TE-CRG-CI

Demonstration of

superfluid helium properties

European Course of Cryogenics - CERN

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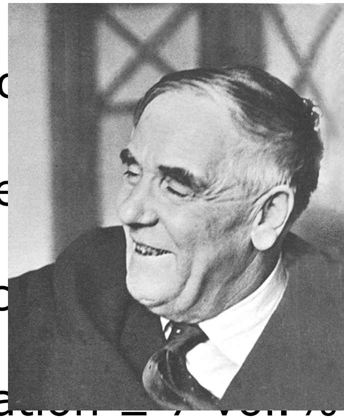
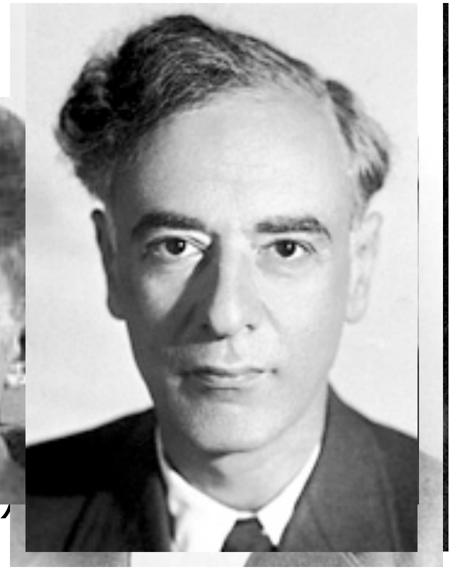
02.09.2010

- Introduction to ^{4}He as a cryogenic liquid,
- Experimental set-up in the Cryolab at CERN – glass cryostat,
- Phase transition of He I to superfluid He II – some properties,
- Two-Fluid model,
- Demonstration:

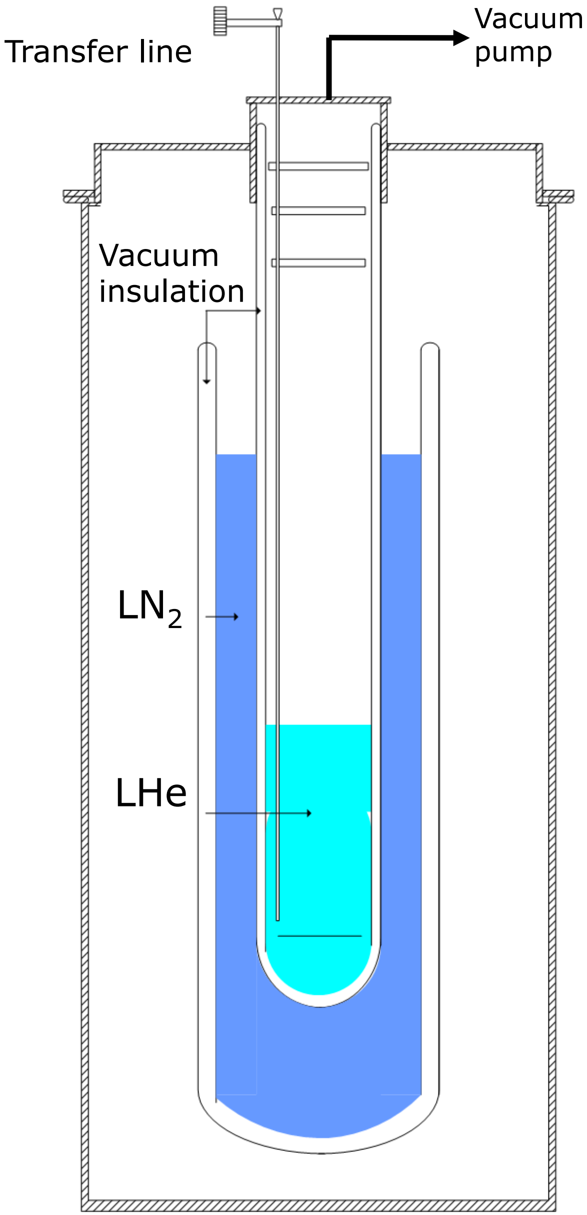
  - Fountain effect,
  - Superfluid film flow,
  - Second sound - critical heat flux.

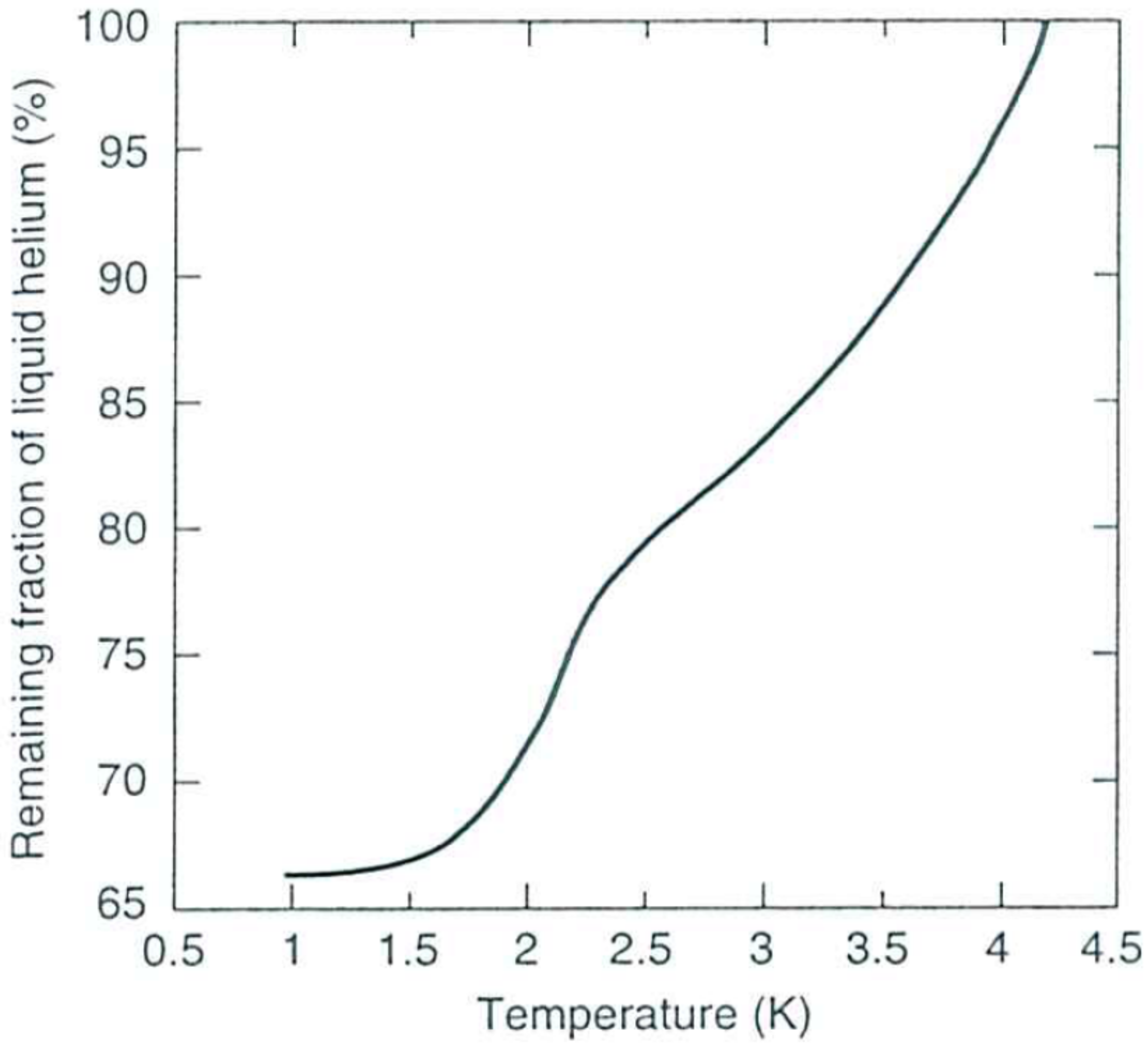
History of ^{4}He:





