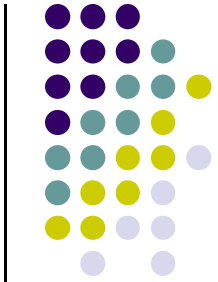
Total Neutron Scattering Cross Section of Solid Methane Confined in Aerogel Glass

Haiyang Yan

Neutron Properties which makes it an unique probe



- Charge : 0

Interact with atoms by short range residual nuclear force;

Not be screened by E & M interaction, see the nuclei directly;

Can penetrate very deep into the bulk materials.

- Mass : 939.566Mev

It is massive. Spatial resolution depends on wavelenth, $\lambda = h / p, E = p^2/2\mathrm{m}$,

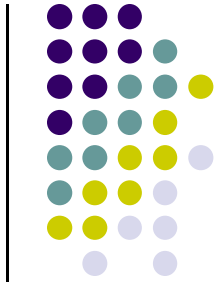
For same spatial resolution, neutrons energy resolution is much smaller.

e.g. for ~ Å neutrons, energy and energy resolution are in order of meV

- Spin : 1/2 and magnetic moment : -1.913μ_N

It can interact with the magnetic moment of the material, which can be differentiated from the nuclear interaction.

Disadvantage:



Limited flux
Large size
High cost
Hard to slow down

The Nobel Prize in Physics 1938

"for his demonstrations of the existence of new radioactive elements produced by neutron irradiation, and for his related discovery of nuclear reactions brought about by **slow neutrons**"

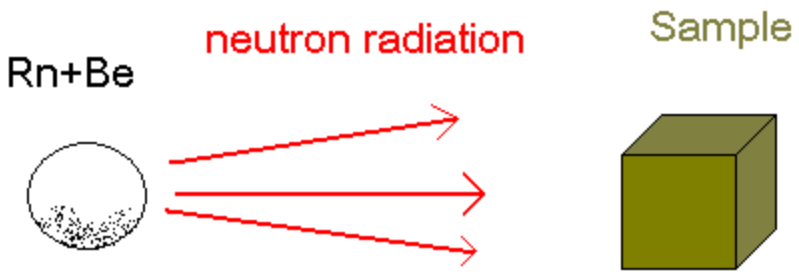
Enrico Fermi

Italy

Rome University
Rome, Italy

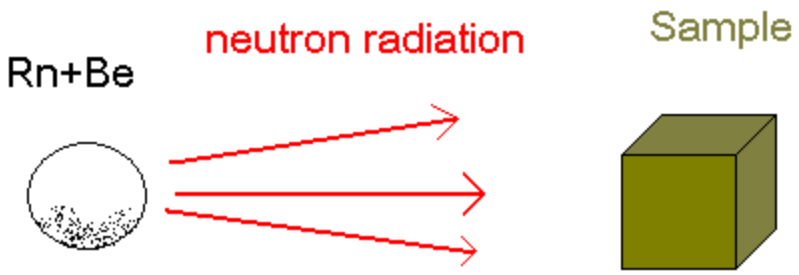
b. 1901
d. 1954

The Discovery of Slow Neutron Effects



- $\mathrm{Rn} \rightarrow \alpha + \mathrm{Po}$
- $\alpha + {}^{9}\mathrm{Be} \rightarrow n + {}^{12}C$
- radiates 2×10^{7} neutrons/second
- Small size & simply setup

The Discovery of Slow Neutron Effects



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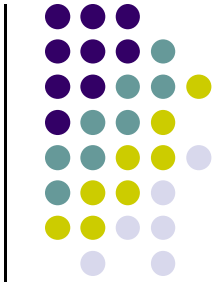
"The intensity of the activation as a function of the distance from the neutron source shows in some cases anomalies apparently dependent on the objects that surround the source. A careful investigation of these effects led to the unexpected result that surrounding both source and body to be activated with masses of paraffin, increases in some cases the intensity of activation by a very large factor (up to 100). A similar effect is produced by water, and in general by substances containing a large concentration of hydrogen. Substances not containing hydrogen show sometimes similar features, though extremely less pronounced."

The Slow Neutron Effects



● Neutrons are neutral, they do not need high energy to penetrate deep into the nucleus since they will not be stopped by the Columb force.

● The slower the neutrons, the longer time they can spend inside nucleus, the larger the chance that they can induce nuclear reactions.

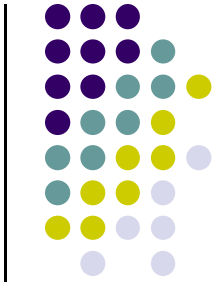
●For 3He or 1H,

neutron absorption cross section $\propto$ 1/v

●The discovery of nuclear fission makes mankind more eagerly to slow down the neutrons:

Slower the neutrons → larger the fission cross section(235U,or 239 Pu)

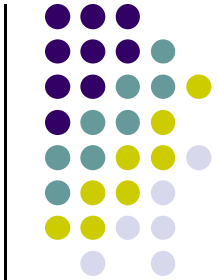
Competition



- Hydrogen has very high efficiency in slowing down:

Element	Total Scatt Xs(barn)
H	82.023
D	7.64
4He	1.34
12C	5.559

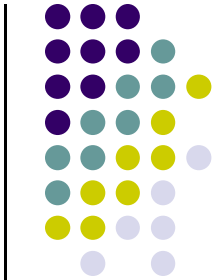
Competition of the Neutron Moderators



- Unfortunately neutron absorption cross section of Hydrogen is also very large:

