Group of Cryogenics and Superconductivity

Department of Magnetic Resonance and Cryogenics

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THEMATIC RESEARCH FOCUS

Research area

- Low temperature physics
- Cryogenics
- Thermal radiation and near field heat transfer
- Fluid dynamics, turbulence
- Quantum phase transitions
- Applied superconductivity

Excellence

- Basic research in fluid dynamics – Rayleigh-Bénard cryogenic convection
- Characterization of thermal radiative properties of materials for cryogenics and space applications
- Near field heat transfer at low temperatures
- Quantum phase transitions in mesoscopic systems
- Design and optimization of special cryogenic systems
- Design of special superconducting magnet systems

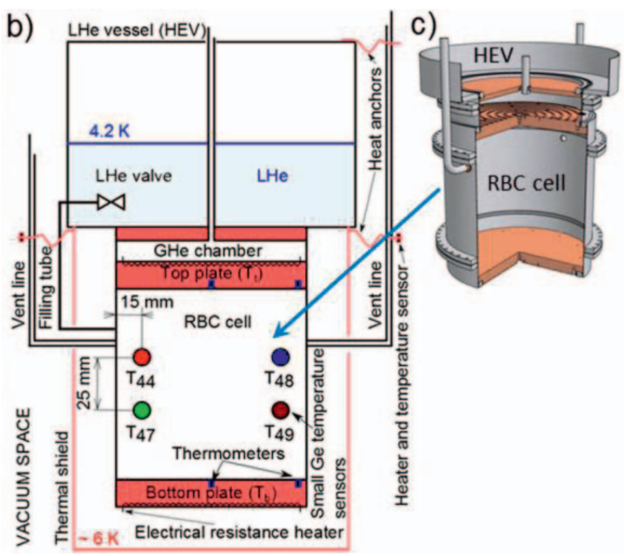
Mission

- Deeper understanding of turbulence - one of unsolved problems of modern physics on both classical and quantum levels
- Experimental verification of theory of near field heat transfer
- Expanding of our unique material database of thermal radiative properties and understanding the impacts of surface treatment on emission or absorption of thermal radiation
- Analysing of thermal conductivity of insulating materials, especially those used in multilayer insulations
- Theoretical understanding of quantum phase transitions - structural changes in mesoscopic systems, like atomic nuclei, molecules and low-dimensional crystals at zero temperature

UP-TO-DATE ACTIVITIES

Research orientation

- Modelling of natural turbulent flows at extreme dynamical conditions in table-top experiments using cryogenic helium within the paradigmatic model system – the Rayleigh-Bénard Convection (RBC)
- Studying transitions between different regimes of classical RBC flows at extreme values of Rayleigh numbers, and determining respective heat transfer scaling laws
- Understanding connections between the classical and quantum turbulence via theoretical and experimental analyses of heat transfer laws
- Radiative heat transfer over a microscopic gap exceeds the black body limit by the effect of near field. The gaps are down to tens of micrometres at low temperatures. Superconductivity affects the heat transfer in the near field regime
- Temperature dependence of emissivity and absorptivity of various metallic and non-metallic materials



a) Experimental cryostat developed at ISI Brno for studies of RBC in a very wide range of Rayleigh numbers
b) Schematic depiction of the He parts of the cryostat
c) Section through a 3D model of the existing cryogenic RBC cell

- Developing group theoretical models to study collective dynamics in mesoscopic systems, which display quantum phase transitions

