Flow of Solid Helium through Narrow Constrictions

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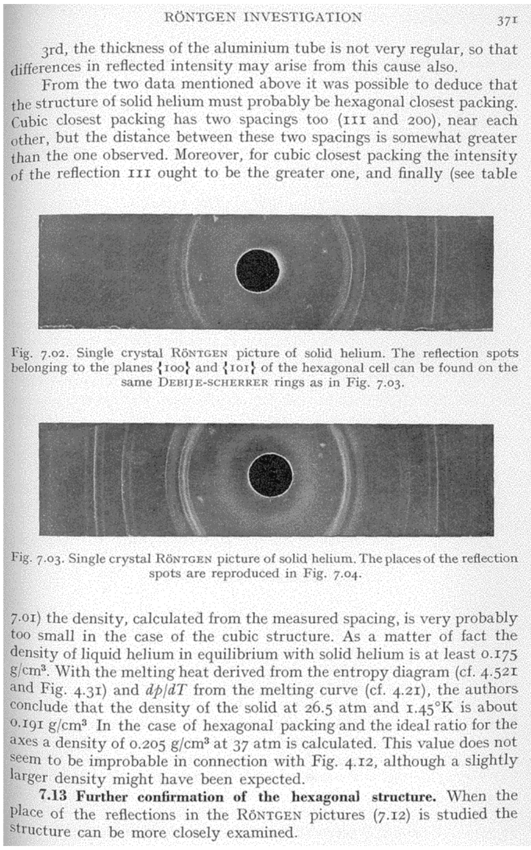
Outline

1. Solid Helium: An Ordinary Solid?
2. The Geyser Phenomenon *
3. Geyser Anomalies *
4. Pressure Measurements
5. Minigeysers Produced by Capillaries
6. Present Model
7. Summary

* G. Benedek, F. Dalfovo, R. E. Grisenti, M. Kaez and J. P. Toennies,
Phys. Rev. Letters 95,095301 (2005)



3rd, the thickness of the aluminium tube is not very regular, so that differences in reflected intensity may arise from this cause also.

From the two data mentioned above it was possible to deduce that the structure of solid helium must probably be hexagonal closest packing. Cubic closest packing has two spacings too (111 and 200), near each other, but the distance between these two spacings is somewhat greater than the one observed. Moreover, for cubic closest packing the intensity of the reflection 111 ought to be the greater one, and finally (see table 7.01) the density, calculated from the measured spacing, is very probably too small in the case of the cubic structure. As a matter of fact the density of liquid helium in equilibrium with solid helium is at least 0.175 g/cm³. With the melting heat derived from the entropy diagram (cf. 4.521 and Fig. 4.31) and dp/dT from the melting curve (cf. 4.21), the authors conclude that the density of the solid at 26.5 atm and 1.45°K is about 0.191 g/cm³ In the case of hexagonal packing and the ideal ratio for the axes a density of 0.205 g/cm³ at 37 atm is calculated. This value does not seem to be improbable in connection with Fig. 4.12, although a slightly larger density might have been expected.

Fig. 7.02. Single crystal RÖNTGEN picture of solid helium. The reflection spots belonging to the planes {100} and {101} of the hexagonal cell can be found on the same DEBIJE-SCHERRER rings as in Fig. 7.03.

Fig. 7.03. Single crystal RÖNTGEN picture of solid helium. The places of the reflection spots are reproduced in Fig. 7.04.

7.13 Further confirmation of the hexagonal structure. When the place of the reflections in the RÖNTGEN pictures (7.12) is studied the structure can be more closely examined.

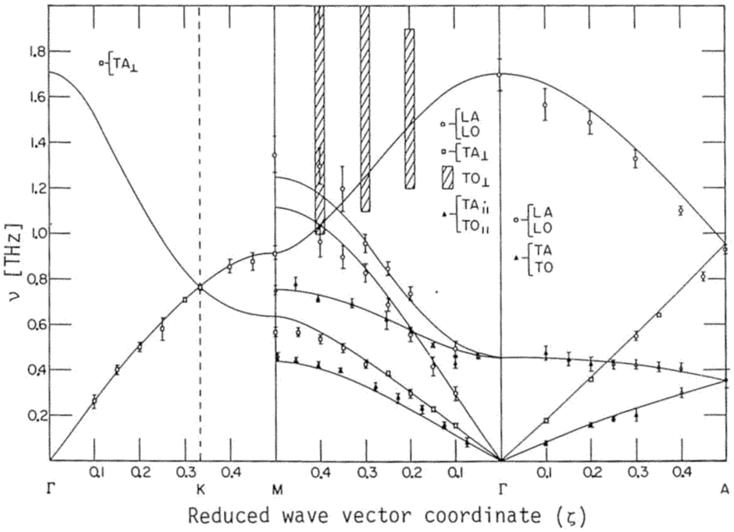
P_0 = 37 atm.

T_0 = 1.45 K

W.H.Keesom and
K.M.Taconis,

Physica **5** 161 (1938)

Phonon Dispersion Relation of He



T_0 = 4.2 K

P_0 = 230 bar

V_{mol} = 16 cm³

R.A.Reese, S.K.Sinha, T.O.Brun and C.R.Tilford,
Phys.Rev.A **3**, 1688 (1971)

Blocked Capillary Method for Melting Pressures

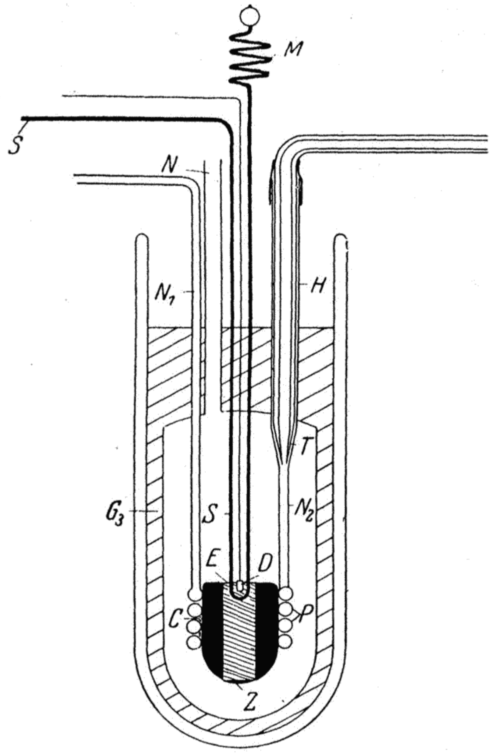
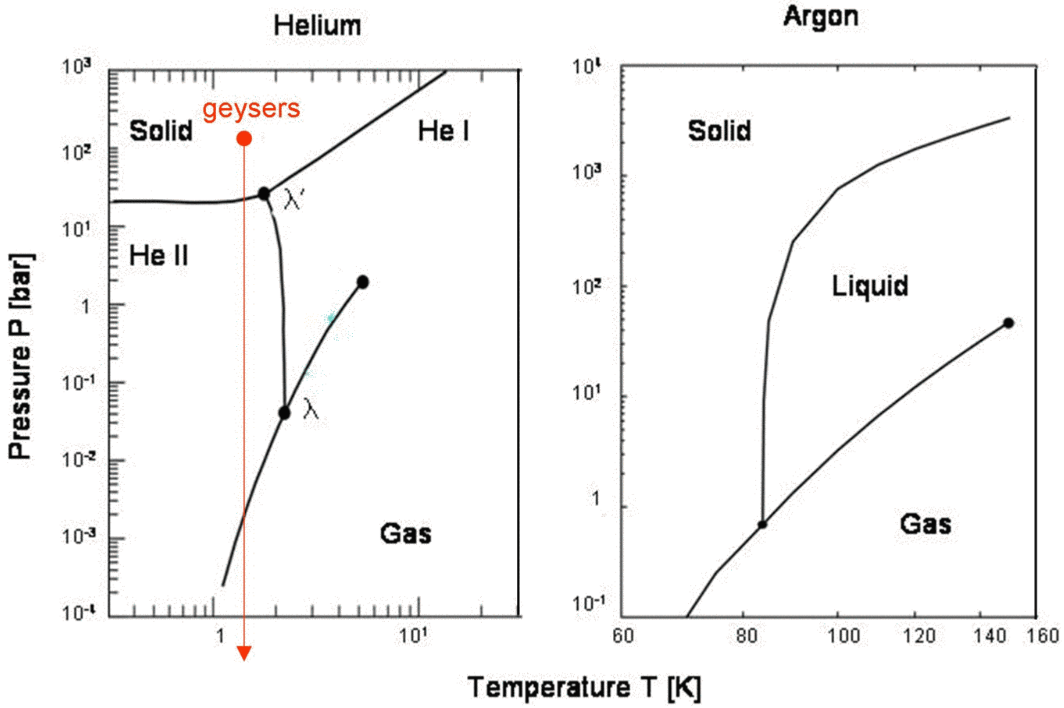


Fig. 4.08. Apparatus for determining the melting pressures of helium.