Element	Total Scatt Xs(barn)	Abs xs(barn)
H	82.023	0.3326
D	7.64	0.000519
4He	1.34	0
12C	5.559	0.00353

Competition of the Neutron Moderators



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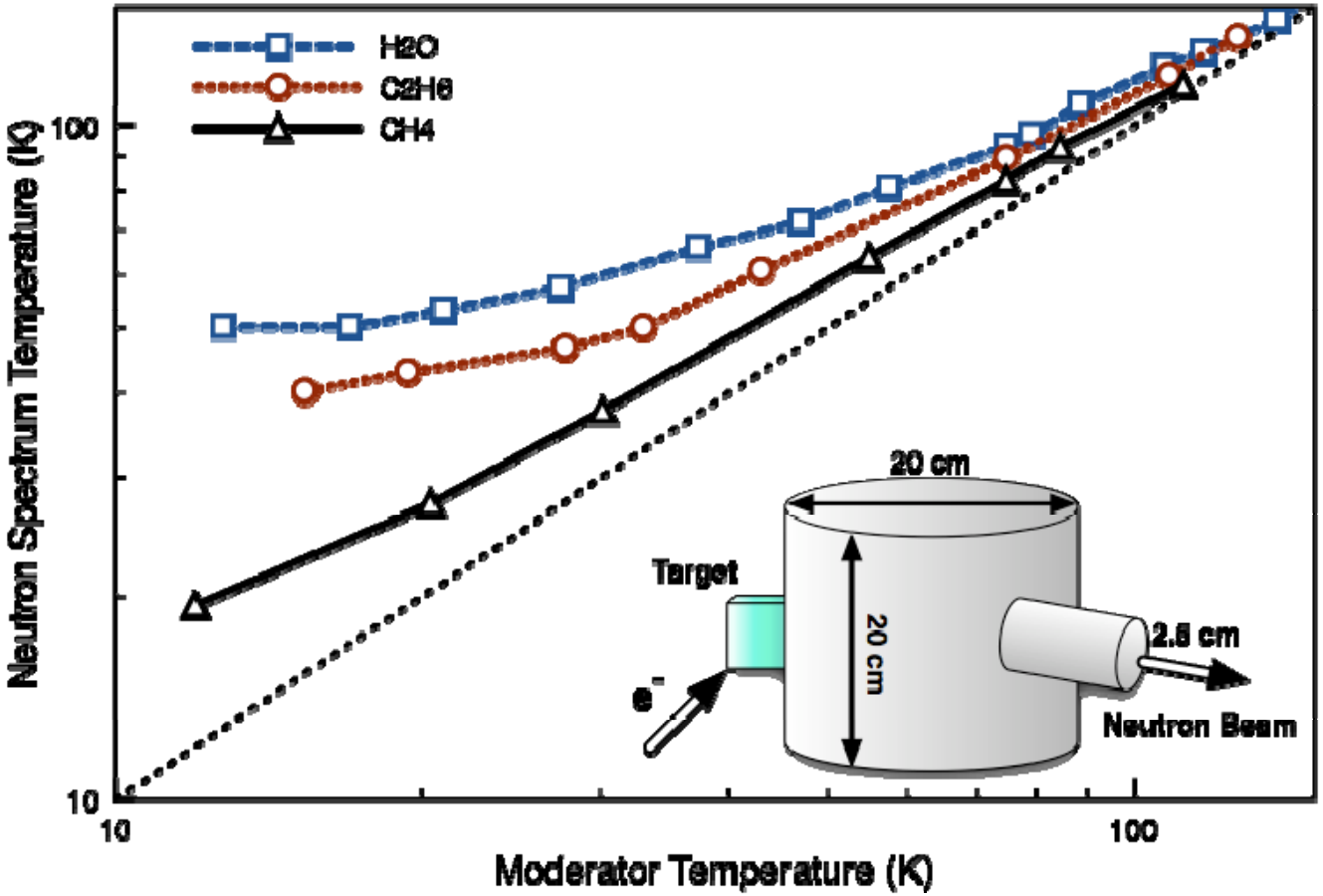
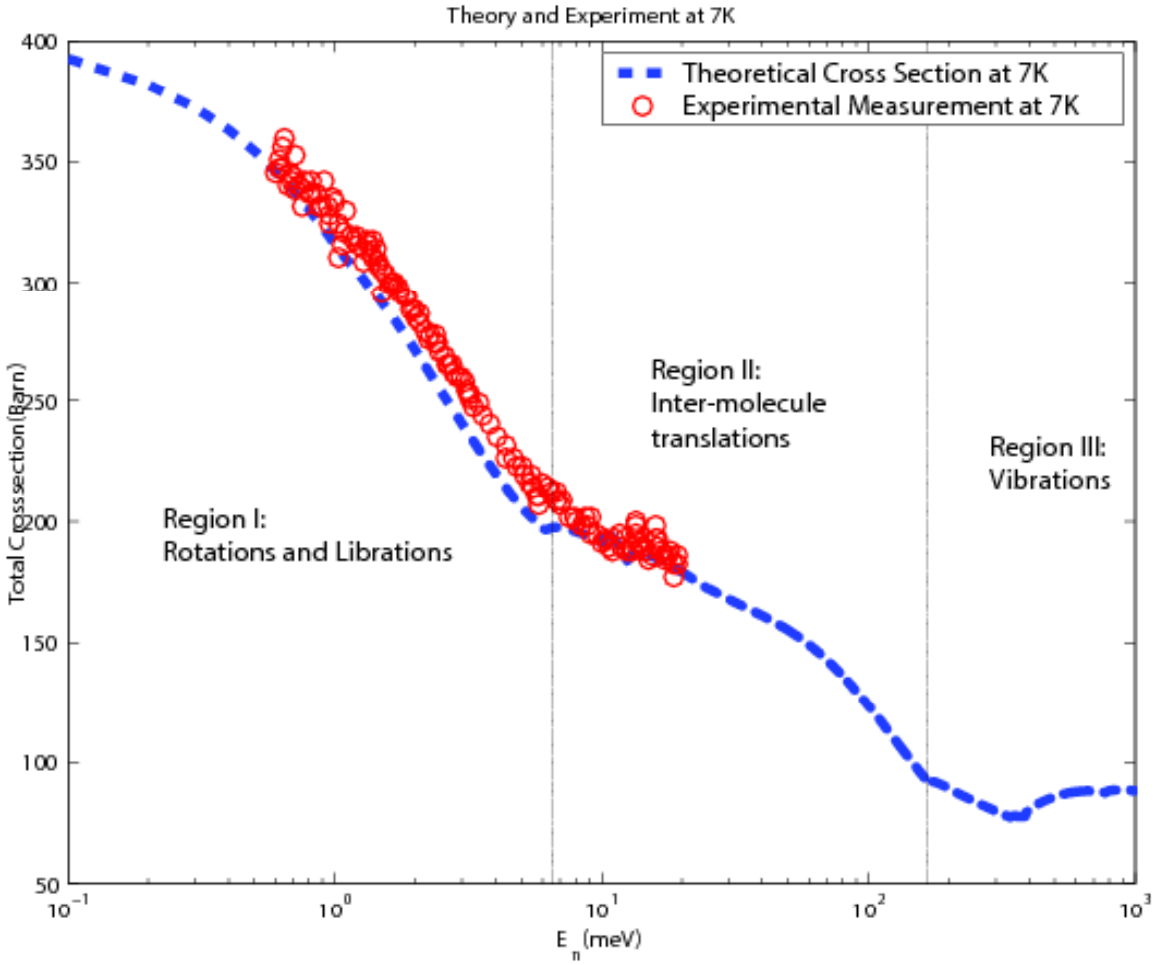
Graphite Reactor:238U→239Pu→A Bomb

