Challenges of neutron scattering: signal, background, energy resolution

What advantages and disadvantages are encountered in neutron scattering as the peak of the spectrum is shifted from 3 meV (Cold Neutrons) to 0.3 meV (Very Cold Neutrons)?

Examples of scattering physics that exhibit wavelength (λ) dependence. Consider as well new technologies (since 2005), e.g., additive manufacturing, nanomanufacturing that might enable technologies that were previously thought to be impractical to apply for neutron instrumentation.

Index of refraction, *n*.

$$n \approx 1 - \lambda^2 \frac{\rho}{2\pi^2} = 1 - \delta$$

Where ρ is the neutron scattering length density (with nuclear and magnetic components).

The perturbation to n (or the dispersive component of n), δ, varies as λ^2.

Critical angle of reflection, θ_c.

$$\theta_c = \sqrt{2\pi\delta} = \lambda\sqrt{\frac{\rho}{\pi}}$$

Reflection optics should be easier to achieve as λ becomes large. Focal lengths could be made correspondingly shorter (shorter flight paths, larger bandwidth…).

Absorption

Absorption increases with λ. Detector thickness will become correspondingly smaller, reducing uncertainty in measuring times-of-flight, reducing number of absorbing elements in a solid state detector which may enable reduced pixel size compared to gas detectors… Can the third dimension of the detector be usefully exploited? For example each layer comprising the 3rd dimension of a detector record data independently then used to extract spectral information.

Requires additional attention paid to absorbing windows, flight paths, optics…

Gravity

Perturbation to vertical trajectory of a neutron varies as the square of time-of-flight, t^2, which is proportional to λ^2.

Refractive optics

The size of a Fresnel lens, L, varies as

$$L = 2\sqrt{2N\lambda f}$$

where N is the number of zone plates and f is the focal length. L varies as $\lambda^{1/2}$, meaning that larger lens can be made for fixed N and f, or shorter focal lengths, fewer zones, etc. as λ increases for fixed *L*.

The depth of the parabolic cut into a neutron Fresnel focusing lens (a concave lens) varies as $1/(f\lambda^2)$. Thus, the shape of a lens for a long λ application is less severe than for short λ (for constant f).

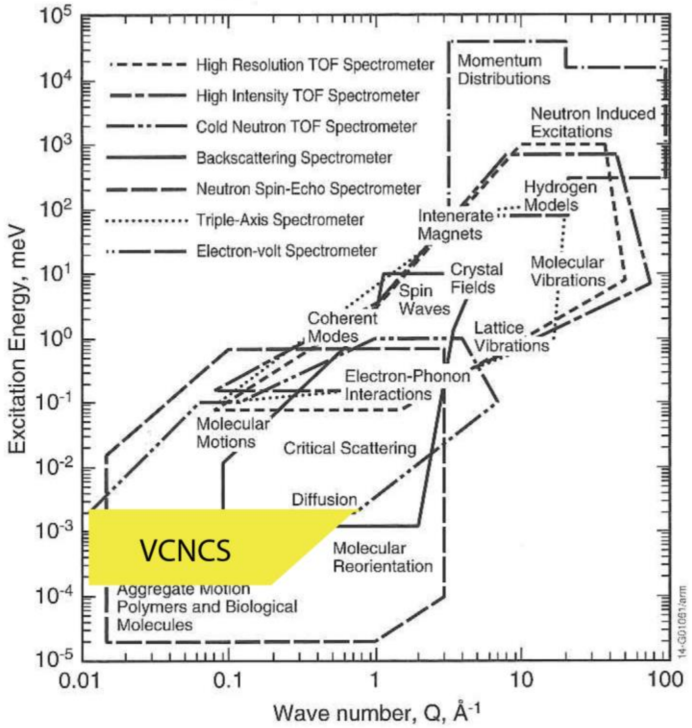
Focusing can be used to concentrate a reasonably collimated neutron beam into a spot. With a short focal length, the lens can be placed close to the sample, or a larger fraction of the neutron beam can be focused. All become easier with larger λ.

Alternatively, focusing can be used to magnify an image. A magnification of ~2000 may be technically feasible.

Collimation

As λ increases the scattering moves to larger scattering angles with a concomitant improvement in resolution possible. The brightness of the beam to which the sample is exposed varies with the product of the areas (normal to the beam direction) of two apertures (one may be the sample). As scattering angle increases collimation can be relaxed, i.e., one dimension of each aperture will increase with scattering angle or λ. Consequently the brightness increases with λ^2. Even if the peak of the VCN spectrum has the same magnitude as that of the CN spectrum, we expect an increase in performance of $25 = (15Å/3Å)^2$, for some experiments.

Access to Q-E space



Yellow shows the range of Q-E space accessible by reducing the incident energy available on the CNCS instrument by an order of magnitude, perhaps enabled by a VCN source. This region might enable studies of soft matter presently in the domain of spin echo.

Might the 3rd dimension of a neutron detector, or some other means, enable isolation of elastic scattering from inelastic scattering in a convenient manner to improve the quality of data taken for example with SANS?

Neutron guides

We can more effectively guide long-λ neutron beams with lower m-value guides which are cheaper and have higher reflectivity, than larger m-value guides needed for short-λ beams.

Polarized beams

Because the $m\theta_c$ angle of a supermirror is proportional to λ, as λ increases we can more easily transport neutron beams of large cross-section. We can also afford to use lower m-value mirrors, which have significantly greater spin-dependent reflectivities than more expensive high m-value mirrors.

^{3}He filters tuned for long- λ neutron beams can operate at lower pressures and need not be as long as filters tuned for short- λ beams. Consequently, the cells can be bigger.

Homework charge:

Keeping in mind the thoughts above, *what new science would be enabled by neutron scattering instrumentation optimized for a VCN source, and what would the instrumentation look like?*

Reflectometry
SANS
Inelastic neutron scattering, what Q and E?
Imaging, perhaps achieve < 0.1 μm, in scanning/raster mode?
Larmor precession
Microscopy
Digital holographic microscopy (?)
Neutron Spin Echo to > 10 μs and what Q?
Neutron Resonant Spin Echo > 10 μs

Soft matter
Hierarchical structures & mesoscale
Nanomaterials
Chemistry

In situ, in operando characterization, synthesis

Quantum physics, interferometry

Ultra-cold neutrons

Electric dipole measurement