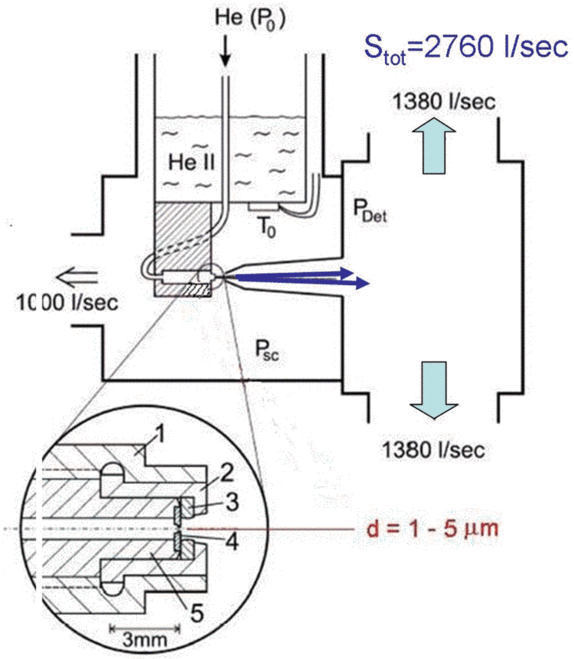
Measuring range: 827-5630 bar

F.Simon, M.Ruhemann and W.A.M.Edwards, Z.Physik.Chem. **B 6**, 62 (1929)

Helium has a Unique Phase Diagram



Apparatus: Expansion of Solid into Vacuum



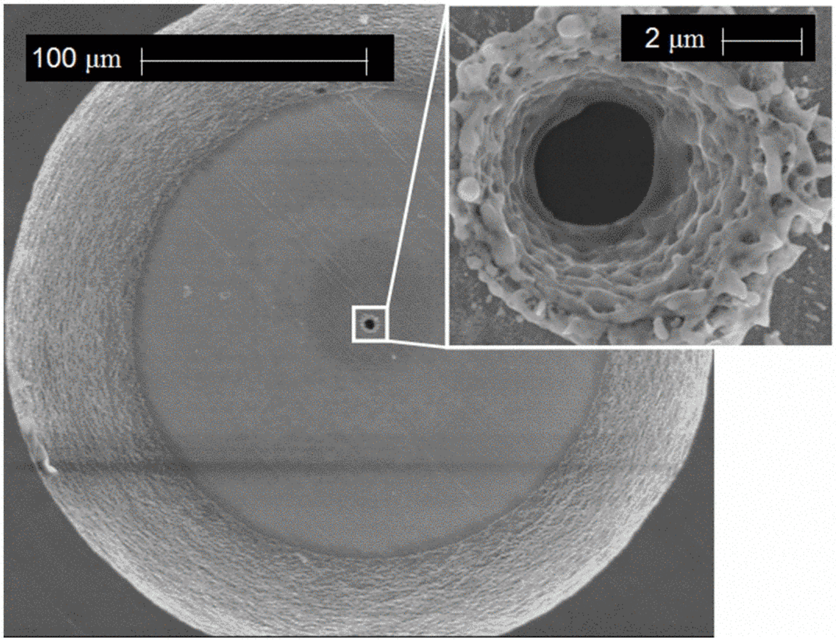
$$\text{flux} = n \cdot v_{liq} \cdot \text{area}$$

$$= P_{det} \cdot S_{pump}$$

$$\boxed{P_{det} \propto \text{flux}}$$

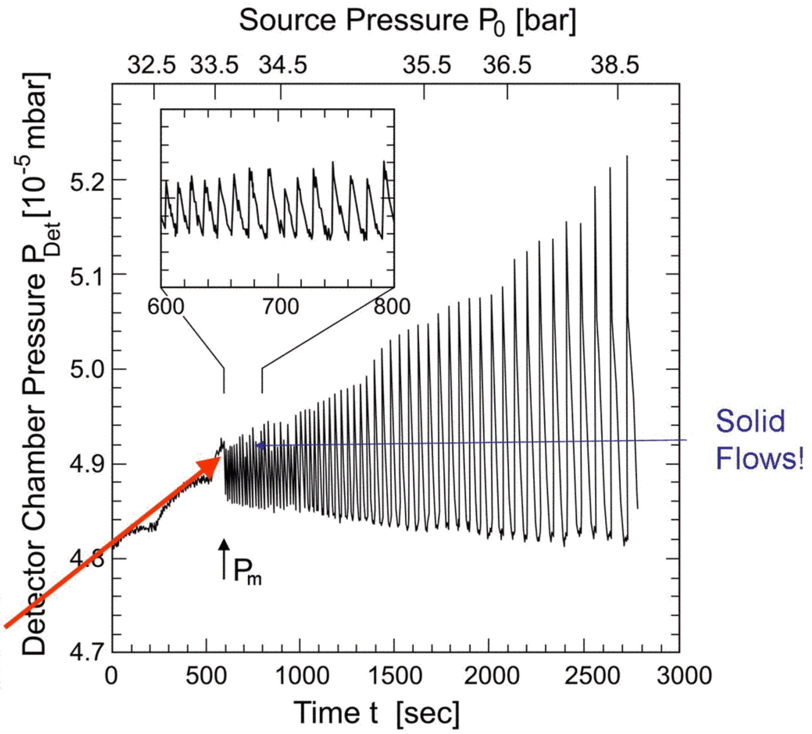
$$\tau = 12\text{msec}$$

Electron Microscope Picture of Orifice



National Aperture Co.