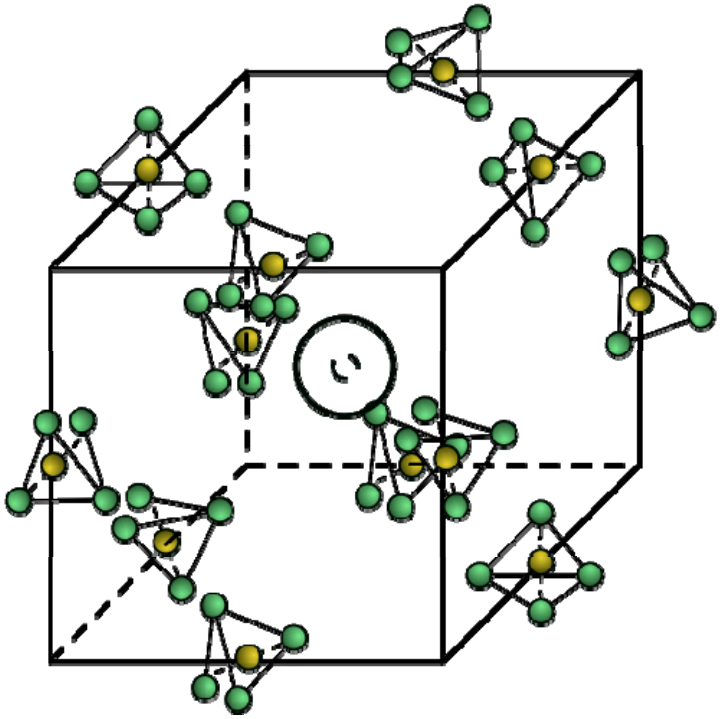
No need for isotope separation!

