GRANIT-2010

NEUTRON SCATTERING ON DEUTERIUM AND HEAVY WATER GEL SAMPLES IN SUPERFLUID HELIUM He-II

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A.V. Strelkov, E.V. Lichagin, A.Yu. Muzychka and A.A. Levchenko
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● Abstract

- Ultra-cold neutrons (*UCN*, $E<10^{-7}$ eV) provide an excellent tool for high-sensitive experiments in fundamental physics.
- Recently a new idea was elaborated: to use D_2 and D_2O nanocluster condensates in superfluid He-II (quantum gels) as a tool for production of *UCN* at high densities.
- The reason for significant interplay between nanocluster condensate with slow neutrons is, on one hand, in an approximate equality of wavelength of the last and characteristic size of innomogeneities in gels and, on another hand, relatively high cross-section of neutrons scattering on a backbone of the condensate.
- Numerical modeling of gel formation processes in a cold gas flow and in a cell filled with He-II has shown that finite size of the cell (and, hence, geometry of the gas flow inside) affects strongly the formation process and the resulting gel structure.

Motivation-1

1. The reason for this study:

   The idea to increase the UCN density in the vessel filled with superfluid He-II by equilibrium cooling of very cold neutrons (VCN) down the bath temperature (T~5mK) ***owing to their many collisions with nanoparticles***, made of low-absorbing materials (D_2O, D_2,O_2), during diffusion motion of VCN through a macroscopically large ensemble of weakly bounded nanoparticles forming the frame (backbone) of the impurity gel sample in He-II.

2. The first step - ***measurements of cold neutrons transmitton*** through the D_2O sample at T=1.5K have shown that the neutron scattering depends strongly on the neutron velocity V: ***from near-forward scattering at V = 160-100m/s to near-spherical scattering at V=40-30 m/s.***

3. Next step - ***elastic scattering of cold neutrons*** (with λ≈ 6A) ***on D_2 and D_2O gel samples*** in He-II at T≥ 1.4 K; the main results are as follows: **characteristic dimensions of clusters in as-prepared at 1.66 K D_2O samples are d_c ≤ 15 nm; and in D_2 samples 5≤ d_c ≤ 150 nm.**

Further development

Propagation of cold ~9*A* neutrons through pure HeII cooled below 1 K should result in production of UCN due to phonon emission by the neutrons in bulk of HeII. If the mean free path l_{eff} of very cold neutrons drifting through the massive D_2 or D_2O gel sample in He-II is much less than dimensions of the helium vessel L (near spherical scattering in bulk) then *diffusive motion of those neutrons through the gel soaked with He-II should result in strong increase, in L/l_{eff} times, of the effective time of propagation between two collisions of neutrons with walls of the vessel.*

This means that:

a) ***dimensions of the vessel filled with the gel could be reduced significantly in comparison with a vessel filled with pure He-II, only;***

b) ***keeping in mind that there exists a finite probability of inelastic scattering of VCN on D_2 or D_2O clusters forming the gel backbone diffusion motion of neutrons through a macroscopically large ensemble of weakly bounded nanoparticles in He-II cooled below 5 mK could result in additional increasing of the UCN density in the vessel due to equilibrium cooling of very cold neutrons down the bath temperature*** .

Storage of UCN in the metal vessel

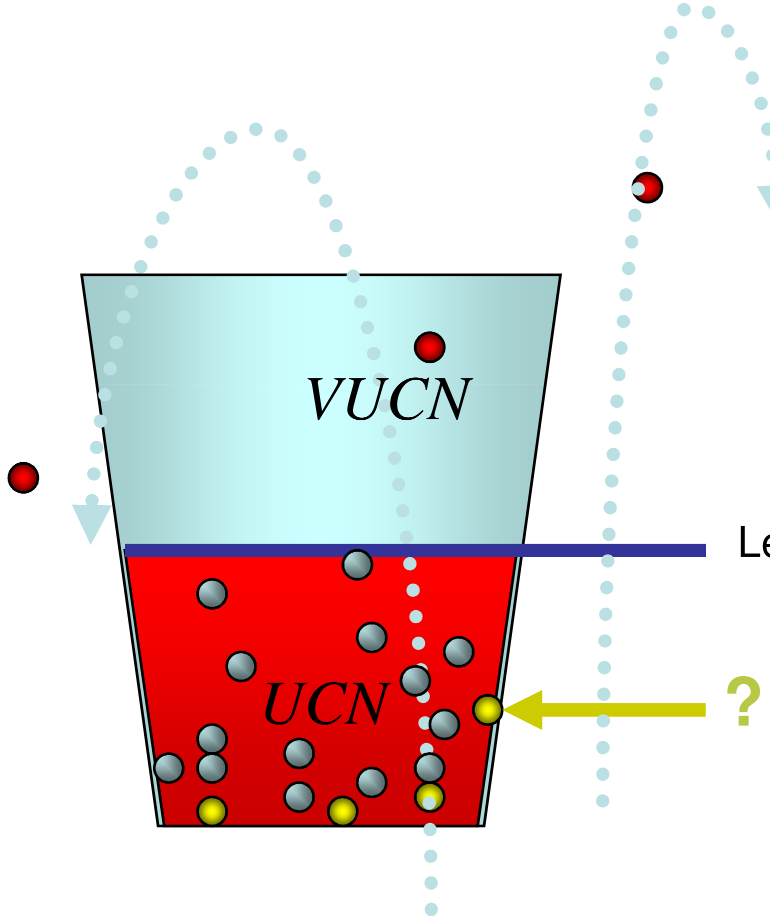
$UCN:$

$V_{UCN} \sim (1 \div 6) m/s$

$E_{UCN} \sim 10^{-7} eV$

$H_{UCN}^{\substack{Earth's \\ field}} \sim 1m$

$T \sim 1mK$



Level of UCN gas

$VUCN:$

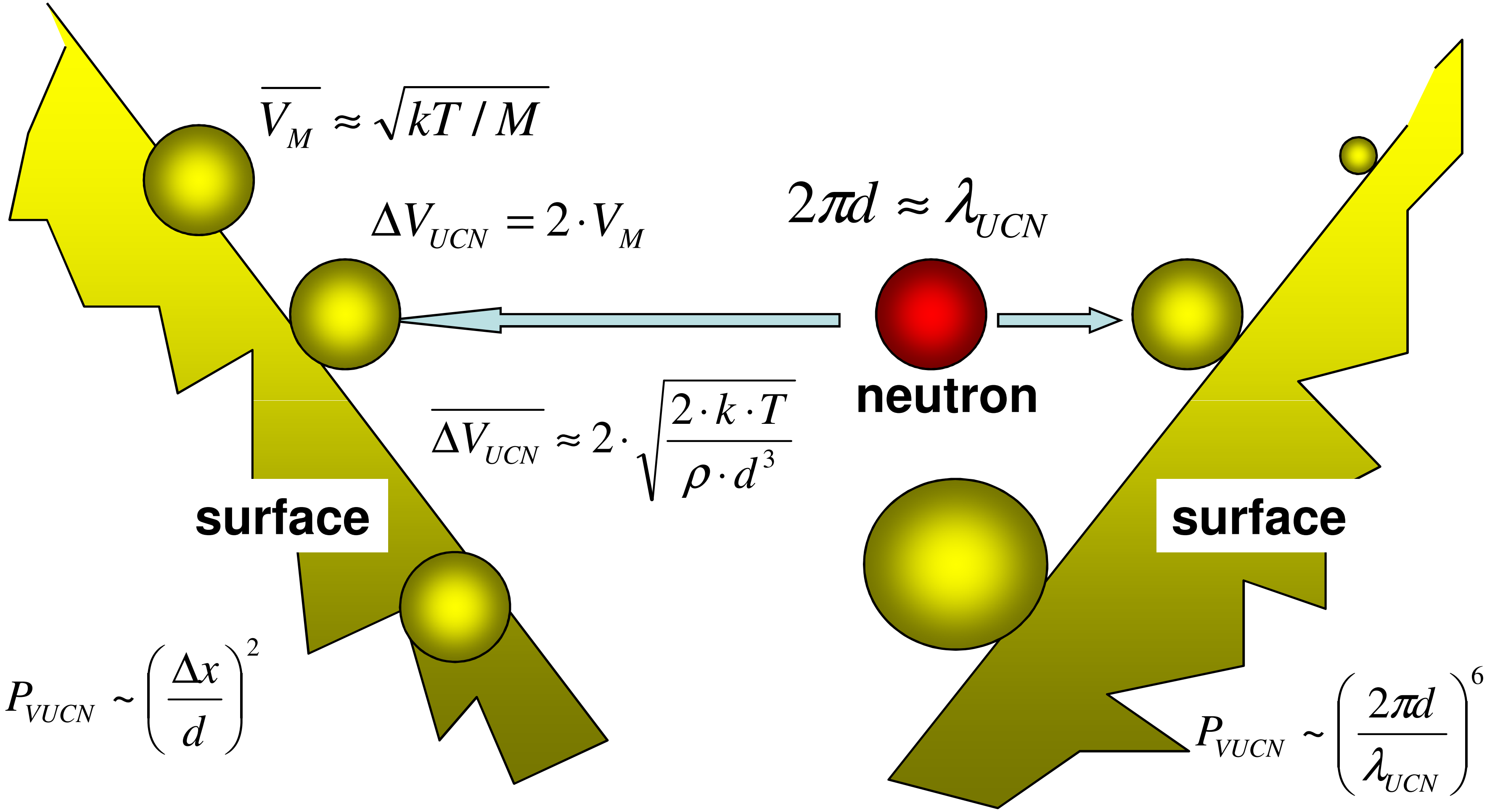
$\Delta E \sim 10^{-7} eV$

$\Delta V \sim 1m/s$

$P_{VUCN} \sim 10^{-8} - 10^{-3}$

Interaction of neutrons with nanoparticles.

V.V.Nesvizhevsky, Physics of Atomic Nuclear, 2002. 65(3): p. 400-408.



Thermalization of cold neutrons at the net of mutually crossing filaments from weakly interacting ultracold nanoparticles that form a backbone of impurity gel samples in superfluid He-II

$$\frac{\lambda_n}{2\cdot\pi}[nm] \approx \frac{63}{V_n[m/s]}$$

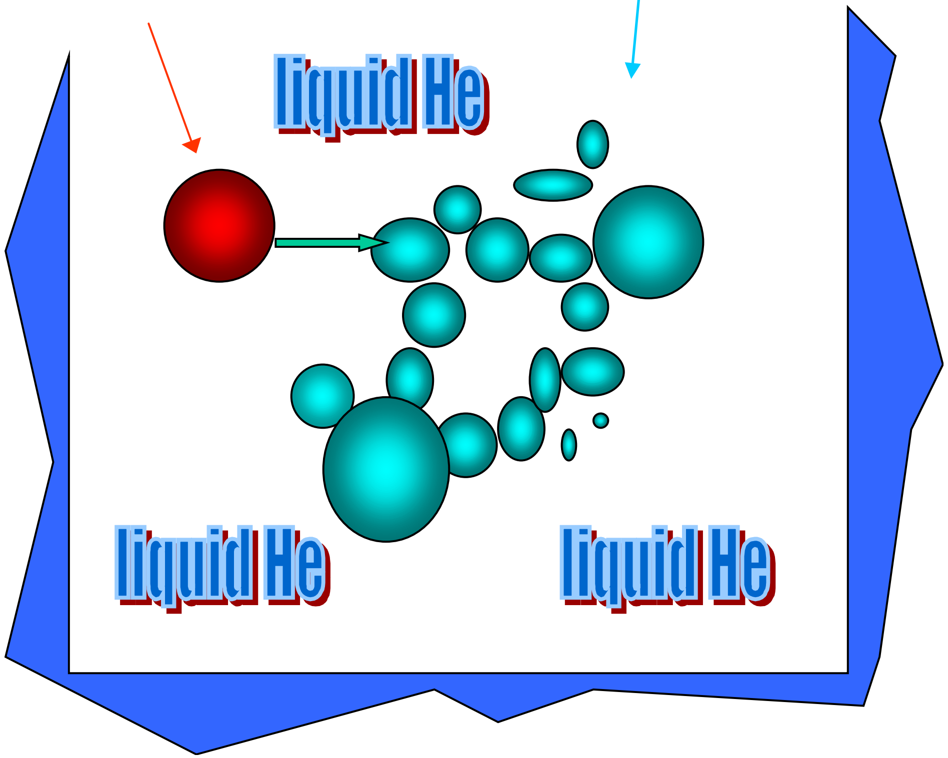
$$V_n \sim (1 \div 100)[m/s]$$

$D_2O, D_2, O_2, C \ldots$

$\bar{d} \approx 5\,nm$

$\overline{\Delta l} \sim 10 \div 25\,nm$

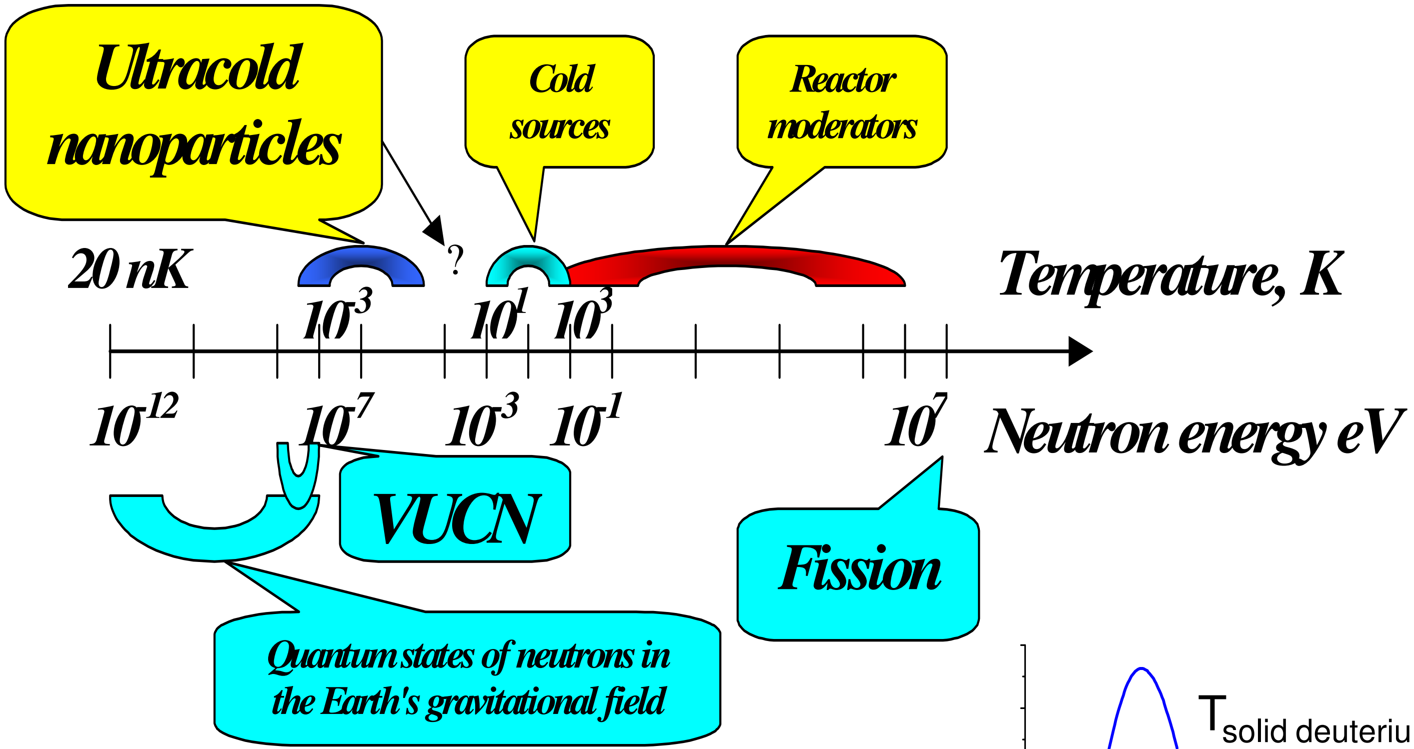
$T \approx 1\,mK$

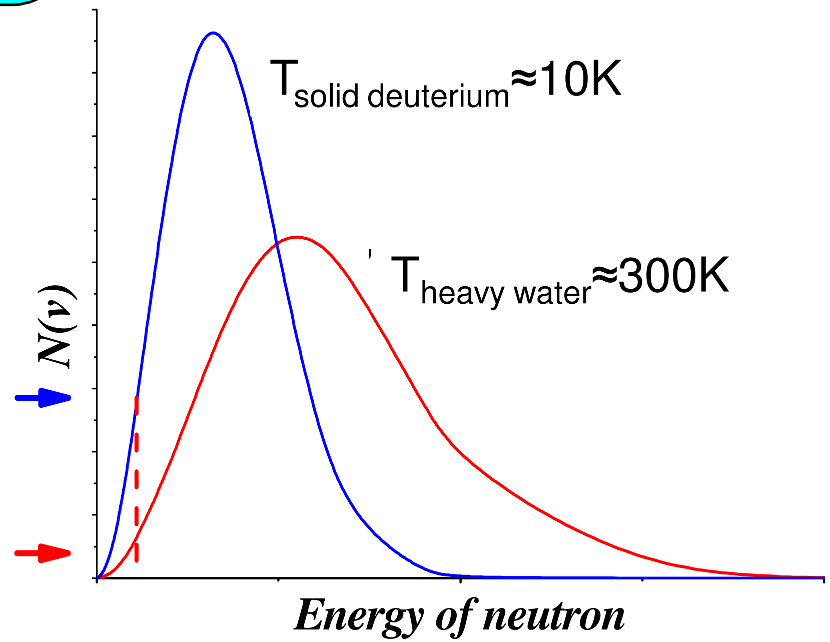


$L > 10\,cm$

$T \approx 1\,mK$

Energy and temperature scales for neutrons





Journ. Phys. USSR, 10, No. 3, p. 299 (1946).

COAGULATION OF FOG IN THE LIQUID HELIUM II

By P. Savich and A. Shalnikov

Institute for Physical Problems, Academy of Sciences of the USSR

(Received March 26, 1946)

Working with liquid helium, we observed a phenomenon which possibly presents certain interest.

We have used in our experiments a long Dewar vessel, in the lower part of which it was possible to keep liquid helium for a considerably long time. In one of our experiments, after the liquid helium had been coold down to 2.5° K, we were obliged to connect the Dewar vessel to the external communication. As a result, the gaseous helium with a little amount of impurities reached the vessel. These impurities in the form of a high dispersed fog slowly precipitated in the lower part of the Dewar vessel.