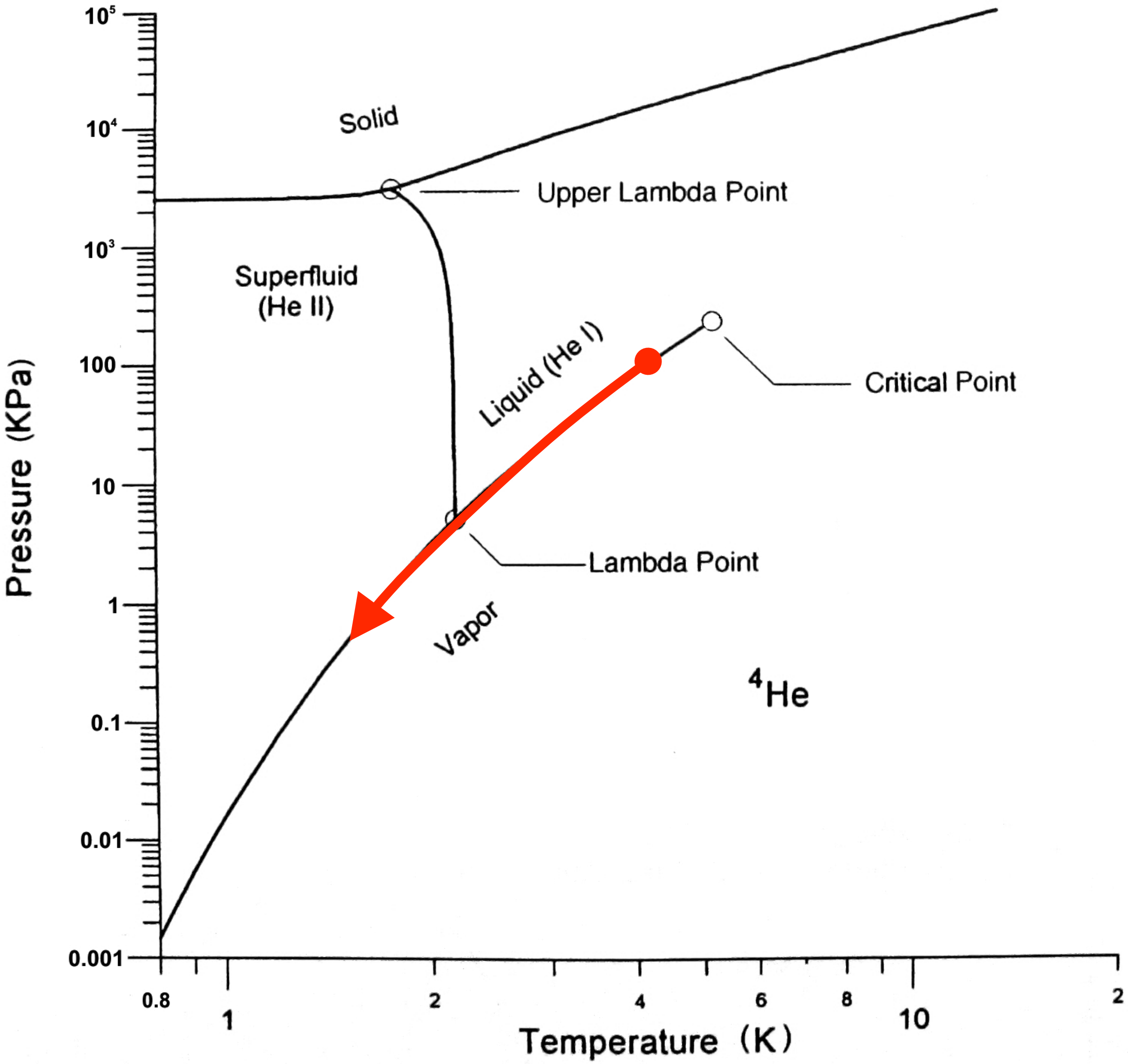
- 1868 first discovered in the solar spec … en
- 1892 vacuum insulated vessel invente
- 1895 helium was found in mineral roc … /.
- 1903 helium in natural gas, concentra … (…)
- 1908 first liquefaction of helium at 4.2 K =>60 g of 4He (H. Kamerlingh-Onnes)
  LHC has an inventory of 120 t !!!
- 1932 first industrial helium liquefier supplied to Uni Charkov, Ukraine (C. Linde)
- 1937 discovery of superfluidity in ^{4}He (P. Kapitza, J. Allen and D. Misener)
- 1938 introduction of a Two-Fluid model (L. Tisza)
- 1941 mathematical theory of superfluidity and Two-Fluid model (L. Landau)





From Ekin, Experimental Techniques for Low Temperature Measurments, 2006.

Phase diagram ^4He



Heat of evaporation

^4He: 20.9 J/g

N_2: 189 J/g

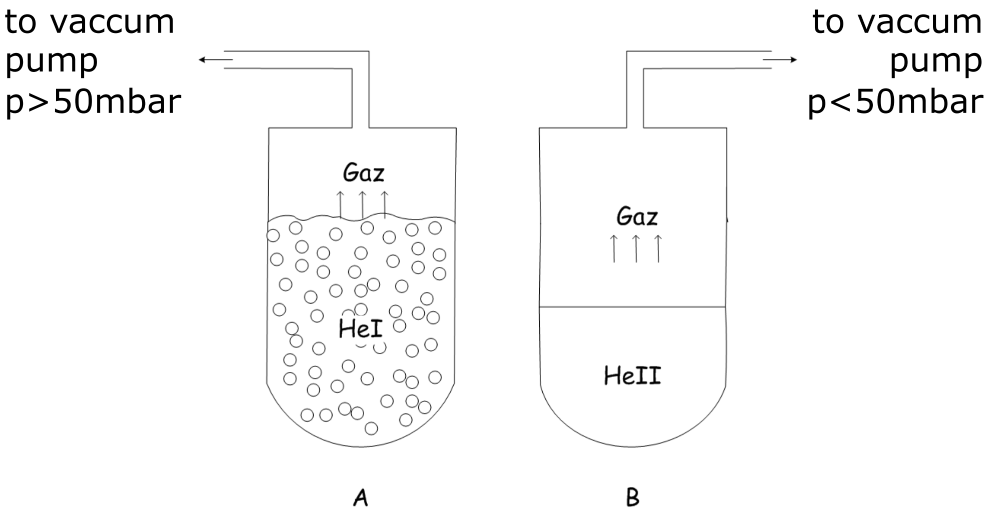
$T_\lambda \approx 2.18$ K @

p ≈ 49.7 mbar

From Weisend, Handbook of Cryogenic Engineering, 1984.

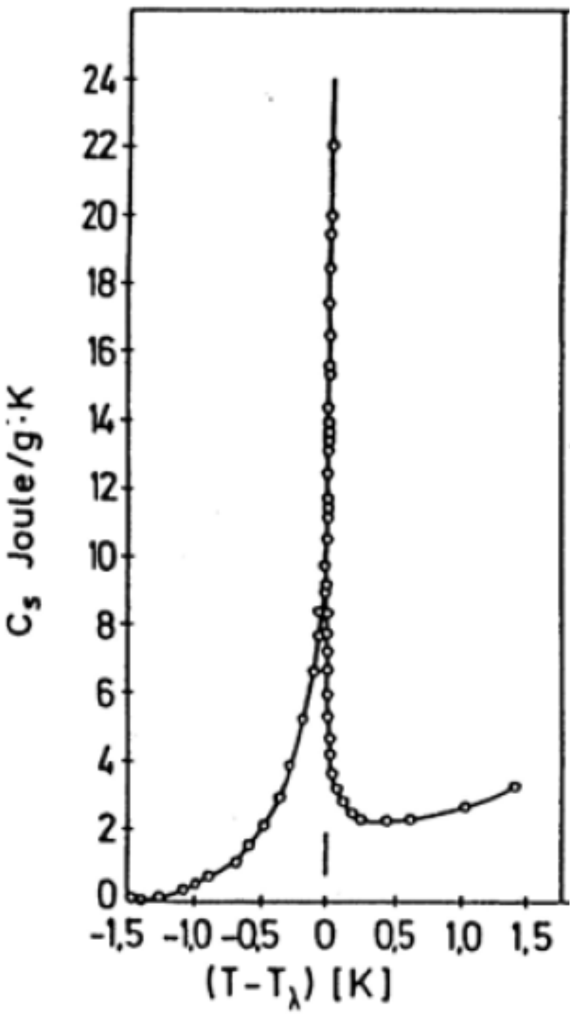
- $T > T_\lambda$: - liquid He is boiling
  - latent heat of evaporation is removed from bath
  - temperature is decreasing

- $T \approx T_\lambda$: - temperature is decreasing only slowly → large specific heat
  - temperature does not stay constant → no latent heat, 2. order transition
  - ***boiling suddenly stops !!!***



Superfluid helium

- λ point => heat capacity peak
- vanished viscosity
- very high thermal conductivity
- uniform temperature in the liquid
- no vapor bubbles in the liquid