Competition problem for the Neutron Moderators

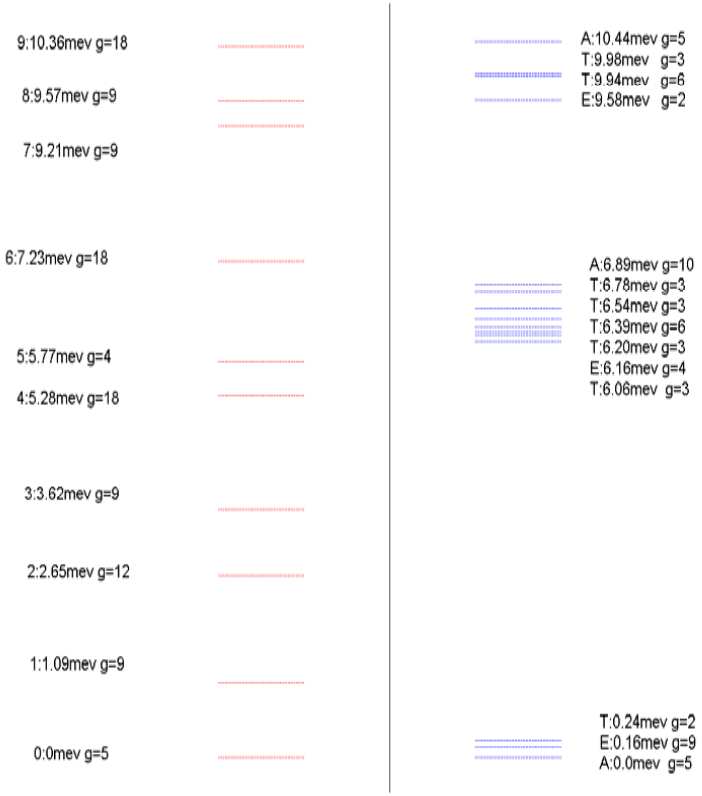


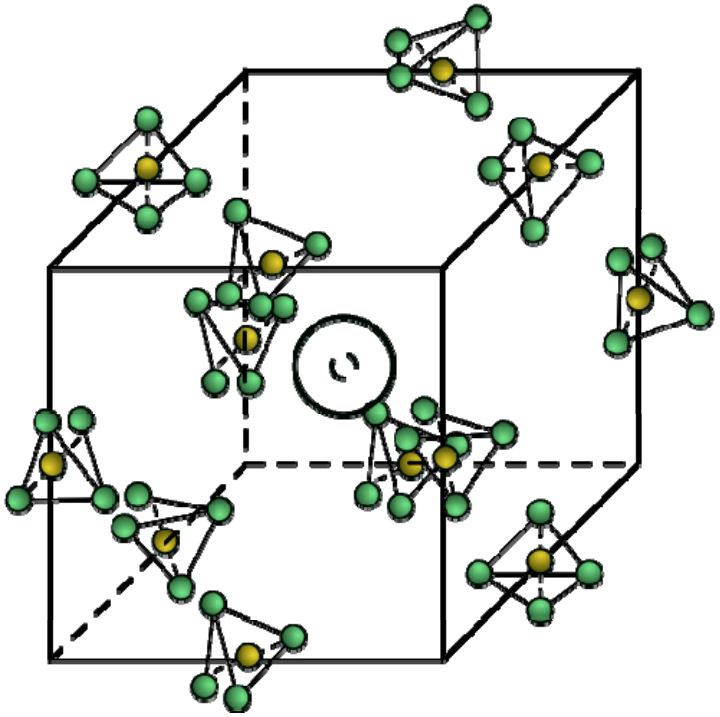
K.Inoue et al, Nuclear Instruments and Methods, 192, 129-136, (1982)


Theory and Experiment at 7K
Theoretical Cross Section at 7K
Experimental Measurement at 7K
Region I:
Rotations and Librations
Region II:
Inter-molecule
translations
Region III:
Vibrations
Total Cgssection (Barn)
E n (meV)
400
350
300
250
200
150
100
50
10−1
10 0
10 1
10 2
10 3



Competition: Decreased Slowing Down Efficiency

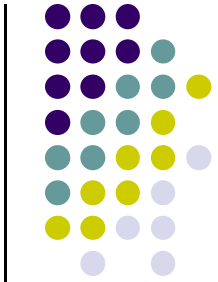




¼:Free rotors

¾: Hindered rotors

Competition: Increased Absorption XS



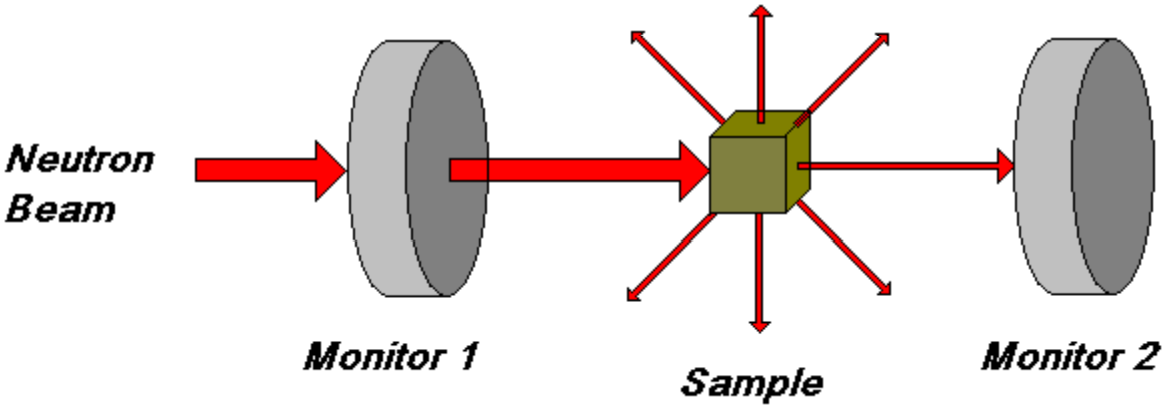
Neutron Absorption Cross Section of Hydrogen:

$$\sigma = \frac{6.2 \times 10^4 b}{v(cm/s)}$$

Motivation: Increase the Slowing down efficiency.

