Helium in confinement: the filling parameter.

A Neutron Scattering investigation.

Francesco Albergamo

Institut Laue-Langevin, France
introduction and motivation
**outline**

- introduction and motivation
- pressure isotherms technique
  - principle
  - information
outline

- introduction and motivation
- pressure isotherms technique
  - principle
  - information
- inelastic neutron scattering results
the \( \lambda \) transition

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- superfluidity
  - observed zero viscosity
  - superfluid fraction $\rho_s$ (two-fluid model)
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- Bose-Einstein Condensation - BEC
  - observed Dirac $\delta$ shaped excitations
  - condensate fraction $\eta_0$
the $\lambda$ transition

- superfluidity
  - observed zero viscosity
  - superfluid fraction $\rho_s$ (two-fluid model)

- Bose-Einstein Condensation - BEC
  - observed Dirac $\delta$ shaped excitations
  - condensate fraction $n_0$

bulk helium at SVP

\[ T_s = T_{\text{BEC}} = T_\lambda = 2.17 \, K \]
results for confined helium

confinement should deplete BEC...
results for confined helium

confinement should deplete BEC... but results show:

- that $T_s$ reduces with pore size
- no change in microscopic quantities
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What actually the sample is?

experimental pressure is SVP; bulk helium is coexisting with its vapour
results for confined helium

confinement should deplete BEC... but results show:

- that \( T_s \) reduces with pore size
- no change in microscopic quantities

What actually the sample is?

experimental pressure is SVP; bulk helium is coexisting with its vapour
(how) does the bulk liquid affect the behaviour of the system?

\( \Rightarrow \text{need for a better knowledge of filling} \)
Calibrated set of volumes
pressure isotherms - principle

- calibrated set of volumes
- good precision pressure measurements
pressure isotherms - principle

- calibrated set of volumes
- good precision pressure measurements
- temperature control
pressure isotherms - principle

- calibrated set of volumes
- good precision pressure measurements
- temperature control
- probe gas equation of state
pressure isotherms - principle

gas handling system

turbo pump
helium bottle
nitrogen trap
buffer volume
baratron volume
cryostat
sample volume
pressure isotherms - principle

1. sample installing

- Turbo pump
- Helium bottle
- Nitrogen trap
- Buffer volume
- Sample volume
- Baratron volume
pressure isotherms - principle

2. outgassing

- Turbo pump
- Helium bottle
- Nitrogen trap
- Buffer volume
- Baratron volume
- Sample volume
pressure isotherms - principle

3. probe gas purification

- Turbo pump
- Helium bottle
- Nitrogen trap
- Buffer volume
- Baratron volume
- Sample volume
- Cryostat
4. buffer filling

- turbo pump
- helium bottle
- nitrogen trap
- buffer volume
- baratron volume
- sample volume
- cryostat

Helium in confinement: the filling parameter. – p.7/13
5. injection volume isolation

- Turbo pump
- Helium bottle
- Nitrogen trap
- Buffer volume
- Baratron volume
- Sample volume
- Cryostat

Helium in confinement: the filling parameter.
pressure isotherms - principle

6. injection

Helium in confinement: the filling parameter. – p.7/13
isotherms - information

\[ n_{\text{ads}} = \frac{N_{\text{ads}}}{M} \]

\[ p = \frac{P_{\text{eq}}}{P_0(T)} \]

Helium in confinement: the filling parameter. – p.8/13
isotherms - information

\[ p = \frac{p_{eq}}{p_0(T)} \]

\[ n_{ads} = \frac{N_{ads}}{M} \]

Reduced variables

Helium in confinement: the filling parameter - p.8/15
isotherms - information

\[ p = \frac{p_{eq}}{p_0(T)} \]

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Isotherms - information

\[ p = \frac{P_{eq}}{P_0(T)} \]

\[ n_{ads} = \frac{N_{ads}}{M} \]

Reduced variables

- Monolayer
- Multilayer
- Capillary condensation
isotherms - information

\[ n_{\text{ads}} \text{ (mmol g}^{-1}) \]

\[ p = \frac{P_{\text{eq}}}{P_0(T)} \]

\[ n_{\text{ads}} = \frac{N_{\text{ads}}}{M} \]

- monolayer
- multilayer
- capillary condensation
- saturation

Helium in confinement: the filling parameter. – p.8/13
isotherms - information

- $N_2$ isotherms (standard)
- pore size distribution
- specific surface
N₂ isotherms (standard)
- pore size distribution
- specific surface

⁴He isotherms
- maximum helium intake
- wetting processes (capillary condensation)
isotherms - information

- $N_2$ isotherms (standard)
  - pore size distribution
  - specific surface

- $^4$He isotherms
  - maximum helium intake
  - wetting processes (capillary condensation)

⇒ choice of a good sample (MCM-41)
⇒ choice of filling state
neutrons - results (MIBEMOL)

![Graph showing the adsorption of helium at T=2.47 K.](image)

- The graph plots the adsorption of helium ($n_{ads}$ in mmol g$^{-1}$) against the filling parameter ($p$).
- The data points indicate a sharp increase in adsorption near $p=1$. 
neutrons - results (MIBEMOL)

\[ n_{ads} \text{ (mmol g}^{-1}\text{)} ]

- \( F_0 \) (void)
- \( F_1 \) (BET monolayer)
- \( F_2 \) (multilayer)
- \( F_3 \) (capillary condensation)
- \( F_4 \) (full)

Helium in confinement: the filling parameter – p.10/13
neutrons - results (MIBEMOL)

$n_{ads}$ (mmol g$^{-1}$)

raw intensity (a.u.)

$E$(meV)
neutrons - results (MIBEMOL)

Graph showing the relationship between $n_{ads}$ (mmol g$^{-1}$) and $p$ with raw intensity (a.u.) versus $E$(meV) in the inset.
results (IN6)

- The graph shows the net intensity (a.u.) as a function of energy (E, meV) for different q values.
- The red line represents ripplons.
- The inset graph highlights the q=1.50 Å⁻¹ case, showing an increase in net intensity.
results (IN6)

\[ q = 1.50 \, \text{Å}^{-1} \]

net intensity (a.u.)

E (meV)

Helium in confinement: the filling parameter – p.11/13
results (IN6)
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- Helium in confinement: the filling parameter.
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Summary and Conclusions

- Improvement in the sample characterization
  - $N_2$ isotherms (pore size distribution)
  - $^4$He isotherms (thermodynamic state of the sample)
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  - $\text{N}_2$ isotherms (pore size distribution)
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Results

- 3D-like elementary excitations are supported by the capillary condensed liquid
- 2D surface capillary waves (ripplons) are supported by the liquid multilayer
- Excitation dispersion suggest that the density of capillary condensed liquid could drop 10% with respect to the bulk value