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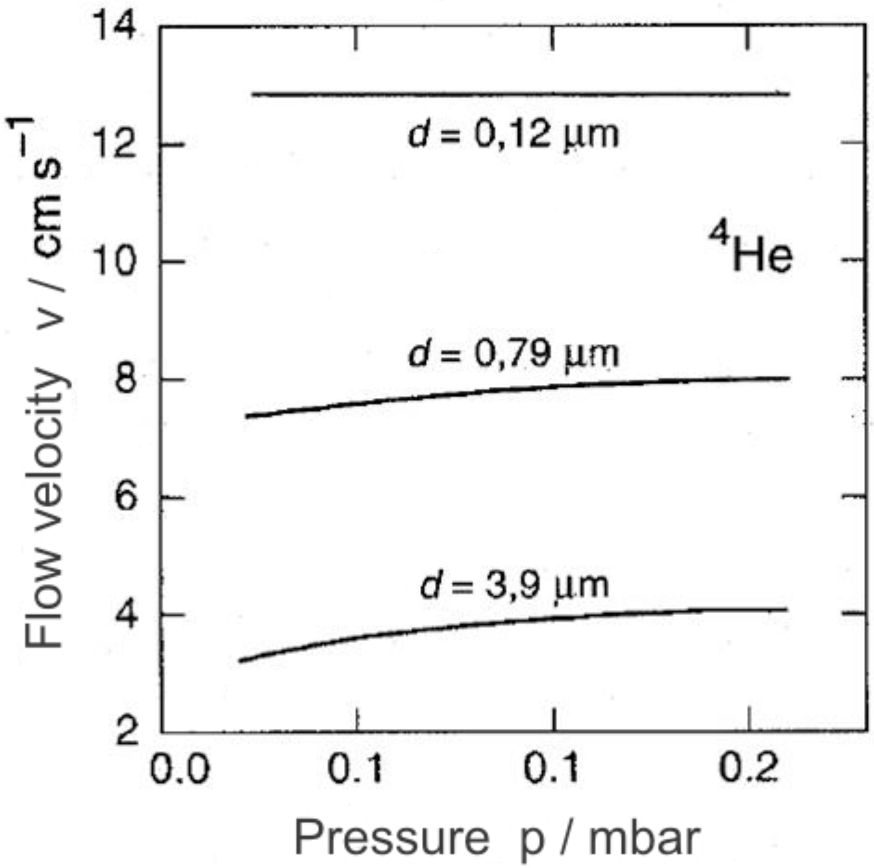

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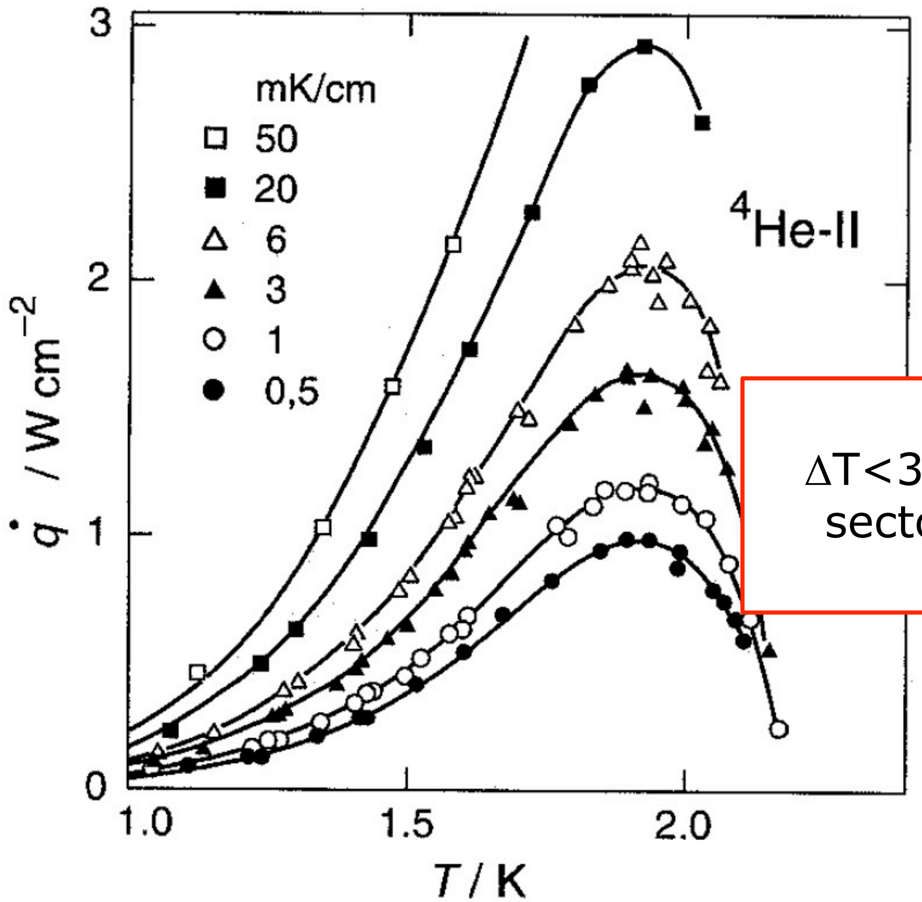
The observed viscosity of He II is depending on the method of measurement !

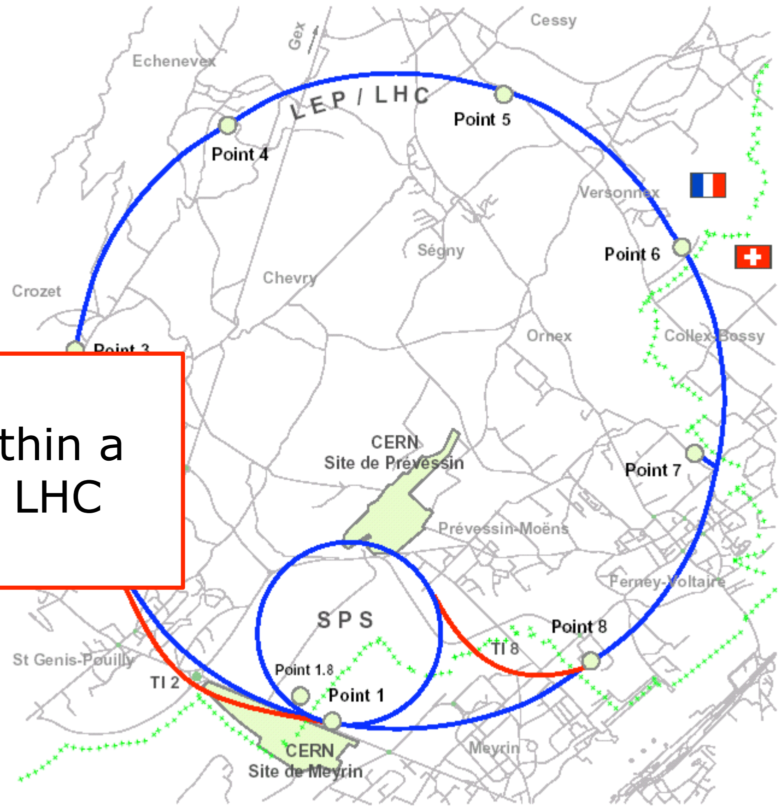
Thermal conductivity of He II



Heat flux in Helium II as a function of temperature, measured at differend temperature gradients. Capillary diameter 0.3 and 1.5 mm.

[W. H. Keesom, B. F. Saris, L. Meyer, Physica 7, 817 (1940)]

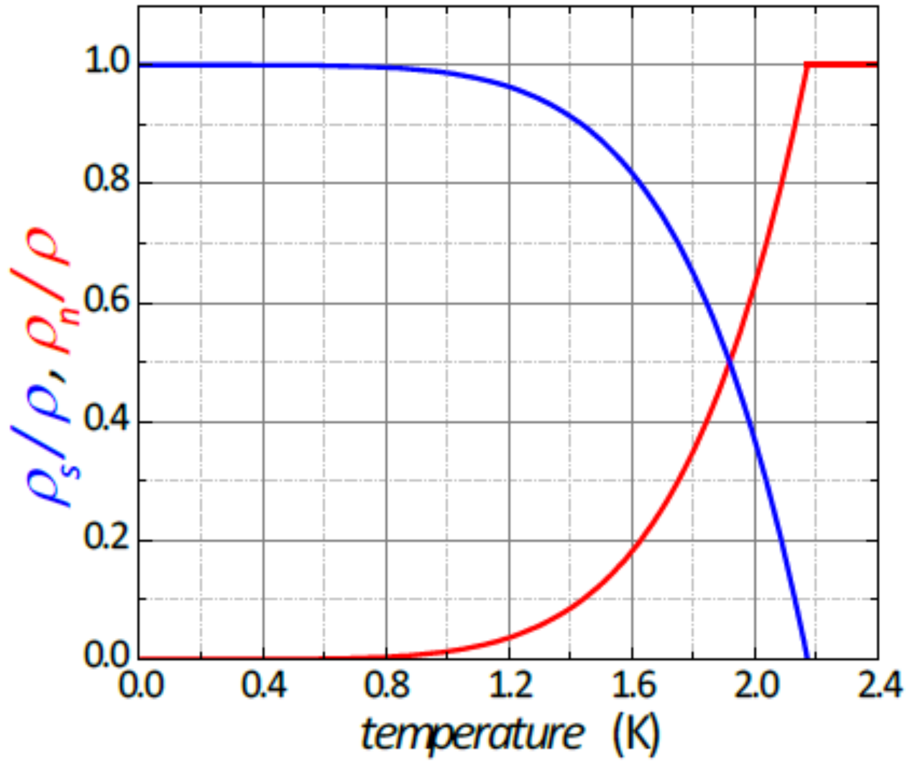
ΔT<30 mK within a sector of the LHC



8 helium cryogenic plants:

1 plant serves 1 sector

=> 18 kW @ 4.5 K, 2.4 kW @ 1.8 K and 600 kW LN_2 precooler

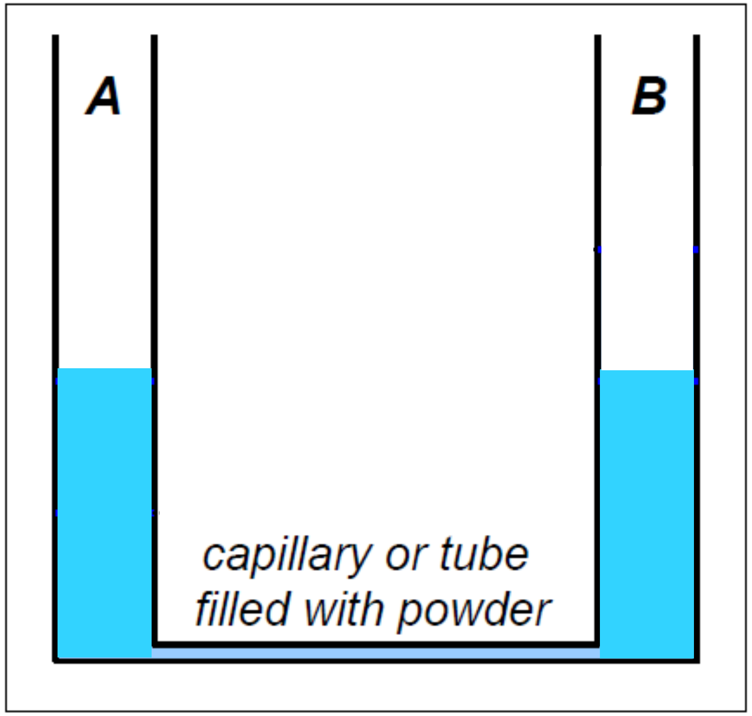


- Anomalous properties of He II can be well described by two-fluid model (I.Tisza, 1938),

- Formal description of He II as the sum of a normal and a superfluid component.

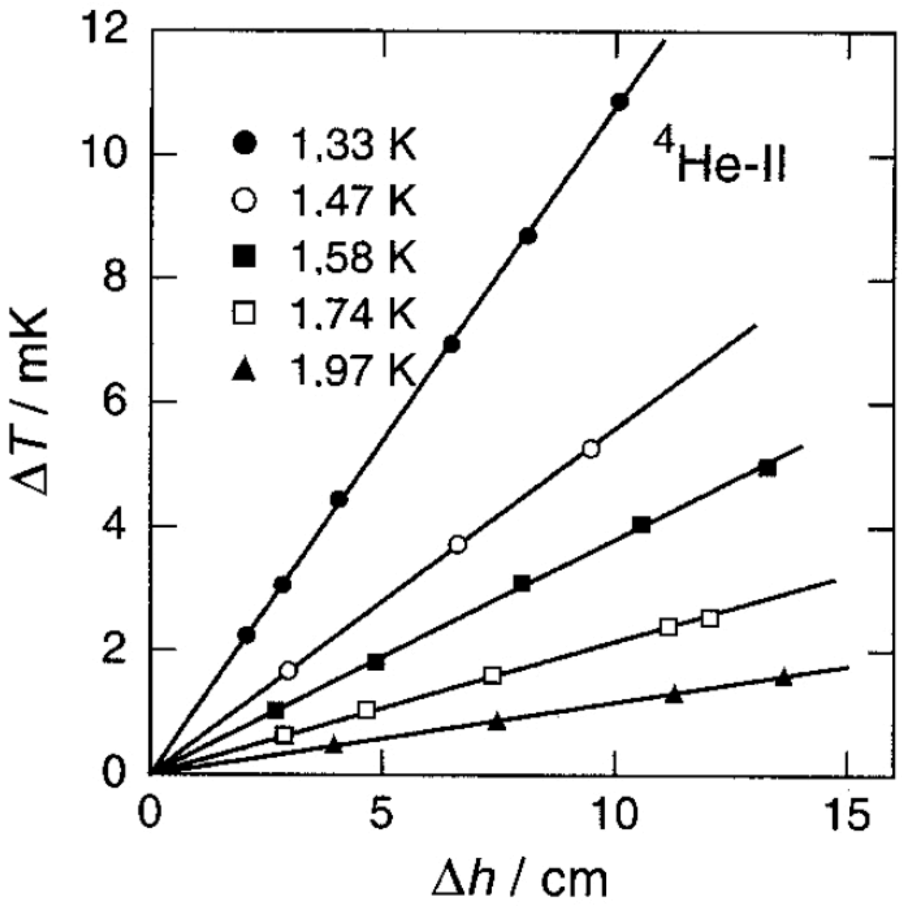
- superfluid component: *no entropy: $S_s = 0$,* *zero viscosity: $\eta_s = 0$*
- normal component: *carries total entropy: $S_n = S$,* *finite viscosity: $\eta_n = \eta$*

From Gross, Marx, Wather-Meissner Institut, 2009.



Inverse effect: superfluid helium fountain

From Gross, Marx, Wather-Meissner Institut, 2009.