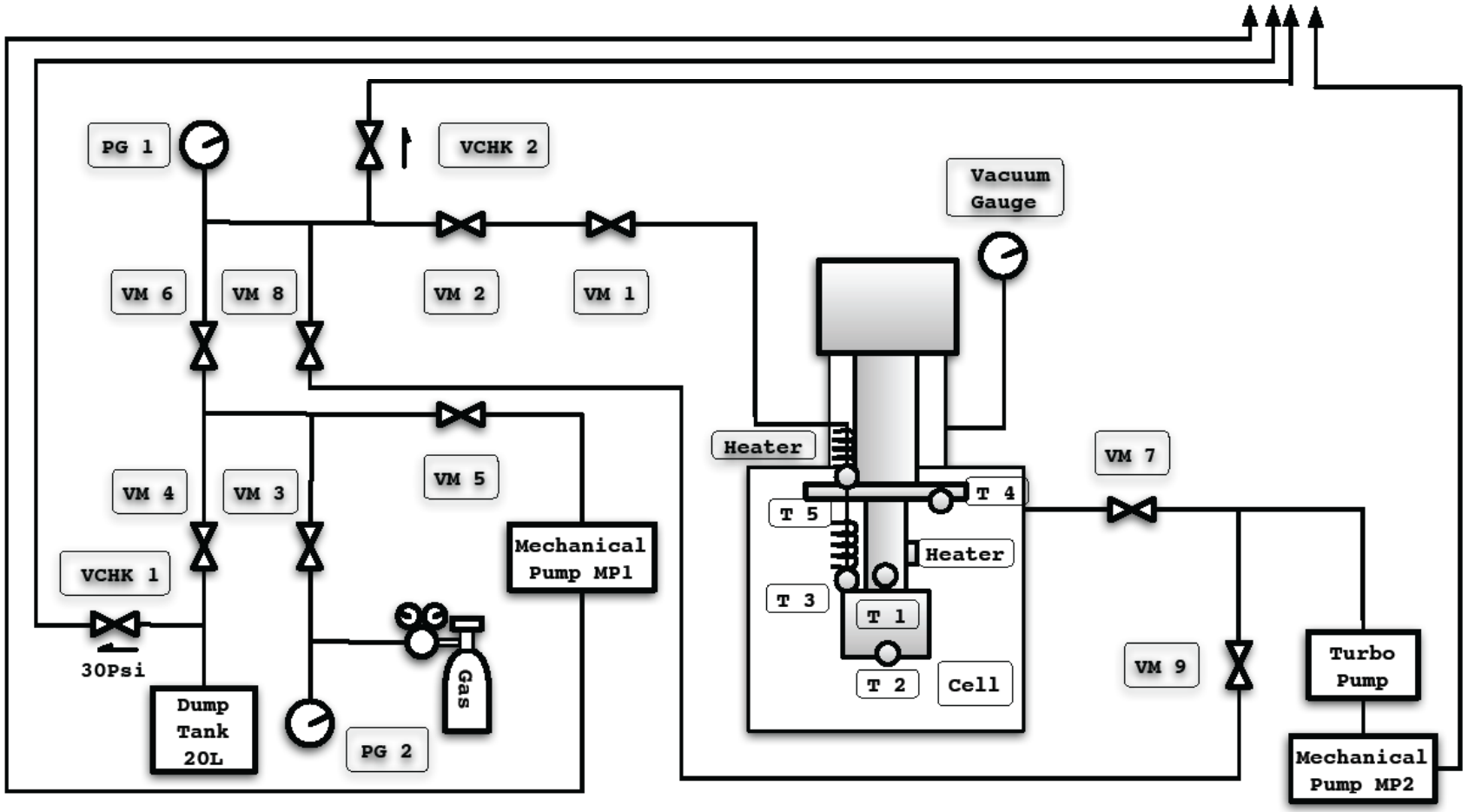
Aerogel glass is a kind of very porous glass.
It is composed of more than 99% air and less than 1% silica.
The pore sizes ranges from 50 ~ *500 ° A.*

