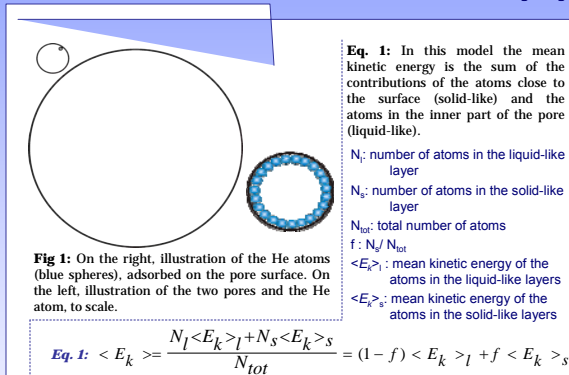# Mean kinetic energy of liquid helium systems
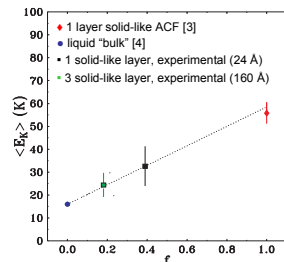
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[1] Indiana University Cyclotron Facility – [2] Università di Roma Tor Vergata

Eq. 1: In this model the mean kinetic energy is the sum of the contributions of the atoms close to the surface (solid-like) and the atoms in the inner part of the pore (liquid-like).

N_l: number of atoms in the liquid-like layer

N_s: number of atoms in the solid-like layer

N_{tot}: total number of atoms

f : N_s / N_{tot}

$<E_k>_l$: mean kinetic energy of the atoms in the liquid-like layers

$<E_k>_s$: mean kinetic energy of the atoms in the solid-like layers

Fig 1: On the right, illustration of the He atoms (blue spheres), adsorbed on the pore surface. On the left, illustration of the two pores and the He atom, to scale.

$$Eq.\ 1:\ \ <E_k> = \frac{N_l <E_k>_l + N_s <E_k>_s}{N_{tot}} = (1-f)<E_k>_l + f<E_k>_s$$

Tab. I: $<E_k>$ experimental results for the two samples with mean diameter pore of 24 Å and 160 Å, compared with the bulk liquid value [4].

Sample	$<E_k>$ (K)
"bulk"	16.2 ± 0.4
160 Å	24.4 ± 5.3 K
24 Å	32.6 ± 8.7 K

Fig. 2: $<E_k>$ dependence on the fraction f. Blue circle: bulk value; green square: exp. value for the 160 Å pore; black square: exp. value for the 24 Å pore; red diamond: slit geometry [3].

In the case of ^{4}He in porous matrices (Xerogel powders with mean pore diameters of 24 Å and 160 Å), helium atoms have a $<E_K>$ higher than the bulk value in the same conditions (T=2.5 K and saturated vapor pressure, Tab. I). The results are interpreted in terms of a model (Eq. 1) where ^{4}He atoms are arranged in concentric annuli along the cylindrical pore axis (Fig. 1), with the $<E_K>$ mainly dependent on the ratio between the atomic diameter and the pore diameter. In the case of the pore of 24 Å diameter, the experimental $<E_K>$ is well reproduced by assuming the first layer to be solid-like with all other inner layers in the liquid phase [1]. The $<E_K>$ extrapolated value of the first layer is 58.5 K. For the pore of 160 Å diameter the result is interpreted in term of three solid-like layers [2].
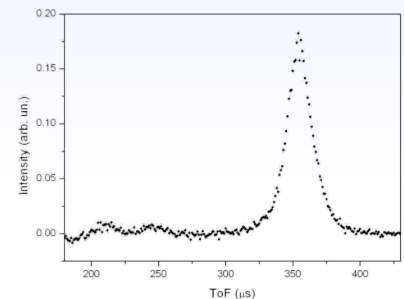
He in nanoporous systems

Fig. 4: Example of Time of Flight spectrum obtained by means of VESUVIO spectrometer. In this case the three peaks correspond to the ^{3}He, ^{4}He and Al scattering contribution respectively (from left to right).

In this work we present the study of the single-particle dynamics of liquid helium in two systems where disorder is added: a statistic disorder (provided by isotopic mixtures) and a spatial disorder (^{4}He in nanometric porous systems). In both cases the microscopic dynamics is influenced by the disorder, showing a change in the mean kinetic energy value, $<E_K>$, of the helium atoms.

Deep Inelastic Neutron Scattering
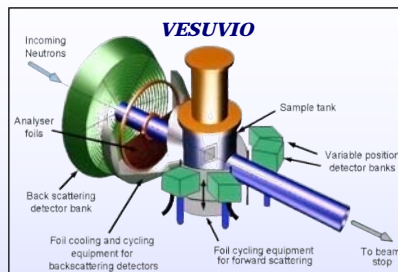
VESUVIO

Fig. 3: Picture of the VESUVIO spectrometer (Isis pulsed neutron source - UK), used for the studies of the liquid helium dynamics.
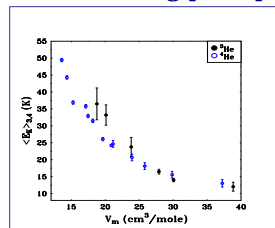
^{3}He-^{4}He mixtures

Fig. 7: $<E_K>_3$ as function of the molar volume for pure ^{3}He (open circles) and for ^{3}He in ^{3}He-^{4}He mixture (full circles). The red full circles are the results of the presented work.

| V_m (cm^3/mol)	$<E_K>_3$ (K)
25.3	12 ± 3
23.4	16.5 ± 3.0
22.7	26.4 ± 4.1
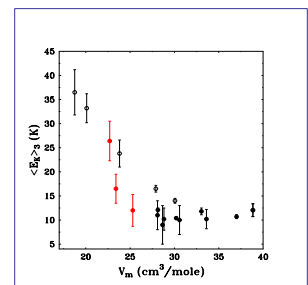
Previous experiments showed that in pure fluids, the mean kinetic energy of ^{3}He and ^{4}He are remarkably dependent on the molar volume, as expected from the Heisenberg principle (Fig. 5) [5-6-7-8]. On the other hand, the $<E_K>$ of the ^{3}He, when in mixture, seems to be independent of the molar volume (Fig. 6), for $V_m > 28$ cm^3/mol [9-10-11-12]. Thus we have performed new measurements to extend the range of investigated molar volumes down to the melting point. The presented Deep Inelastic Neutron Scattering measurements on mixtures, performed at T=2 K and pressures ranging between 15 bar and 40 bar, reveal that the $<E_K>$ of ^{3}He is dependent on the total mixture density and is less than the value of the pure bulk ^{3}He, while, near the melting point, the two values are comparable (Fig. 7).

Fig. 5: Molar volume dependence of mean kinetic energy for pure ^{3}He (full circles) from [5-6] and pure ^{4}He (open circles) from [7-8].
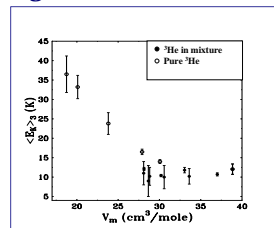
Fig. 6: $<E_K>_3$ as function of the molar volume for pure ^{3}He (open circles) and for ^{3}He in ^{3}He-^{4}He mixture (solid circles) [9-10-11-12].

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