Geyser Oscillations appear at Solidification Pressure

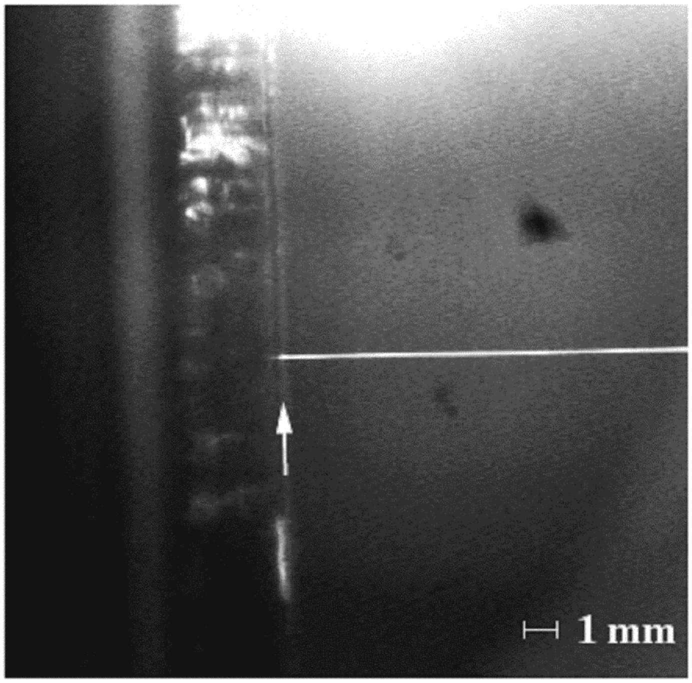


Flux of fluid
follows
Bernoulli's law

$$\boxed{\Phi = n \cdot v}$$

$$\boxed{v = \sqrt{2P_0/\rho_0}}$$

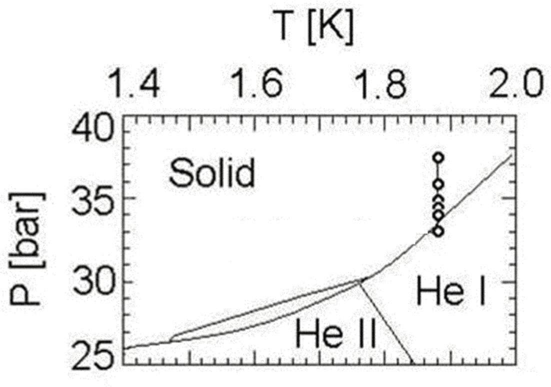
Observation of Liquid Jet

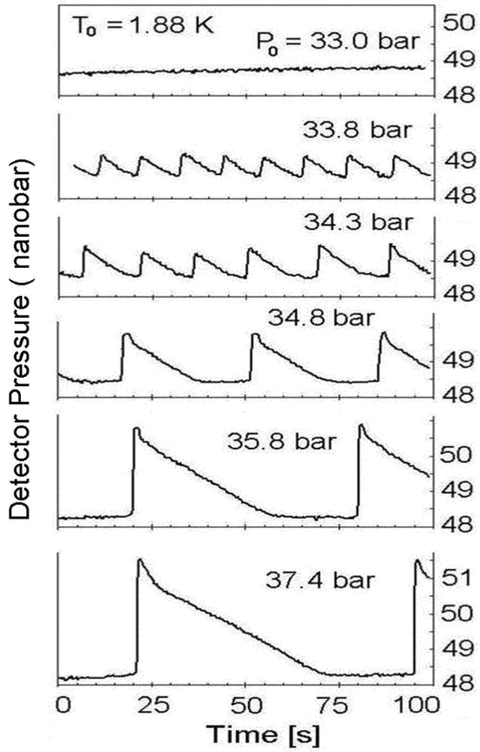


$v_{liq} = 200$ m/sec

$v_{solid} = 50\ \mu m/sec$

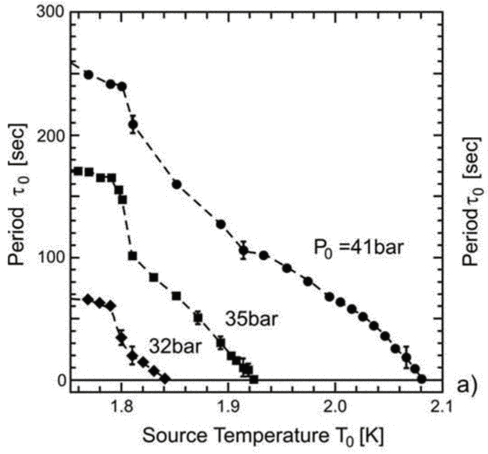
Normal Behaviour

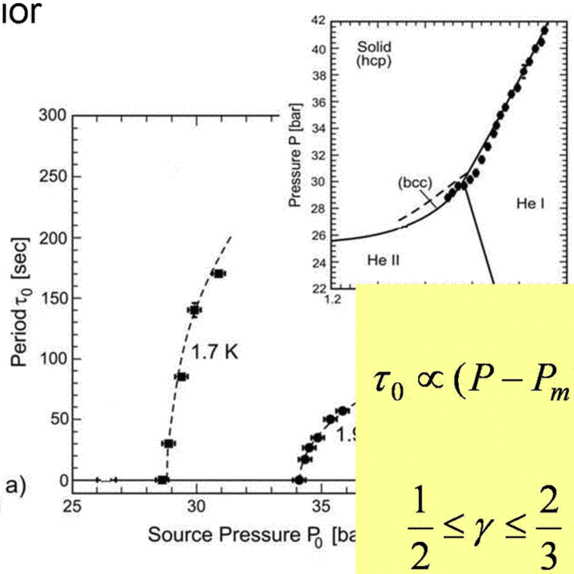




Temperature and Pressure Dependence of Period

Normal Behavior





$$\tau_0 \propto T_m - T$$

$$\tau_0 \propto (P - P_m)^\gamma$$

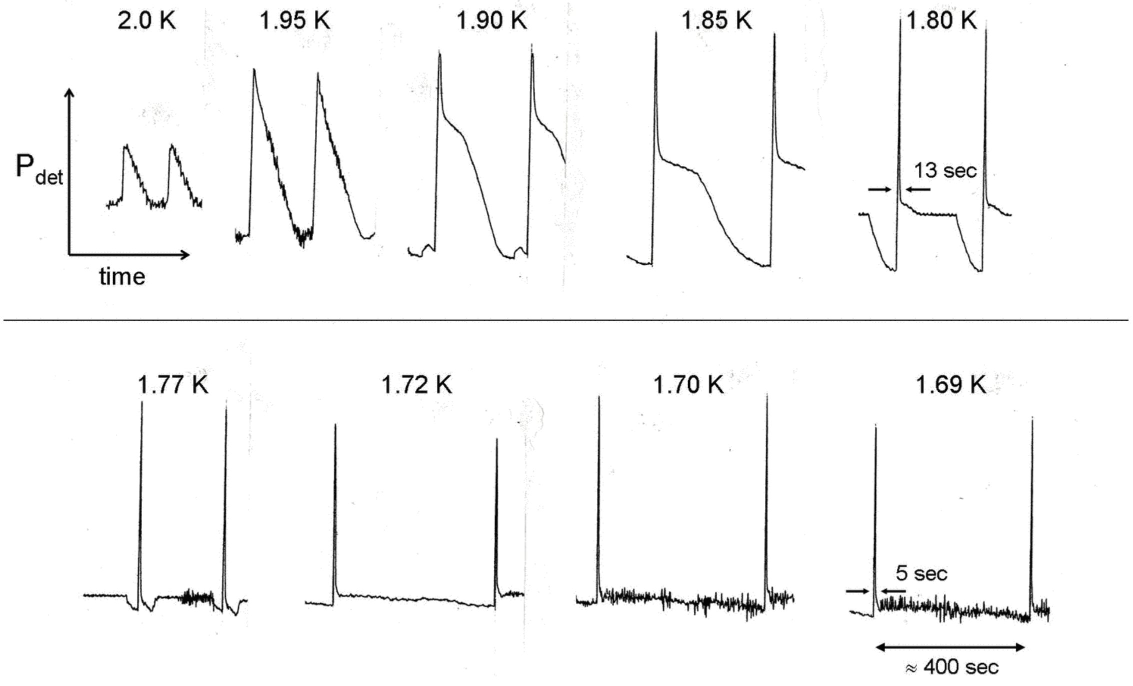
$$\frac{1}{2} \le \gamma \le \frac{2}{3}$$

Anomalous Behavior

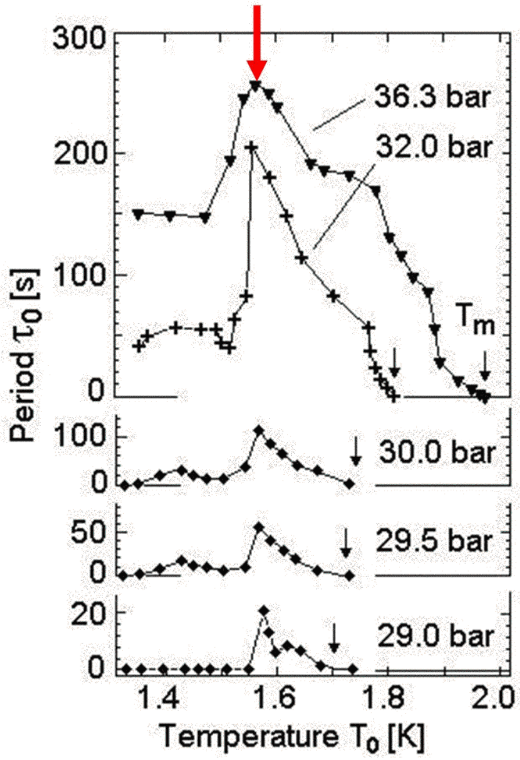
- Below about 1.76 K (upper λ - point)
  - 1) Pulses sharpen at $T \leq 1.76$ K for $P_o \leq$ 45 bar
  - 2) Delayed onset of geysers with pressure P_o
- Below about 1.60 K
  - 1) Sharp decrease in τ_o

Sharpening of the Pulses with Decreasing Temperature

P_0 = 34 bar



Drop in Period Below 1.58 K



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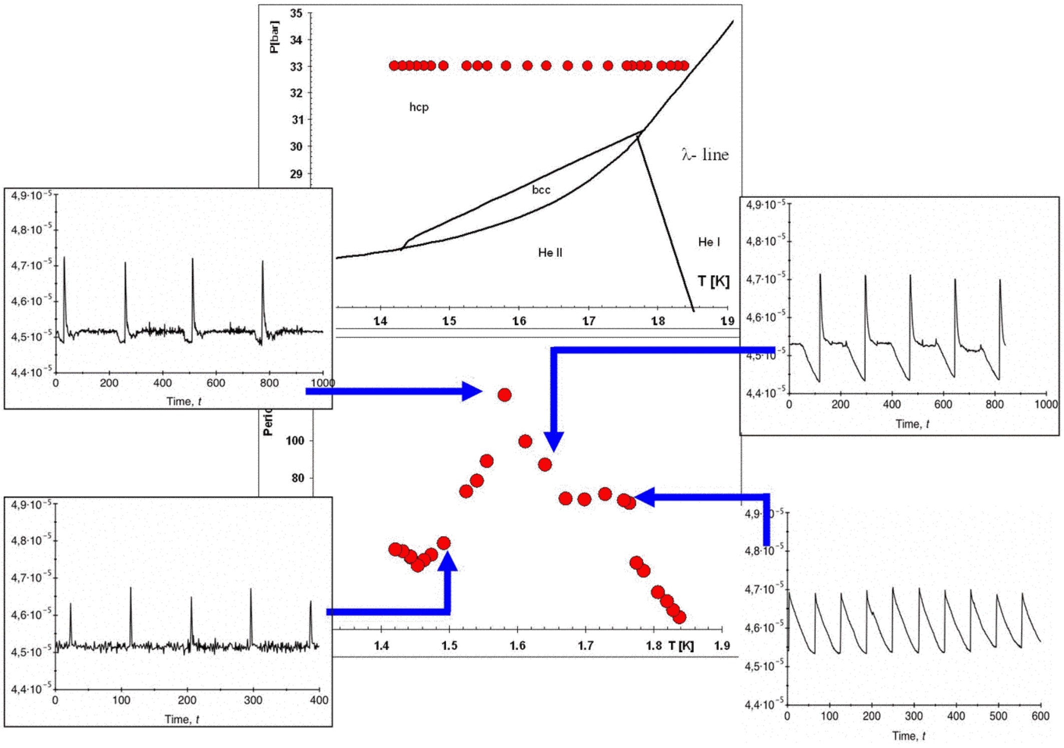
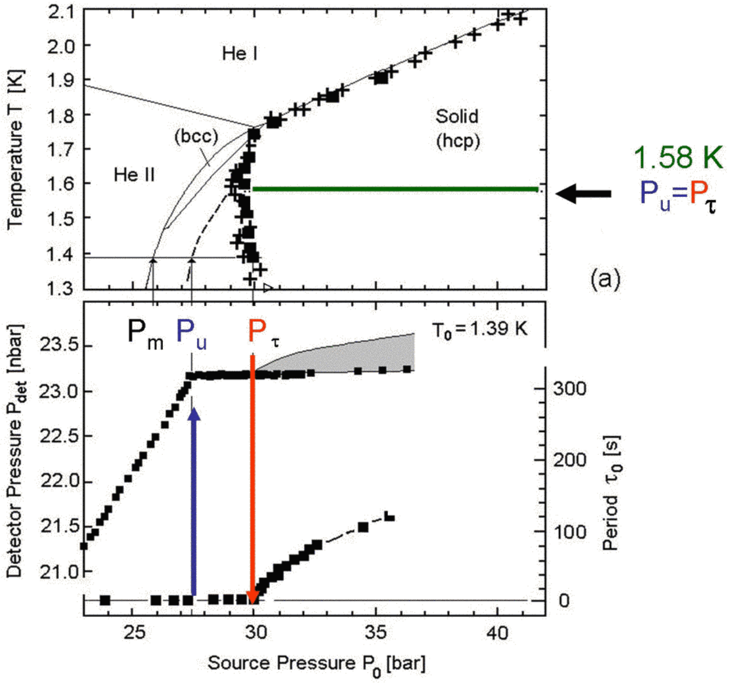
Drop in Period and Pulse Sharpening Go Together



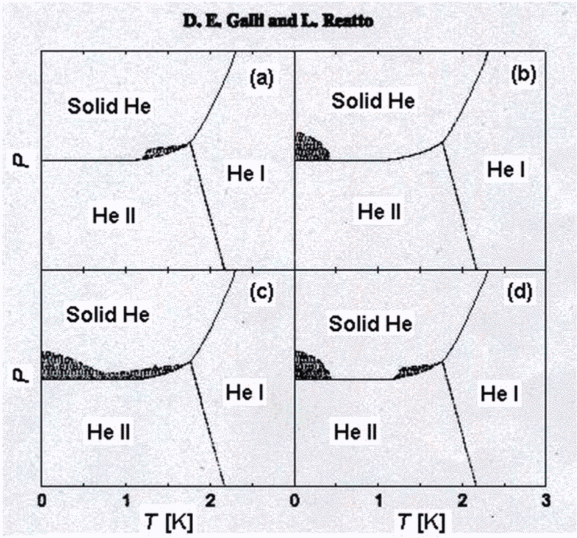
In Anomalous Region: 1) Bernoulli up to $P_u > P_m$ And 2) Gysers set in at $P_\tau > P_u$



Galli & Reatto
2001

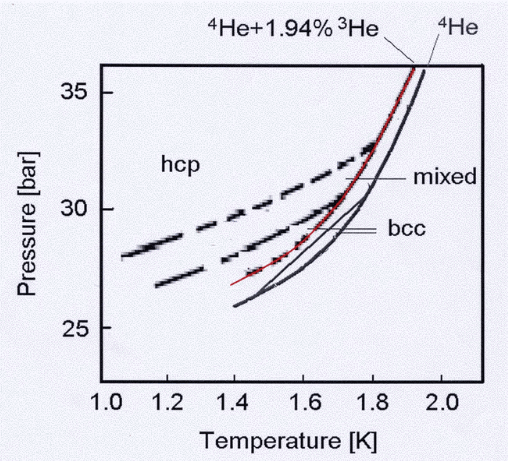
(a) *no ground state vacancies but only thermal vacancies*

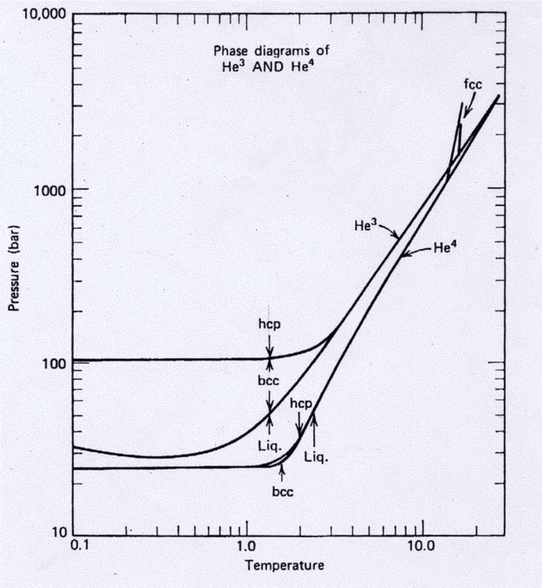
(b-d) *ground state + thermal vacancies (for different vacancy formation energies)*



what about injected (non-equilibrium) vacancies?