When reaching the calm surface of the overcooled helium the fog, penetrated into the helium, is continuing to precipitate with a rate about 3 mm per minute.

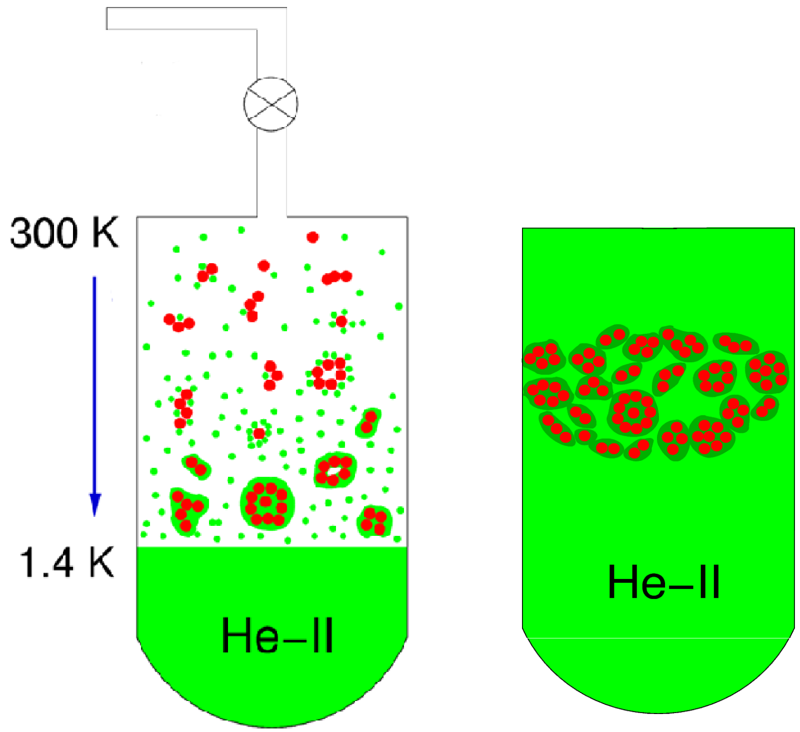
If now the temperature of the helium is lowered down to 2.19°K the opaque liquid becomes at once clear and there began some thing like a snowfall. The size of the flakes was exceedingly greater than that of the fog particles.

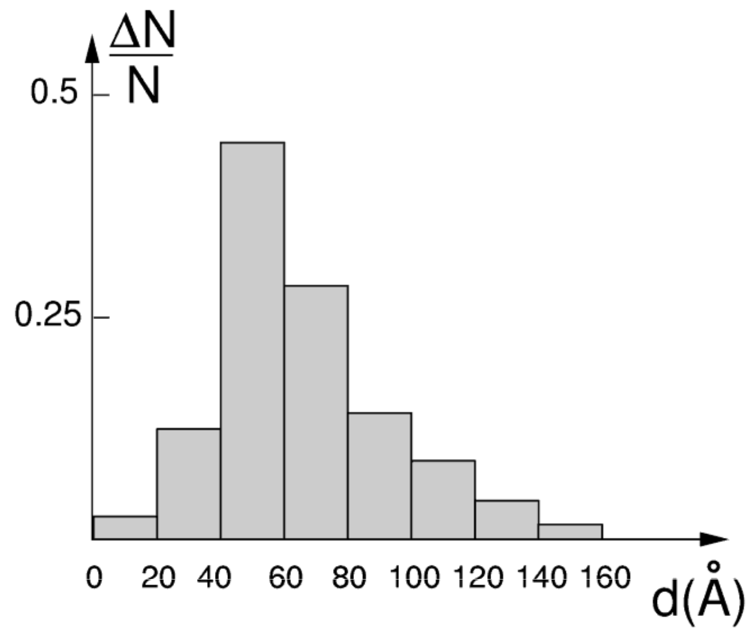
The fog which continued to precipitate from the gaseous phase coagulated also in liquid helium II.

We also performed a number of other experiments in which an artificial fog was obtained by means of introducing helium into Dewar vessel along a special pipe. This helium contained a small amount of air or hydrogen. In all the cases we observed the same phenomenon of rapid fog coagulation in the moment of phase transition helium I — helium II.

In the experiments with hydrogen the inverse phenomenon was clearely pronounced. The fog coagulated into large particles, began to disperse again when reaching the temperature higher than that of the λ-point. This could be seen by the foggy nimbus surrounding the solid particles.

L.D.Landau, A.I.Alikhanov, A.I.Shalnikov, and P.Savich at the garden near the Institute for Physical Problems (P.L.Kapitza Institute for Physical Problems RAS now). Moscow, 1946.





Preparation a gel sample in He-II.

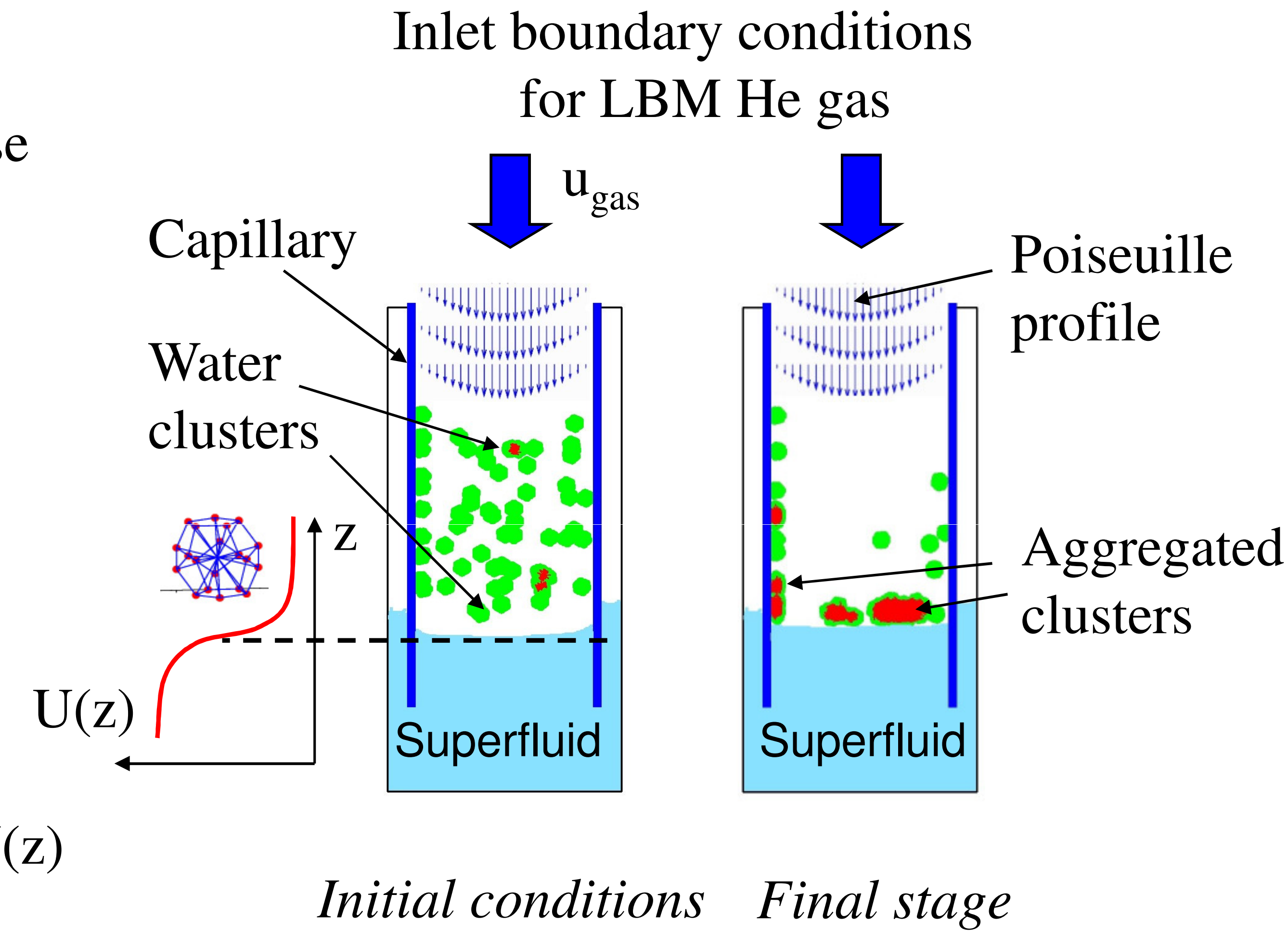
From results of X-rays and ultrasound attenuation measurements made by the Cornell University group it follows that the mean dimensions of impurity clusters, covered by a layer of solidified He (the backbone of the gel), are **d_{clust} ~ 5 - 10 nm, and the pores diameters are distributed in a wide range d_{pores} ~ 8 -800 nm.**

Dimension distribution of **the metallic particles** formed on evaporation of a metal in a dense vapor of liquid ^4He: **d_{mean}~ 6 nm**.

L.Ya.Vinnikov, and A.O. Golubok "Methods of direct observations of magnetic structures at the surface of superconductors". Preprint ISSP RAN, Chernogolovka, Moscow region, 1984.

● Computational Arrangement

- **Initial conditions**
  * Randomly placed clusters in gas phase
- **Later stages**
  * Aggregation of clusters
    - in gas phase
    - at He-II surface
    - at capillary walls
- **Gas/Fluid Interface**
  * Potential barrier U(z)
- **Forces at capillary walls**
  * Attraction due to van der Waals interaction



● Aggregation of Clusters in Gas Phase

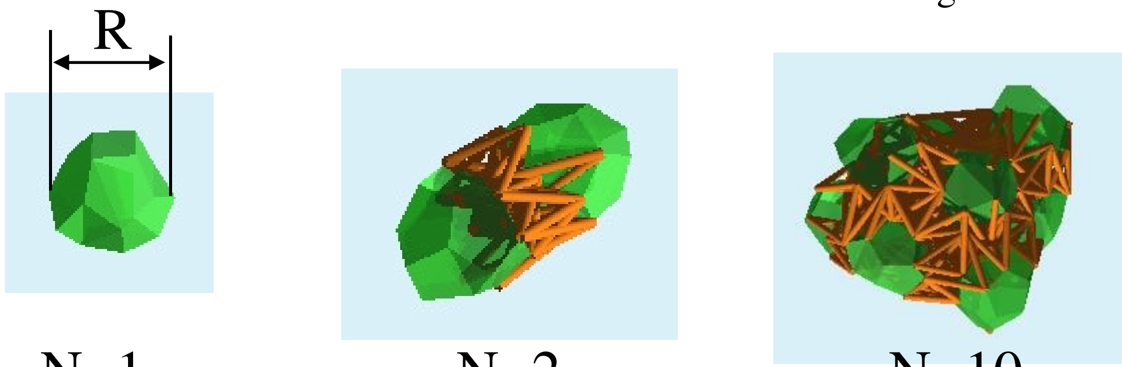
- **Reynolds number**

  $Re = Ru_{gas}/\nu_{gas}$

- **Peclet number**

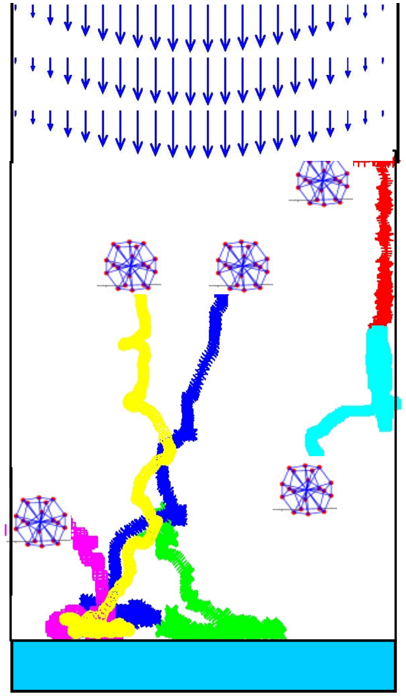
  $Pe = Ru_{gas}/D_{cl}$

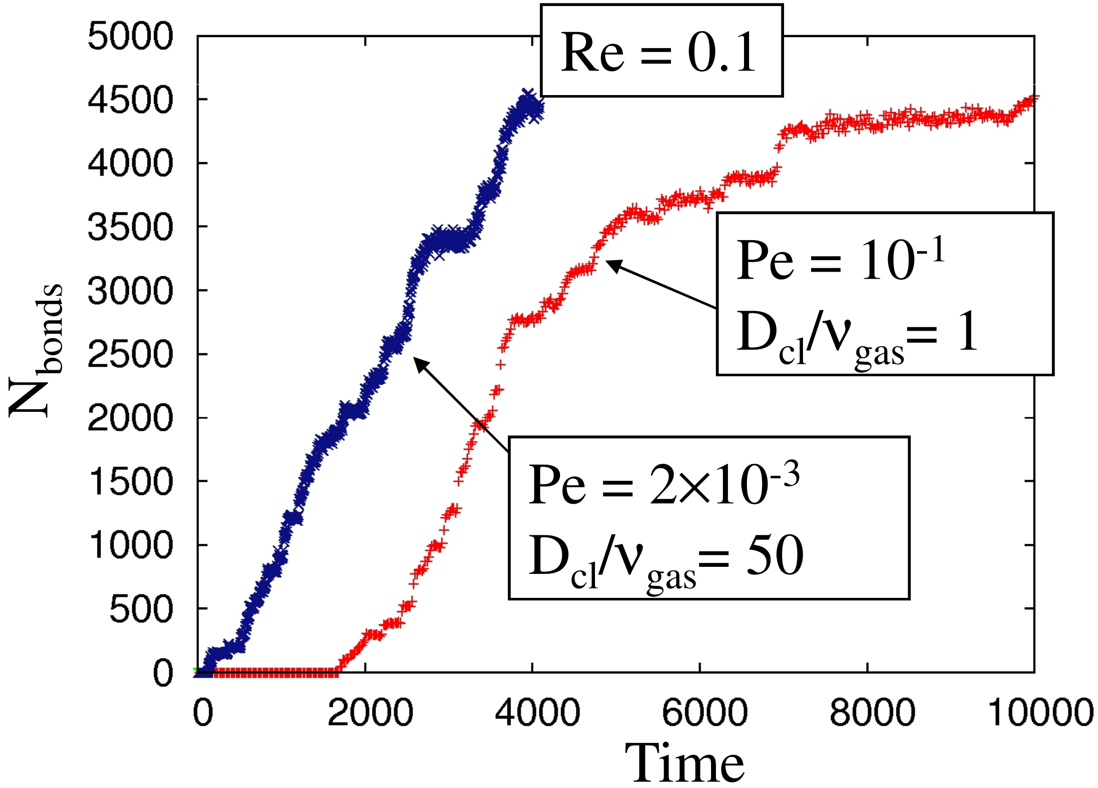
- **Role of diffusion**: $Re/Pe = D_{cl}/\nu_{gas}$



N=1 N=2 N=10

Trajectories of clusters
$Re=10^{-1}$, $Pe = 2\times10^{-3}$



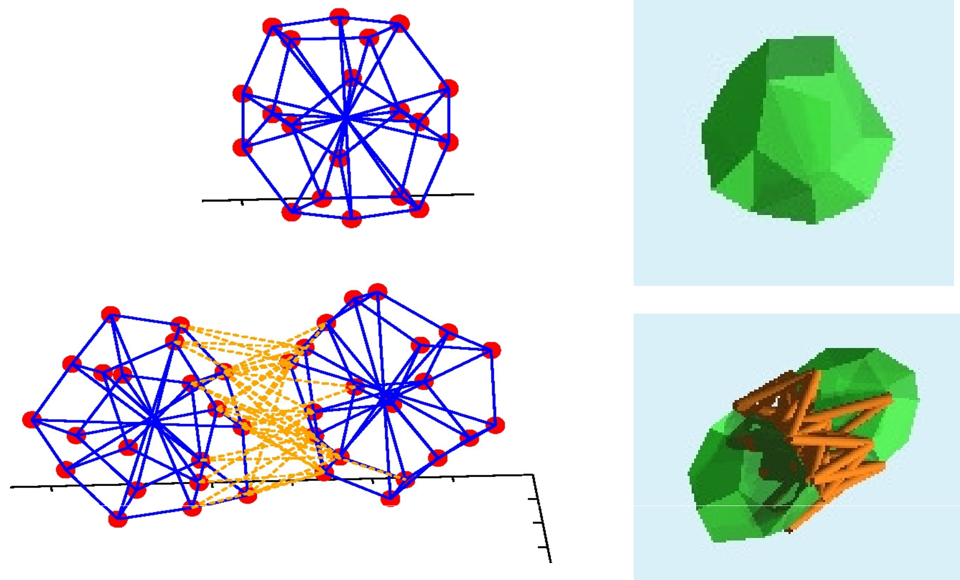


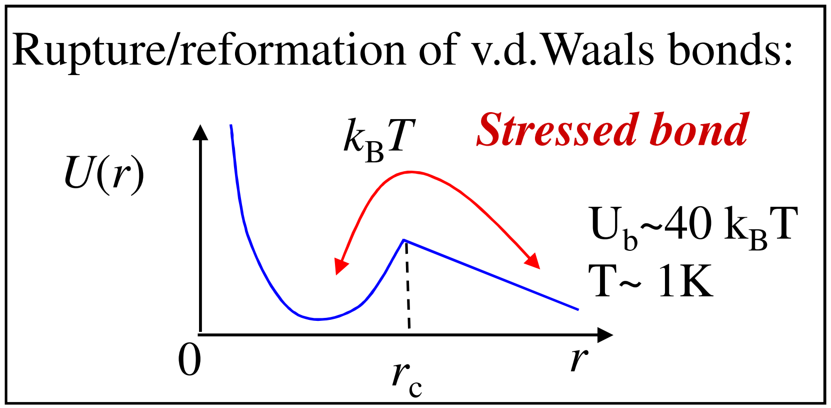
● Numerical Technique

- **Gas: Lattice Boltzmann model [1]**
  - * Discretization in real and momentum space
- **Solid: Lattice Spring Model [2]**
  - * Point masses & springs
- **Gas-Solid interaction**
  - * Gel-like systems [3]
- **Interaction between clusters**
  - * Bell model [4]
- **Equations of Motion**
  - • 4^{th} order Runge-Kutta scheme

$$\frac{d^2\boldsymbol{r}_i}{dt^2} = \boldsymbol{F}_i^{(LSM)} + \boldsymbol{F}_i^{(Fluid)} + \boldsymbol{F}_i^{(Langevin)}$$