Main capabilities

Basic research

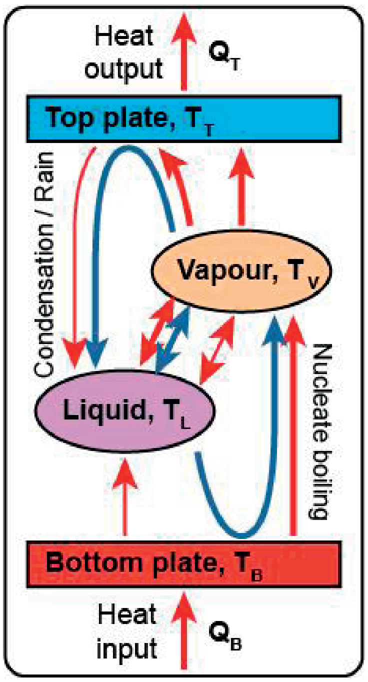
- Research activities at our unique experimental facilities for study of turbulent Rayleigh-Bénard natural convection. Our two helium cryostats allow to study natural turbulent flows up to very high Rayleigh number about Ra~1e15, utilizing the cryogenic helium gas (up to 3 bars). The first one contains a cylindrical fixed geometry (30 cm diameter, aspect ratio one) Rayleigh-Bénard cell of arguably one of the best designs so far. The second one contains a cylindrical (10 cm diameter) Rayleigh-Bénard cell with continuously adjustable geometry.
- Study of the radiative heat transfer over a microscopic gap between various thin films on dielectric substrates with variable temperatures (5 K – 15 K for the colder sample and 9 K – 60 K for the hotter sample). The results measured on plane parallel configuration are directly compared with existing theories.
- Collaboration with CERN on the cryogenic part of the project NA58 "COMPASS". The main goal of the experiment is the study of hadron structure and hadron spectroscopy via interactions between low temperature polarised target and high intensity muon and hadron beams.

Applied research

- Design of special thermal insulation pads, characterized by low thermal conductance, high mechanical stiffness and small dimensions. These pads are used in UHV SEM/SPM microscopy as sample holders at variable temperatures (20 – 700 K).
- Design of flow cooling systems using cryogenic helium (5 K) or nitrogen (77 K) as a coolant. Systems consist of a flow cryostat and a flexible low-loss transfer line connecting a Dewar vessel with the flow cryostat.
- Analysis of thermal conductivity performance of insulating materials under controlled conditions
- Assessment of a given surface´s ability to emit/absorb radiation energy in a wide range of temperatures of thermal radiation source
- Determination of electrical resistivity by cryogenic four point probe up to room temperature (thin layers, foils, sheets)

Sub-fields of group activities

- Materials science (study of physical properties of materials used in cryogenics and space)
- Two-phase cryogenic convection
- Special measuring instruments for cryogenics
- Low temperature thermometry
- Cryogenic safety

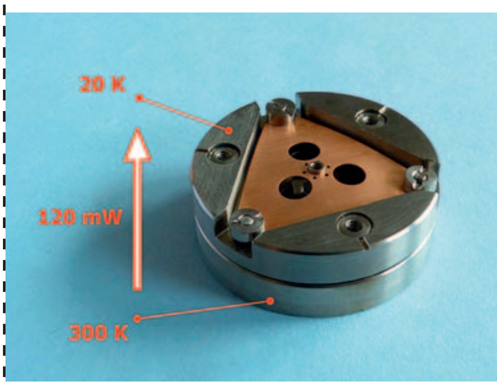


Schematic illustration of heat flows (red arrows) and mass flows (blue arrows) in two-phase He vapour-liquid system

KEY RESEARCH EQUIPMENT

List of devices

- Helium liquefier L1410 (Linde Process Plants) with 500 l Dewar, 18 l of liquid helium per hour, complete helium recovery system for helium gas savings
- Helium Dewars with up to 50 mm neck diameter and 30 – 100 litre volumes
- Precise NMR magnetometer PT 2025 (Metrolab Instrum.), range 0.7 – 13.7 T
- Low temperature controllers Lakeshore (Model 340, 350, 372, 332, 218) for precise temperature measurement and control with different sensor types
- Helium leak detector ASM 310 (Adixen Vacuum Products)
- Mass spectrometer PrismaPlus (Pfeiffer Vacuum) up to mass number A=100
- Apparatuses for research of near-field and far-field radiative heat transfer made by the research team
- Thermal conductivity meter, made by the research team, for analysis of various insulating materials



Thermal insulation pad (InBallPad)

– Special apparatuses for study of natural thermally driven convection using cold helium gas (ConEV) made by the research team
– Unique small helium bath cryopump made by the research team

ACHIEVEMENTS

We contributed to elucidation of the thermally driven turbulence processes and developed special cryogenic apparatuses for characterization of thermal radiative properties of materials at low temperatures. We published about 30 papers in impacted journals with very good citation response and about 25 contributions in conference proceedings or local journals in last five years. Our research results has had impact on the space research.