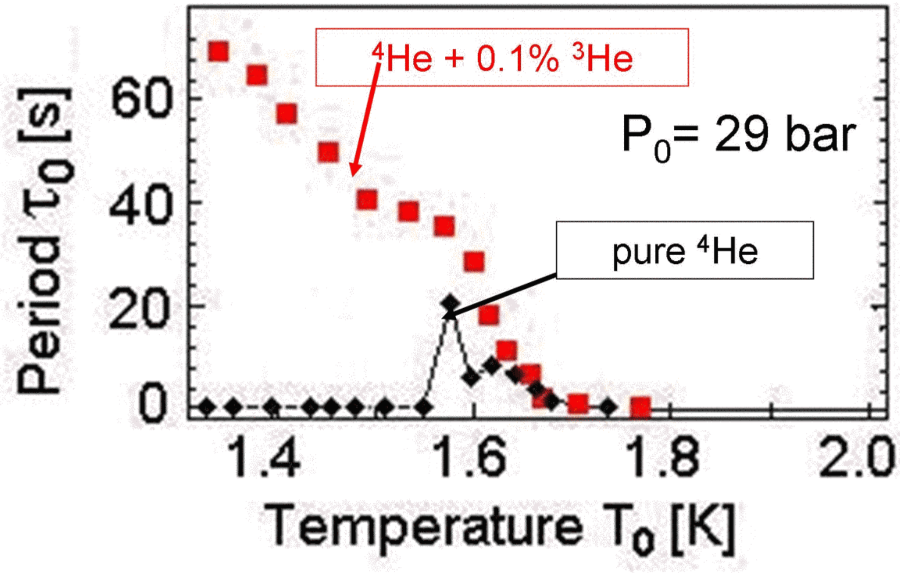
Effect of ^{3}He on Melting Line





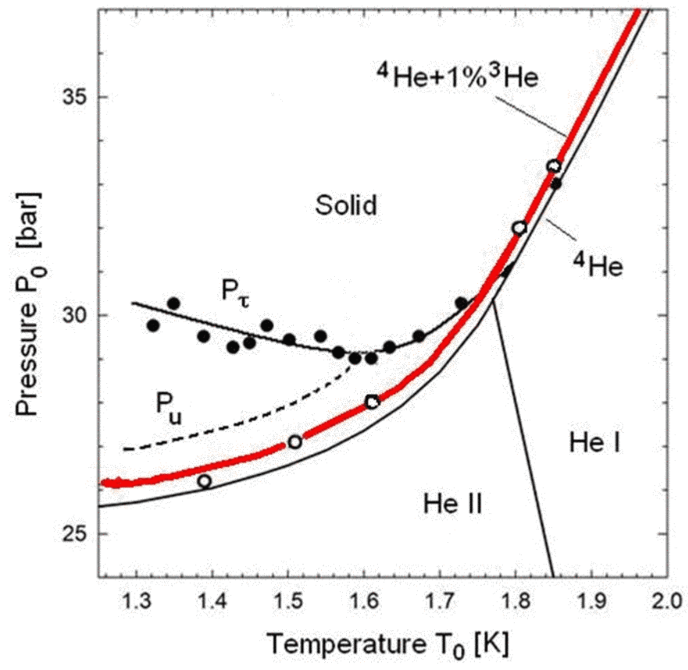
from R. Richardson et al

^{3}He Removes Anomalous Drop-Off



Same effect seen for 15ppm

^{3}He Removes Anomalous Behavior



New Cell with Internal Pressure Sensor

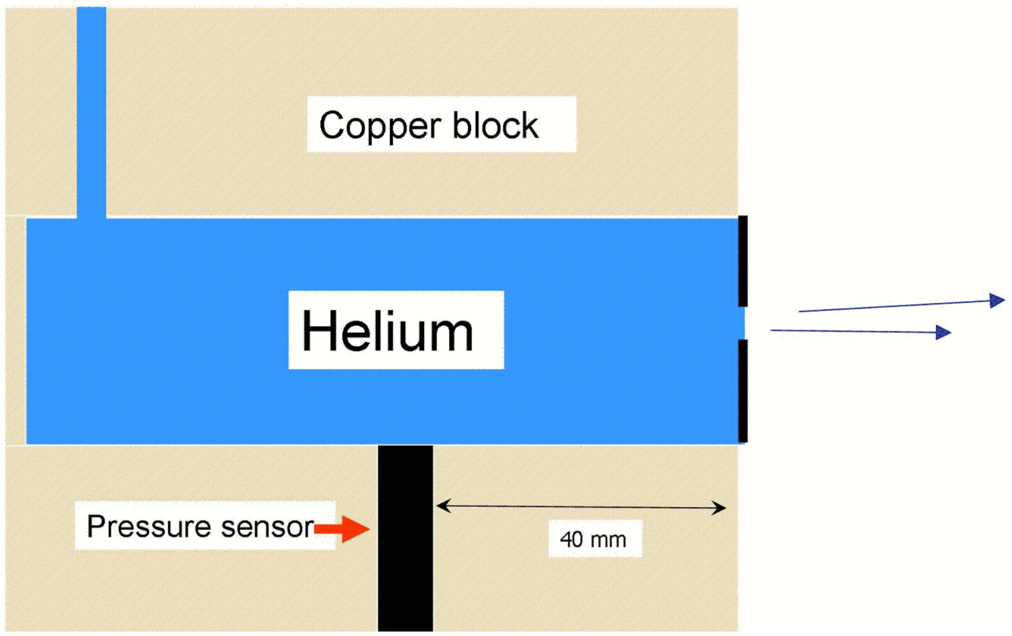
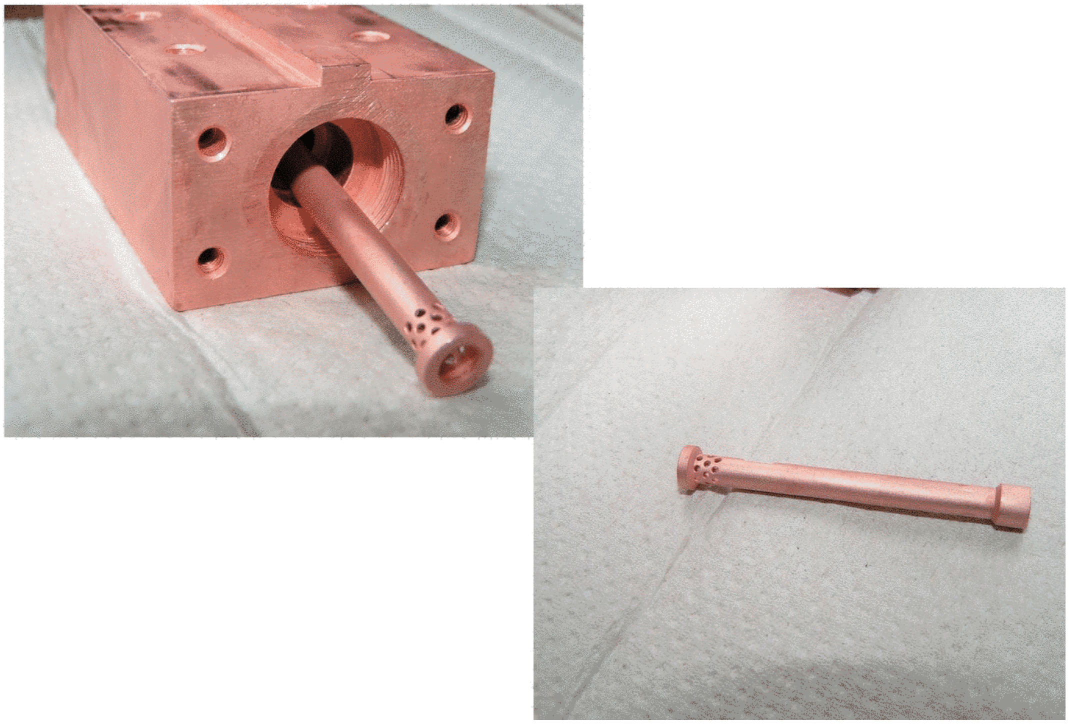


