Group of Cryogenics and Superconductivity

Department of Magnetic Resonance and Cryogenics

Institute of Scientific Instruments
The Czech Academy of Sciences

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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

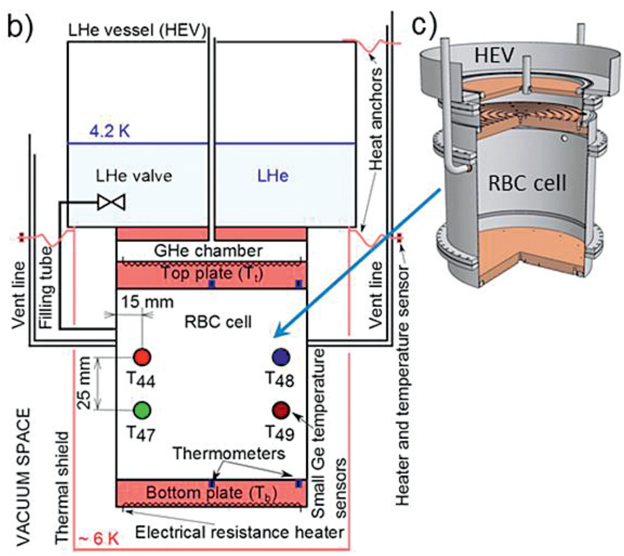
Mission

- 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 how they are affected by surface topology and its treatment
- 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 stationary or rotating conditions and different boundary conditions (constant or harmonically modulated temperatures, constant heat flux) in table-top experiments using cryogenic helium within the paradigmatic model system – the Rayleigh-Bénard Convection (RBC). Study of heat and mass flows in two-phase 4He vapour-liquid RBC system
- 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
- Low temperature measurements of near field radiative heat transfer between metals beyond Planck's black-body limit. Effect of superconducting transition on the near field radiative heat transfer



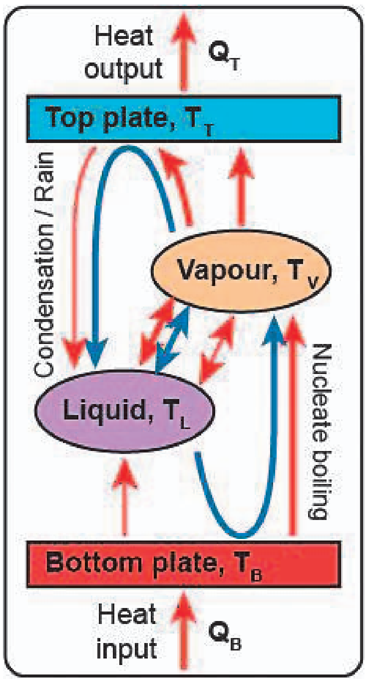
a) Experimental cryostat developed at ISI Brno for studies of RBC in a very wide range of Rayleigh numbers
b) Schematic depiction of the He parts of the cryostat
c) Section through a 3D model of the existing cryogenic RBC cell

- Systematic measurements of cryogenic emissivities and absorptivities of various materials with primary focus of further developing our unique public database
- Developing group theoretical models to study collective dynamics in mesoscopic systems, which display quantum phase transitions

Main capabilities

Basic research

- Many systems found in Nature, like interiors of giant planets and, rapidly rotating stars, the Earth's outer liquid core, as well as open ocean deep convection are affected by thermal forcing and also by rotation. Stationary and rotating Rayleigh-Bénard convection (RBC) represents a universally recognized physical model used to study flows affected by both forces. The objective of our research is to measure and model the stationary and rotating RBC at extreme values of the control parameters, the Rayleigh (Ra) and the Ekman number (Ek) number. Our laboratory is equipped with a unique RBC apparatus with rotating platform, using cryogenic helium gas (5 K) as a working fluid, allowing to reach of the following dimensionless control parameters: 1E6 < Ra < 1E15 and 1E-8 < Ek < 1E-5
- Study of the near-field radiative heat transfer over a microscopic gap between various thin films including superconducting ones 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 present theory
- Collaboration with CERN on the cryogenic part of the project NA58 "COMPASS". Project studies hadron structure and spectroscopy via interactions between low temperature target and high intensity muon and hadron beams



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

Applied research

- Assessment of thermal emissivities and absorptivities of different surfaces that are essential for ground-based cryogenics and space applications, covering various materials and wide range of temperatures
- 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

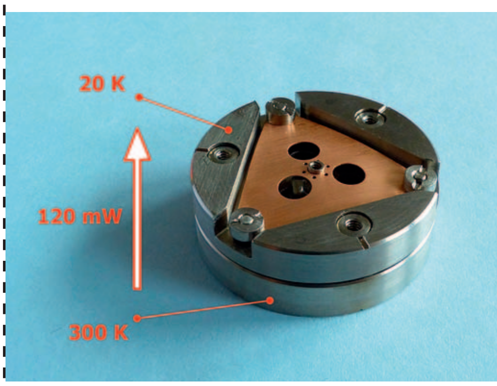
Sub-fields of group activities

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

KEY RESEARCH EQUIPMENT

List of devices

- Helium cryostat for study of natural turbulent flows up to very high Rayleigh number about Ra ~1E15, utilizing the cryogenic helium gas (up to 3 bars) in a cylindrical (30 cm diameter and height, aspect ratio one) Rayleigh-Bénard cell
- Unique small helium bath cryopump made by the research team
- 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
- Low temperature controllers Lakeshore (Model 340, 350, 372, 332, 218) for precise temperature measurement and control with different sensor types



Thermal insulation pad (InBallPad)