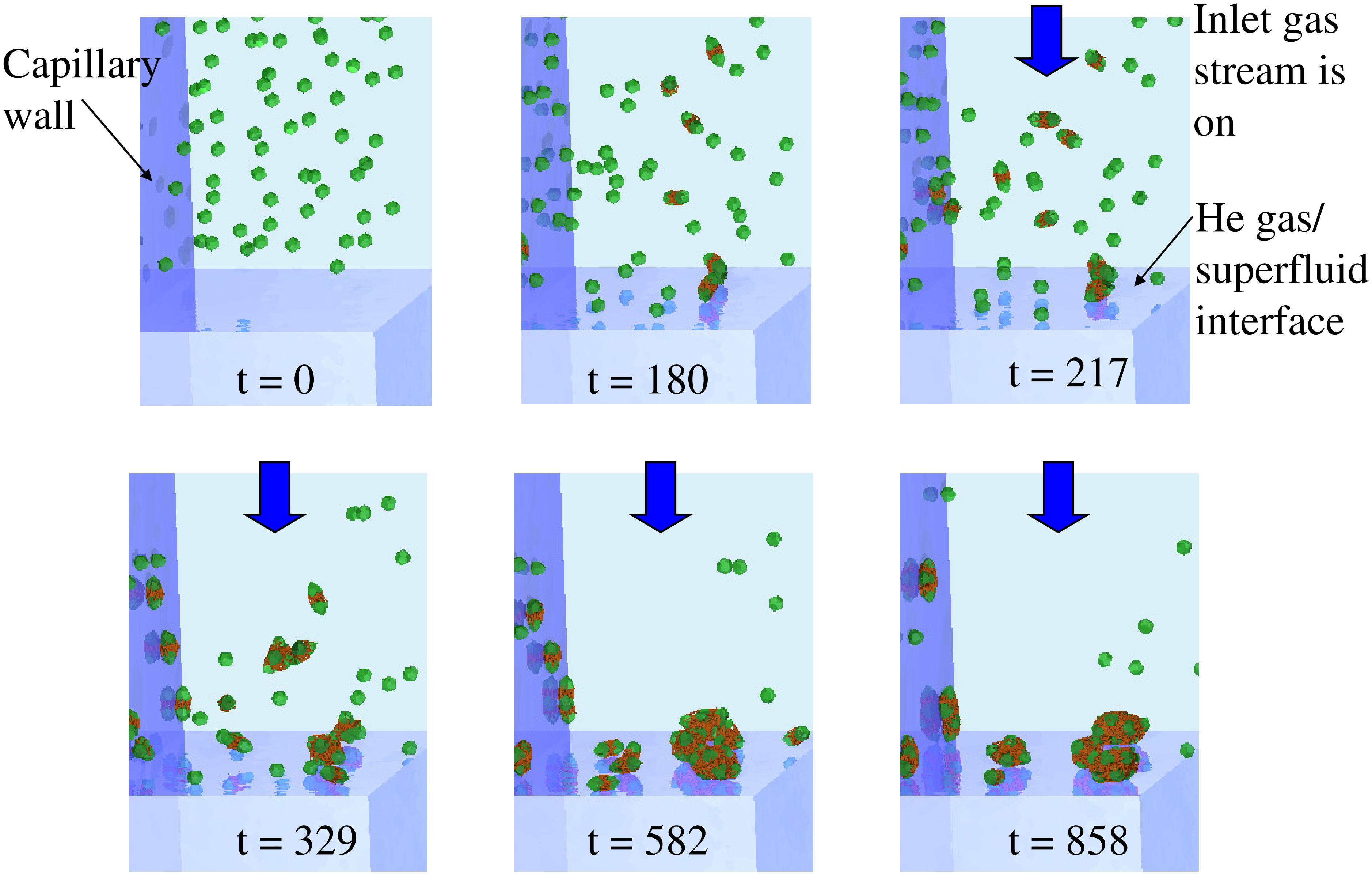
3-dim. numerical unit



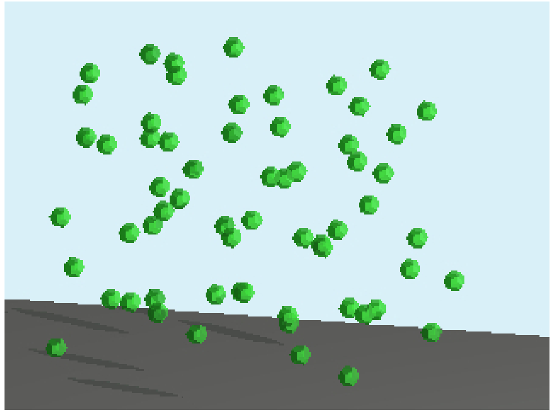


[1]G. Buxton et al., *Modelling Simul. Mater. Sci. Eng* **9**, 485 (2001). [2]S. Chen and G. Doolen, *Annu. Rev. Fluid Mech.* **30**, 329 (1998). [3]B. Dünweg, U.D. Schiller, and A.J.C. Ladd, *Phys. Rev. E* **76**, 036704 (2007). [4]G.I. Bell, *Science* **200**, 618 (1978).

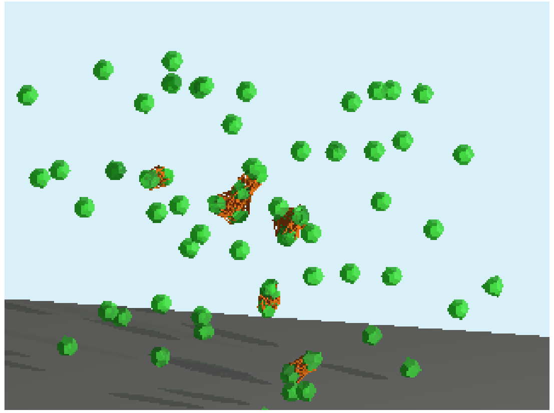
• Numerical Results: Re = 0.1, Pe = 2×10^{-3}



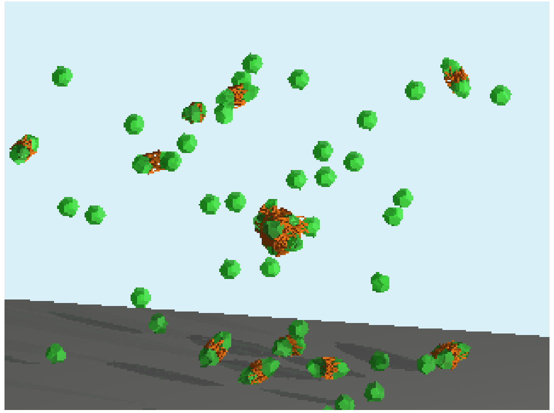
Numerical Results: Re = 0, $D_{cl}/\nu_{gas} = 1.5\times10^2$



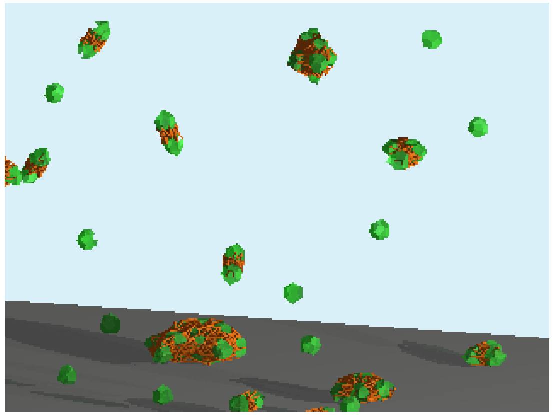
t = 0



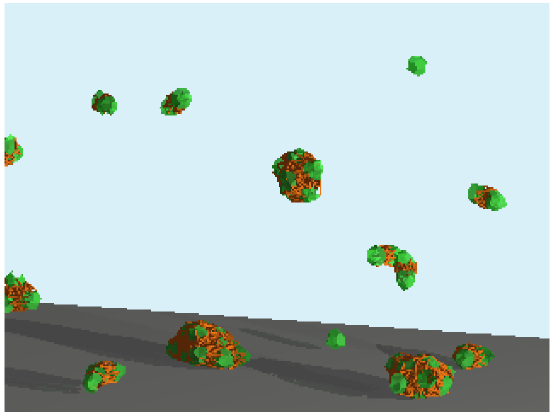
t = 41



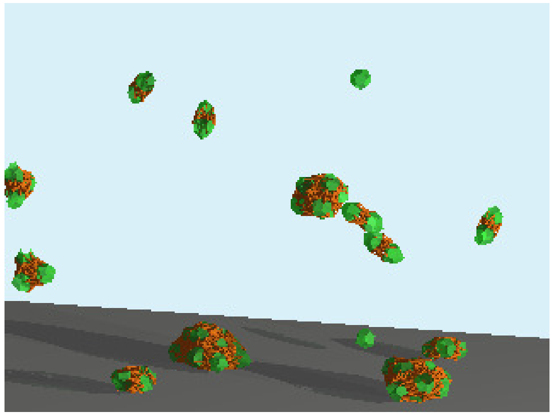
t = 83



t = 257



t = 440



t = 468

David M. Lee, Cornell University

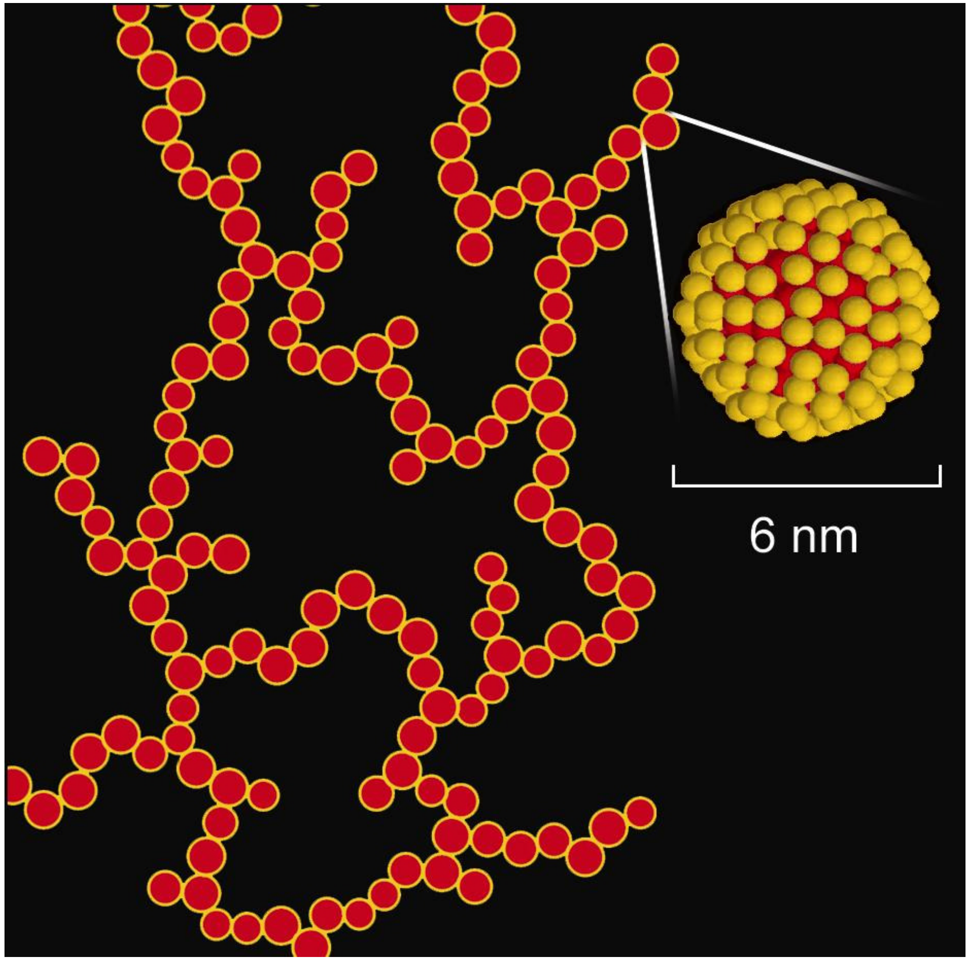
Applications:

Impurity-Helium Condensates (IHCs or impurity gels) can host low temperature chemical reactions at much higher concentrations than materials.

Large amounts of chemical energy can be stored in unpaired atoms trapped in IHCs.

Study of the formation of the nanoclusters within impurity gel samples could lead to a better understanding of the formation of catalysts, which possess a similar structure but are made of precious metals.

IHCs made of deuterium and heavy water in superfliud He-II and cooled to a few mK could be used for cooling very cold neutrons down to very low temperatures.



IHCs are assemblages of nanocrystalites of impurity molecules (**red**), each separated by a thin layer of solidified helium (**yellow**).

CAPTURE OF THE WATER MOLECULES BY SUPERFLUID He-II DROPLETS FLYING THROUGH THE VESSEL WITH WATER VAPORS

K.Nauta, R.E. Miller, Formation of cyclic water hexamer in liquid helium: the smallest piece of ice, *SCIENCE* **128**, 29 (2000).

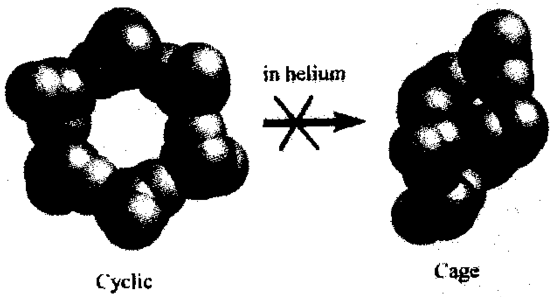
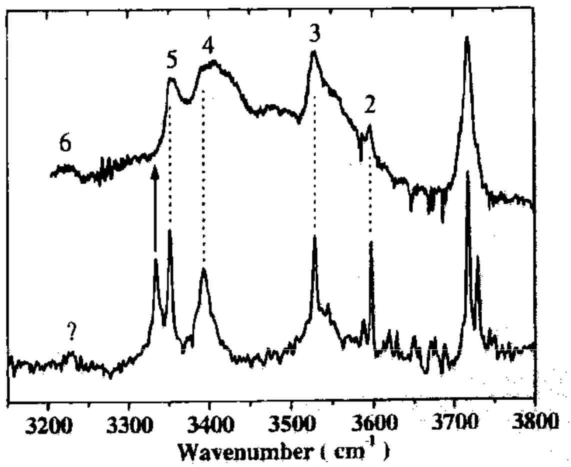
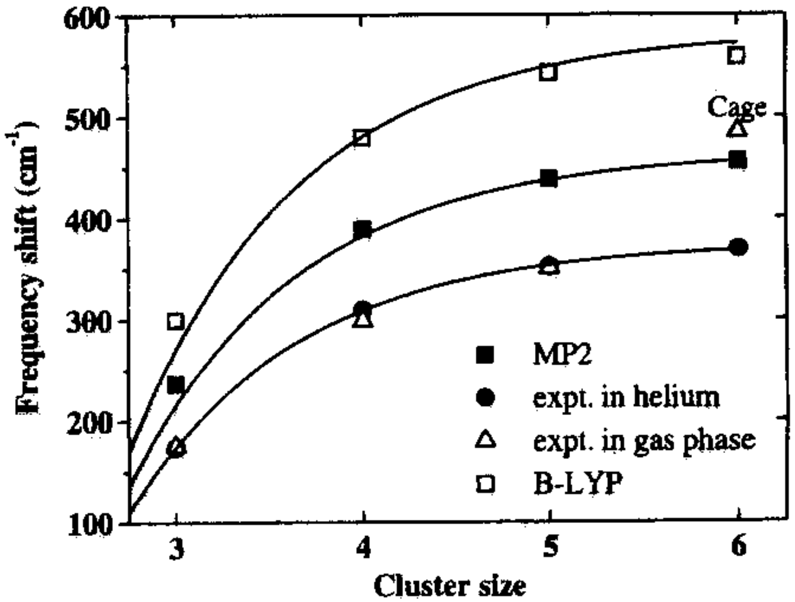


Fig. 1. Cyclic and cage isomers of the water hexamer, based on the ab initio calculations of Xantheas (*25*).



Infrared spectra of the vibrational degree of freedom in O-H radical in clusters formed in cold gas (upper curve) and in flying He droplets (lower curve) cooled below 1K. Numbers on curves correspond to dimensions of clusters. Question mark corresponds to vibrations in a “cage” isomer of the water in liquid helium.



Red shift of the infrared absorption lines by the water clusters of different structures (from trimer to hexamer): as observed (points) and calculated (solid curves).

Preparation and characterization of the impurity gel samples.

Preparation techniques:

a). Jet injection of the gas beam ^4He + Impurity molecules/atoms into superfluid He-II through its surface.

b). Slow condensation of the gas flow mixture at the surface of He-II.

Characterization of the samples obtained:

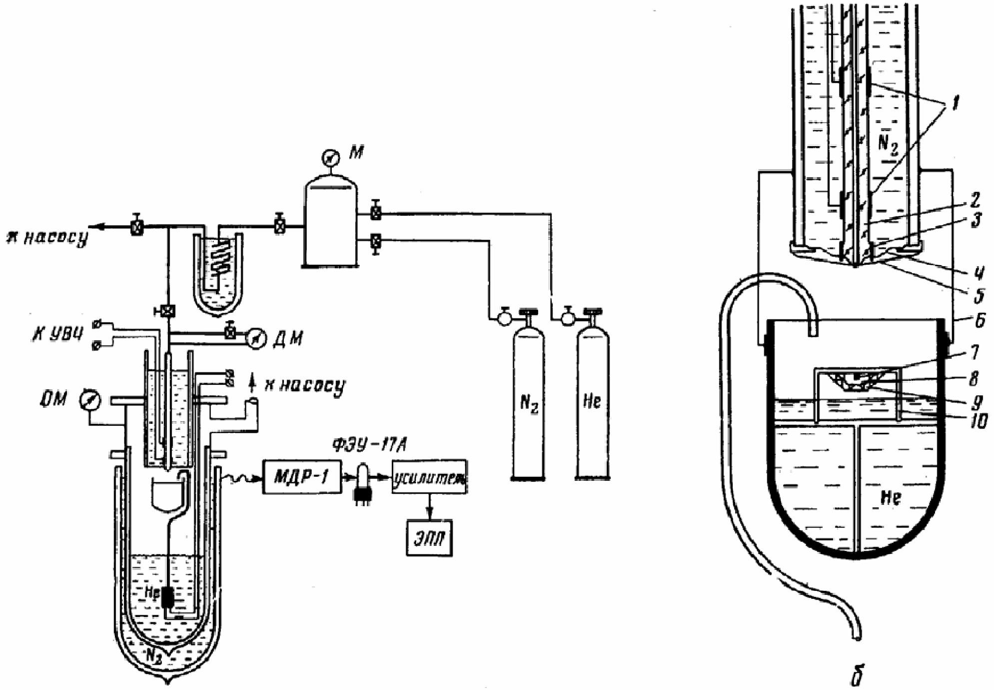
a). Determination of the stoichiometry composition and the density of the gel samples by mass-spectrometry methods.

b). ESR studies of free radicals stabilization efficiency.

c). X-ray diffraction studies of the gel sample structure.