Photo of Cell with Inner Tube

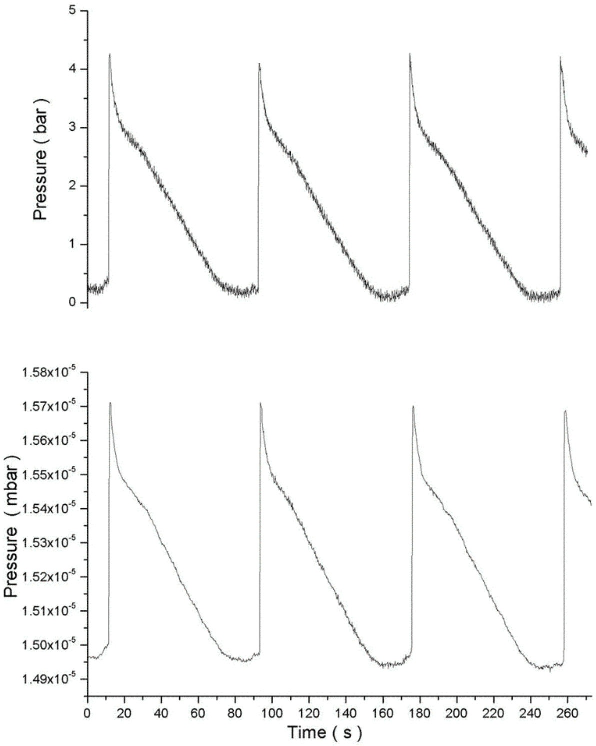


Pulse Shapes inside and in Detector are Identical

P_0=35 bar
T_0=1.88 K

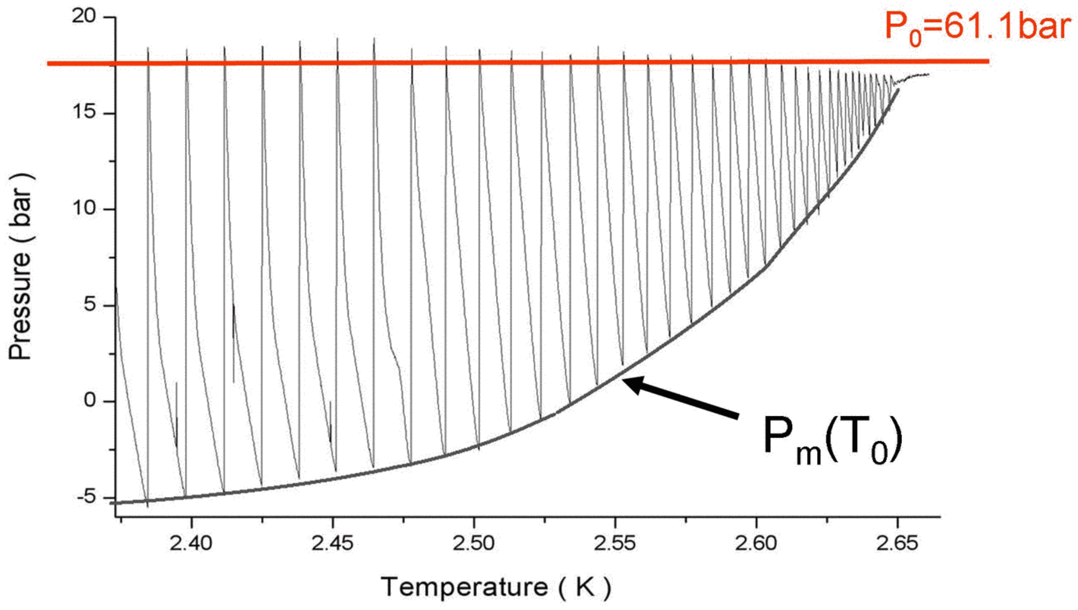
Pulse in Cell

Pulse at External Flux detector

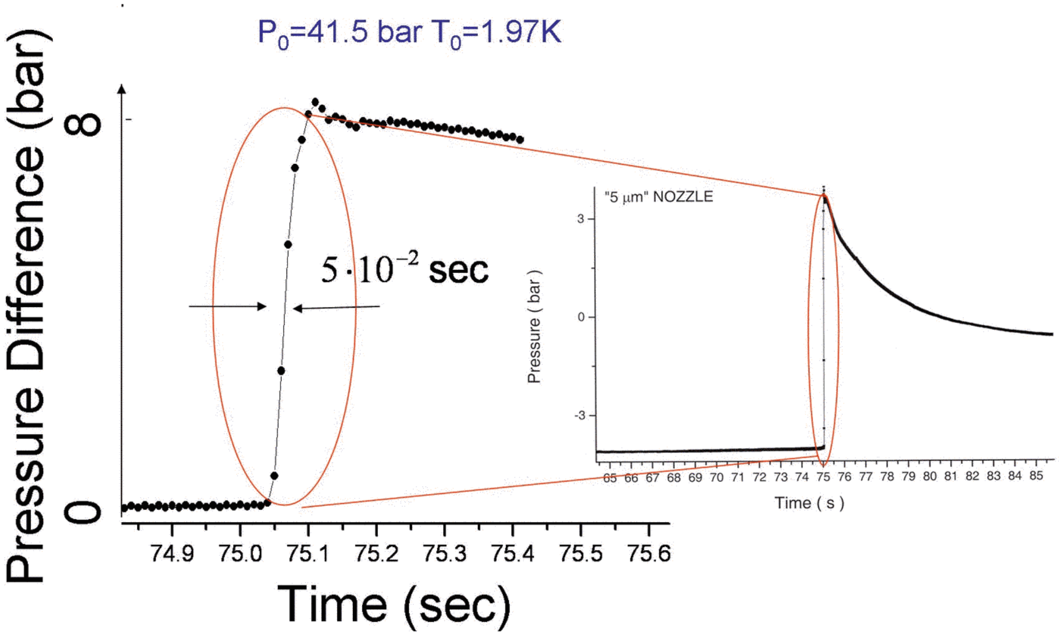


Sensor Pressure Pulses = P_0 - P_m

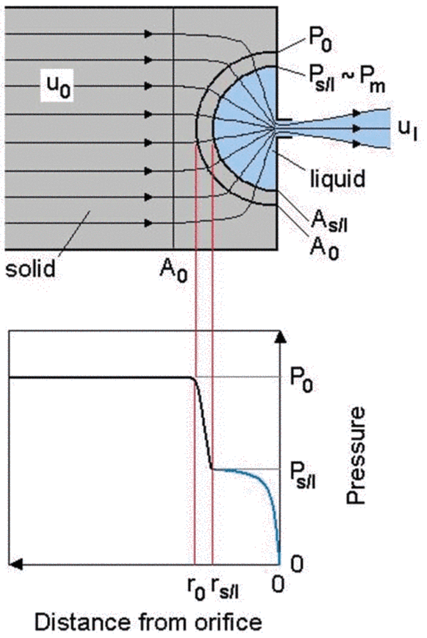
Note: Sensor sees only pressure differences



Sensor Pressure Rises at 200 bar/sec

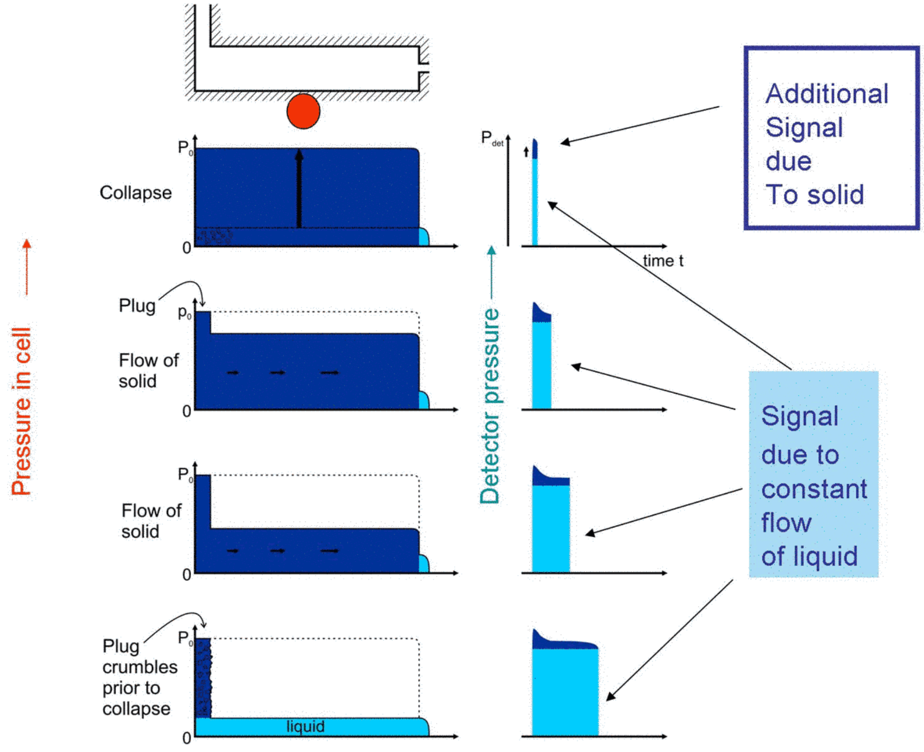


Large Pressure Jumps throughout the Entire Cell are at Variance with Earlier Model:



Benedek et al Phys. Rev. Lett 95,095301 (2005)