– 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

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 http://www.isibrno.cz/en/cryogenics-and-superconductivity

The most important results:

Ultimate state of turbulent natural convection/RBC
– P. Urban, P. Hanzelka, T. Králík, M. Macek, V. Musilová and L. Skrbek: *"Elusive transition to the ultimate regime of turbulent Rayleigh-Bénard convection."* Physical Review E **99**, 011101(R), 2019
– 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

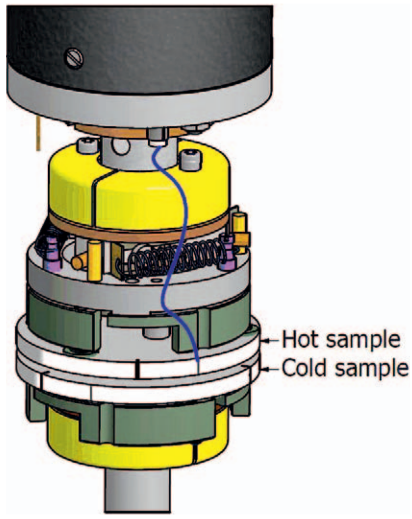
Two-fluid convection
– P. Urban, D. Schmoranzer, P. Hanzelka, K. R. Sreenivasan, L. Skrbek: "*Anomalous heat transport and condensation in convection of cryogenic helium",* Proc. Natl. Acad. Sci. USA **110** (20), 8036–8039, 2013

Thermal insulation pad (InBallPad) for a sample holder of UHV SEM/SPM microscope
– P. Hanzelka, L. Dupák, V. Krutil, V. Krzyžánek, R. Skoupý, A. Srnka, I. Vlček, P. Urban: *"Low conductive thermal insulation pad with high mechanical stiffness."* Int. Journal of Refrigeration **132**, 92–99., 2021

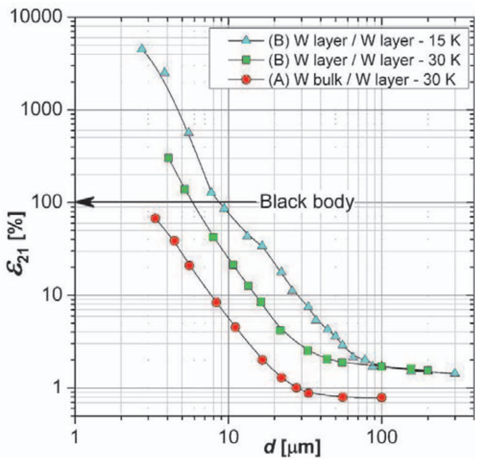
Investigation of radiative heat transfer by near-field effect at low temperatures
– V. Musilová, T. Králík, T. Fořt, M. Macek: *"Strong suppression of near-field radiative heat transfer by superconductivity in NbN."* Physical Review B **99**, 024511, 2019

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
– J. Frolec, T. Králík, V. Musilová, P. Hanzelka, A. Srnka, J. Jelínek: *"A database of metallic materials emissivities and absorptivities for cryogenics."* Cryogenics **97**, 85–99, 2019

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

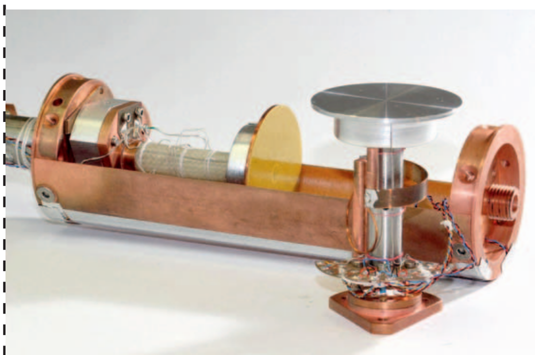


Schematic view of the apparatus for near-field heat transfer measurement



Example plot of normalized emissive power versus gap between samples

Opened chamber of the apparatus for measurement of thermal emissivities and absorptivities



- **Unified theory of excited state quantum phase transitions in systems with low number of degrees of freedom:**
  - P. Cejnar, P. Stránský, M. Kloc, M. Macek: *"Excited-state quantum phase transitions."* Invited Review, Journal of Physics A: Mathematical and Theoretical **54**, 133001, 2021

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 State University (Tallahassee, 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)
- ESA´s European Space Research and Technology Centre (Noordwijk, The NL)
- Frentech Aerospace s.r.o. (Brno, CZ)
- Chart Ferox, a.s. (Děčín, CZ)
- Thermo Fischer Scientific, s.r.o. (Brno, CZ)
- První brněnská strojírna, a.s. (Velká Bíteš, CZ)

EXPECTATIONS

Offers

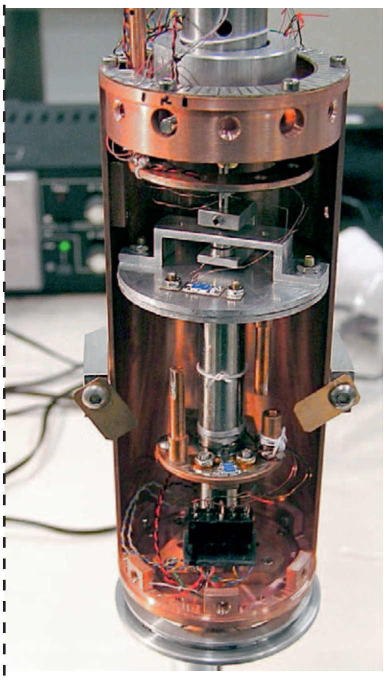
We offer partnership in international projects and collaboration in the areas of our expertise, namely:

- 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

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