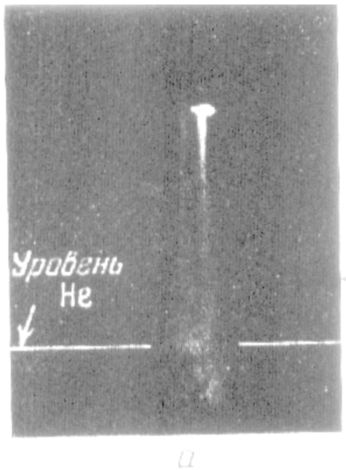
d). Slow neutron propagation through the D_2 and D_2O gel samples and SANS measurements.

Jet injection of the gas ^4He + Impurity stream into superfluid He-II through its surface.

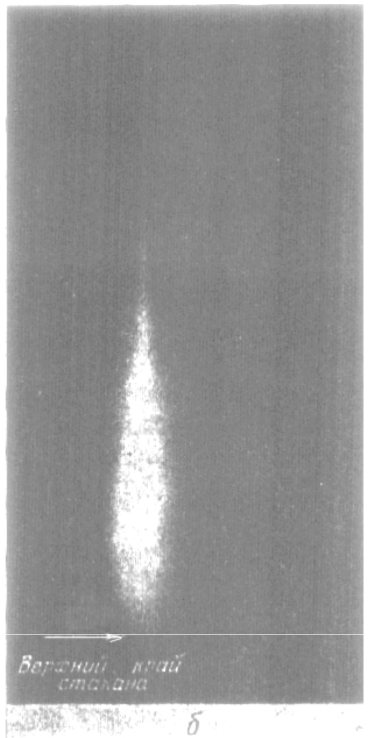


а — схема установки: *М* — манометр; *ДМ*—дифференциальный манометр; *ОМ* — образцовый мановакуумметр; *УВЧ* — высокочастотный генератор; *МДР*-1 — дифракционный монохроматор. *б* — расположение источника атомов и мишени: *1* — электроды в. ч. разряда; *2* — разрядная трубка; *3* — коваровое кольцо: *4* — медная диафрагма; *5* — медный колпачок; *6* — держатели стакана; *7* — термометр; *8* — клей К-400; *9* — нагреватель; *10* — кварцевая мишень

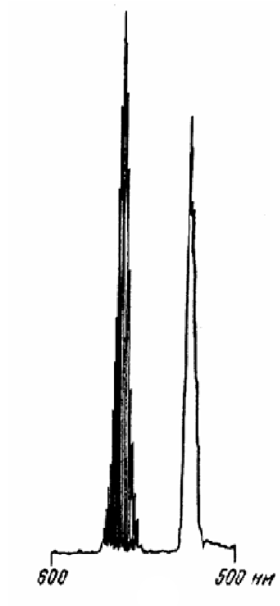
* E.B.Gordon, L.P.Mezhov-Deglin, O.F. Pugachev, “Stabilization of nitrogen atoms in superfluid helium”. JETP Lett. (Russ.) **19**, 103 (1974).
* E.B.Gordon, L.P.Mezhov-Deglin, O.F. Pugachev, and V.V.Khmelenko, “Condensation of atomic beam on cold (T<2 K) surface”, Pribory I Technika Experimenta (Russ.) **6**, 247 (1975).
* E.B.Gordon, L.P.Mezhov-Deglin, O.F. Pugachev, and V.V.Khmelenko, “Thermal instability of condensed systems with free atoms” (in molecular matrices), JETP **73**, 952 (1977).



a)



b)



c)

Evolution of shape of the gas stream from the discharge tube (green glow) with lowering the level of He-II (pointed out by arrow) at the glass cell :

a) Δp = 5 tor, p_{He}= 10 tor, gas mixture of N_2 : He = 1 : 100, the distance from the outlet to the liquid level is L ~ 1.5 cm;

b) Δp = 25 tor, p_{He}= 10 tor, mixture of N_2 : He = 1 : 200; L ~ 3 cm.

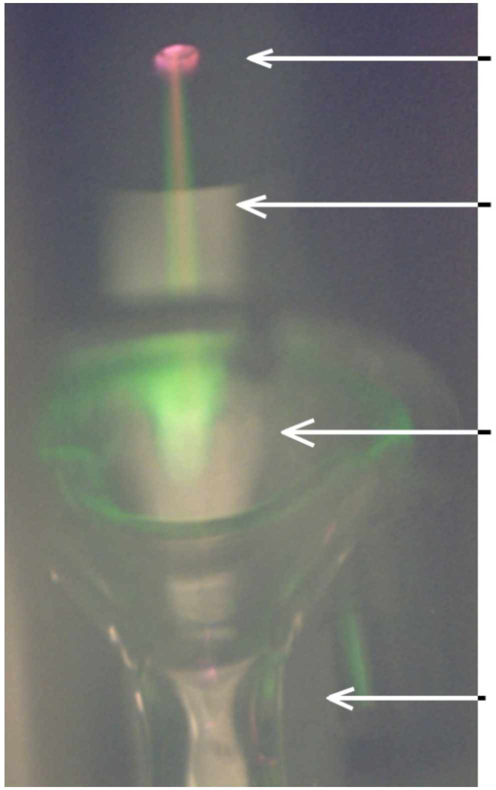
c) modulated spectrum of the after glow : mixture of N_2+He, modulated spectrum belongs to the gas stream (left) and glow of the condensate in bulk of He-II are seen

Impurity – Helium Condensates (IHCs)

From: David M. Lee, Cornell University

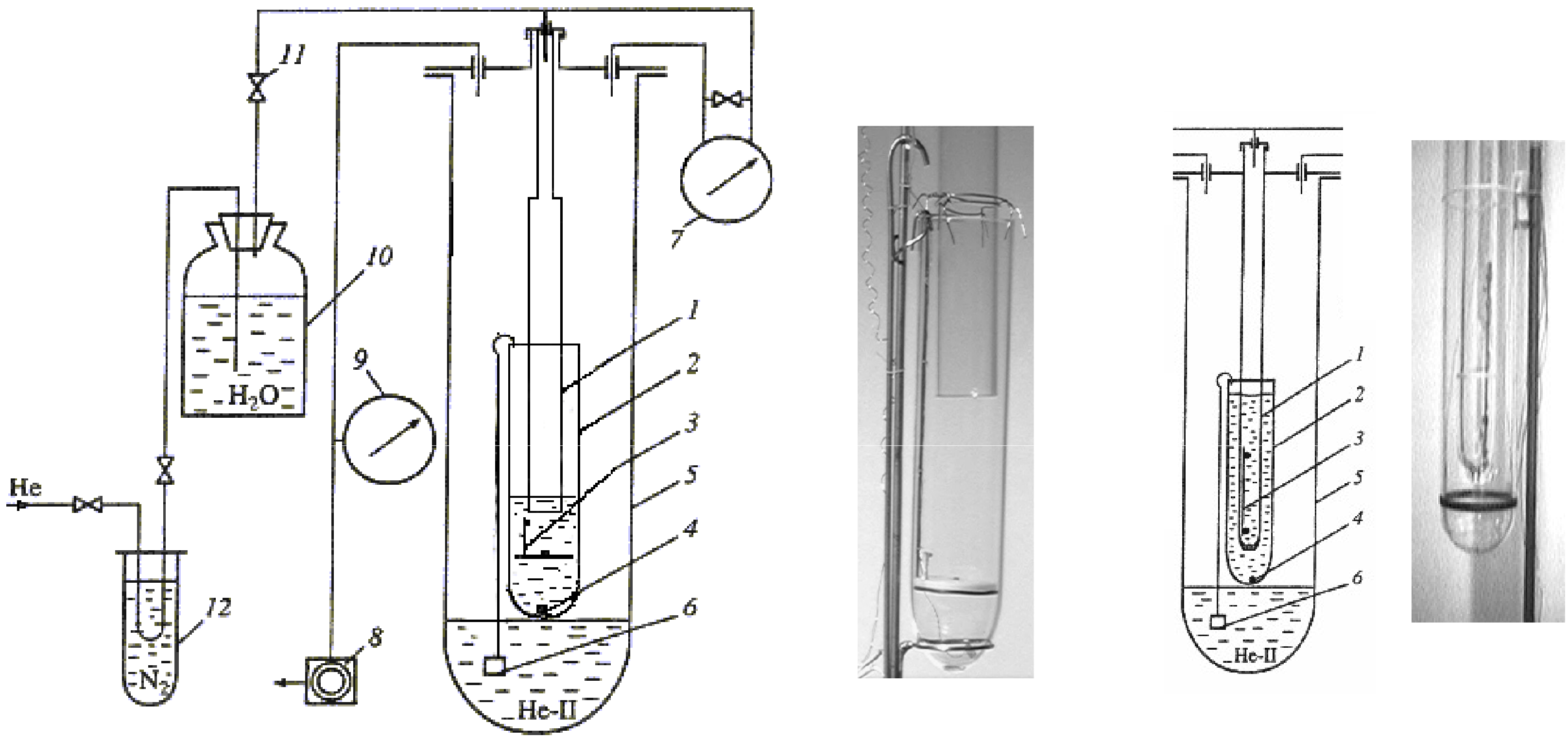
IHCs are created when a mixed jet of helium gas and an impurity gas (such as a nitrogen, deuterium or a noble gas) penetrates through the surface of superfluid helium.

The resulting gel-like solid is composed of an assemblage of nanoclusters of the frozen impurity, separated from one another by thin layers of solid helium. The nanoclusters are 5-10 nm in diameter.



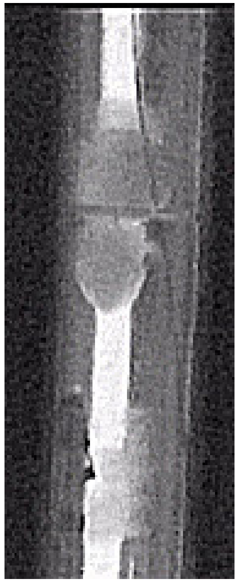
Some of the N_2 or D_2 molecules can be dissociated by exposing the incoming jet to an electrical (RF) discharge. The figure above shows the preparation of a sample containing **nitrogen atoms and molecules**. ***The green glow corresponds to decay of excited metastable states of N atoms over a half hour period.*** Below about 2 K the embedded atoms are completely stable against molecular recombination.

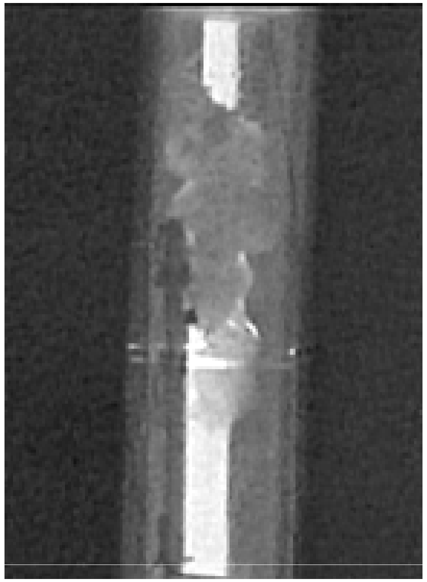
Preparation of the gel samples from liquids or gases at normal conditions by slow condensation of the gas flow mixture at the He-II – ^{4}He vapor interface

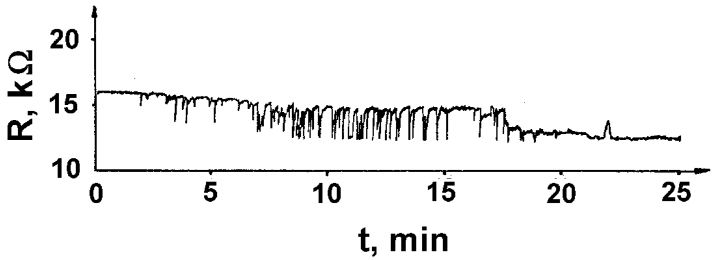


Shown are wide (left, inner diameter d=3 cm) and narrow (right d=0.9cm) glass cells placed inside the glass dewar: 1-filling tube, 2-experimental cell, 3,4-resistive thermometers, 5-the dewar, 6-thermomechanical pump, 7,9-manometers, 8-mechanical pump, 10-glass bottle, 11-discharge cock, 12-charcoal trap cooled by liquid nitrogen.

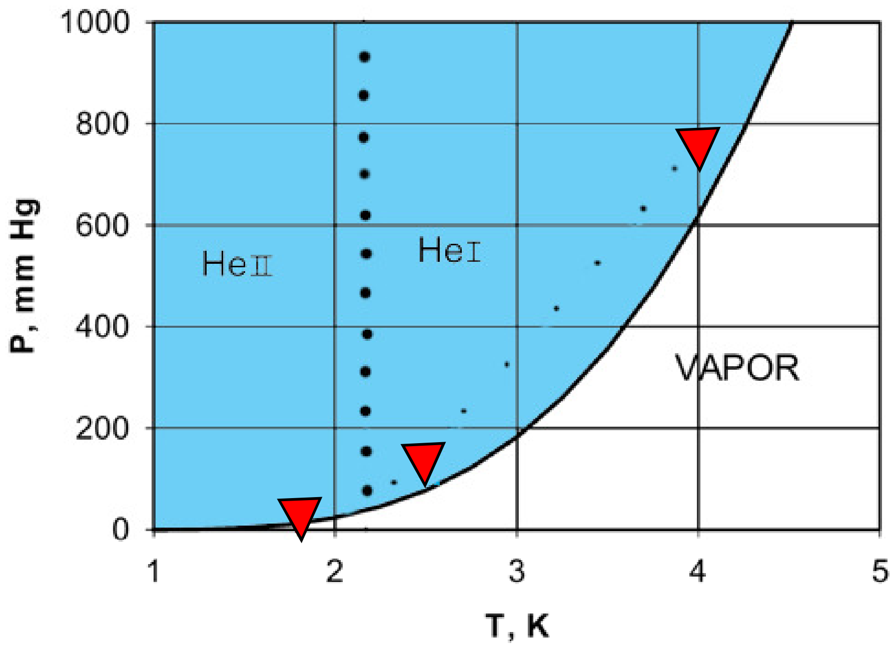
Decay of the water "icebergs", extracted from He-II, on heating in helium vapor at constant pressure (the narrow cell).





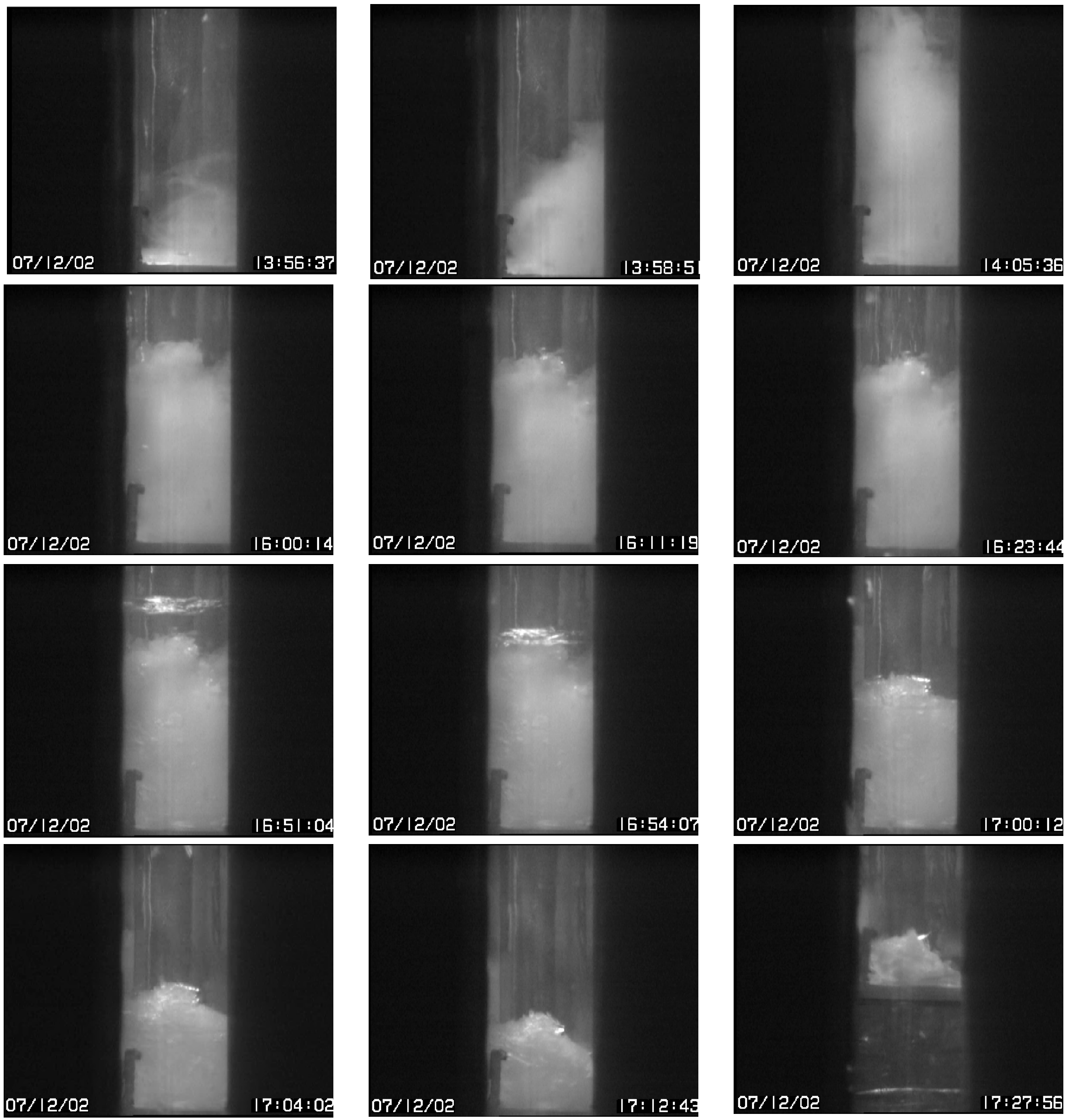


The temperature jumps registered by the upper thermometer on heating the sample above 1.8 K. The initial temperature (temperature of the liquid) was 1.6 K. The amplitude of the jumps ΔT ~ 0.3 K.