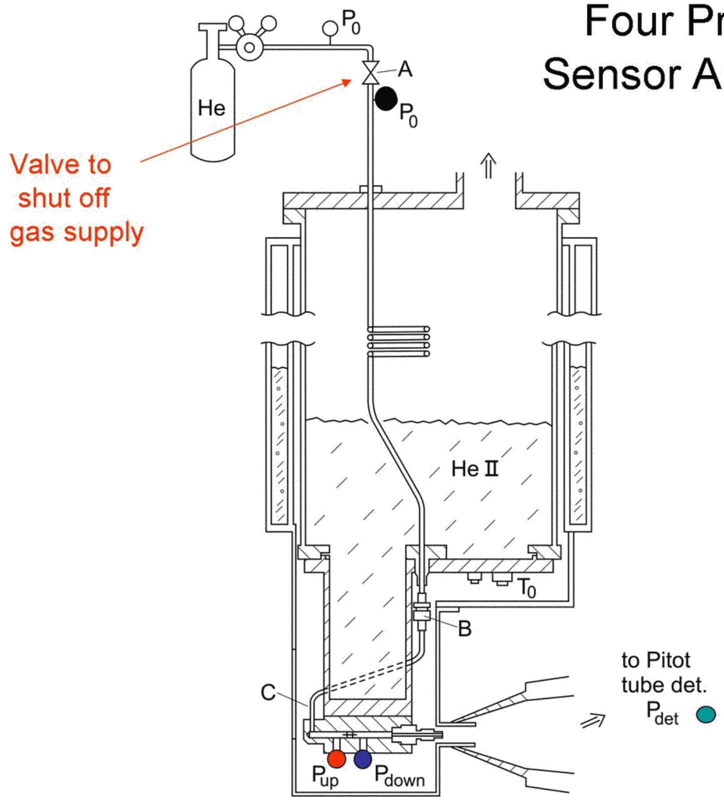
New Model for the Geyser Effect



Additional Signal due To solid

Signal due to constant flow of liquid

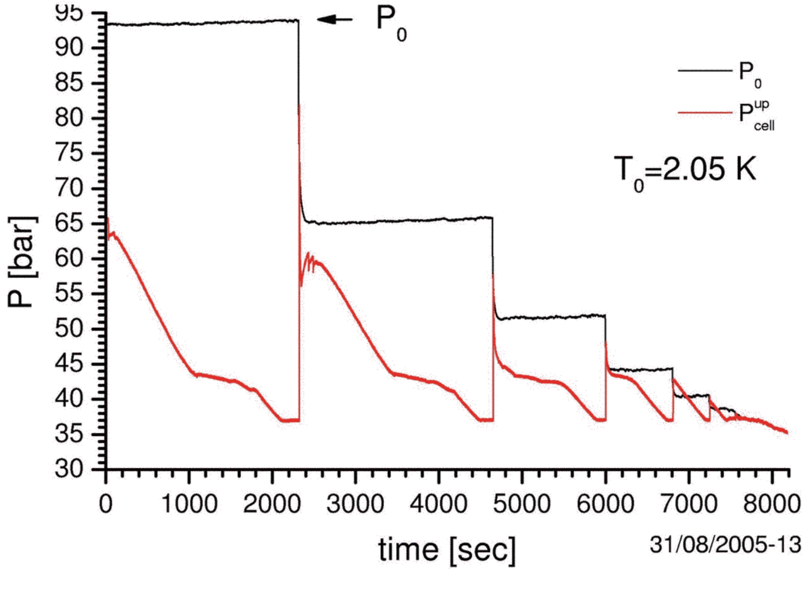
Four Pressure Sensor Apparatus



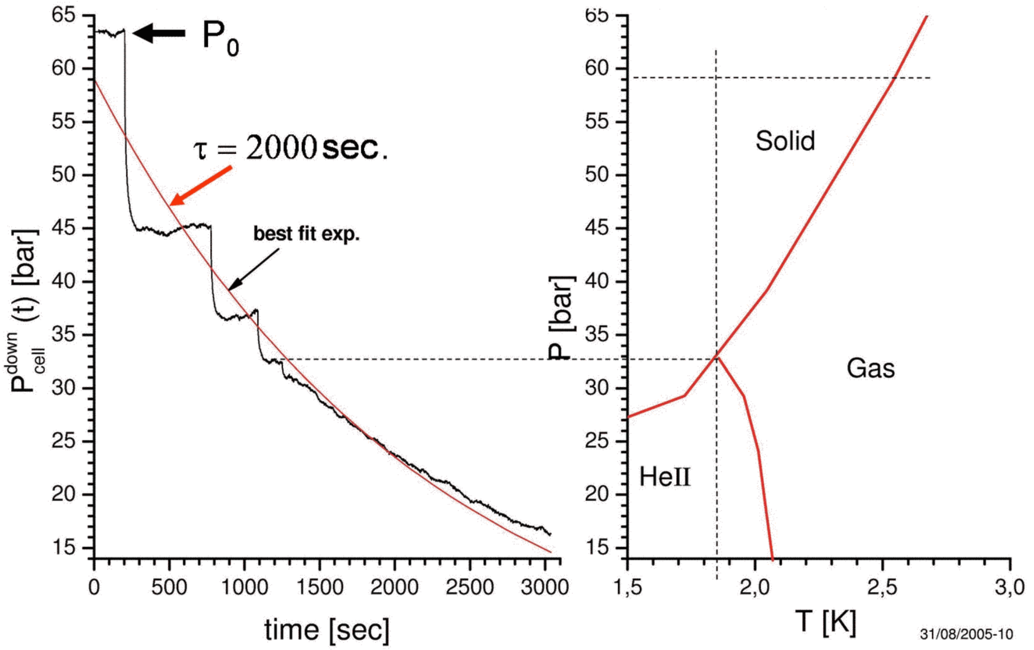
Valve to shut off gas supply

Geysers Measured with Valve Shut Off and Without Capillary

At Every Geyser Pulse in the Cell the Upstream Gas Pressure Drops Sharply

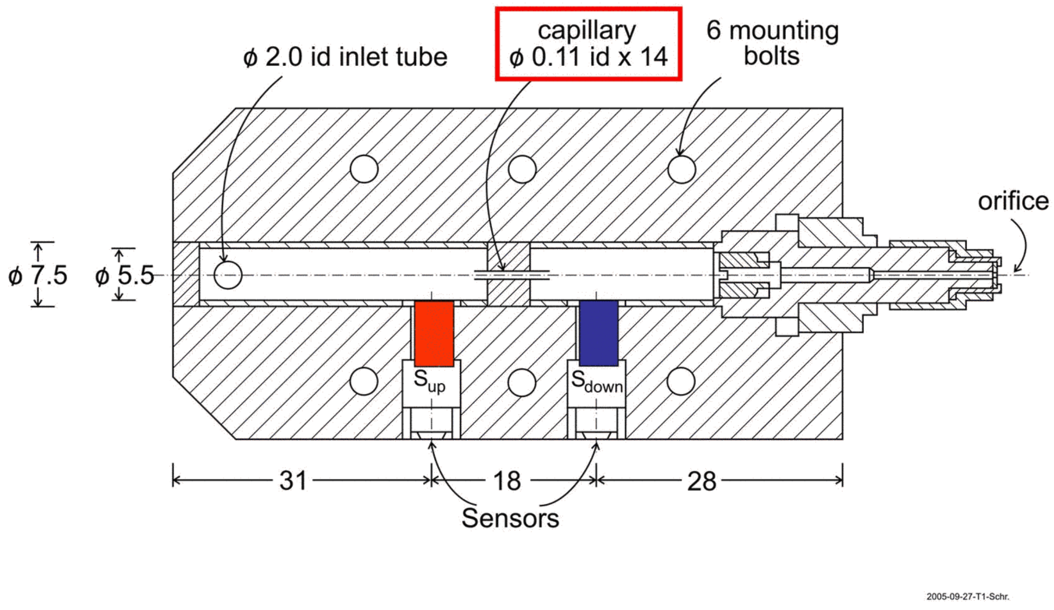


Upstream Gas Pressure „Drop-offs“ Cease at Melting Pt.



31/08/2005-10

Top View of New Two Pressure Sensor Cell



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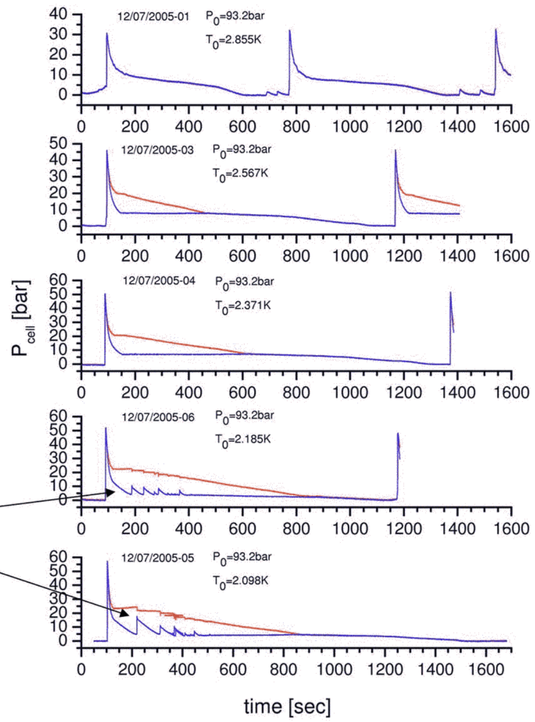
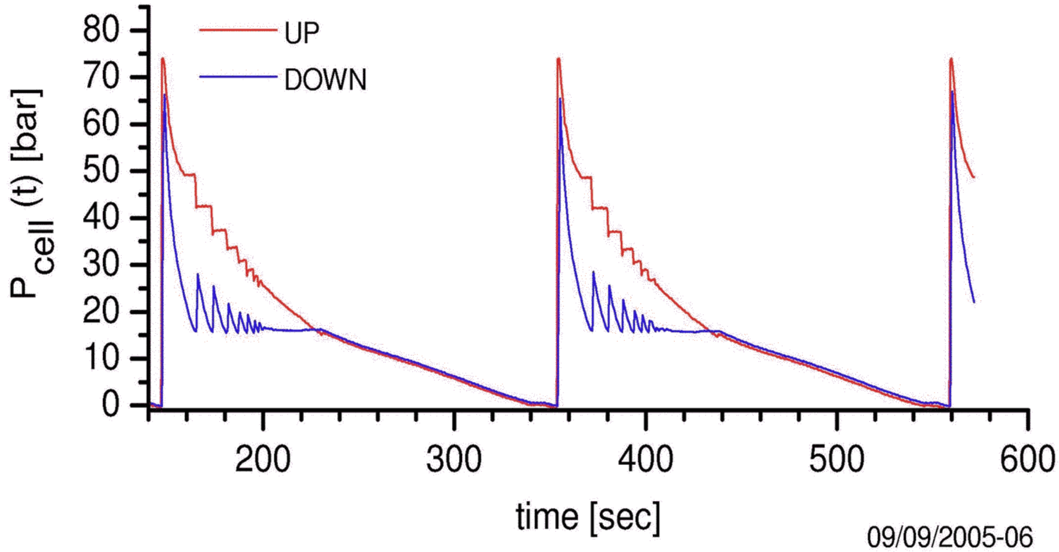
Onset of Minigeysers on Lowering the Temperature