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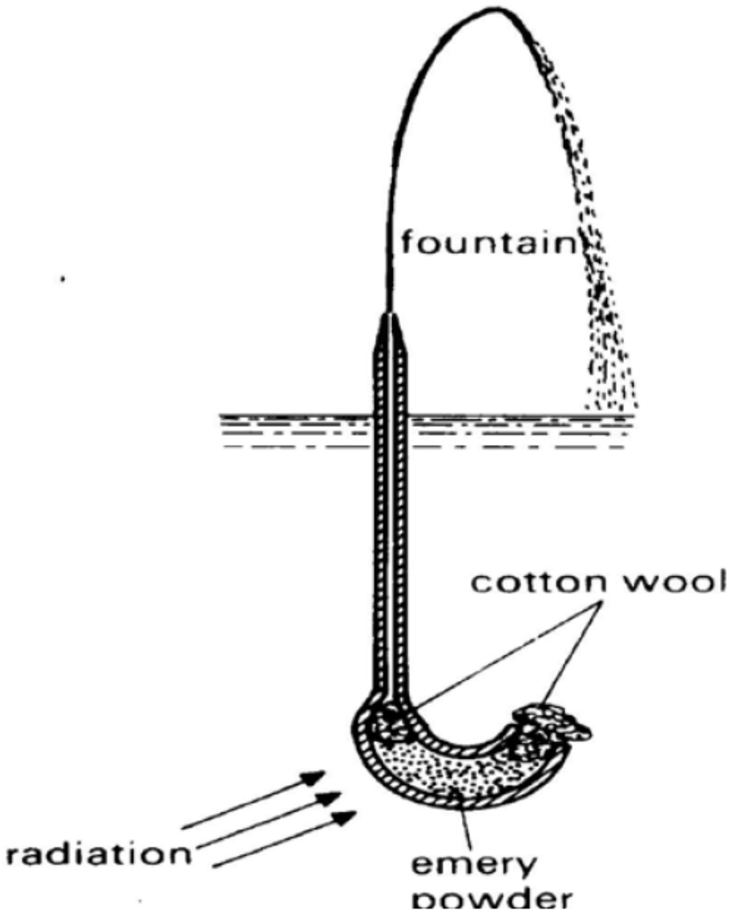
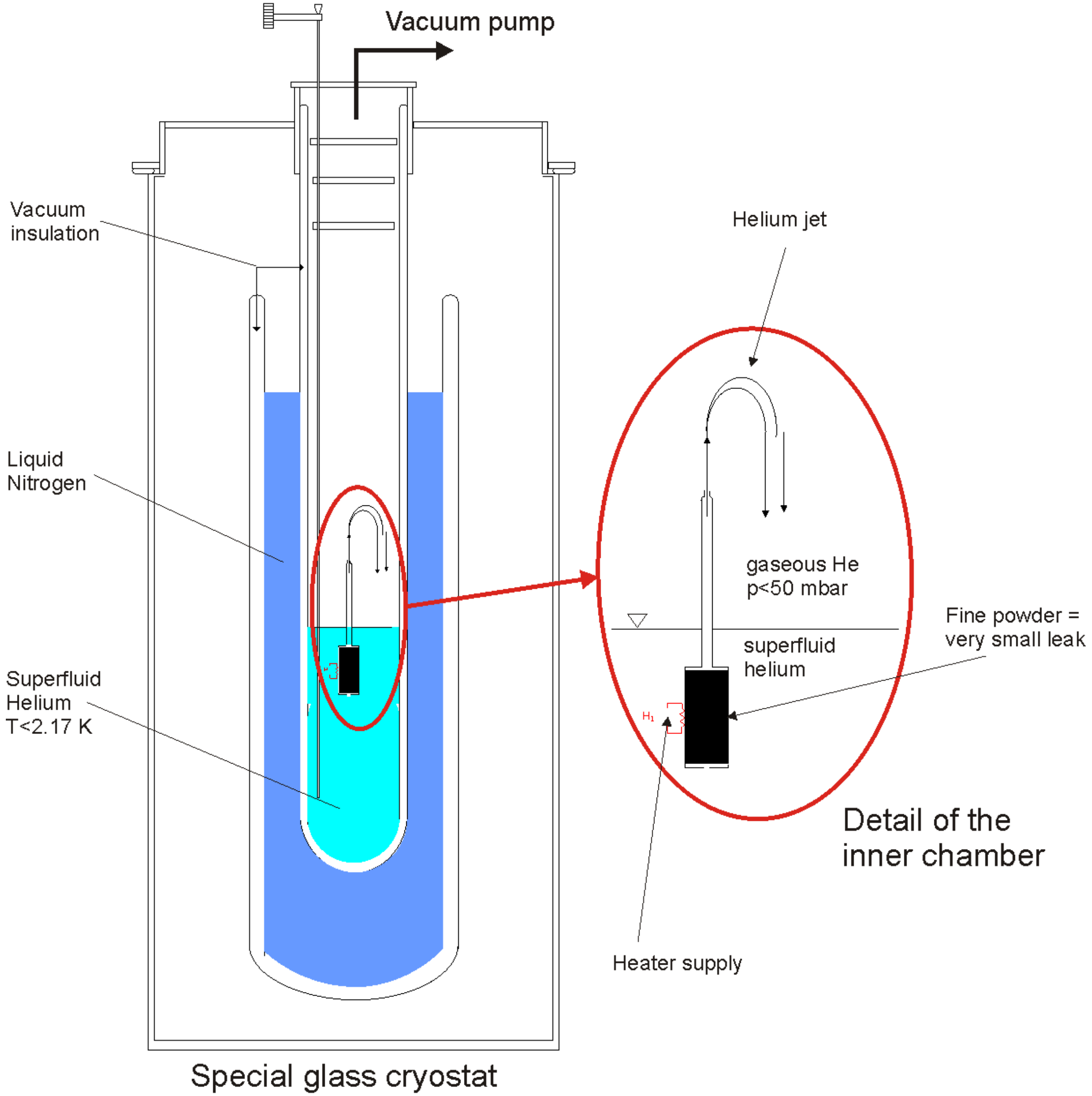


From J. Allen, 1937



He II Fountain Effect:

- Use of fine aluminum powder as a porous plug,

- Only superfluid helium component can pass through,

- Inserting heat induces motion of the superfluid component towards the warm parts inside the chamber,

- The superfluid component is converted to normal fluid at the heater,

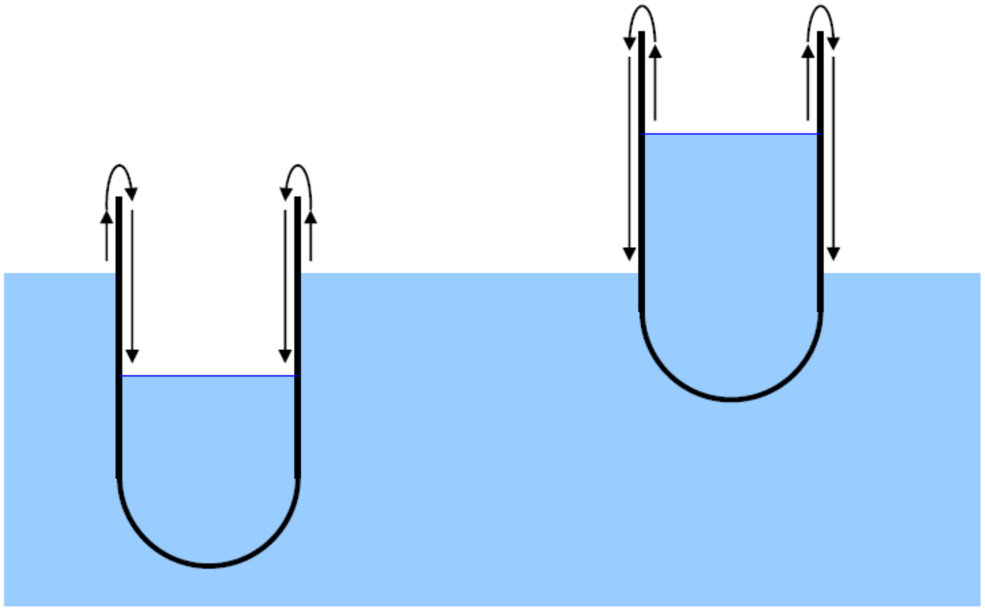
- Continuous compensation by superfluid helium trough the plug,

- The pressure increases inside the chamber,

- Liquid helium jet.

Live demonstration glass cryostat

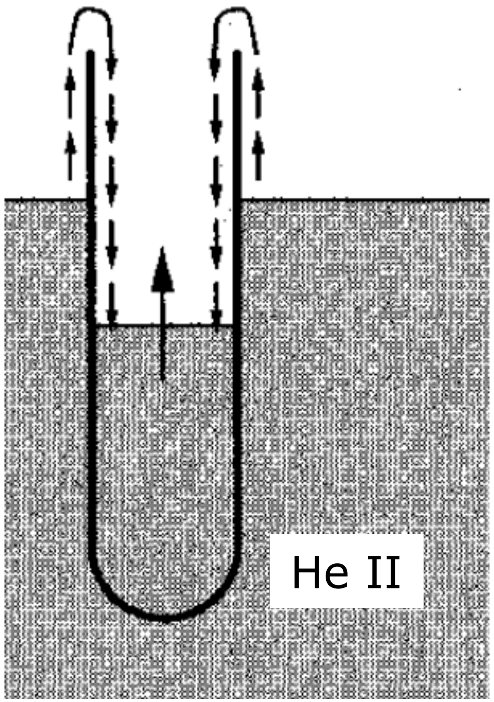
- *helium film covers container via absorption of atoms from the vapor phase (van der Waals forces)*
- *superfluidity of He: „mobile“ film*

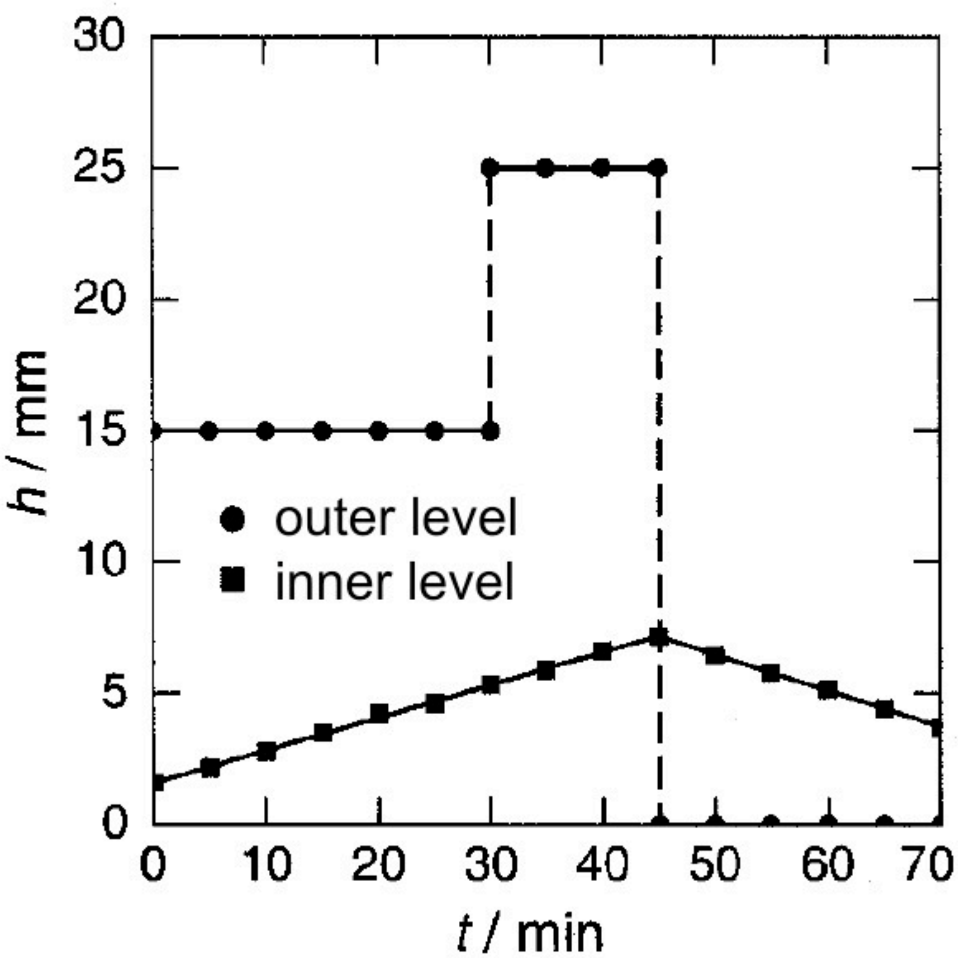


container fills up

container is draining out

From Gross, Marx, Wather-Meissner Institut, 2009.