Measure the total scattering XS

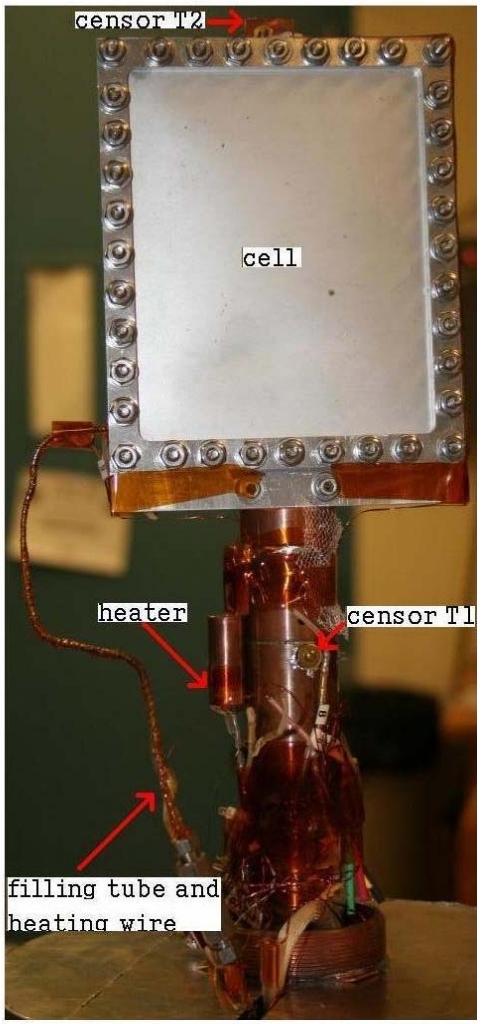


$$\frac{N_2}{N_1} = e^{-n \cdot \sigma \cdot l}$$

Target System




Fridge
Silicon Window

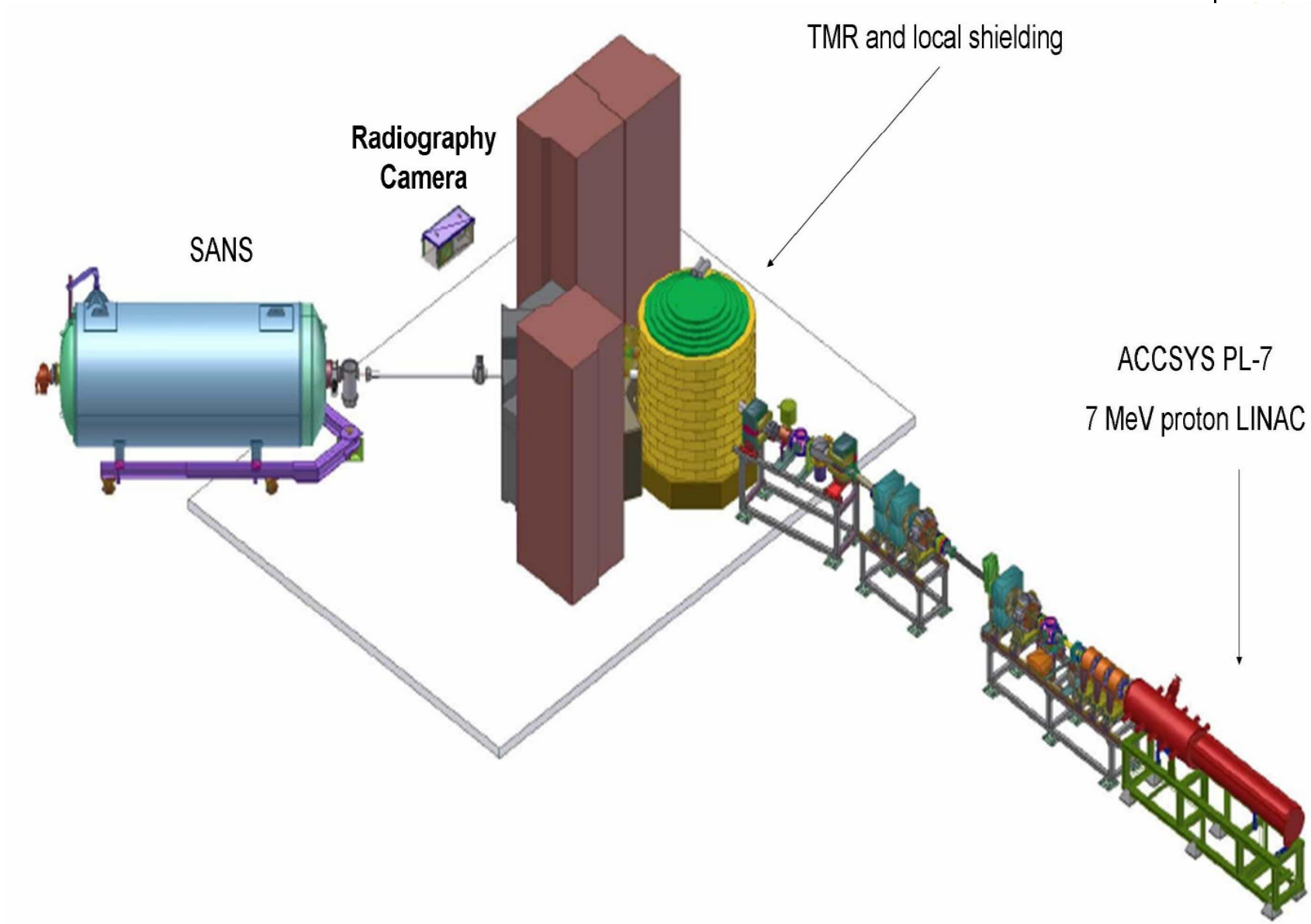

