.63	0.56	0.51	0.48
F_{exit-v}	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.97	0.96	0.94	0.93
$G_{ideal-h}$	0.41	0.82	1.63	2.45	3.26	4.08	4.90	5.71	6.53	7.34	8.16
$G_{ideal-v}$	0.65	0.72	1.36	2.04	2.72	3.40	4.08	4.76	5.44	6.12	6.80
$G_{actual-h}$	0.41	0.82	1.63	2.45	3.11	3.49	3.60	3.60	3.60	3.60	3.60
$G_{actual-v}$	0.65	0.72	1.36	2.04	2.72	3.37	3.94	4.43	4.86	5.23	5.55
G_{ideal}	0.27	0.59	2.22	4.99	8.88	13.87	19.98	27.19	35.51	44.95	55.49
G_{actual}	0.27	0.59	2.22	4.99	8.45	11.76	14.18	15.96	17.51	18.84	19.98

1.4.2 Guide Curvature

This guide is not curved.

1.4.3 Converging Funnel

A converging funnel is used to enhance the flux on the sample. The effects of this funnel are best indicated by the Monte Carlo simulations below.

1.4.4 Monte Carlo Simulations

Monte Carlo simulations were used to obtain a more accurate estimate of the performance of the INEL2 guide system. Parameters were the same as in Table 1 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 10 Å is only 0.017 radians, this range of angular divergence was more than enough to include all neutrons that could be accepted by the INEL2 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 takes on the appropriate supermirror value for the particular set of guide surfaces. Table 6 shows the results of these simulations.

Table 6a. Simulated guide gains for INEL2 ($L_{inc} = 2.5$ m with 0.5 m gap).

λ	1	3	6	10
$G_{actual-h}$	1.24	4.04	4.51	4.53
$G_{actual-v}$	0.97	2.66	4.43	5.23
G_{actual}	1.20	10.75	19.98	23.69

Table 6b. Simulated guide gains for INEL2 ($L_{inc} = 2.5$ m with no gap).

λ	1	3	6	10
$G_{actual-h}$	1.26	4.21	4.68	4.75
$G_{actual-v}$	0.98	2.76	4.72	5.66
G_{actual}	1.23	11.62	22.09	26.89

Table 6c. Simulated guide gains for INEL2 ($L_{inc} = 1.5$ m with no gap).

λ	1	3	6	10
$G_{actual-h}$	1.27	4.34	4.71	4.85
$G_{actual-v}$	0.92	2.78	5.17	6.82
G_{actual}	1.17	12.07	24.35	33.08

Comparing Tables 5a and 5b with Tables 6b and 6c indicates that the funnel has increased the guide gain by a factor of about 2 at all wavelengths considered. The funnel gain is actually probably somewhat more than this, since the overall performance in the simulation is reduced by the use of the more realistic supermirror reflectivity.

Extending the guide to 1.5 m from the moderator makes a small but significant improvement. The inclusion of a gap for a T_0 chopper results in a small, but significant reduction in guide gain.

Somewhat more extensive studies than are indicated in Table 6 were carried out to roughly optimize the funnel parameters for this instrument. However, considerable improvement in the performance of this guide system may be possible with further optimization studies.

1.5 Crystal Analyzer Arrays

Figure 1 shows schematically the nested-arm design chosen for INEL2. The figure shows 16 arms, each having a graphite analyzer crystal array in the scattered beam. The actual number of arms is a variable to be optimized. The graphite 002 reflection near 45° Bragg angle selects ~ 4.7 Å neutrons. Each arm has a focused array of graphite crystals with its own set of detectors and with a beryllium filter in front of the detectors. The focusing permits use of 3° mosaic graphite, giving significant cost savings. These arrays are arranged to provide nearly continuous scattering angle coverage from 20 to 160° . This arrangement, with the 45° Bragg angle, requires nesting of the analyzer arms, so that not all arms have the same path length. The beryllium filter eliminates neutrons from the 004 and higher order reflections, leaving a wide dynamic range for inelastic scattering measurements. Elastic resolution should be ~ 70 μeV using the 002 reflection. This instrument is optimized for quasielastic and low-energy elastic scattering, but is also quite good for spectroscopy with incident energies up to ~ 100 meV.