The region of existence of the water gel samples in liquid helium (red triangles).

Solid line – P-T diagram of liquid ^{4}He; dark circles – the line of transition He-II – He-I; points shown for the eyes convenience.

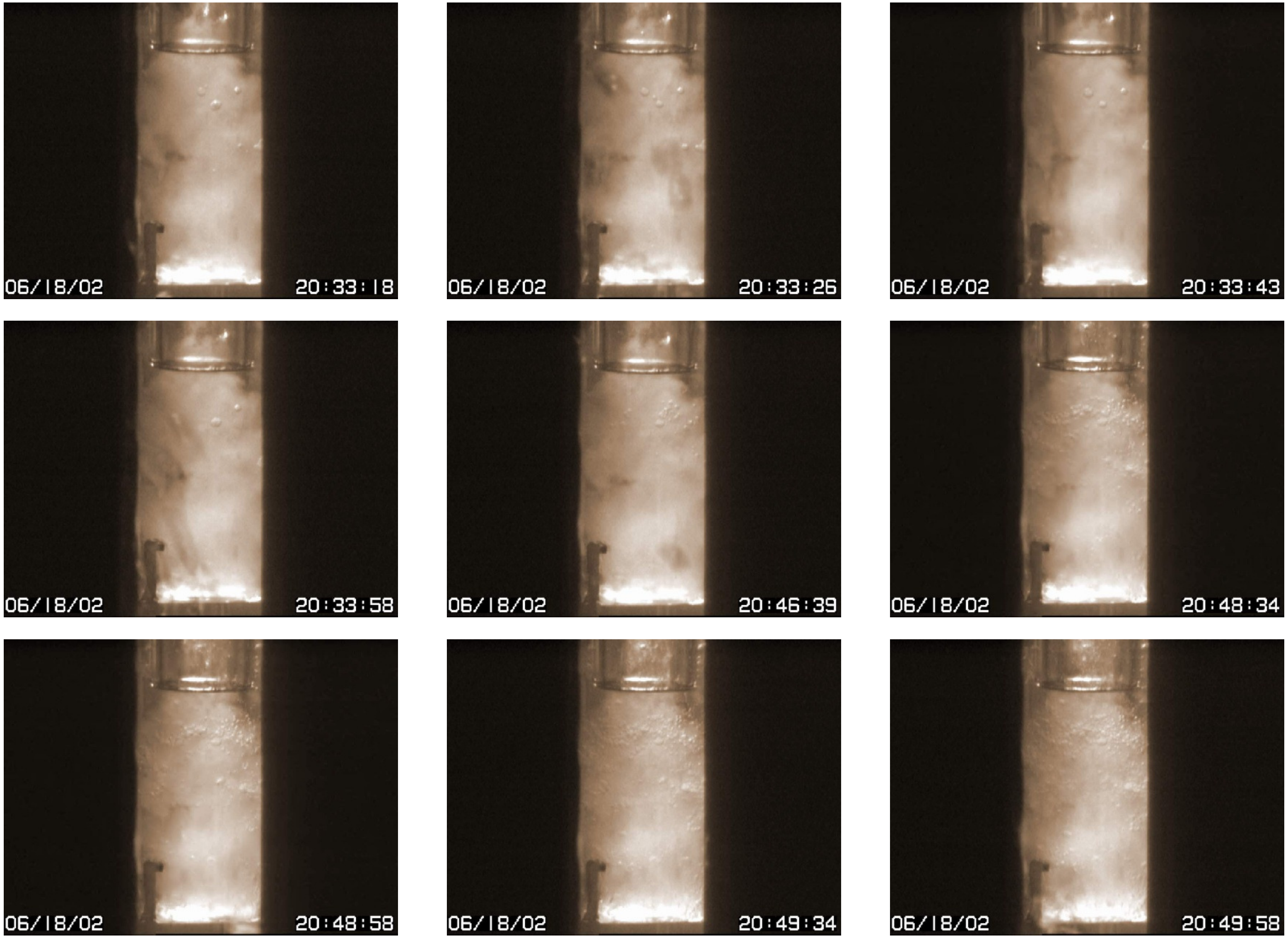


Preparation of the ethanol C_2H_5OH sample at T=1.4 K (upper row), and evolution of its shape with increasing the temperature from 1.4 to 2 K (second raw).

Two lowest rows show evolution of shape of the sample in liquid helium with raising the temperature above T_λ and with lowering the level of the liquid.

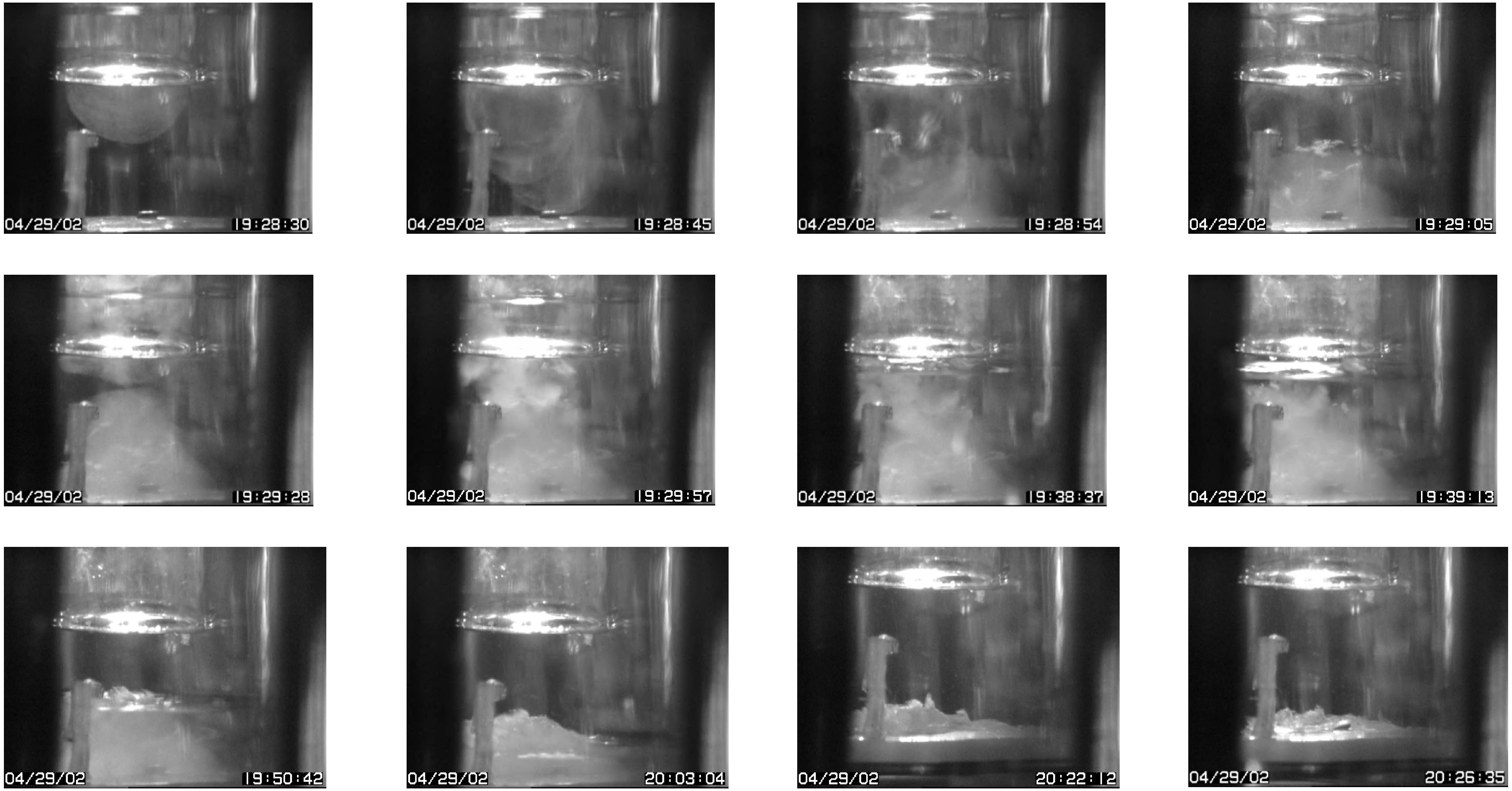
The last frame shows decay of the sample in He-gas atmosphere. Temperature of the support plate is close to 4.2K.

ETHANOL GEL IN BULK OF NORMAL HELIUM He-I

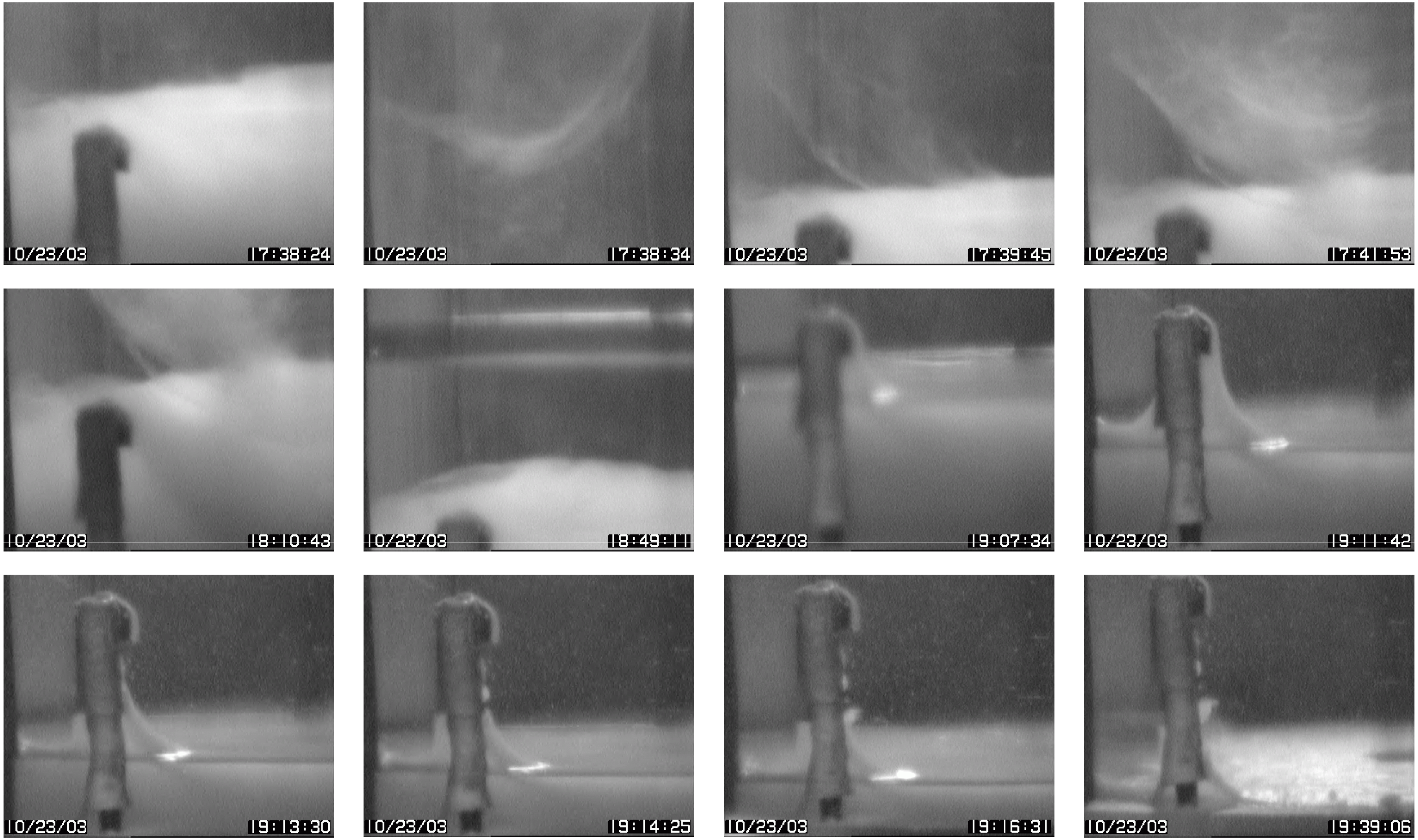


The liquid temperature T~2.3K, vapor pressure above the liquid is P ~ 50 tor

Formation and evolution of the watergel sample in the wide cell.

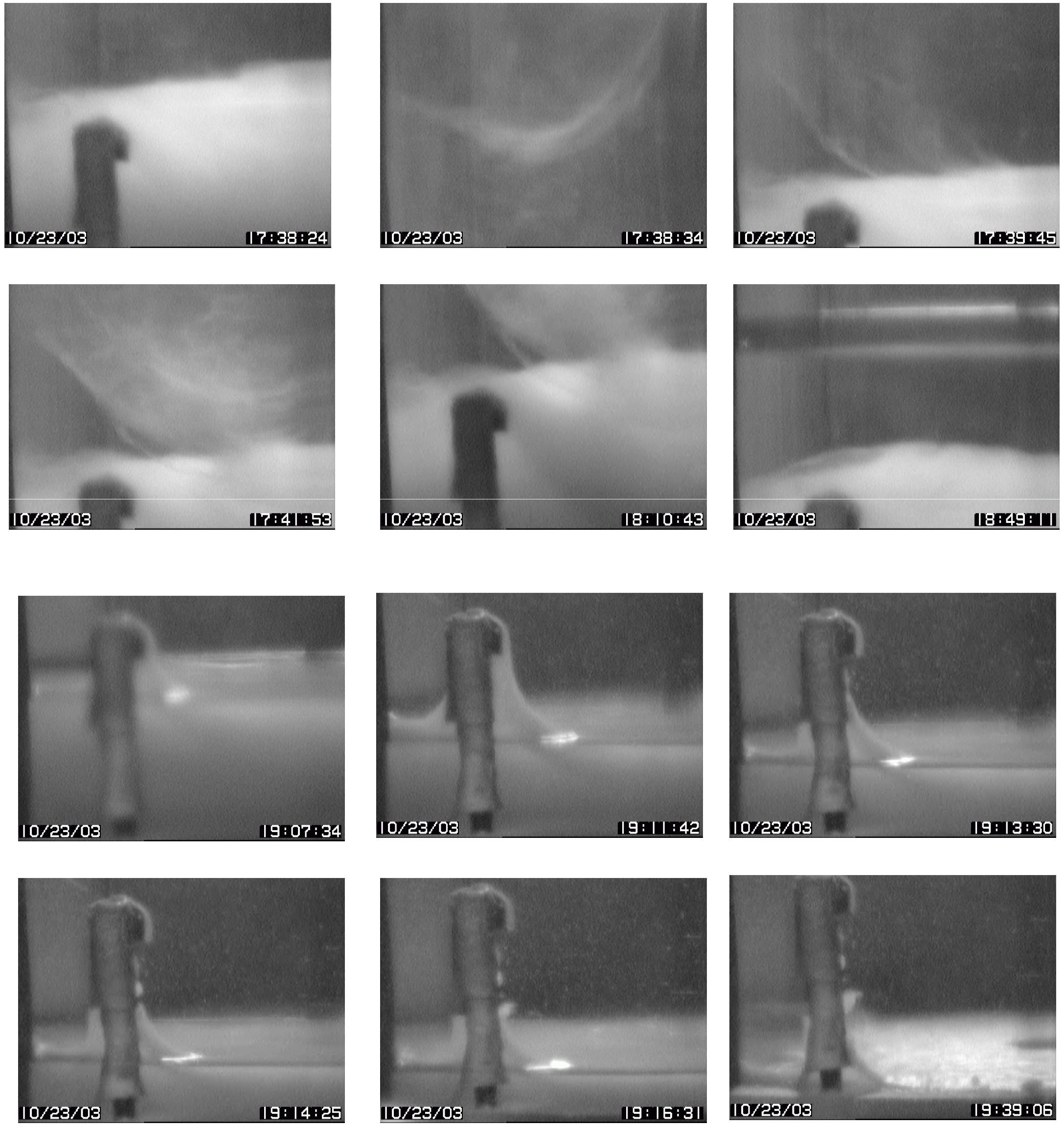


Upper raw – the sample formation in He-II at constant T=1.4 K. The level of liquid He-II is placed above the end of the filling tube. ***Middle raw*** – the sample evolution with time and with lowering the liquid level at T=1.4K. ***The last raw*** - ***two first frames*** show the sample decay in the cold helium vapor above the liquid at T=1.4 K, the vapor pressure P~2.2 Torr; ***two last frames*** show the sample decay in He vapors on heating the upper edge of the sample to 2.6 K; the temperature of the teflon support is 2.18 K and of the liquid He-II at the bottom of the cell is ~ 1.4 K (so, the vapor pressure is P~2.2 Torr).



Formation of the deuterium gel sample in superfluid He-II at T=1.4 K (top rows) and decay of the sample with lowering of the level of He-II (middle and bottom rows). Diameter of the Teflon plate at the bottom of the cell is ~3 cm, and the height of the column supporting the resistive thermometer placed above the plate is ~1 cm.

Preparation (two upper raws) and decay (with lowering of He-II level) of D_2 gel sample in the wide cell . The bath temperature is fixed at T=1.4 K



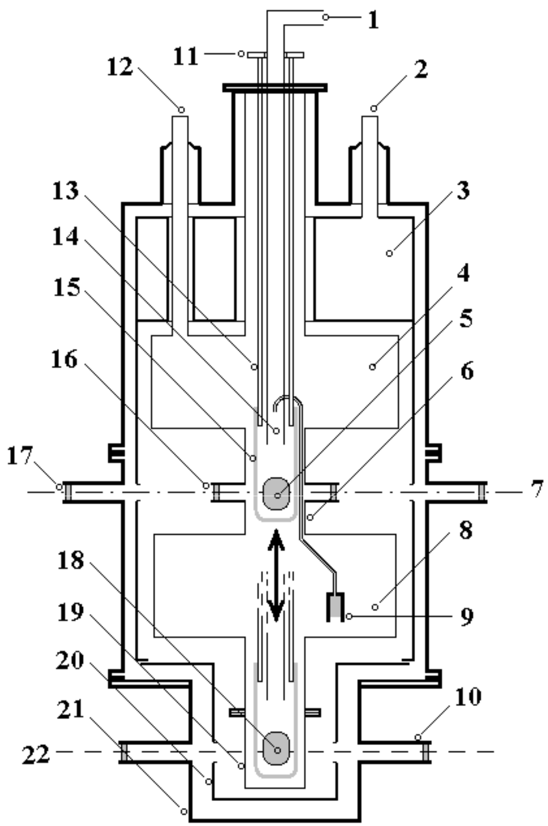
Preparations for the neutron studies of the gel samples.