For more details and publications see www.cryogenics.isibrno.cz

The most important results:

Ultimate state of turbulent natural convection/RBC
– L. Skrbek, P. Urban: "*Has the ultimate state of turbulent thermal convection been observed?*", J. Fluid Mech. **785**, 270–282, 2015
– P. Urban, P. Hanzelka, T. Králík, V. Musilová, A. Srnka, L. Skrbek: "*Reply: Effect of Boundary Layers Asymmetry on Heat Transfer Efficiency in Turbulent Rayleigh-Bénard Convection at Very High Rayleigh Numbers*", Phys. Rev. Lett. **110**, 199402, 2013
– P. Urban, P. Hanzelka, V. Musilová, T. Králík, M. La Mantia, A. Srnka, L. Skrbek: "*Heat transfer in cryogenic helium gas by turbulent Rayleigh-Bénard convection in a cylindrical cell of aspect ratio 1*", New J. Phys. **16**, 053042, 2014

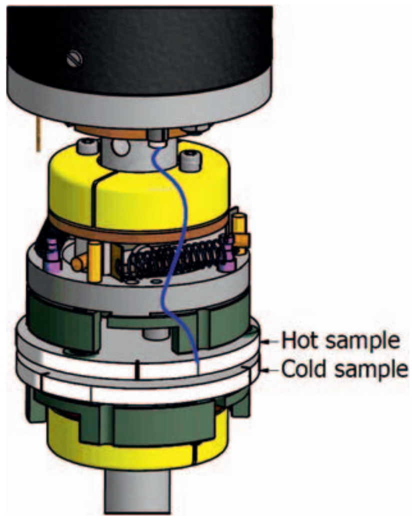
Two-fluid convection
– P. Urban, D. Schmoranzer, P. Hanzelka, K.R. Sreenivasan, L. Skrbek: "*Anomalous heat transport and condensation in convection of cryogenic helium*", Proc. Natl. Acad. Sci. USA **110** (20), 8036-8039, 2013

Thermal insulation pad (InBallPad) for a sample holder of UHV SEM/SPM microscope
– P. Hanzelka, J. Voňka, V. Musilová: "*Low conductive support for thermal insulation of a sample holder of a variable temperature scanning tunneling microscope*", Rev. Sci. Instrum. **84**, 085103, 2013

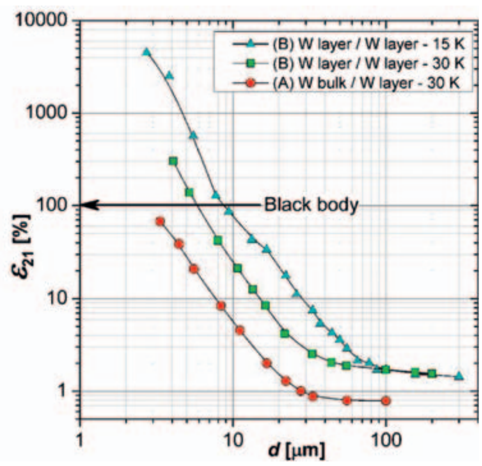
Investigation of radiative heat transfer by near-field effect at low temperatures
– T. Králík, P. Hanzelka, M. Zobač, V. Musilová, T. Fořt, T.; M. Horák: "*Strong near-field enhancement of radiative heat transfer between metallic surfaces*", Phys. Rev. Lett. **109**, 224302, 2012

Emissivity and absorptivity at low temperatures
– T. Králík, V. Musilová, P. Hanzelka, J. Frolec: "*Method for measurement of emissivity and absorptivity of highly reflective surfaces from 20 K to room temperatures*", Metrologia **53**, 743-753, 2016

Thermal properties of spacers for multilayer insulation
– The unique apparatus for thermal characterization of materials used as spacers under precisely controlled compression was designed. Apparatus measures simultaneously heat transfer by conduction and radiation across sample.