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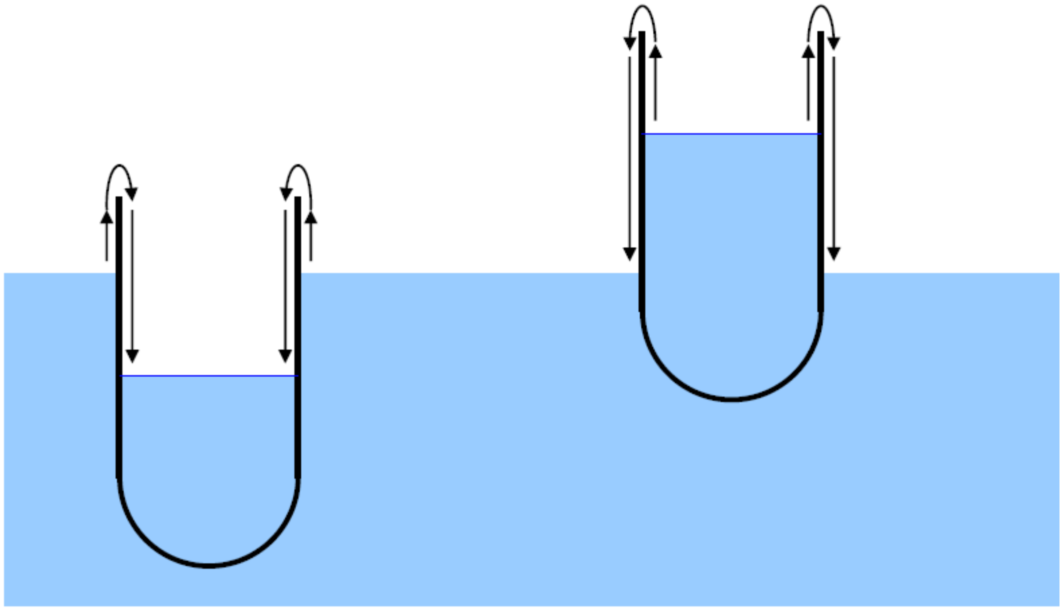

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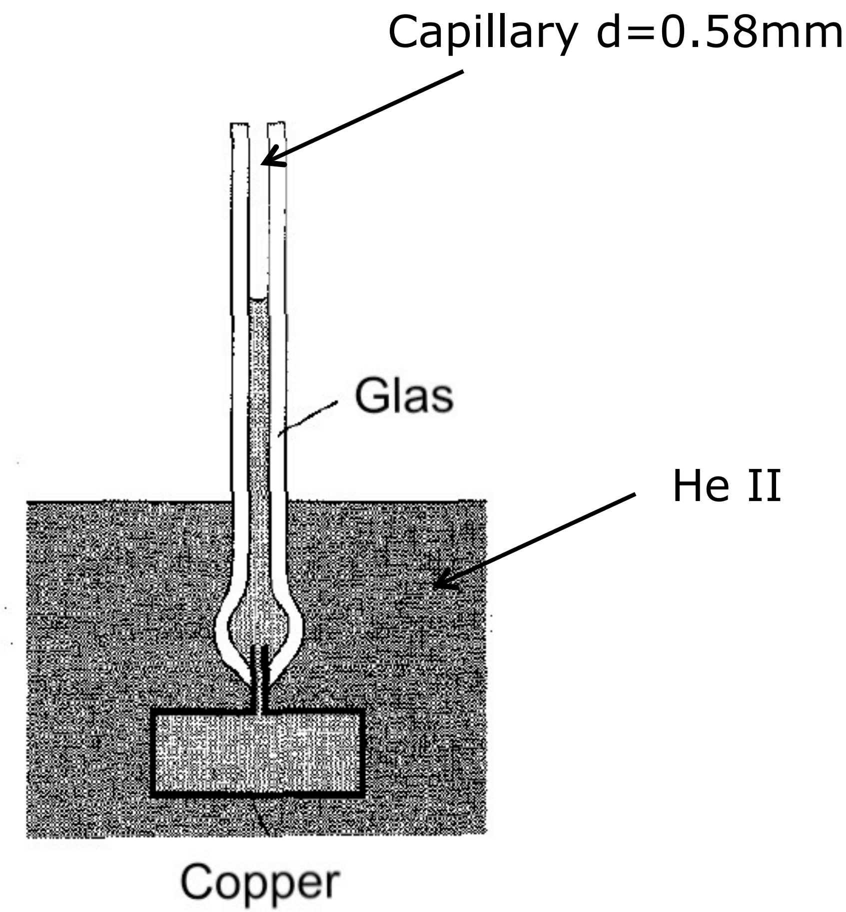