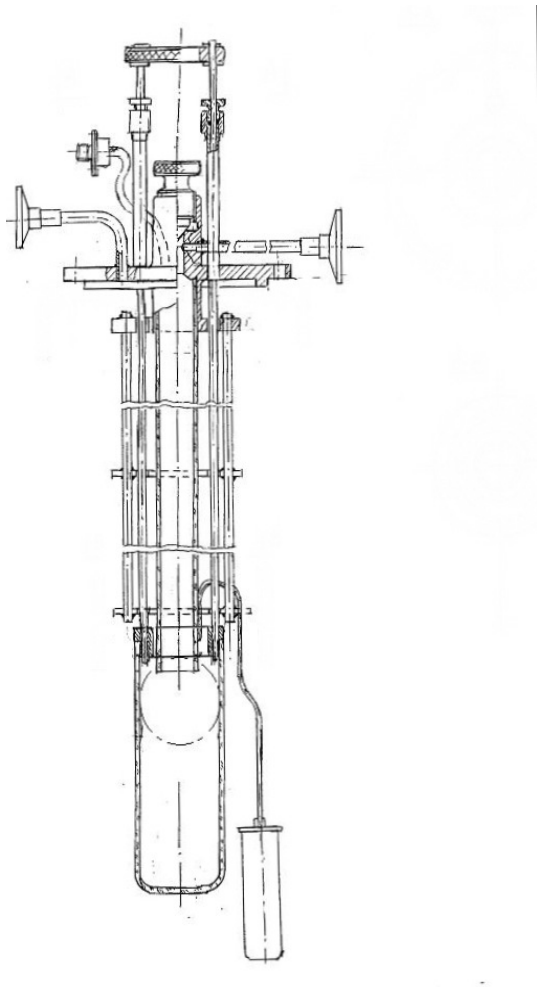
Quartz glass windows used for observations of the sample preparations

The neutron beam collimator; the experimental cell with the sample was shifted down the tail for the neutron studies

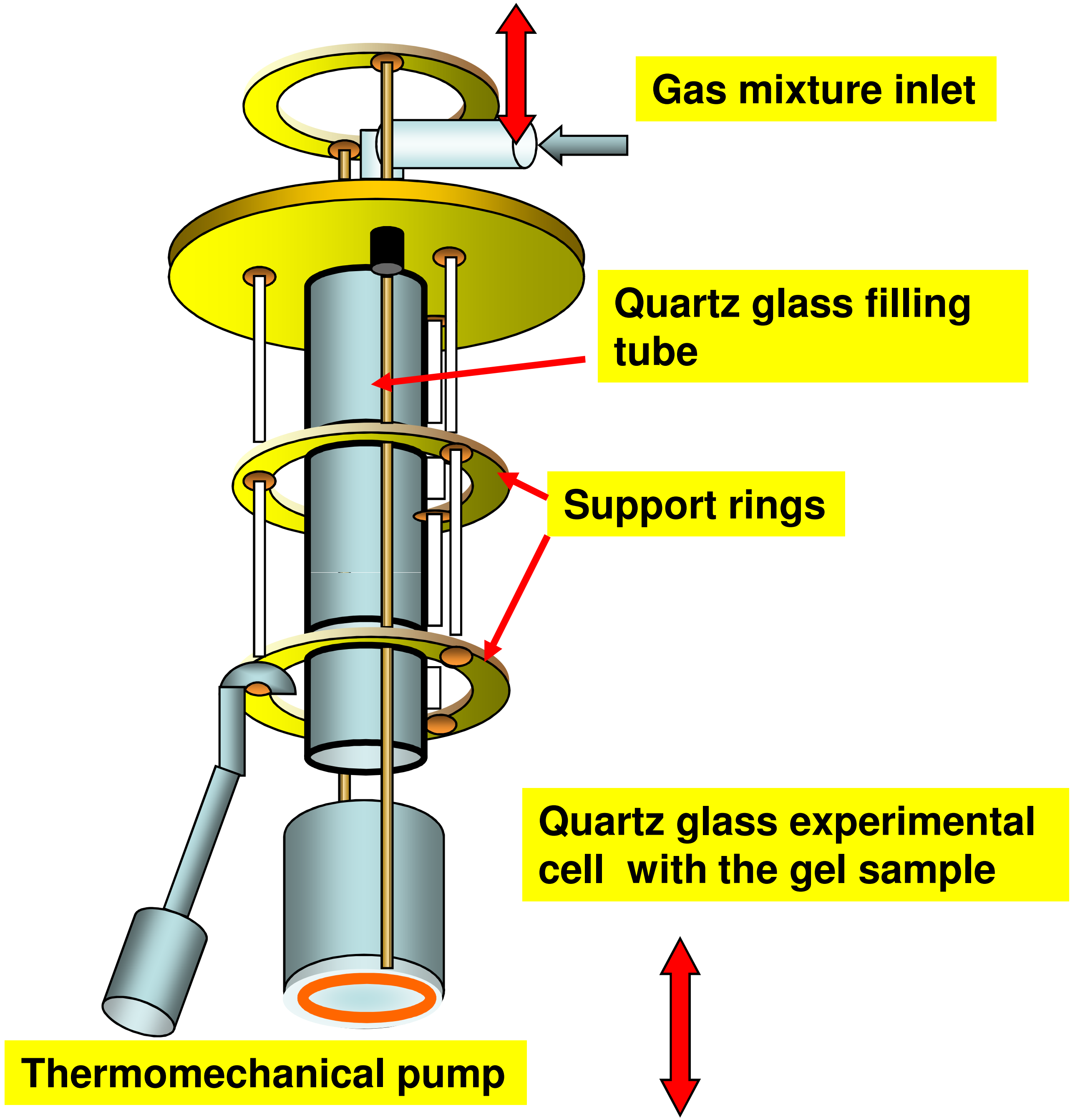
Outer quartz glass with the Al screen inside; in further experiments at the SANS D22 spectrometer and IN10A quasi elastic scattering spectrometer the quartz glass was changed to Al one.

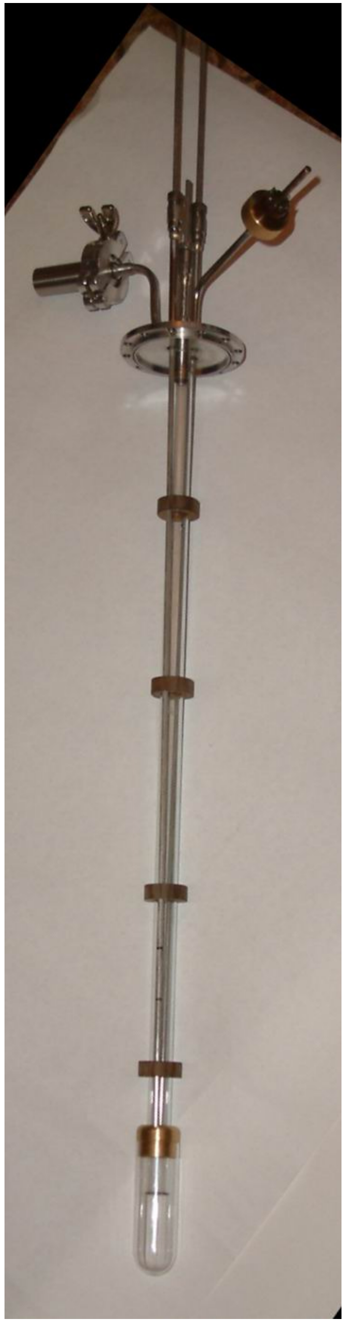
Scheme of the cryostat for neutron studies





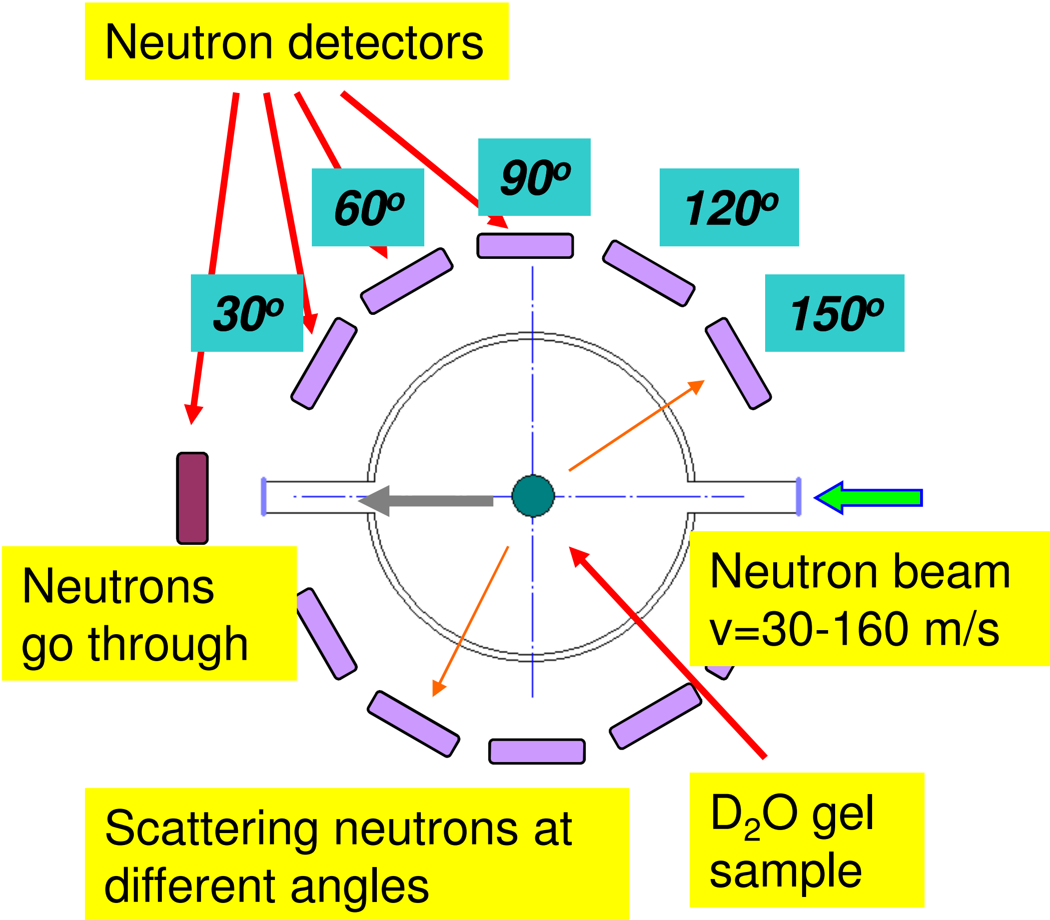
1- Mixture inlet; 2-filling tube and 3-vessel with liquid nitrogen; 4, 8 - containers for liquid helium; 5- gel sample in He-II; 6-steel tube; 7, 16, 17-glass windows; 9-thermomechanical pump; 10, 22-neutron guides; 11-ring connector; 12-liquid helium inlet; 13-tube for transmission the cup 15 up and down; 14-filling glass tube; 18-the experimental cell at the lower position for the neutron studies; 19- replaceable cup; 20-aluminium shell; 21-outer aluminum shell.


Gas mixture inlet
Quartz glass filling tube
Support rings
Quartz glass experimental cell with the gel sample
Thermomechanical pump



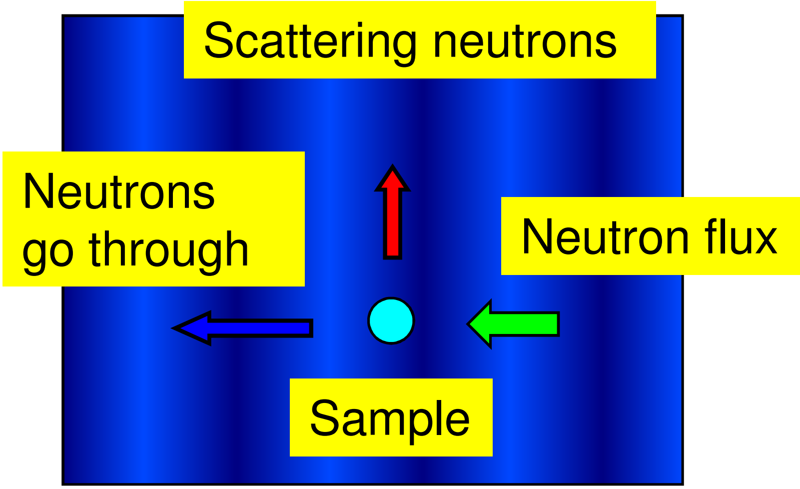
The cryostat details

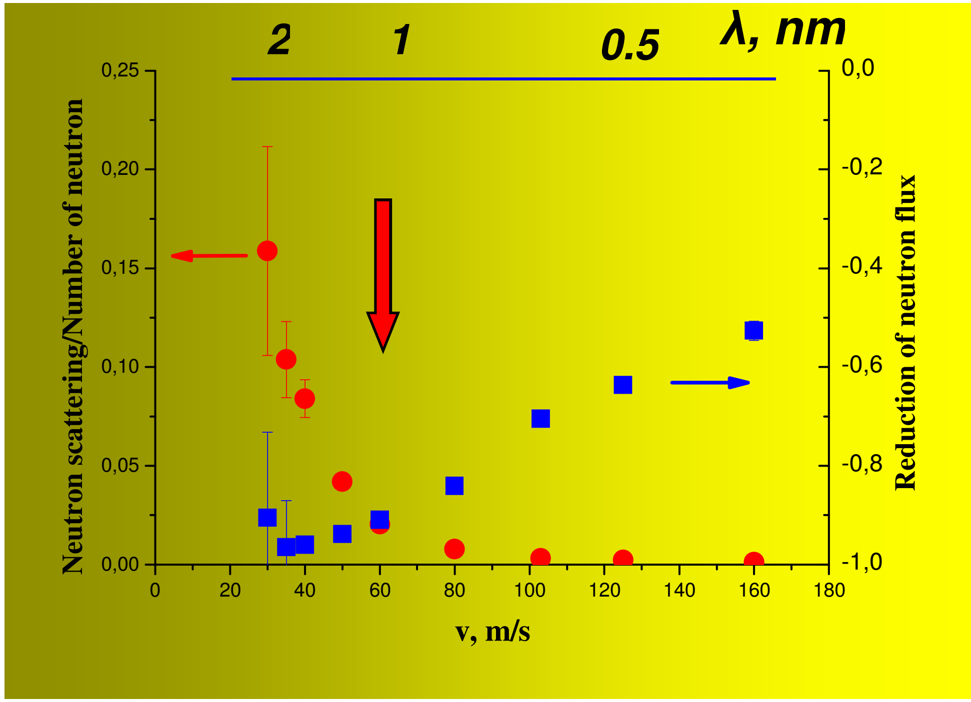
The neutron beam transmittion through the heavy water gel sample in He-II

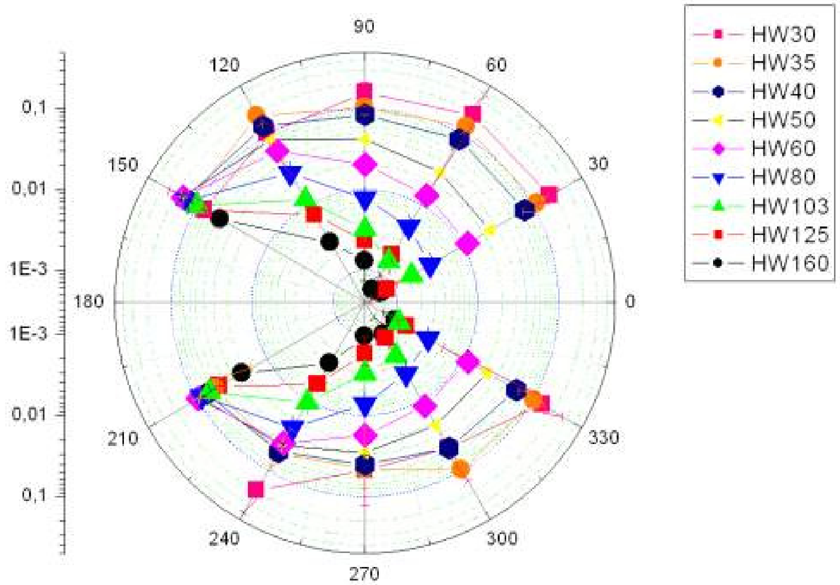


- The neutron velocity V=160, 125, 103, 80, 60, 50, 40, 35, 30 m/s (cold neutrons).
- The proper wave-lengths are λ = 0.3 -2 nm

Transmittion of the cold neutron through the D_2O sample at T=1.5K.



