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Radiative heat transfer at low temperatures over microscopic distances in vacuum

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ABSTRACT

We present experimental results on heat transfer between plane parallel surfaces of samples separated with microscopic vacuum gap. **Radiative heat flux** between metallic samples **exceeding 50 times heat flux between black surfaces** was observed for gaps of several micrometres at temperatures below 50 K. Comparison with near field theory of radiative heat transfer is presented.

Introduction

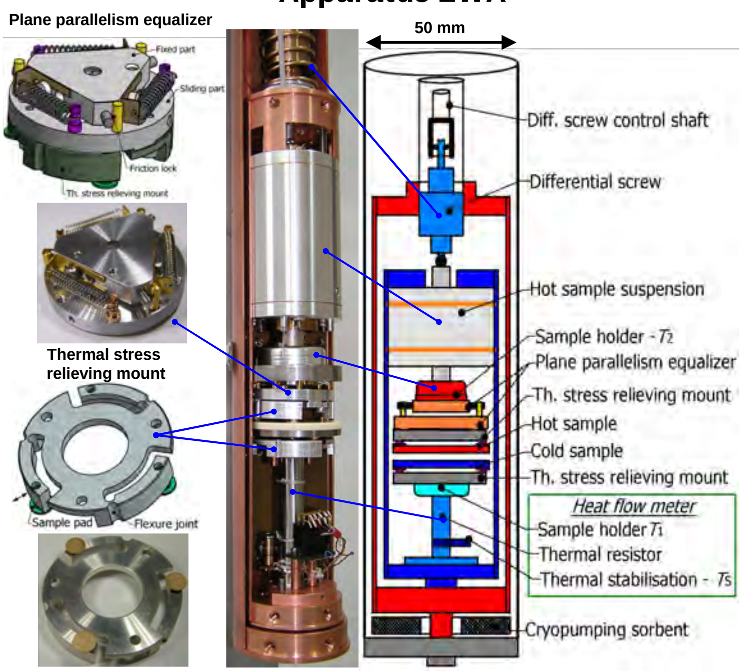
In vacuum, heat can be exchanged between two surfaces through emission and absorption of thermal radiation.

The Stefan-Boltzmann law states that the radiative heat flux between two flat plates separated by a vacuum gap is equal to $\sigma(T_2^4 - T_1^4)$ where σ is the Stefan-Boltzmann constant and T_1 and T_2 are the temperatures of the two media, respectively.

This law is applicable only when the width *d* of the vacuum gap is greater than the characteristic wavelength of thermal radiation λ_m that can be obtained from Wien's displacement law. As the **distance decreases** and becomes comparable with or shorter than λ_m, **near-field effects** become important and the **radiative heat transfer can be significantly increased**.

Similar experiments with planparallel geometry:
Domoto (1970): Copper disks at 10 K and 4.2 K, gap 1000 μm – 10 μm, 2 times increase in the heat transfer
Hargreaves (1973): Glass plates with Cr layer at various temperatures (300 K – 77 K), gap 15 μm–1 μm, 3 times increase in the heat transfer
Ottens (2011): Sapphire plates at room temperature, ΔT=9.8 K-19 K, air in the gap 100 μm–3 μm, 2 times increase in the heat transfer.

Apparatus EWA

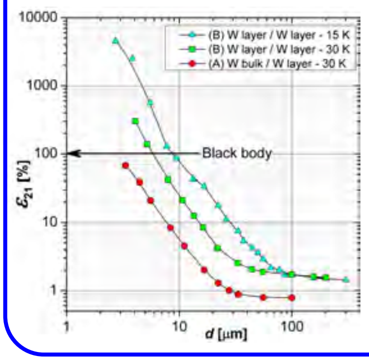


Whole apparatus is inserted in wide neck LHe dewar vessel.

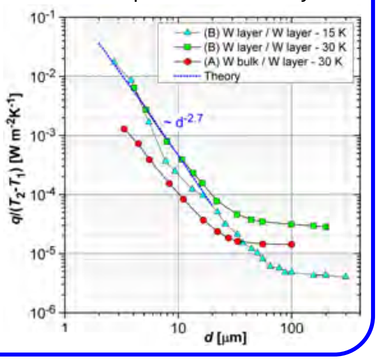
Results

Measured results in dependence of the distance *d* between samples. Temperature of the hot and cold sample were T_2=15 K and 30 K and T_1=5 K.

"Mutual emissivity" $\varepsilon_{21} \equiv q_R / q_{BB}$ transferred radiative heat normalised to the one between black surfaces in far field.



Transferred heat flux divided by temperature difference between surfaces of the samples. Comparison with theory.



Summary of the Experiment

- Demonstration of near field effect in radiative heat transfer.
- Near-field heat transfer become significant (2 times increase of heat flow) when the vacuum gap was lower than λ_m**/3** for „W layer/W layer" and λ_m**/5** for „W layer/W bulk". λ_m is given by Wien's displacement law for the thermal radiation of the hot sample.
- At distances of few micrometers the transferred heat flux significantly exceeds "black body limit" (mutual emissivity exceeds 100 %).
- Experimental data on near field heat fluxes are in good agreement with theoretical calculation.

Possible Applications

- Enhanced heat transfer when physical contact between bodies should by avoided.
- Near field effect can provide highly dynamic thermal coupling (feedback) when varying the gap width between two objects.

Samples

Disks, 2.5 mm thick and 35 mm in diameter.

Tungsten: nonmagnetic material, mechanically hard, providing normal skin-effect.

„**W bulk**": sample, made of polished pure tungsten metallic disc with planarity ~7 μm (slightly convex) .

„**W layer**": sputtered 150 nm thick layer on polished pure alumina substrates (Al_2O_3 of 99.8% purity, density of 3.87 g/cm³). A planarity of 0.1 μm and 0.6 μm. (slightly concave shape)

Sample geometry

W layer W bulk

Al_2O_3 samples with W layer (cold and hot sample) and sample made of bulk W. Images are from the HeNe laser interferometer (628 nm).

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