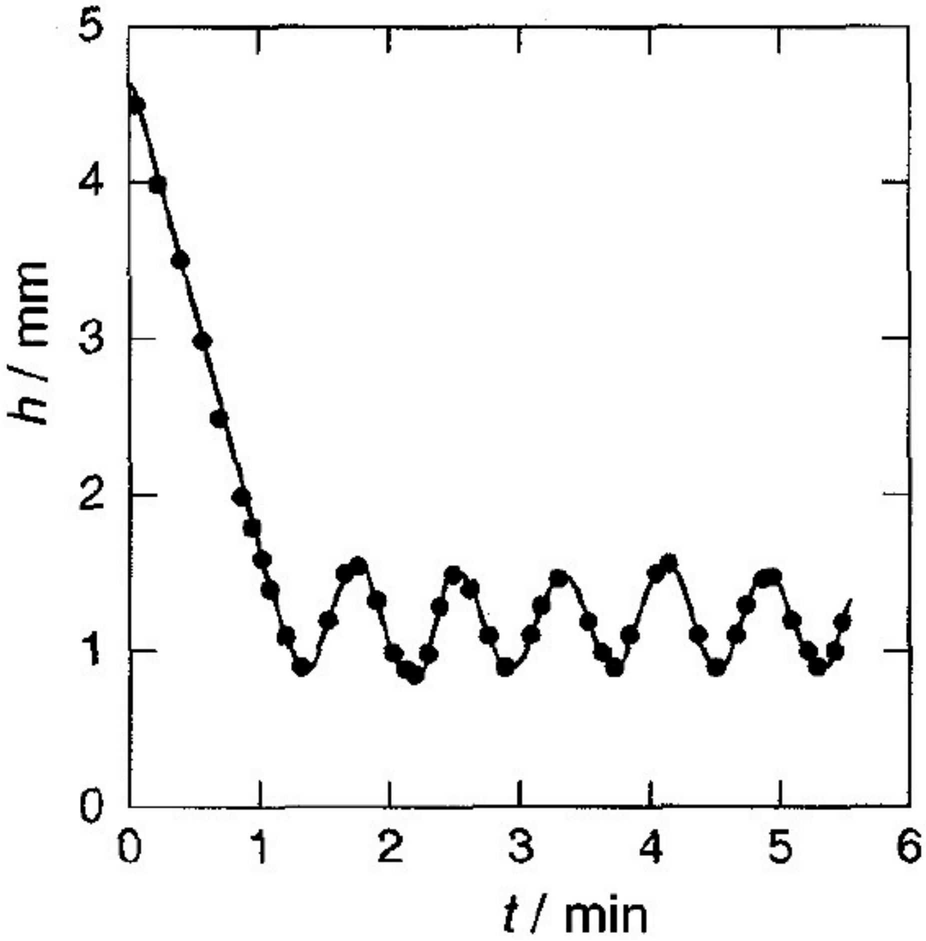

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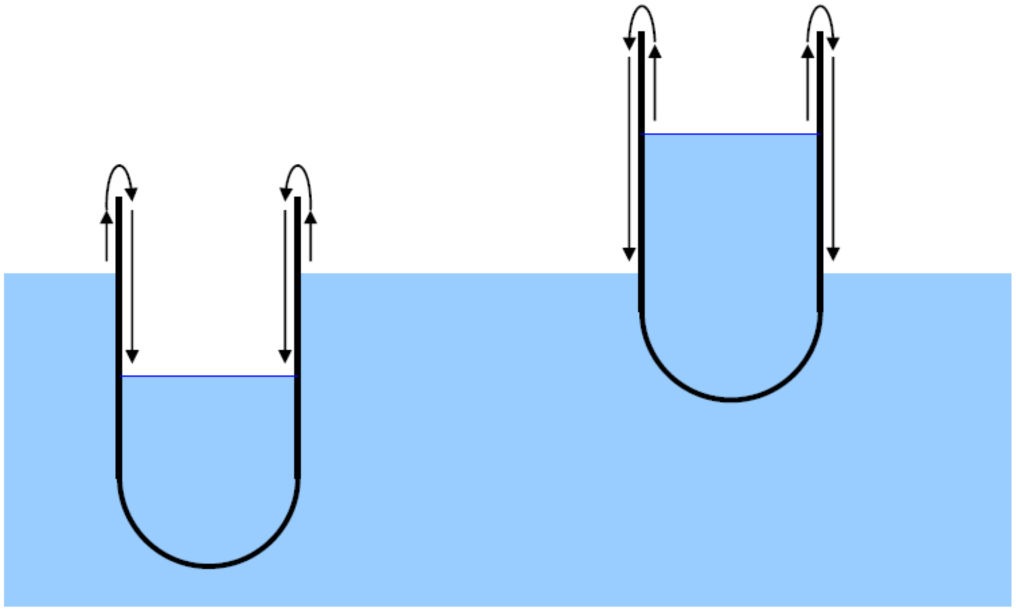

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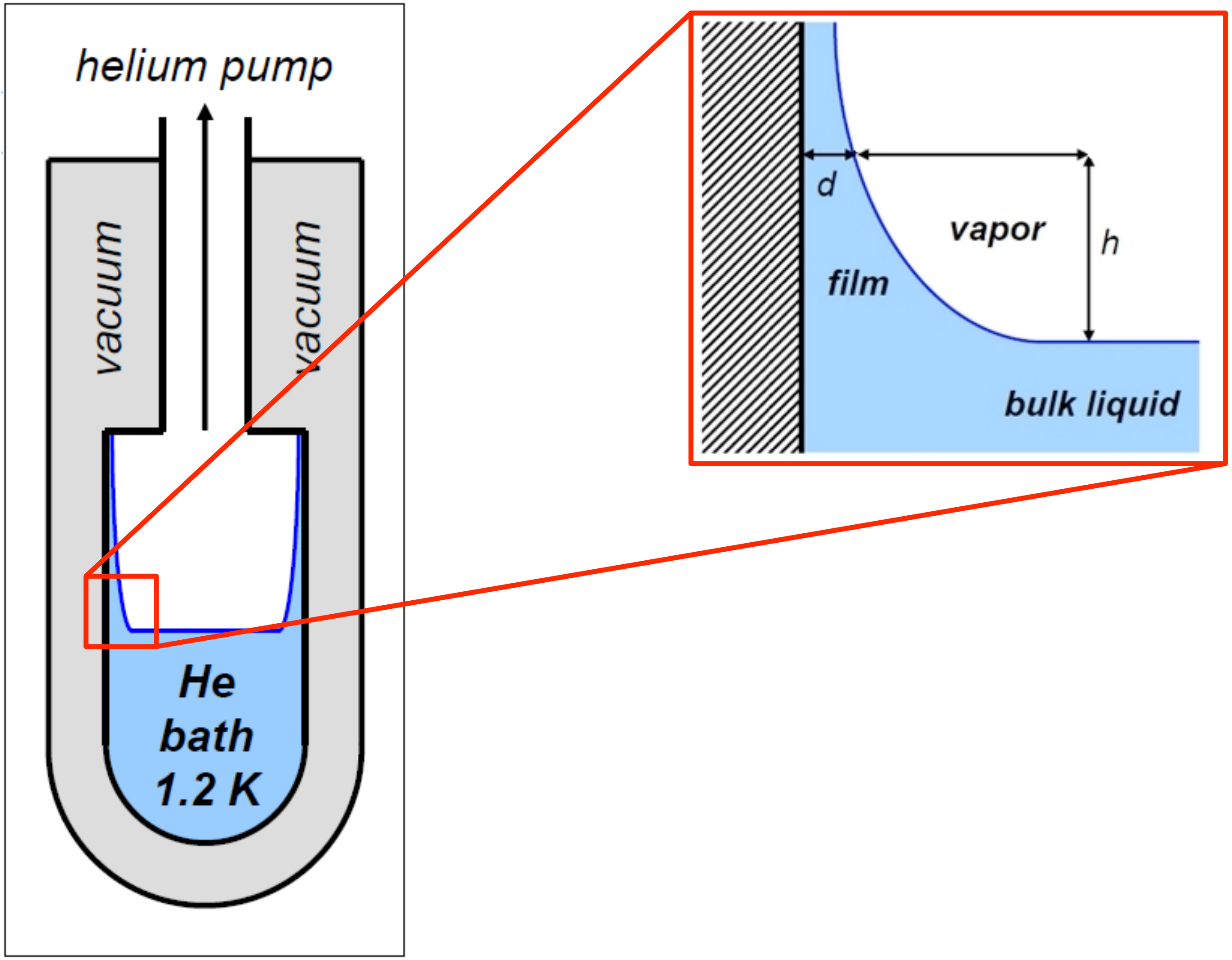


In our cryostat:

1 drop / min

Have a look

From Gross, Marx, Wather-Meissner Institut, 2009.

