What can be done using NEUTRON SPIN ECHO

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discovery of the principle by F. Mezei in 1972

polymer dynamics researches by D. Richter in 1980's

P. G. de Gennes Nobel Prize in Physics 1991

Further improvement and development of the NSE technique!

Still increasing the technique papers

searched using web of science: keyword=neutron spin echo
how to choose a spectrometer

1. length scale
   diffraction? small-angle?
structure research & method

neutron energy [meV]

thermal neutron

cold neutron

crystalline, magnetic structure

dna

protein

DNA

micelles

zeolites

miscro-porous

vesicles

polymers, gels

viruses

polymer phase separated structure

neutron diffraction

small-angle neutron scattering

x-ray diffraction

small-angle x-ray scattering

ultra small-angle neutron scattering

ultra small-angle x-ray scattering

electron microscope

optical microscope

size [m]

10^{-10} 10^{-9} 10^{-8} 10^{-7} 10^{-6} 10^{-5}

~100 ~1 ~0.01
how to choose a spectrometer

1. length scale
   - diffraction?  small-angle?

2. energy scale
   - neV?  meV?
dynamics research & method

\[ d \, [\text{Å}] \]

\[ \Delta E \, [\text{eV}] \]

\[ q \, [\text{Å}^{-1}] \]

- Hydrogen modes
- Molecular vibrations
- Spin waves
- Lattice vibrations
- Heavy Fermions
- Molecular rotations
- Critical scattering
- Diffusion
- Tunneling spectroscopy
- NSE: highest energy resolution among other neutron spectrometers

NSE: NSE

Raman, Brillouin, DLS, XPCS
dynamics research & method

\[ \Delta E \text{ [eV]} \]

\[ d \text{ [Å]} \]

\[ q \text{ [Å}^{-1}] \]

**Methods**
- Raman
- Brillouin
- NMR
- TOF
- BS
- XPCS
- DLS
- Reptation motion
- Segment motion
- Local motion
- Side chain motion
- Collective diffusion motion

**Time**
- \( t \) [ns]
how to choose a spectrometer

1. length scale
   - diffraction? small-angle?

2. energy scale
   - neV? meV?

3. dynamics
   - excitation? relaxation?
**inelastic vs quasi-elastic scattering**

**excitation:** neutrons exchange energy with an oscillation motion which has a finite energy transfer

phonon, magnon, ...

**relaxation:** neutrons exchange energy to make another new equilibrium state (no typical finite energy transfer exists)

mean energy of neutrons are the same before and after the scattering
NSE works in time domain: $S(q, \omega)$ vs $I(q,t)$

$$I(q,t) = \int S(q, \omega) \exp(-i\omega t) d\omega$$

Intermediate scattering function is the Fourier transform of dynamic structure factor excitation $I(q,t)$ shows an oscillating function
NSE works in time domain: \( S(q, \omega) \) vs \( I(q, t) \)

\[
I(q, t) = \int S(q, \omega) \exp(-i\omega t) d\omega
\]

intermediate scattering function is the fourier transform of dynamic structure factor

\[ I(q, t) \text{ shows a decaying function} \]

NSE is the best suited to see relaxation dynamics
how to choose a spectrometer

1. **length scale**
   - diffraction? small-angle?

2. **energy scale**
   - neV? meV?

3. **dynamics**
   - excitation? relaxation?

4. **intensity**
   - coherent dynamics? incoherent dynamics?
Scattering Intensity

Reptation motion
Collective Diffusion
Segment motion
Local motion
Side chain motion

larger scale objects: slower dynamics
coherent dynamics
incoherent dynamics at high q

problems to observe incoherent dynamics ...
1: limitation of the detection area
2: spin flip scattering
Spin flip scattering

we loose 1/3 of signals when we measure incoherent dynamics

settings of NSE spectrometer for coherent nucleus scattering and magnetic scattering experiments are different
summary: usage of NSE

1. length scale

We can cover q-range from 0.02 to 1.8 Å⁻¹. However, the detection area is limited and normally high-q experiment takes longer time.

2. energy scale

We can cover energy range from several neV to sub meV (time range from ps to hundreds of ns). Highest energy resolution among inelastic/quasi elastic neutron scattering spectrometers.

3. dynamics

Suited to observe relaxation dynamics.

4. intensity

Coherent core scattering at low q is the best measured by NSE so far. Incoherent dynamics and magnetic scattering can also be measured.

large length scale (>1nm), small energy scale (neV), coherent dynamics, relaxation, ...
some keywords today

Neutron Spin Polarization & Precession
Neutron Spin Echo & Echo Signal
Fourier Time

how NSE achieves highest energy resolution

Coherent, Incoherent & Magnetic Scattering

Intermediate Scattering Function
we use I(q,t) and S(q,t) as the same meaning

Relaxation, Diffusion, Thermal Fluctuation,...
THANK YOU FOR YOUR ATTENTION!