censor T2
cell
heater
censor T1
filling tube and
heating wire

Canon EOS DIGITAL REBEL XT F5.0 1/60s ISO400

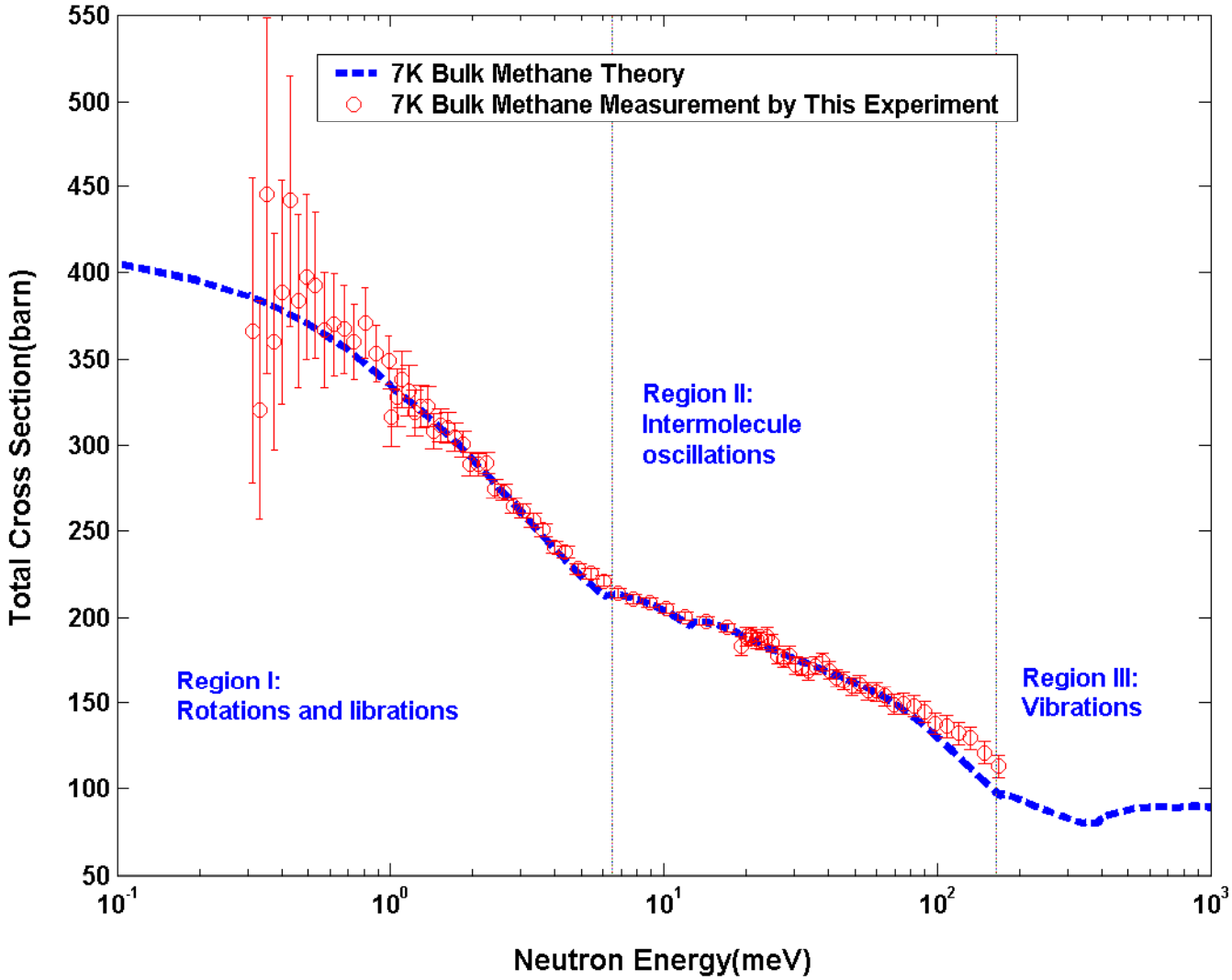
Canon EOS DIGITAL REBEL XT F5.0 1/60s ISO400