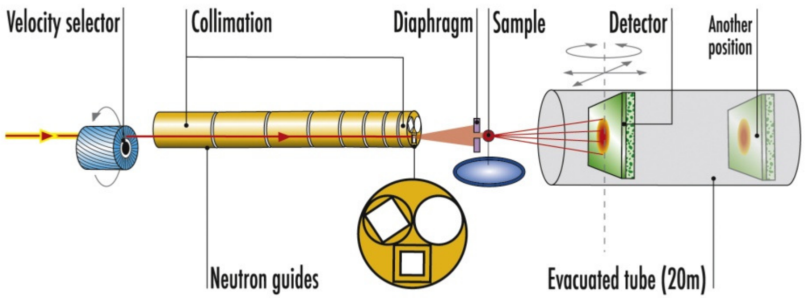


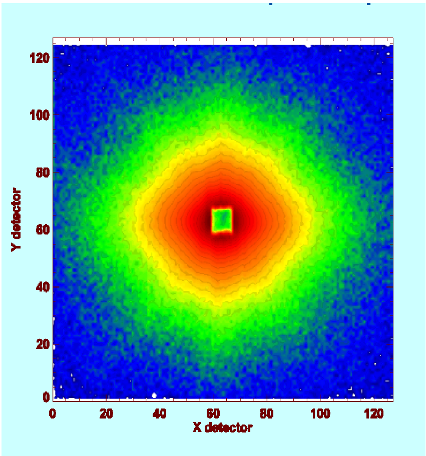


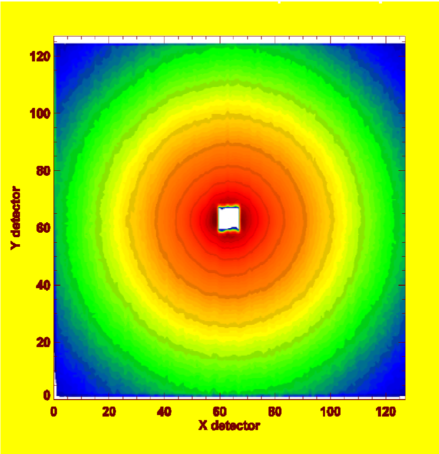
5m/s ~ 1 mK
30m/s ~ 50 mK
100m/s ~ 0.6 K
400m/s ~ 10 K

$$\lambda_n[nm] = \frac{63}{V_n[m/s]}$$

SANS measurements at the D22 spectrometer





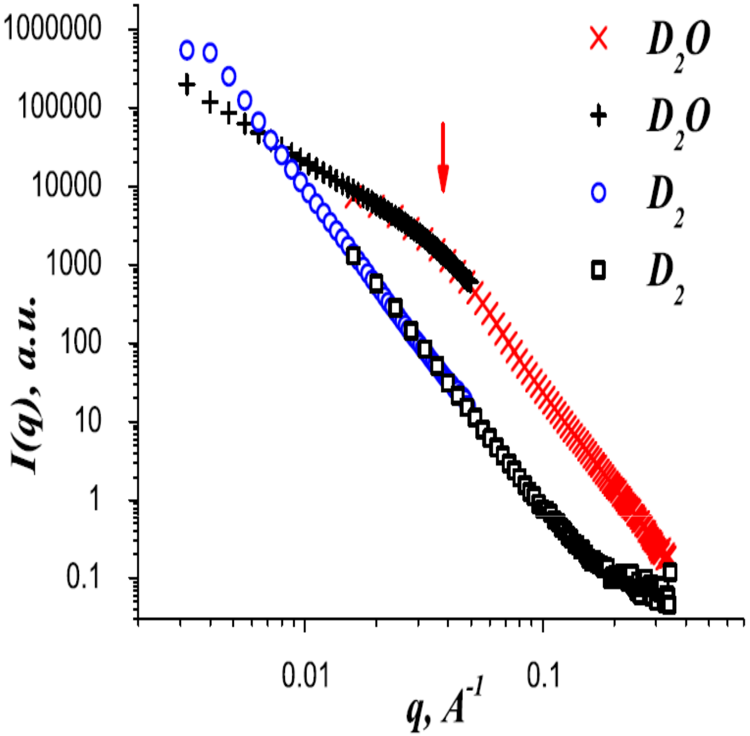


Cell without the gel sample

Cell with D_2O sample in superfluid He-II

SANS studies

1-st series



$$q = \frac{4\pi}{\lambda}\sin\theta$$

$$qr \sim 4; \quad r \sim \frac{4}{q}\ [A]$$

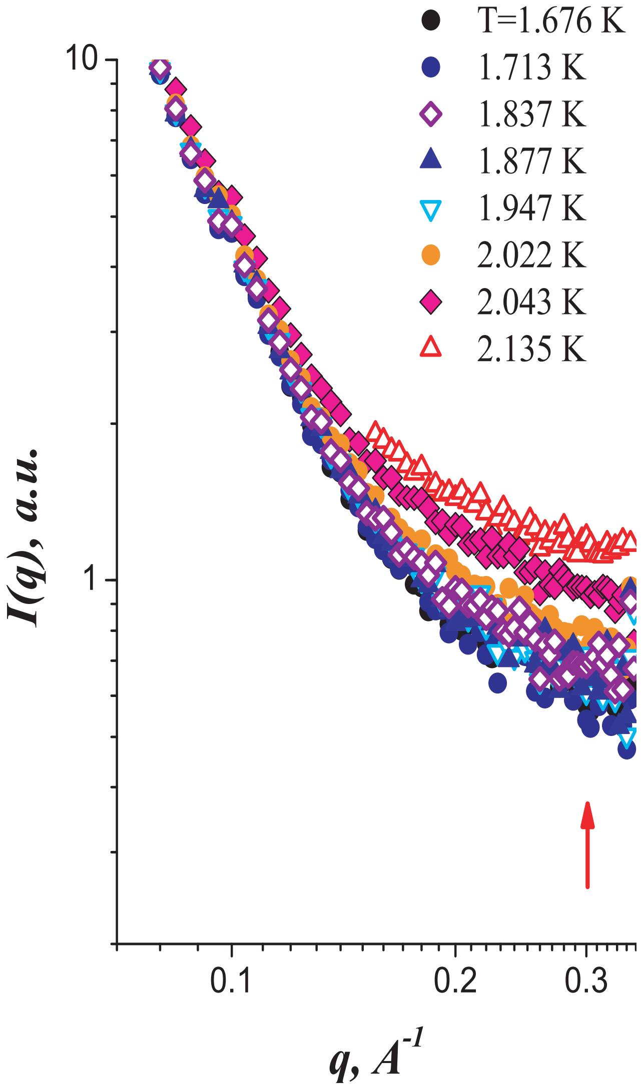
$$l = 6.3\ A \rightarrow \quad T_n \sim 22\ K$$

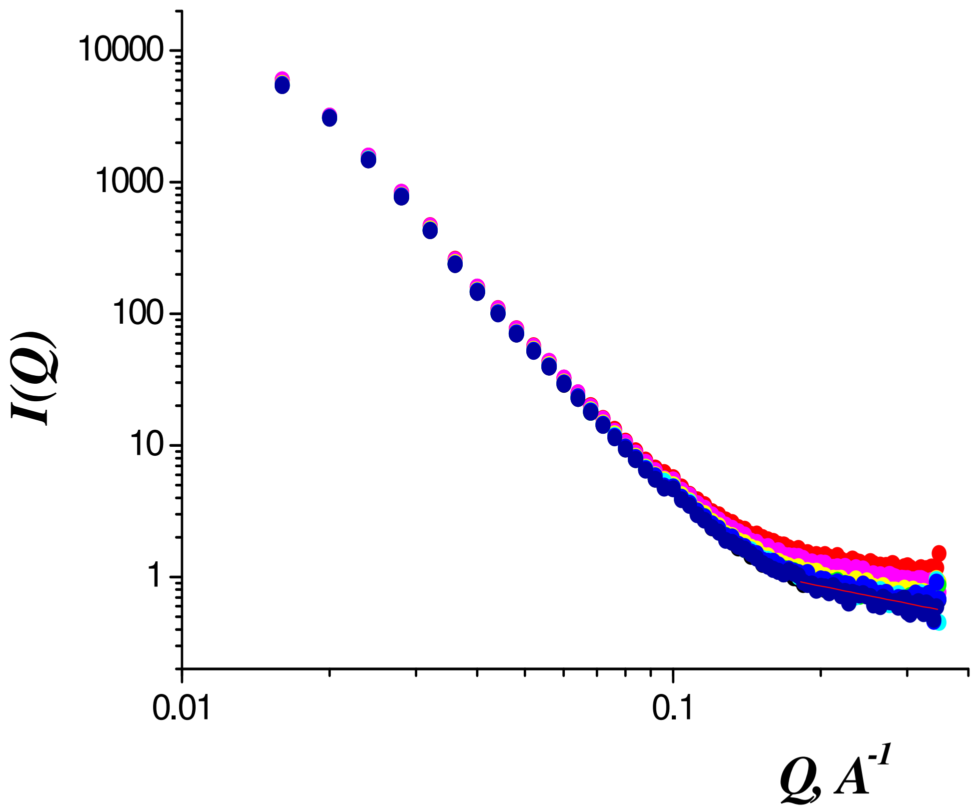
The flux of scattered neutrons ***I(q)*** (in a.u.) as a function of the momentum transfer ***q*** for ***D_2O* (red and dark crosses)** and ***D_2* (the open circles and squares)** gel samples in superfluid He-II at a temperature of *1.6 K*. The **red arrow** indicates the neutron momentum transfer value corresponding to the breaking of the ***I(q) ~ q*** $^{-4}$ dependence for *D_2O* gel samples and the singularity corresponds to ***r ~100 A***.

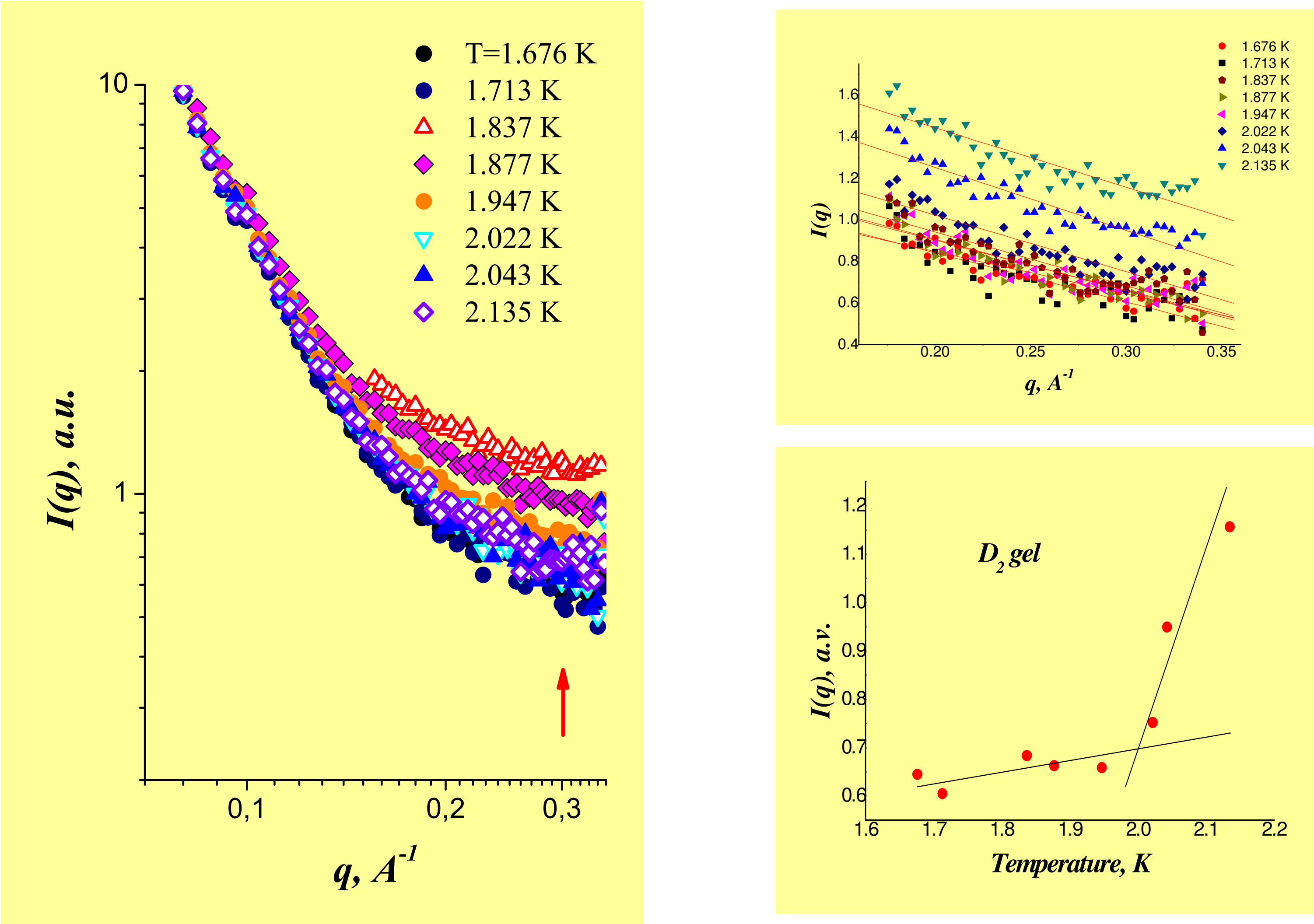
SANS measurements

Evolution *of the I(q)* curves

with increasing the temperature of the D_2 gel sample in superfluid He-II

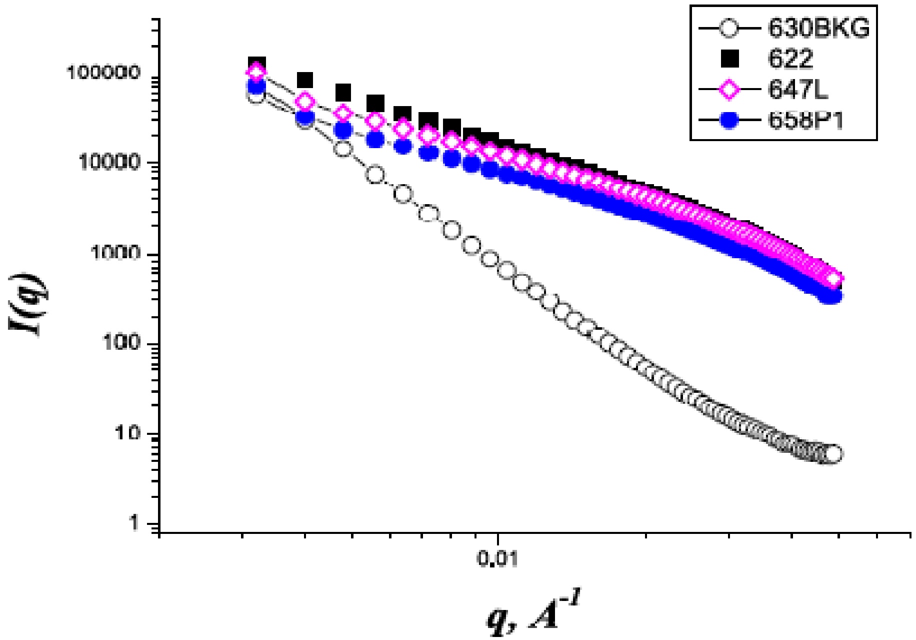




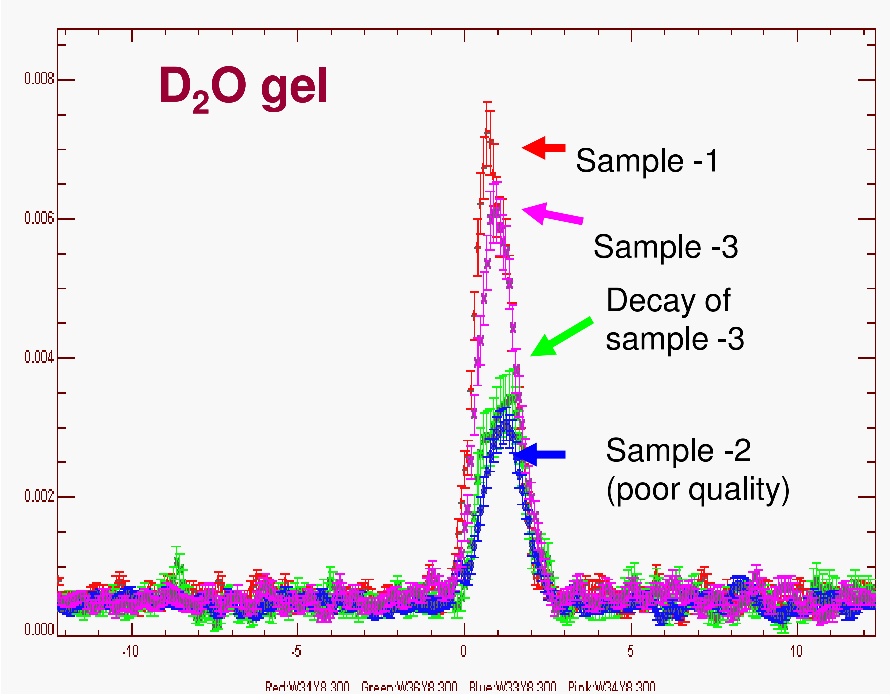


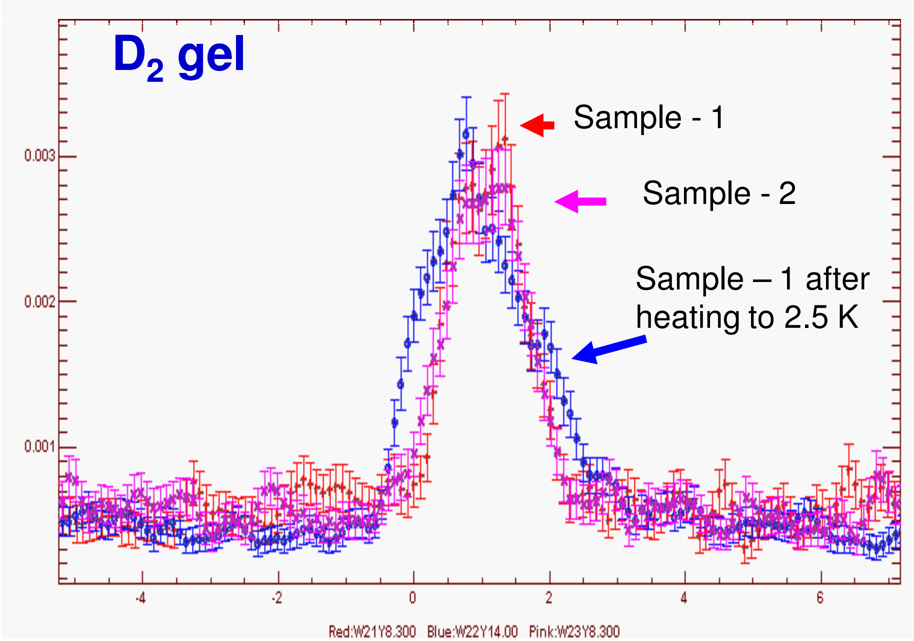
Evolution of *I(q)* curves with rising the temperature of D_2 gel sample from 1.676 to 2.135 K (left). Right figures show evolution of *I(q)* curves in the range *q*= 0.15 - 0.35 A^{-1} (upper frame) and dependence of $I(0.3A^{-1})$ on temperature (lower one)

SANS measurements on the D_20 gel sample

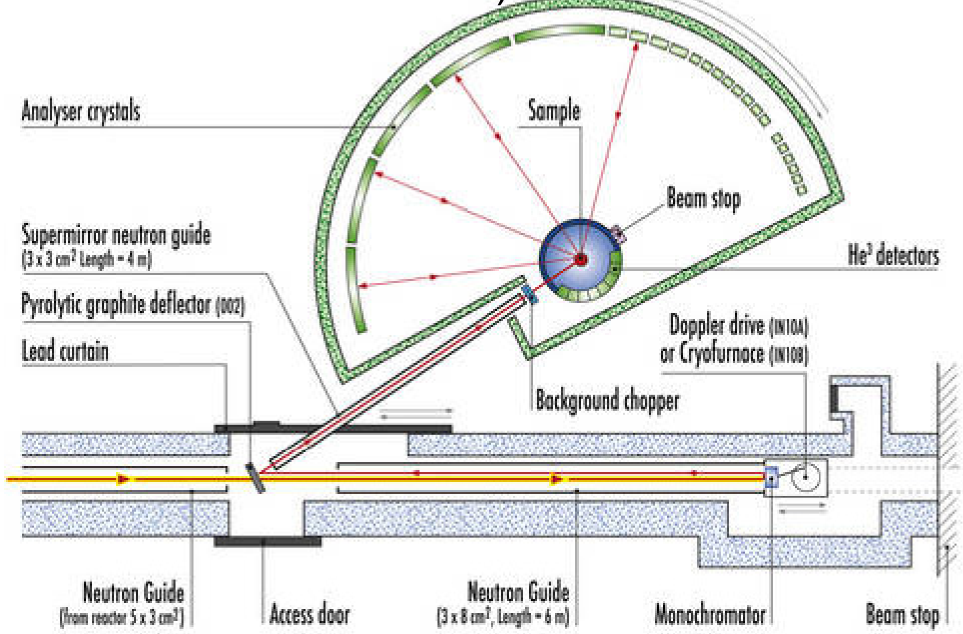


Evolution of the ***I (q)*** curves with time and temperature: **black squares *(run 622)* – the sample after preparation, *T* ~ 1.67 *K*; magenta rhombi (*run 647*) – after holding for 9 hours at the same temperature** and **blue cycles (*run 658*) - after rapid increasing of pressure and temperatures up to 4.2 K. The *open cycles show the background at T ~ 1.67 K measured without the sample*** (***the background was not subtracted from the upper curves***).