Pressure waves

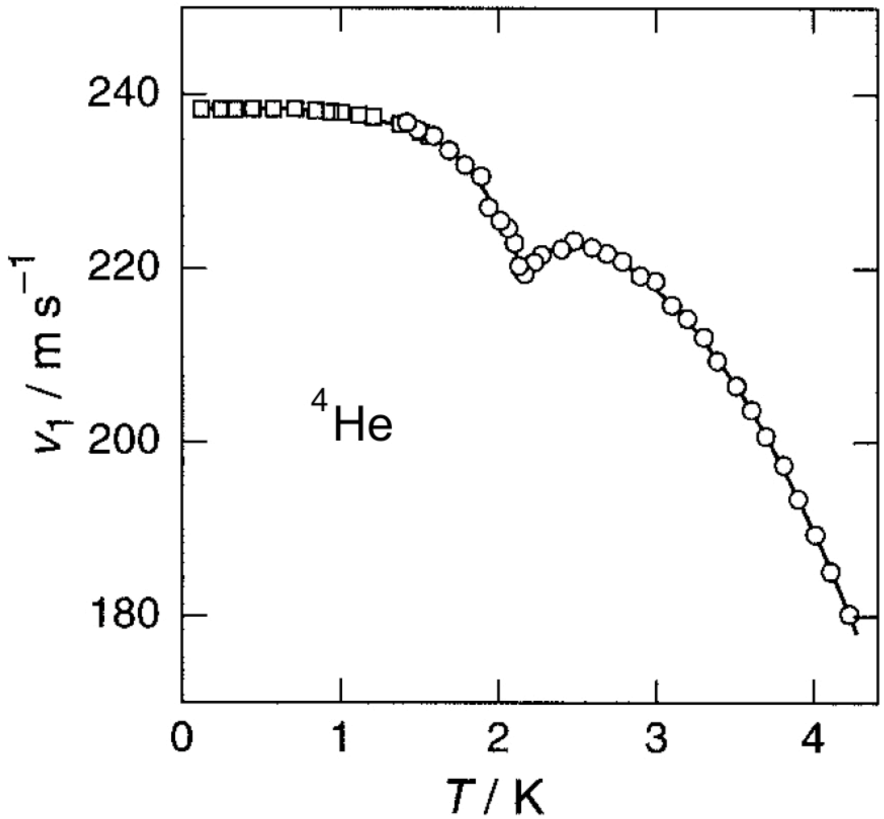
First sound v_1

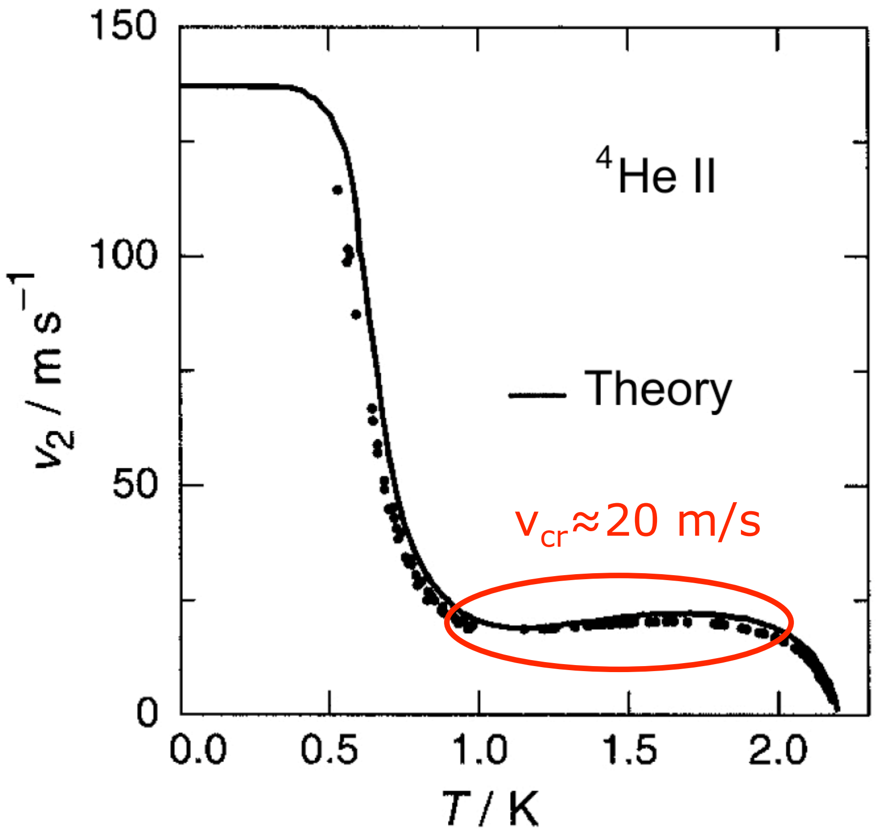
Below the λ point the two components move in phase

Temperature waves

Second sound v_2

The two components move antiphase





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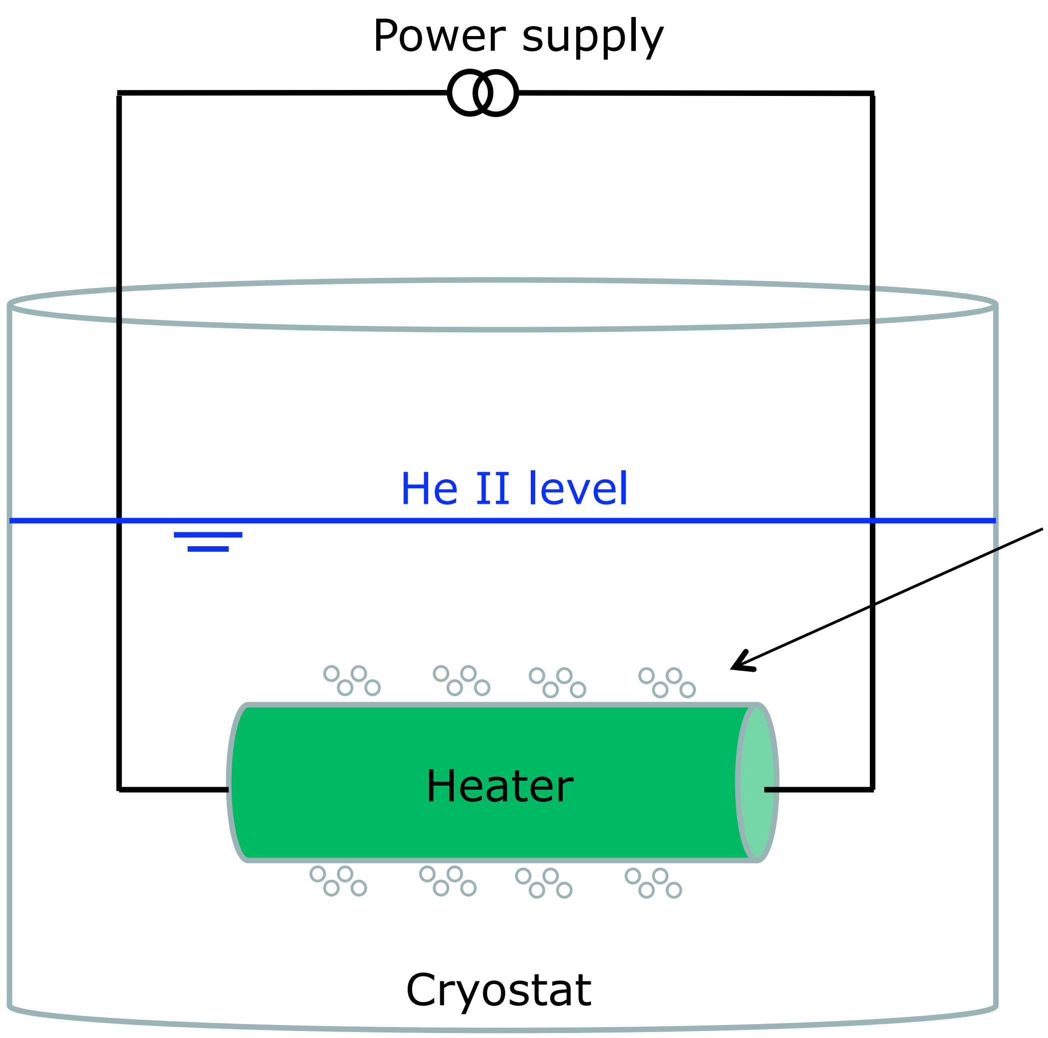


Heat and mass flow are limited by the critical velocity:

$v > v_{cr}$

Superfluid behavior becomes non-linear

$\lambda \downarrow$ and $\eta \uparrow$

Formation of gas bubbles at the surface of the heater

In He II recondensation of the vapor

Surface tension let the bubbles implode

Implosion speed exceeds v_1

Shock wave => cavitation

Demonstration of the superfluid phenomena:

- Film flow
- Fountain effect and
- Critical heat flux

- Further information about He II => Lecture tomorrow by P. Lebrun,
=> Enss, Hunklinger, Low Temperature Physics
=> Youtube BBC superfluid He part 1-6.

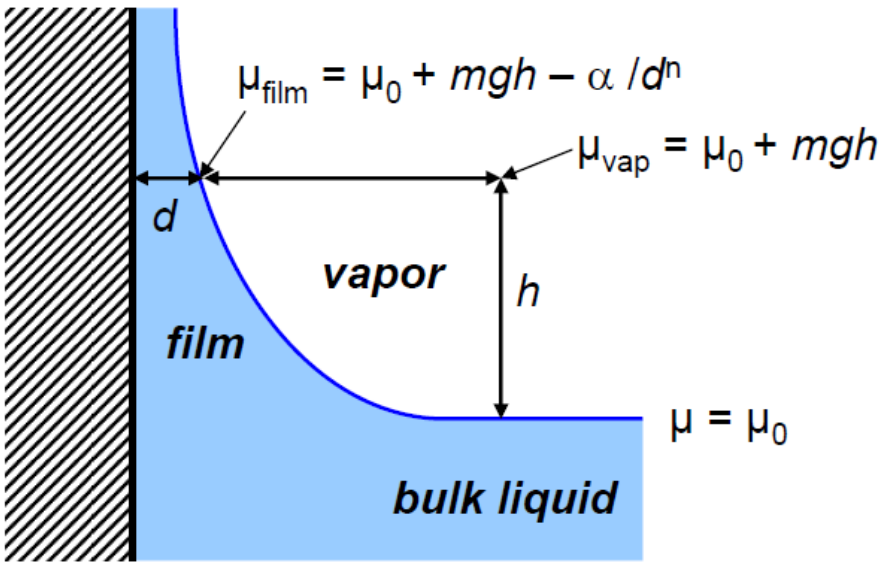
Thank you for your attention

➔ *estimate of superfluid film thickness*

- in equilibrium chemical potentials are identical: $\mu_{film} = \mu_{vap} = \mu_0$
- for film: $\mu_{film} = \mu_0 + mgh - \alpha / d^n$ (*n* ~ 3 for *d* < 5 nm, α = Hamaker constant, α is determined by dielectric properties of wall and He at

  bulk liquid, *gravitation*, *van der Waals potential*

- for vapor: $\mu_{vap} = \mu_0 + mgh$



equilibrium condition:

$$d = \left(\frac{\alpha}{mgh} \right)^{1/3}$$

typical values:

d (nm) ≈ 30 / [h (cm)]$^{1/3}$
h = 5 cm ➔ d = 20 nm

normal fluid blocked in thin film
➔ ***superleak***

From Gross, Marx, Wather-Meissner Institut, 2009.