P_0=93.2 bar

Call these „minigeysers“

The Minigeysers Fall Off Much Faster than the Drain Time



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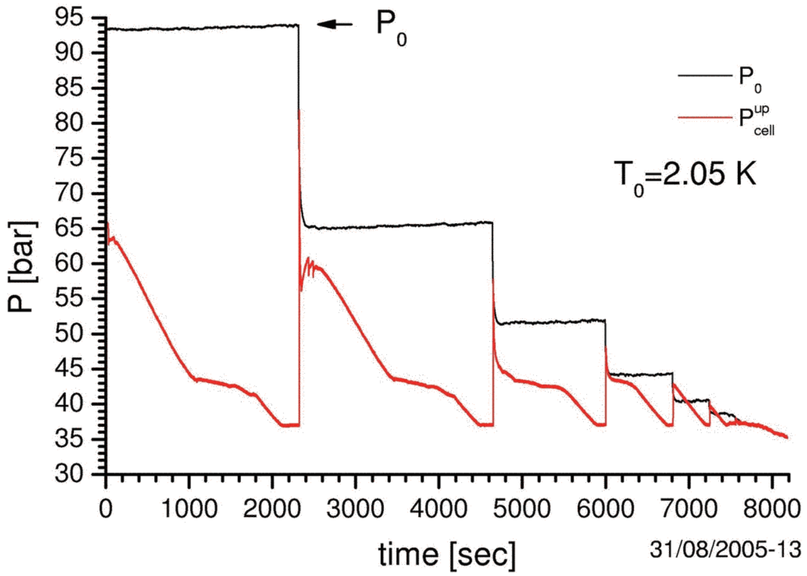
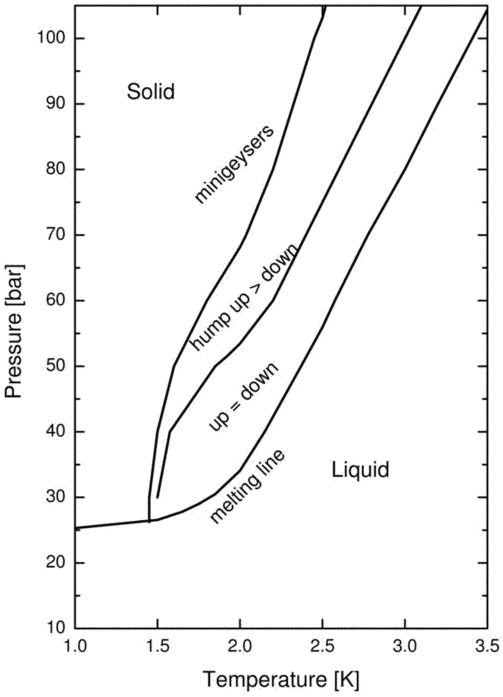
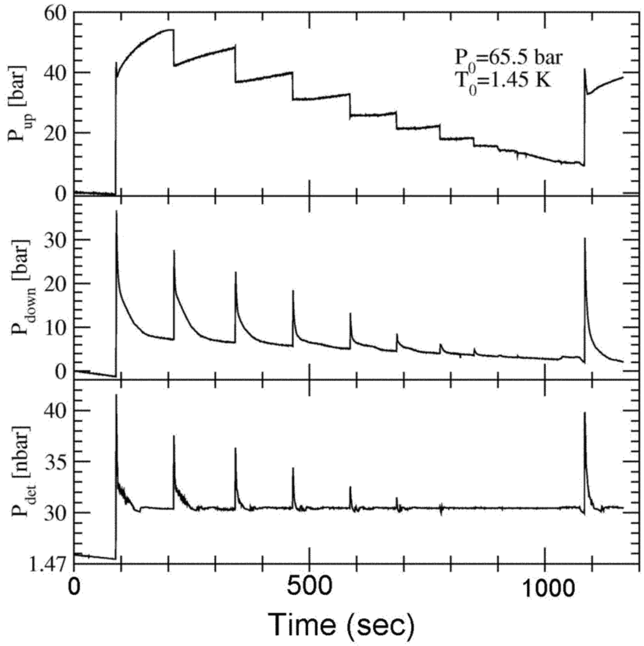
Note the Remarkable Similarity to the Main Geysers:



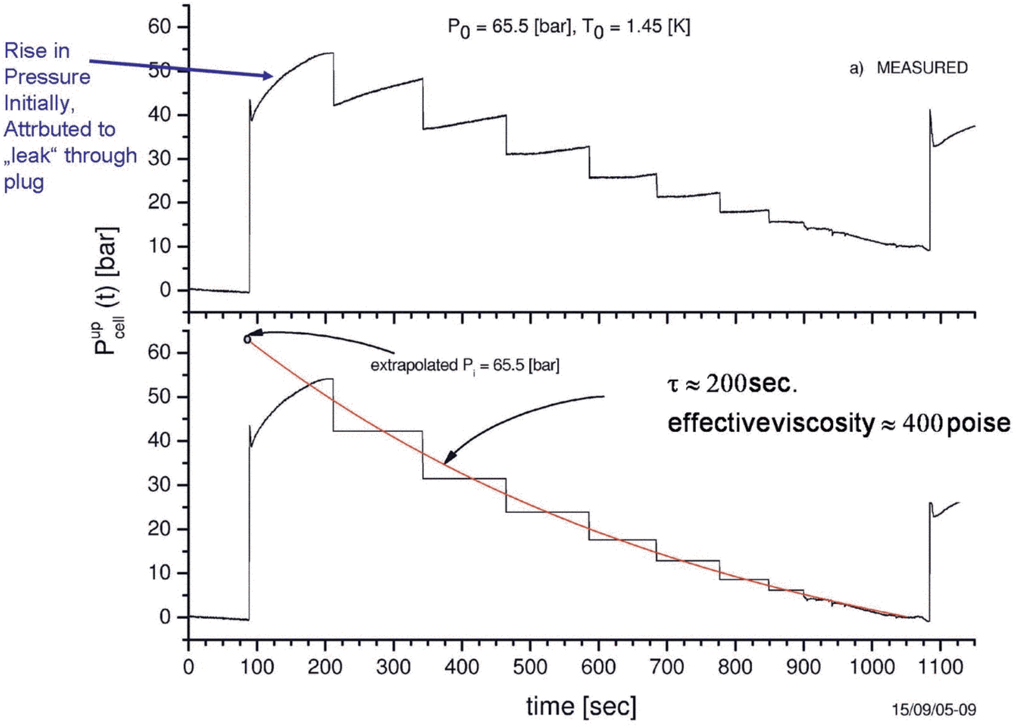
„Phase Diagram“ for Minigeysers



Sharp Minigeysers at Low Temperature in the Anomalous Region



If We Correct for „Leak“ from Upstream get Exp. Fall-Off

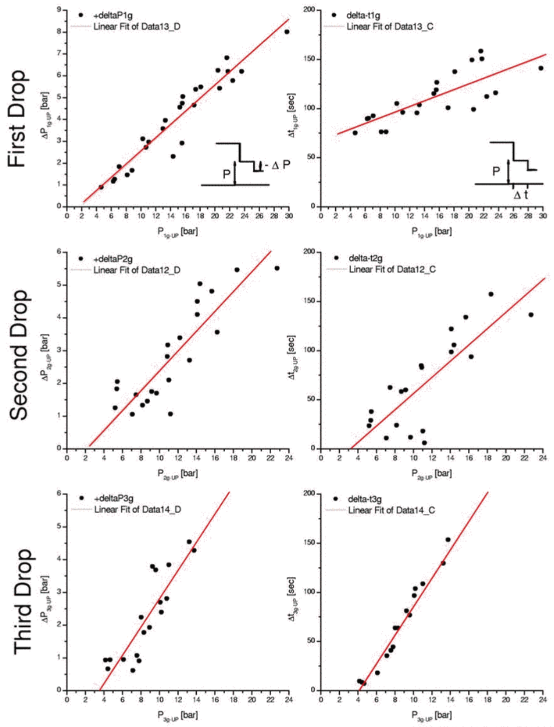


Rise in Pressure Initially, Attrbuted to „leak“ through plug

$\tau \approx 200$sec.

effectiveviscosity ≈ 400poise

Down Steps ΔP and Time between Jumps Δt Scale with Prior Pressure



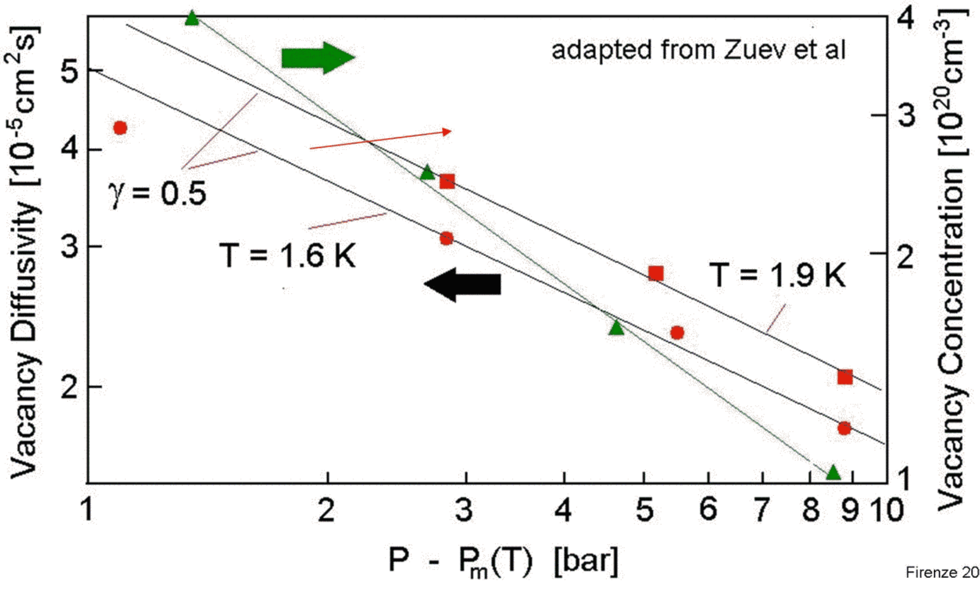
28.07 and 04.08.2005

26 Expts.

Geysers can not be due to Stick-slip Mechanism

Stick-slip: Period would decrease with pressure

Geysers: Period increases with pressure! Consistent with decreasing vacancy diffusivity



