Inelastic X-ray Scattering with meV Resolution

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• Current meV Spectrometers
• meV – IXS at NSLS II

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Spectrometers for Inelastic X-ray Scattering

Energy resolution: 10 - 1 meV

$\delta E \sim 1/E^4$ !
IXS-Monochromator

Resolution: 1.3 meV
Flux: $10^9$ phts/sec
Tunable: 21.5-21.7 keV

Similar monochromator for 0.9 meV @ 9 keV!

Artificial channel-cut, T. Toellner, D. Shu, APS
Analyzer disk

Diced and dynamically bent silicon substrate
Inelastic spectrometer at APS, 3 IDC-C
Strengths of meV-IXS

- small beam
- purely coherent
- high speed!

ω

V_{\text{liquid}}

V_{\text{neutron}}

Q

thermal neutrons
Science with meV- IXS

Equivalence of sound velocity in water and ice at mesoscopic wavelength, Ruocco et al., Nature 1996.


**Levitated Liquid Al$_2$O$_3$ @ 2050°C**


1.8 meV, 21.6 keV
Phonons in MgB2

FIG. 1 (color online). Energy loss scan in almost transverse geometry measured at $\mathbf{Q} = (1 2 0.3)$ corresponding to 0.6 $\Gamma$-$A$. The data, normalized to the incident flux, are shown with the least-squares fit (dashed line) and the ab initio spectrum with and without broadening due to experiment and electron phonon coupling (solid lines). The broad peak corresponds to the damped $E_{2g}$ mode and is shown in greater detail in the inset. The peak at zero is due to diffuse scattering.

Crystal 400 x 400 x 40 $\mu$m
Energy resolution: 6 meV, 15.8 keV

A. Shukla et al., PRL 90, 095506 (2003)
Phonons in $\delta$-Plutonium-Gallium

Polycrystalline foil
Grain size: 90 x 90 x 10 $\mu$m
Energy resolution: 1.8 meV
Energy: 21.7 keV

meV-Spectrometers

Running
- ESRF: 2 spectrometers 1.5 – 10 meV
- APS: 1 spectrometer 2 meV
- Spring8: 1 spectrometer 2-6 meV

Under construction:
- APS IXS-CDT: 0.9 – 2 meV

Conceptual phase:
- PETRA III: 0.5 – 3 meV
- Diamond (?)
IXS- CDT: APS, Sector 30

CDT directors: J. Hill (BNL), E. Alp (APS)

Project managers: Mohan Ramanahan, Yeldez Amer

HERIX: H. Sinn, B. Brajuskovic, D. Shu

MERIX: C. Burns, J. Hill, S. Coburn
HERIX spectrometer: 0.9 meV

- 9 m long arm
- 9-18 analyzers
- focus at sample 30 x 6 μm
- moved weight 6 tons
IXS-CDT 2003

Start of commissioning: 2005
meV-IXS at NSLS-II

Permanent magnet
S.C. Undulator NbTi/Cu
S.C. Undulator Nb$_3$Sn

APS: 7 GeV, 100 mA, 8mm gap
NSLS-2: 3 GeV, 500 mA, 5 mm gap

Brilliance vs. Energy (keV)

Flux/0.1% bandwidth vs. Energy (keV)
**Energy resolution for different arm lengths**

For $E \leq 20$ keV: 5 m analyzer arm!
Analyzers with 1-2 meV @ 10 keV?

1. Sapphire

2. Asymmetric silicon

Courtesy: Y. Shvydko, Univ. Hamburg
+ E.E. Alp, H. Yavas, APS

Y. Shvydko
Conclusions

• **NSLS-II** very competitive in flux and superior in brilliance for $E \leq 20$ keV.

• **IXS spectrometer** could be built with $\delta E \geq 2$ meV (maybe even better).

• Instead of glasses and liquids, phonons in micro-crystals!

• Instead of multiple analyzers, vertical scattering geometry with one (big) analyzers.
Vertical versus horizontal scattering plane

$I \sim Q^2 f^2(Q) \cos^2(2\theta)$

21.6 keV
IXS at NSLS-II: 5 m vertical arm?
Multiple analyzers for single crystals?

1 analyzer:
$\delta Q = 0.13 \text{ Å}^{-1}$

10 analyzers:
$\delta Q_{\text{vert}} = 0.16 \text{ Å}^{-1}$
... $0.9 \text{ Å}^{-1}$