IN10A spectrometer was designed for quasielastic scattering experiments requiring very high energy resolution (up to dE ~ 0.3 micro eV):



flux at sample n cm^{-2} s^{-1}	$4x10^3$
incident energy / K	20.8
incident wave-length λ/Å	6.271
energy transfer range δE/μeV	-15...15

Readings of the detector installed at the angle $\varphi \approx 8^o$

● Neutron Scattering in Gel

- **Low gel density**

  * Quasi-ballistic propagation

$$t_{ballistic} = L_{sample}/v_n$$

- **High gel density**

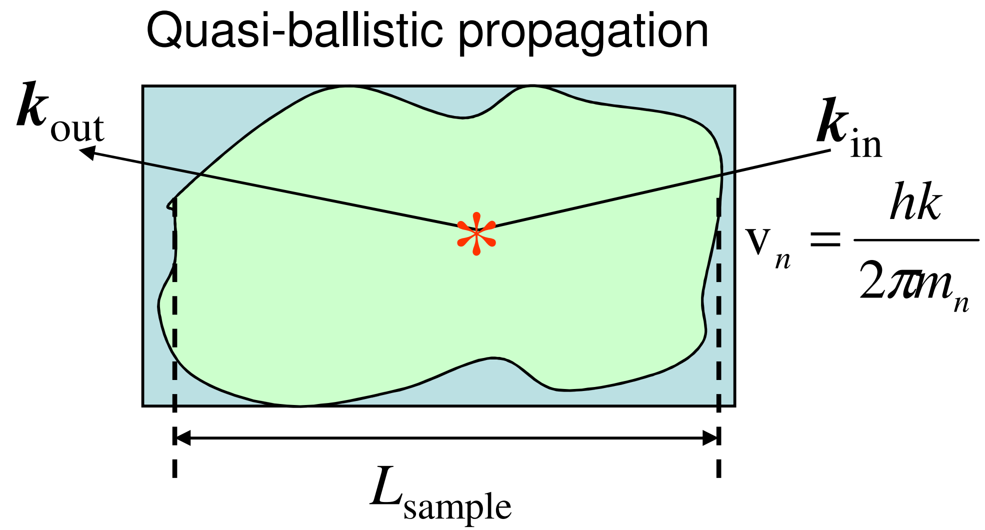
  * Diffusive propagation

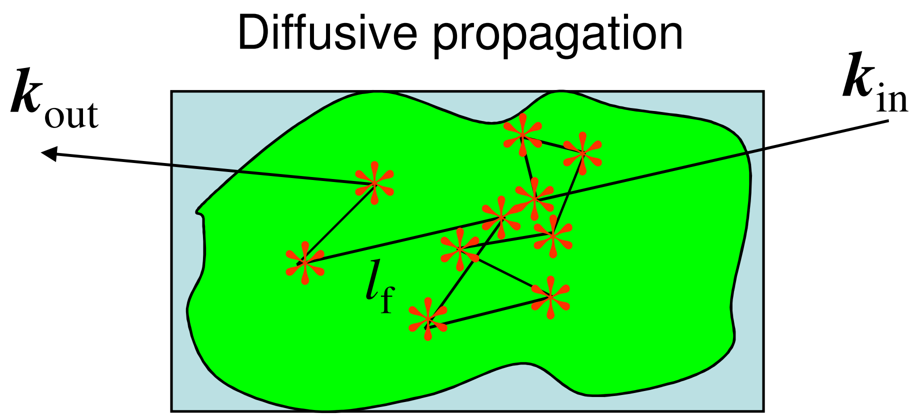
$$D_n = l_f^2/\tau = l_f\, v_n$$

$$t_{diffus} = L^2/D_n = (L/l_f)\times(L/v_n)$$

$$= (L/l_f)\ t_{ballistic}$$

$t_{diffus} >> t_{ballistic}$ at $L/l_f >> 1$





Nesvizhevsky, VV; Pignol, G; Protasov, “Neutron scattering and extra-short-range interactions” *Phys. Rev. D* 77, 034020 (2008).

* -- $|V_{kk'}|^2 \sim |\rho_k|^2$

← -- $G_{kk'}$

MAIN RESULTS AND CONCLUSIONS.

* The original optical cryostat with quartz glass windows and thin walled Al tails.

* Cold neutron propagation through D_2O gel samples: **s-scattering for neutrons with V= 30- 50 m/s ($E_n \geq 0.05$ K) transforms to small-angle scattering with increasing velocity to V≥ 100m/s ($E_n \geq 0.5$ K).**

* SANS studies (neutrons with λ~ 6*A* and energy E_n ~ 22 K): **characteristic dimensions of clusters in as-prepared at 1.66 K D_2O samples $d_c \leq 15$ nm; and in D_2 samples 5≤ $d_c \leq 150$ nm. Heating of samples above 2.1K results in significant rise of the content of small dimension clusters with $d_c \leq 5$ nm.**

*Search for quasielastic neutron scattering (IN10A spectrometer, E_n~22 K, the range of energy transfer is restricted by |δE|< 1.4 K **): the energy shift of neutrons scattered at the angle ~8 deg is less than 0.07 K. Due to strong instrumental restrictions (T ≥ 1.66 K, very narrow |δE| range) any large energy shifts connected with the inelastic neutron scattering on quasiparticles (phonons, rotons) in bulk of He-II or on any intrinsic degrees of freedom of a soft backbone of impurity gel could not be resolved (pay attention that the conventional sound velocity or compressibility of the gel sample and of the pure He-II are the same).**

* Propagation of cold 9-*A* neutrons through He-II should result in production of UCN. If the effective mean free path l_{eff} of 9-*A* neutrons in massive D_2 or D_2O gel samples is much less than dimensions of a helium vessel **$L \geq 20$cm >> l_{eff}** then diffusive motion of VCN should result in strong increase, in L/ l_{eff} times, of the effective time of propagation between two collisions with walls. So, the first, the vessel dimensions could be reduced on filling its volume by the D_2 or D_2O gel, and, the second, the temperature of VCN drifting through the macroscopically large gel sample cooled below 5 mK could be lowered down to the bath temperature due to multiple inelastic (even very weak) scattering of VCN on weakly bounded impurity nanoclusters.

• Conclusions

• We perform numerical modeling of gel formation in a cold gas flow in a cell

• Finite size of the cell plays essential role for gel formation process

• We estimate propagation time of neutrons through the gel

* *at low gel densities* the mean free path $l_f > L_{sample}$ neutrons of wavelength ~ 9 A propagate nearly ballistically through the gel sample,

* *at high gel densities* $l_f \ll L_{sample}$, neutrons diffuse through the gel sample.

This leads to strong increase of effective propagation time, resulting in sharp increase of the total interaction cross-section of neutrons with the sample.

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- THANKS FOR YOUR ATTENTION!

Observation of Ultracold Neutron Production by 9A Cold Neutrons in Superfluid Helium, H.Yoshiki, K.Sakai, M.Ogura, et al. Phys.Rev.Lett, **68** (9), 1992
(*UCN with λ = 8.78± 0.06 A as predicted by the single-phonon emission theory*)

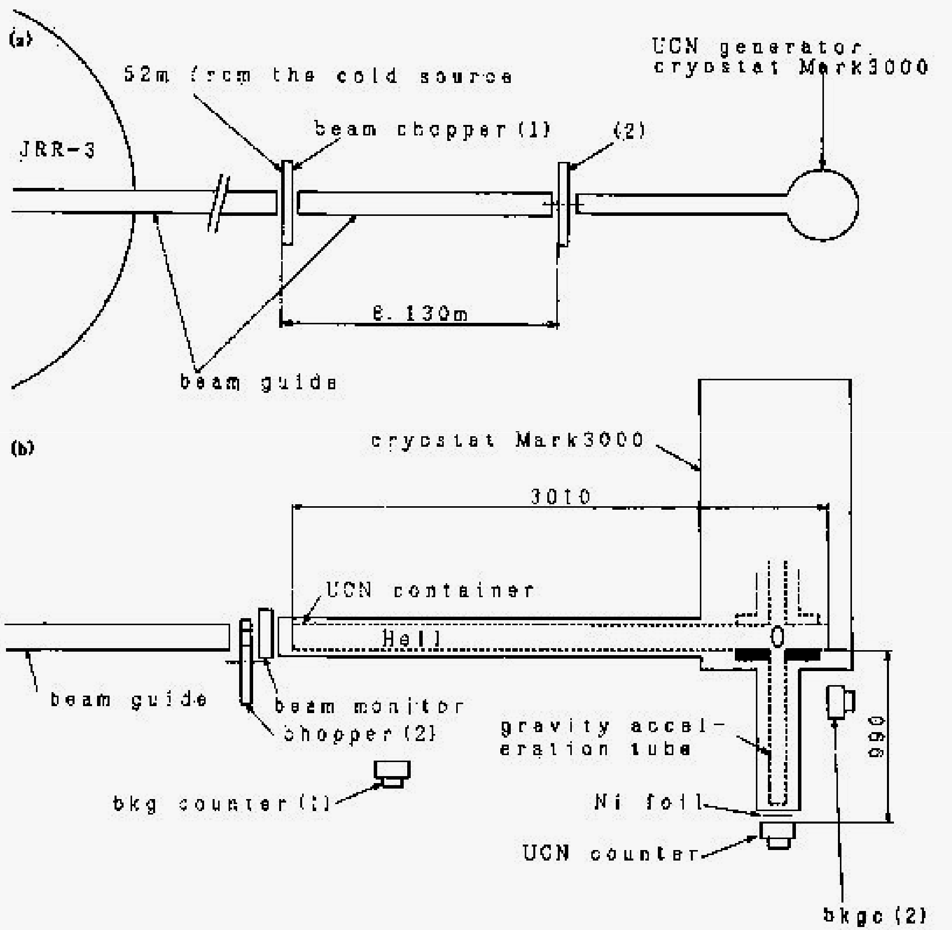

FIG. 1. Experimental layout. (a) Top view and (b) side view.

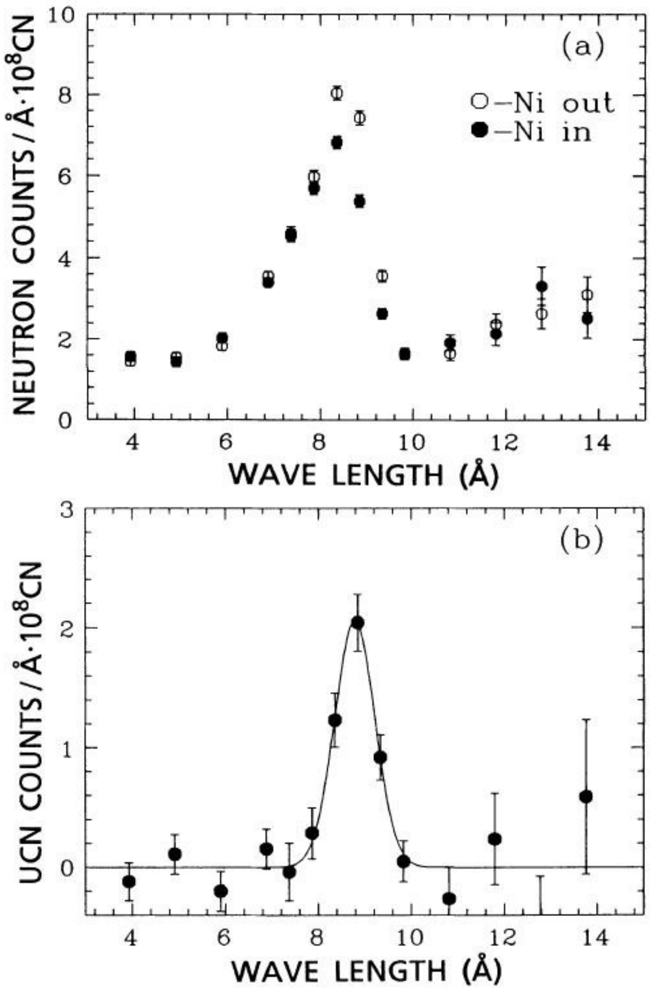

FIG. 2. (a) Counts normalized to incident neutron flux at the wavelength plotted, vs incident wavelength with (solid circles) and without (open circles) Ni foils. (b) UCN yields obtained by subtracting solid from open circles in (a).

UCN production - 1

- **Production of UCN by downscattering in superfluid He[4]**
  Physics Letters A*, *Volume 301, Issues 5-6*, *2 September 2002*, *Pages 462-469 **E. Korobkina, R. Golub, B. W. Wehring, A. R. Young**
- **Abstract** Ultra-Cold Neutrons (UCN) are neutrons with energies so low they can be stored in material bottles and magnetic traps. They have been used to provide the currently most accurate experiments on the neutron life time and electric dipole moment. UCN can be produced in superfluid Helium at significantly higher densities than by other methods. The predominant production process is usually by one phonon emission which can only occur at a single incident neutron energy because of momentum and energy conservation. However UCN can also be produced by multiphonon processes. It is the purpose of this work to examine this multiphonon production of UCN. We look at several different incident neutron spectra, including cases where the multiphonon production is significant, and see how the relative importance of multiphonon production is influenced by the incident spectrum.
- **Experimental measurement of ultracold neutron production in superfluid ^{4}He**
  Physics Letters A*, *Volume 308, Issue 1*, *17 February 2003*, *Pages 67-74 **C. A. Baker, S. N. Balashov, J. Butterworth, P. Geltenbort, K. Green, P. G. Harris, M. G. D. van der Grinten, P. S. Iaydjiev, S. N. Ivanov, J. M. Pendlebury, D. B. Shiers, M. A. H. Tucker, H. Yoshiki**
- **Abstract** The absolute production rate of ultracold neutrons (UCN) produced by the interaction of a cold neutron beam with superfluid helium has been measured over an incident energy range of 0.7 to 4 meV. The neutrons are reduced in energy to become UCN by creating phonon(s) in the superfluid. The separate roles played by single and multi-phonon emission processes have been identified. Detection and identification of UCN, those neutrons with energies less than 250 neV and which can be stored in material bottles, were carried out using solid-state silicon detectors set within the superfluid helium. With a cold neutron flux of 2.62×10^7 neutrons cm^{-2} s^{-1} $Å^{-1}$ at 8.9 Å in the superfluid, the single-phonon production rate of UCN was measured to be (0.91 ± 0.13) cm^{-3} s^{-1}, a value close to theoretical prediction. Multi-phonon emission processes for UCN production by higher energy neutrons were also observed and, in the beam used for this work at ILL, they contributed (24 ± 2)% to the overall UCN production rate.

- **Ultra cold neutron production by multiphonon processes in superfluid helium under pressure**
***Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, *Volume 611, Issues 2-3*, 1 December 2009-11 December 2009, Pages 259-262**
P. Schmidt-Wellenburg, K.H. Andersen, O. Zimmer
- **Abstract** Cold neutrons are converted to ultra cold neutrons (UCN) by the excitation of a single phonon or multiphonons in superfluid helium. The dynamic scattering function $S(q, \omega)$ of the superfluid helium strongly depends on pressure, leading to a pressure-dependent differential UCN production rate. A phenomenological expression for the multiphonon part of the scattering function $s(\lambda)$ describing UCN production has been derived from inelastic neutron scattering data. When combined with the production rate from single phonon processes this allows us to calculate the UCN production for any incident neutron flux. For calculations of the UCN production from single phonon processes we propose to use the values S^*=0.118(8) at saturated vapour pressure and S^*=0.066(6) at 20 bar. As an example we will calculate the expected UCN production rate at the cold neutron beam for fundamental physics PF1b at the Institut Laue Langevin. We conclude that UCN production in superfluid helium under pressure is not attractive.
- **Ultracold-neutron infrastructure for the gravitational spectrometer GRANIT**
Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, *Volume 611, Issues 2-3*, 1 December 2009, Pages *267-271
P. Schmidt-Wellenburg, K.H. Andersen, P. Courtois, M. Kreuz, S. Mironov, V.V. Nesvizhevsky, G. Pignol, K.V. Protasov, T. Soldner, F. Vezzu, O. Zimmer
- **Abstract** The gravitational spectrometer GRANIT will be set up at the Institut Laue Langevin. It will profit from the high ultracold neutron density produced by a dedicated source. A monochromator made of crystals from graphite intercalated with potassium will provide a neutron beam with 8.9 Å incident on the source. The source employs superthermal conversion of cold neutrons in superfluid helium, in a vessel made from BeO ceramics with Be windows. A special extraction technique has been tested which feeds the spectrometer only with neutrons with a vertical velocity component V_v,≤20 cm/s thus keeping the density in the source high. This new source is expected to provide a density of up to ρ~800 cm^{-3} for the spectrometer.