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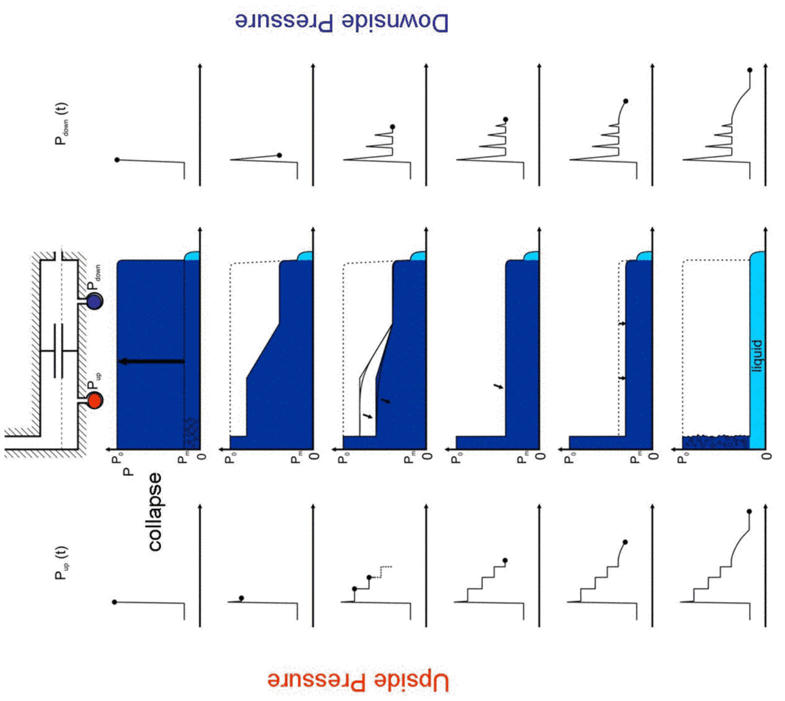
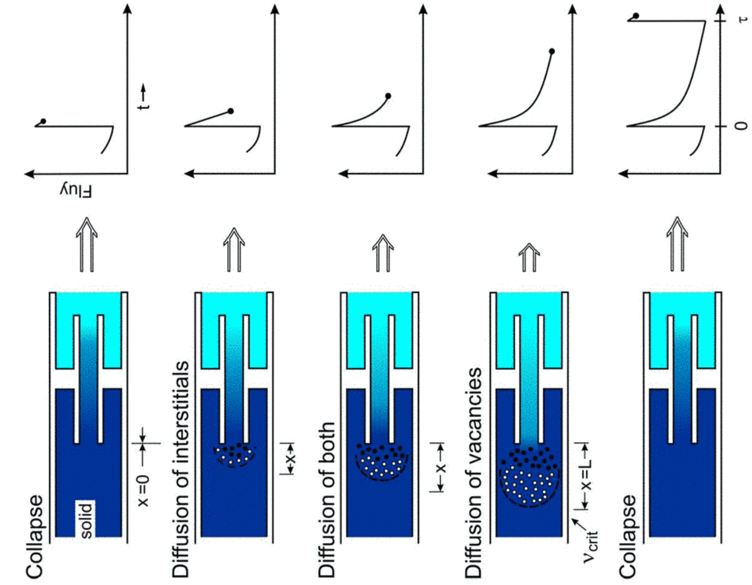
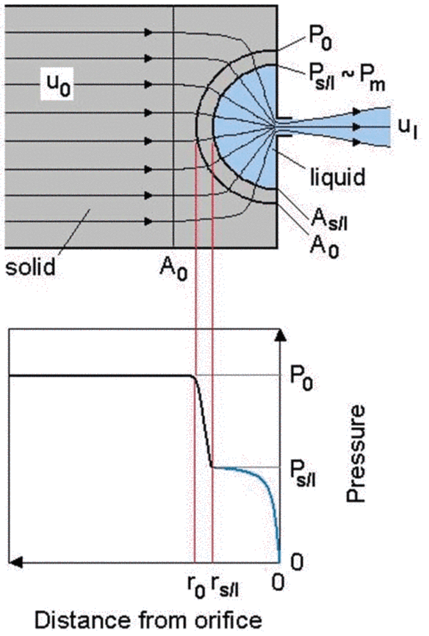
Model for Minigeysers



Schematic Diagram of the Minigeyser Effect

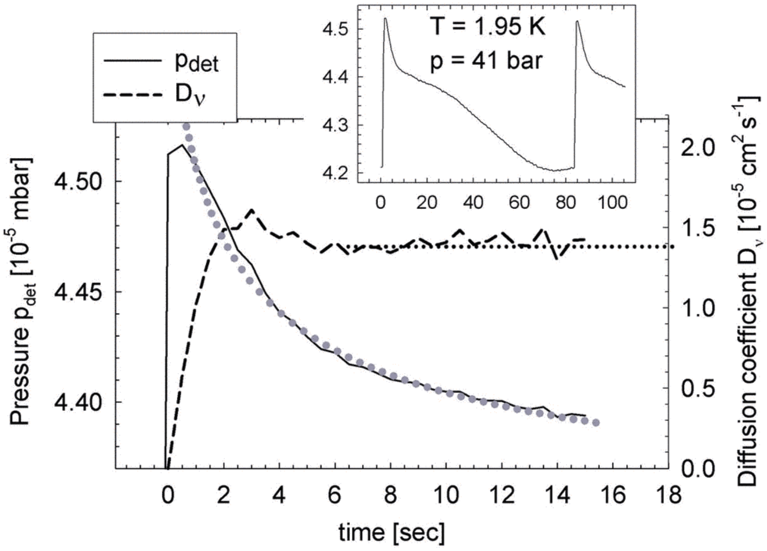


This Model Might Apply to Initial Main Geyser



At Short Times (sec.) Initial Drop-off Depends on Vacancy Diffusion. Constant

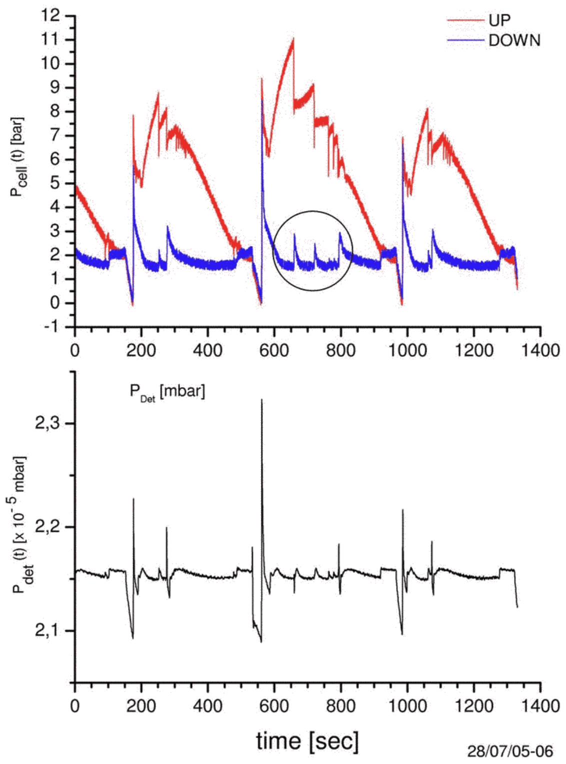
$$\Phi \propto v(t) = \sqrt{\frac{4D_v}{\pi t}}\left(\frac{A_{tube}}{A_0}\right)^2, \quad t << \tau_v, \tau_{rec}$$



Summary

- The geyser effect is very robust. Now seen in two different constrictions. Very regular periods, very reproducible.
- We find that the regularity of the behavior is indeed remarkable! Must be related to vacancy diffusion
- Region of anomalous behavior corresponds to vacancy induced superfluidity predicted by Galli and Reatto

In Anomalous Region Minigeysers are also Very Sharp



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P_0=32 bar

T_0=1.38 K (corrected)

Major Riddle

The sharp fall-offs in the anomalous region are orders of magnitude faster than the pumpdown times in both main and minigeysers chambers.

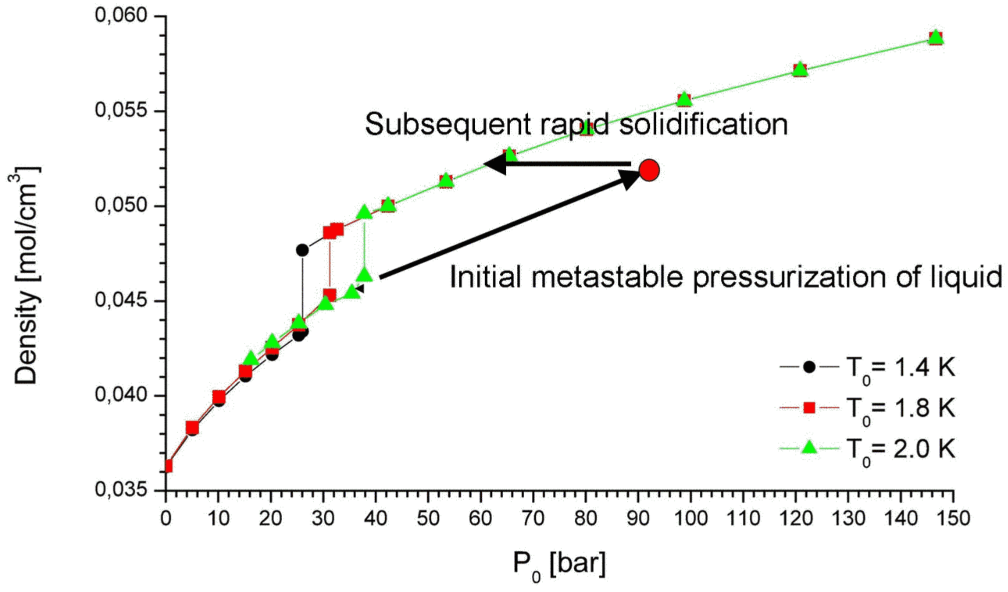
Either

1) the high vacancy concentration resulting from the violent pressurizing (200 bar/sec.) endows material with vanishing viscosity (SUPERGLASS?) .

or

2) In the initial rapid compression the material remains initially liquid and the sharp fall-off is due to the pressure drop accompanying solidification.

Speculative Explanation for Sharp Drop-Off



Thank You

Please ask questions