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FOCUSING OF HYDROGEN ATOMS WITH A CONCAVE He-COATED MIRROR

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We use a concave spherical mirror, coated with liquid He, to focus a highly divergent beam of H-atoms into a small aperture. The temperature dependence of the focussed beam intensity enables us to study the influence of the dynamic surface roughness on the reflection of the H-atoms.

Hydrogen atoms (H) with sufficiently low incident energy, colliding with the surface of liquid ^{4}He, have a probability which approaches unity to undergo purely specular reflection.[1] This is a pure quantum phenomenon related to the large thermal de Broglie wavelength of the atoms at low temperatures and the weak interaction between H and helium. At non-zero temperatures, the small but finite probability for the H-atoms to adsorb onto the He film or to undergo inelastic (non-specular) scattering is governed by processes involving the emission or absorption of ripplons. The theory for scattering of low energy H-atoms from the surface of liquid He is the subject of several papers in the literature.[2,3,4,5]

Indirect evidence for the occurrence of quantum reflection of H from the surface of liquid helium has been obtained experimentally by measurements of the sticking coefficient s[6] defined as the probability for an atom upon collision to enter a surface-bound state. Reflectivities as high as 95% were deduced from these experiments at the lowest temperatures (0.08 K). The reflective properties of He films for H-atoms suggest the feasibility of making near perfect atomic mirrors.

In the present experiment we demonstrate the focusing of a beam of cold ($T < 0.5$ K) hydrogen atoms by the use of such a mirror. In this experiment a buffer volume is filled with H-gas. The atom can escape from this volume through a hole with a diameter of 0.5 mm. A hemi-spherical concave quartz substrate of optical quality with a 9 mm curvature radius is coated with a film of superfluid helium. The mirror is placed in front of the hole and is mounted on a translation stage by means of which its center of curvature can be made to coincide with the exit hole of the buffer volume. The entire cell is linked to the mixing chamber of a dilution refrigerator. When the mirror is in focus particles that scatter from the surface in a small angular range (0.6°) near pure specular reflection will re-enter the buffer volume, thereby reducing the rate at which the density in the volume decays. Hence, by measuring this decay rate as a function of mirror position, the reflectivity of the substrate for normally incident atoms can be obtained. More details of this experiment and its interpretation are given elsewhere.[7]

Fig.1 shows a typical measurement of the decay rate $1/\tau$ versus mirror position, normalized to its value $1/\tau_0$ in the absence of the mirror. The loss factor $\chi \equiv \tau_0/\tau$. The results clearly demonstrate the occurrence of specular reflection of the atoms.

In fig.2 the value χ_{min} of χ when the mirror is in focus, is plotted versus temperature. The triangles represent data for a saturated ^{4}He film of estimated thickness 11.5 nm. Notice that the apparent reflectivity $R_\perp = 1-\chi_{min}$ is decreasing from 73 % at 160 mK to 56 % at 400 mK. The circles represent data in the presence of a ^{3}He monolayer on the film.

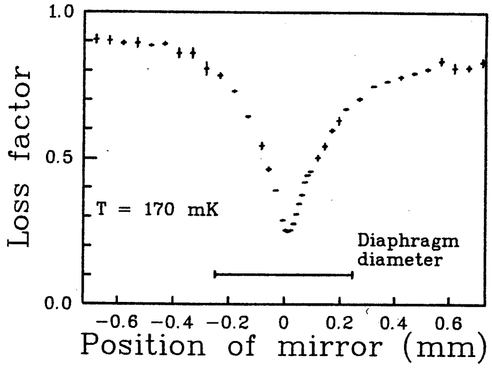

Fig. 1. The loss factor as a function of the vertical mirror position.

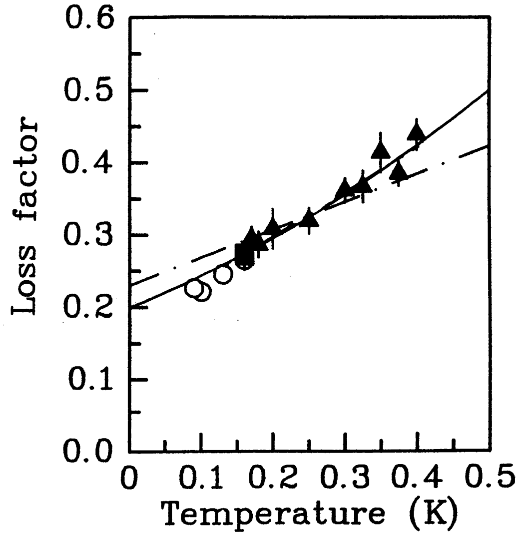

Fig. 2. Measured loss factors as function of temperature. Triangles: results on saturated (115 Å) pure ^{4}He films; circles: results on saturated ^{4}He films with full ^{3}He monolayer coverage. The curves are discussed in the text.

Although the loss factor becomes smaller with decreasing temperature, the extrapolated value for χ at T=0 does not vanish, as was predicted by theory[2] and deduced from measurements of the sticking probability.[6] This is mainly due to errors in the lateral alignment of the mirror. The value 0.2 for χ_{min} at T=0 corresponds to a 40μm off-axis misalignment of an otherwise perfect mirror.

To gain some quantitative insight into the results depicted in fig.2 we assume 3 independent loss mechanisms:

$$\chi_{min} = 1 - \prod_{i=1}^{3} (1 - \chi_i). \qquad (1)$$

Here $\chi_1 = \gamma_1 T$ with $\gamma_1 = 0.5\,K^{-1}$, is due to sticking and can be obtained[7] from the experimental results of ref.6 χ_3 is a temperature independent loss factor associated with the lateral misalignment of the mirror. As the latter quantity is not precisely known χ_3 is treated as an adjustable parameter. The contribution due to inelastic scattering has a quadratic temperature dependence[5] and is usually assumed to be small. If we set χ_2=0, we obtain the dashed-dotted curve in fig.2. If we include $\chi_2 = \gamma_2 T^2$ in the fit we obtain the solid curve in fig.2 with $\gamma_2 = 0.5(1)\,\mathrm{K}^{-2}$. This is in reasonable agreement with the calculated value[5] $\gamma_2 = 0.7\,\mathrm{K}^{-2}$. Because of the high angular resolution (0.6°) this is the first experiment which reveals the contribution due to inelastic scattering, which strongly emphasizes small angles.

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