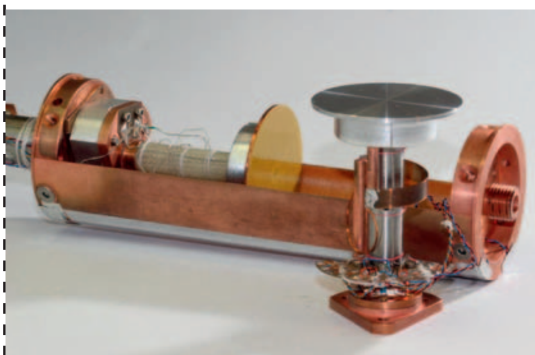


Schematic view of the measuring part of the near-field apparatus



Example plot of normalized emissive power versus gap between samples

Opened chamber of the far field apparatus



- **Formulation of a unified theory of excited state quantum phase transitions in systems with low number of degrees of freedom in a series of papers:**

– P. Stránský, M. Macek, A. Leviatan, P. Cejnar,: "*Excited-state quantum phase transitions in systems with two degrees of freedom II: Finite-size effects*", Ann. Phys. **356**, 57, 2015
– P. Stránský, M. Macek, P. Cejnar: "*Excited-state quantum phase transitions in systems with two degrees of freedom: Level density, level dynamics, thermal properties*", Ann. Phys. **345**, 73, 2014

MAIN COLLABORATING PARTNERS

Collaboration with academic partners

- CERN (Geneva, Switzerland)
- Technical University Ilmenau (Ilmenau, Germany)
- New York University (New York, USA)
- Yale University (New Haven, USA)
- Hebrew University (Jerusalem, Israel)
- Florida University (Gainesville, USA)
- Institut Néel CNRS/UGA (Grenoble, France)
- Charles University (Praha, CZ)
- Brno University of Technology (Brno, CZ)
- Masaryk University (Brno, CZ)
- Palacky University (Olomouc, CZ)

Collaboration with companies

- RUAG Space GmbH (Vienna, Austria)
- Frentech Aerospace s.r.o. (Brno, CZ)
- TESCAN, s.r.o. (Brno, CZ)
- Chart Ferox, a.s. (Děčín, CZ)

EXPECTATIONS

Offers

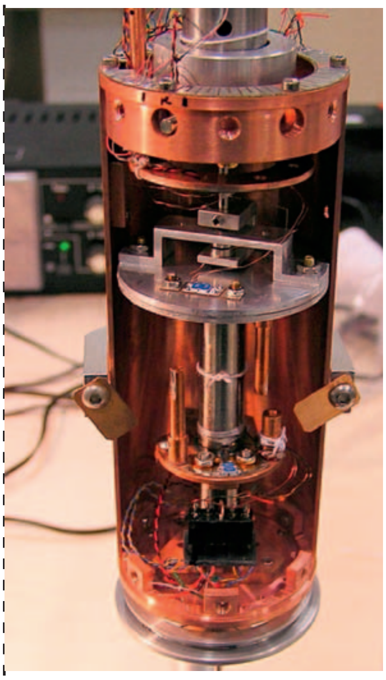
We offer partnership in international projects and collaboration in the areas of our expertise, namely:

- Development, optimization and design of special cryogenic devices
- Calculation and measurement of parasitic heat flows at cryogenic temperatures
- Theoretical and experimental studies based on thermally driven cryogenic turbulence
- Measurements of low temperature properties of materials (electrical and thermal conductivities, emissivity and absorptivity of thermal radiation) in the range 4.2 – 320 K
- Cryogenic cooling systems, calculation of cooling capacities of different liquids and gases
- Low temperature measurement and its accuracy determination
- Vacuum in cryogenic systems
- Expertise in cryogenic safety, training in cryogenic safety
- Research activities under the EuHIT consortium (www.euhit.org), integrating cutting-edge European facilities for turbulence research.

Requirements

We look for cooperation with academic partners as well as companies in the fields:

- Radiative heat transfer (metrology, standardization)
- Partners for EU research projects in the field of cryogenic helium turbulence
- Co-operative research and development of new materials for the thermal insulation of cryogenic systems
- Collaboration with industrial partners on common projects dedicated to applied science in the field of cryogenics (e.g. special cryogenic devices)



Sample sandwiched between two discs - hot radiator and cold absorber in the thermal conductivity meter

Examples of spacers installed on the absorber