The solid angle subtended by each analyzer arm is maximized by increasing the size of the analyzer crystal array as much as possible without spoiling the energy resolution. Focusing techniques are employed to minimize the resolution with these large crystal arrays. Two types of focusing are important. Variations in the flight time from sample to detector directly contribute to the uncertainty in the source-sample flight time, so keeping the sample-detector flight time constant for all scattered neutron paths in the analyzer arm minimizes the incident energy resolution δE_{inc} . On the other hand, keeping the energy E_{scat} accepted by the analyzer constant for all sample-detector flight paths minimizes the final energy resolution δE_{scat} . The choice of the type of focusing determines the type of science for which the instrument is optimized. The constant-final-energy focusing technique is used for INEL2 because it gives the best resolution for quasielastic and low-energy inelastic scattering. Detailed optimization of the focusing geometry of the crystal analyzer arrays will be described in a later Technical Note.

1.6 Detectors

About five detectors are required for each of the analyzer arrays.

Detector arrays are also provided with no analyzer crystals, so that diffraction from the sample can be measured concurrently with the inelastic data.

Either small ^3He detectors or an array of scintillation detectors based on the ZnS-LiF scintillator can be used. ^3He detectors are likely to be more stable and less sensitive to magnetic fields. A final choice has not yet been made.

2 Performance

2.1 Resolution

For INEL2 the resolution in both the energy transfer E and the wavevector transfer Q are of interest.

$$E = \frac{81.787}{\lambda_{\text{inc}}^2} - \frac{81.787}{\lambda_{\text{scat}}^2} \quad (1)$$

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

where 2θ is the scattering angle and

$$\lambda_{\text{scat}} = 2d \sin \theta_B \quad (3)$$

$$\lambda_{\text{inc}} = \frac{3955.4(t - t_{\text{scat}})}{L_{\text{inc}}} = \frac{3955.4 t}{L_{\text{inc}}} - \frac{\lambda_{\text{scat}} L_{\text{scat}}}{L_{\text{inc}}} \quad (4)$$

Here θ_B is the Bragg angle for the analyzer crystals, d is the spacing of the reflecting planes in the analyzer crystals (in Å), and t is the measured time-of-flight time. The energy resolution is given by

$$\begin{aligned} \frac{\delta E}{E_{\text{scat}}} = 2 \left\{ \left(1 + \frac{\lambda_{\text{scat}}^3 L_{\text{scat}}}{\lambda_{\text{inc}}^3 L_{\text{inc}}} \right)^2 \left[\frac{\delta \lambda_{\text{scat}}}{\lambda_{\text{scat}}} \right]^2 + \frac{\lambda_{\text{scat}}^4}{\lambda_{\text{inc}}^4} \left[\frac{\delta L_{\text{inc}}}{L_{\text{inc}}} \right]^2 + \left(\frac{\lambda_{\text{scat}}^3 L_{\text{scat}}}{\lambda_{\text{inc}}^3 L_{\text{inc}}} \right)^2 \left[\frac{\delta L_{\text{scat}}}{L_{\text{scat}}} \right]^2 \right. \\ \left. + \frac{\lambda_{\text{scat}}^4}{\lambda_{\text{inc}}^4} \left(1 + \frac{\lambda_{\text{scat}} L_{\text{scat}}}{\lambda_{\text{inc}} L_{\text{inc}}} \right)^2 \left[\frac{\delta t}{t} \right]^2 \right\}^{1/2} \quad (5) \end{aligned}$$

where δt is the source pulse width and t is the total source-sample-detector flight time. The full expression for the wavevector resolution can be derived in a similar fashion. However, since the wavevector resolution is dominated by the uncertainty in scattering angle this resolution can be written approximately as

$$\frac{\delta Q}{Q} \approx (\cot \theta) \delta \theta \quad (6)$$

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

Table 7. Resolution and dynamic range for INEL2.^a

2θ	$\delta Q/Q$	$\delta E/E_{\text{scat}}$	$Q (\text{\AA}^{-1})$
20°	0.35	0.018	0.46
90°	0.061	0.018	1.89
160°	0.011	0.018	2.63

^a Calculated for $E_{\text{inc}}=E_{\text{scat}}=3.70$ meV, $\delta L_{\text{inc}}=\delta L_{\text{scat}}=1$ cm, $\theta_B=45^\circ$, $\delta\theta_B=0.4^\circ$, $\delta\theta=3.5^\circ$, and $\delta d=0$.

2.2 Bandwidth and Dynamic Range

Only the first frame is needed, and this is accessed with the bandwidth choppers running at 60 Hz. This provides access to an incident wavelength range of ~ 0.48 to 5.02 $\text{\AA}$, for a scattered wavelength of 4.73 $\text{\AA}$. The elastic line for this instrument is nominally at 4.73 $\text{\AA}$, so this range should be adequate.

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 supercritical hydrogen moderator.
2. Technical Note ANL/SNS/98-1