Canon EOS DIGITAL REBEL XT F4.5 1/60s ISO400

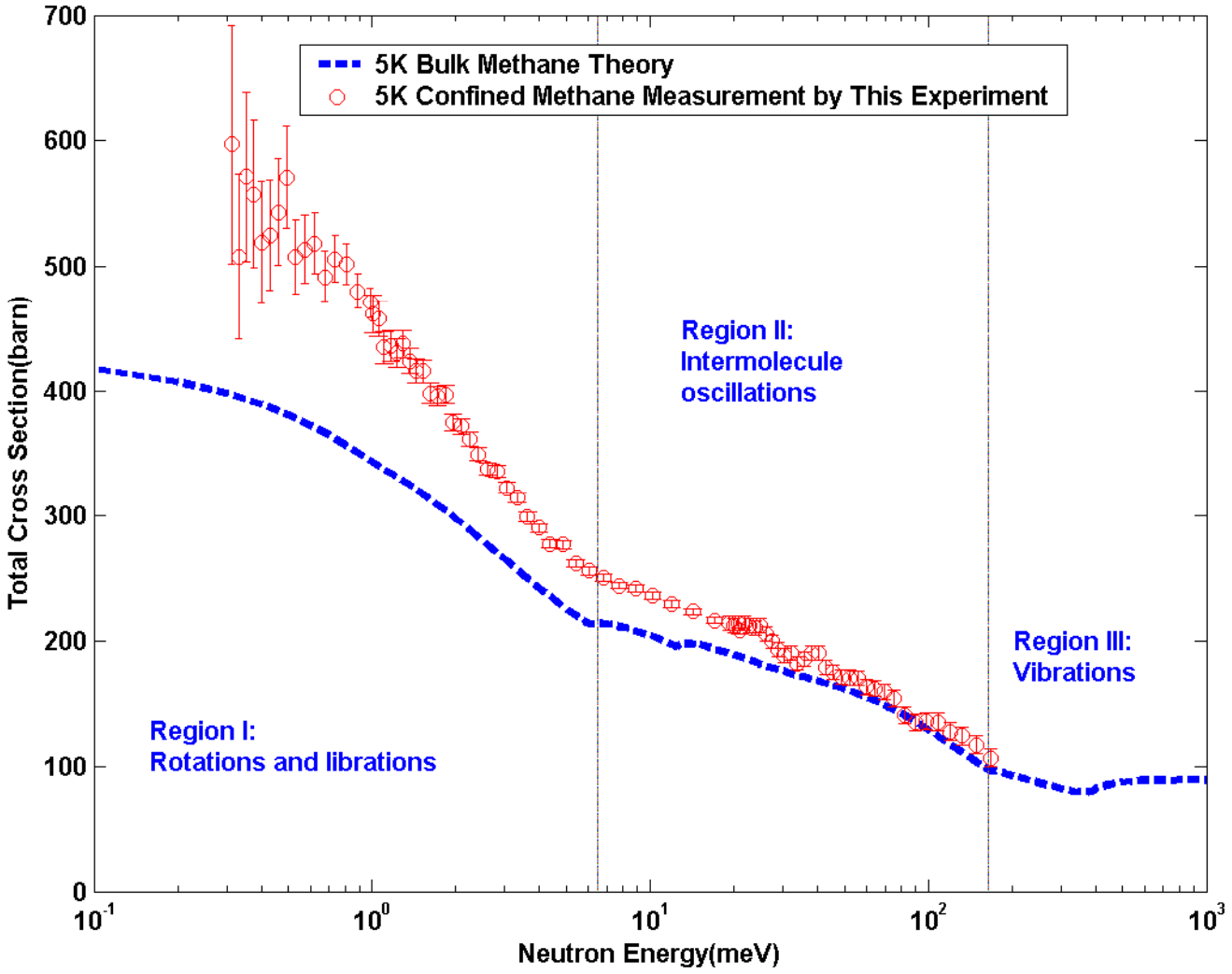
LENS: Low Energy Neutron Source

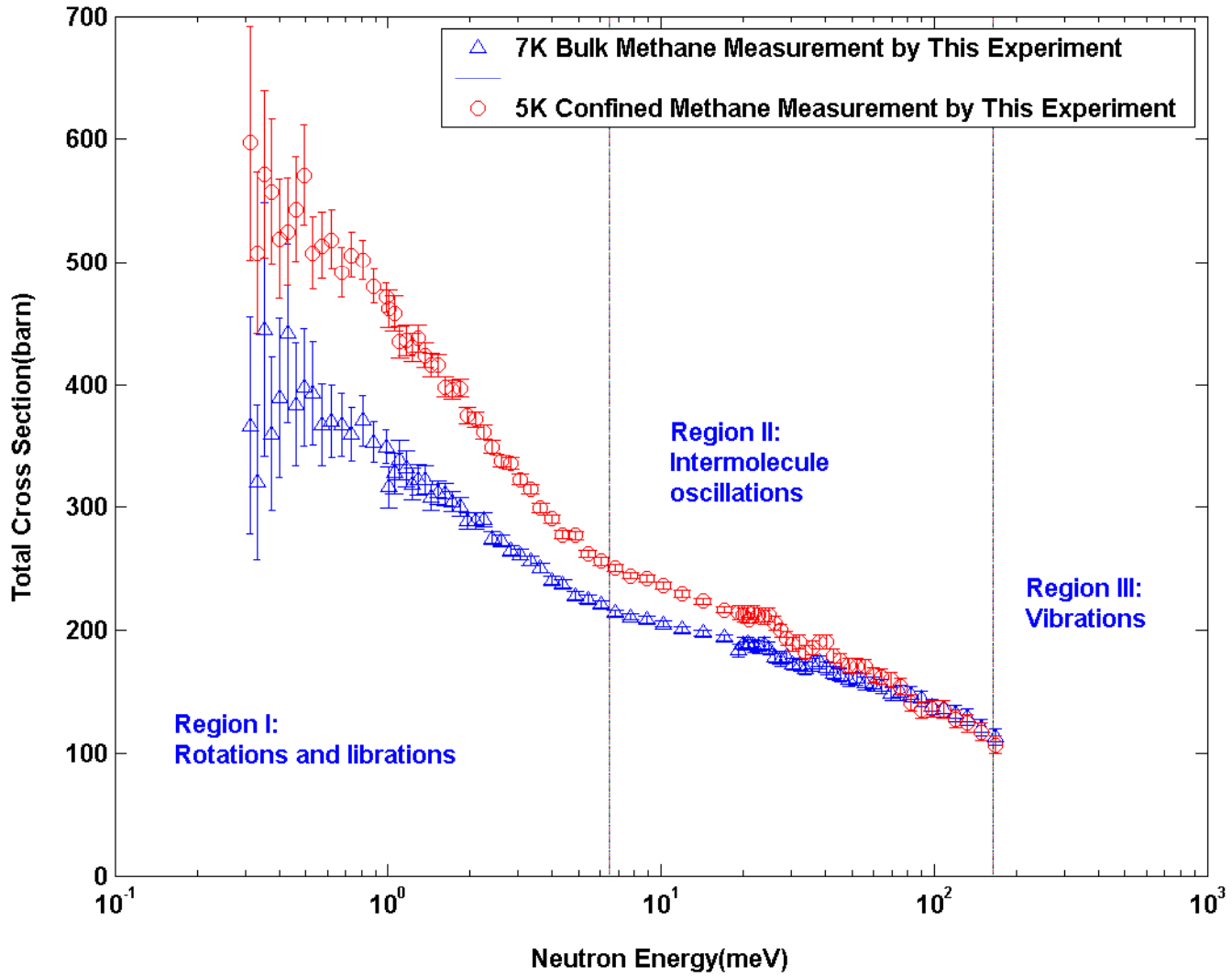


7K Bulk Methane:

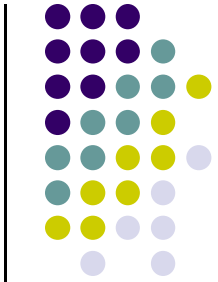


5K Confined Methane:




7K Bulk Methane Measurement by This Experiment
5K Confined Methane Measurement by This Experiment
Region I:
Rotations and librations
Region II:
Intermolecule
oscillations
Region III:
Vibrations
Total Cross Section(barn)
Neutron Energy(meV)
0
100
200
300
400
500
600
700
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}

Summary:



- There appears to be a significant difference between the total cross section for the confined methane and bulk methane, especially the relatively large increase in the lowest energy region.

- In this measurement we cannot tell what microscopic structural or dynamical modification of the confined methane is causing this change of the cross section.

- If the inelastic modes of confined CH4 are a superposition of a bulk-like excitation from the middle of the pores and a set of lower modes from the surface excitations, we can open a path for the neutrons to be moderated to lower energies.

- Further improved measurements have been planned to confirm this effect.