



**Short Course at
International Vacuum Congress
10-11 September, 2022**



<https://ivc22.org>

Title: Vacuum Gas Dynamics: Theory, Experiments and Applications

Lecturers: Prof. Felix Sharipov, Federal University of Parana, Brazil
Prof. Irina Graur, Aix-Marseille University, France
Dr. Oleg Malyshev, Daresbury Laboratory, UK
Dr. Roberto Kersevan, CERN, Switzerland

Aims and motivations: The course is addressed to students, scientists and engineers who are not experts in Rarefied Gas Dynamics but who deals with this field in their routine work. The available textbook and handbooks on vacuum technology usually give just fundamentals of gas dynamics but not deep enough to understand the modern state of analytical and numerical methods of modelling in this field. The special literature is often too hard for non-experts. This short course targets at basic research training in Vacuum Gas Dynamics and provides a coherent and rigorous introduction into this field including relevant theoretical and experimental methods for practical applications. No preceding knowledge of gas dynamics is assumed.

Structure of the course: The course duration is 12 hours (2 days).

- “Theory and simulations”, 6 hours, given by Prof. Felix Sharipov and Prof. Irina Graur
- “Practical Applications”, 6 hours, by Dr. Oleg Malyshev and Dr. Roberto Kersevan

Topics:

- **Theory:** Molecular free path, gas rarefaction and flow regimes. Velocity distribution function. Gas-surface interaction. Accommodation coefficients. Free-molecular flows. Analytical solutions in the free-molecular limit. Test particle Monte Carlo method. Velocity slip and temperature jump conditions. Analytical solutions of the Navier-Stokes equations subject to the slip and jump conditions. Intermolecular interaction and kinetic equation. Flows in the transition regime. Discrete velocity method. Direct simulation Monte Carlo method. Main numerical solutions in the transitional regime with examples of their applications: Poiseuille flow, Couette flow, heat transfer. Transient flows. Numerical models of Holweck and turbo-molecular pumps. Numerical model of Pirani sensor. Rarefied flow calculator. Modelling of gas dynamics processes in vacuum chambers.
- **Applications:** Design of large UHV vacuum systems in free molecular flow regime. Vacuum specification and input parameters. Experimental data: measurements, data analysis, extrapolation and using. Models: overview of different models used with an emphasis on 1D diffusion analytical model and numerical models (test particle Monte Carlo and angular coefficients), pumps and sources of gas in different models. From a model to a mechanical design. Analysis of errors and uncertainties in a final design. Examples of design.

Didactic material: The participants will get hard and electronic copies of presentations and numerical codes to solve basic problems of vacuum gas dynamics.

Information about the lecturers:



Prof. Felix Sharipov graduated from the Moscow University of Physics and Technology, Faculty of Aerophysics and Space Research in 1982. He obtained his Ph.D. in 1987 at the Ural State Technical University. In 1988 he joined the Physics Faculty of the Ural State University where he set up his activity in rarefied gas dynamics. In 1992 he moved to the Federal University of Parana in Brazil where he built up a group on numerical modelling of gas flows in microscale. His research interests are numerical methods of rarefied gas dynamics applied to microfluidics, vacuum technology and aerothermodynamics. His group develops both probabilistic and deterministic approaches. He was an organizer of numerous vacuum gas dynamics meetings and schools. F. Sharipov published over a hundred journal articles, several reviews and chapters in handbooks. He is an author of two books and a member of editorial board of "Vacuum" (Elsevier).



Prof. Irina Graur obtained M.Sc. in applied mathematics in 1984 from Moscow Lomonossov State University. She received a PhD also from Moscow State University in 1989 and the Habilitation from Provence University in France in 2008. Irina Graur was associate professor at Keldish Institute of Applied Mathematics between 1984 and 2000. She is currently professor at Aix Marseille University in France. She has made a number of contributions in the field of rarefied gases for the aerospace research. Her current research interests include the experimental and numerical characterization of the gas properties at micro and nano scales. She heads the research group "Non-equilibrium phenomena and microfluidic" in IUSTI Laboratory. She participated in the organization of a number of international conferences, workshops and summer schools. She has co-authored more than one hundred journal articles and conference papers.



Dr. Oleg Malyshev was graduated in the Physics Department at the Novosibirsk State University in 1989. He started his carrier as a vacuum scientist at the Budker Institute of Nuclear Physics where he obtained his Ph.D. in 1995. His work includes theoretical studies, experimental research and design of various vacuum systems such as VEPP-5, ANKA, BESSY, SSC. From 1998 to 2001, he worked at CERN designing the LHC beam vacuum system. Since 2001 he works in ASTeC at STFC Daresbury Laboratory, he designed a vacuum system for Diamond Light Source, participated in R&D for International Linear Collider, FAIR, KATRIN, NLS, ALICE, etc. He leads experimental and analytical study in ASTeC Vacuum Science Group. He is an editor of international scientific journal VACUUM (Elsevier), an organizer of international workshops, meetings, an author of more than 160 scientific papers and reports. He is a Chartered Physicist and a Fellow of Institute of Physics.



Roberto Kersevan graduated in physics at the University of Trieste, Italy, in 1985. After initial work on the design of the ELETTRA light source from 1988 to 1992, he moved to the SSC Laboratory in Dallas, for the design of the storage rings' cryogenic vacuum system. He then moved to Wilson Lab. of Nuclear Studies, Cornell University, to work on the upgrade of the vacuum system of the e^-e^+ collider CESR. In 1997 he took up the position of head of the vacuum group at the ESRF in Grenoble, France, where he remained until 2009. In 2004 he took a one-year sabbatical leave to work on the installation of the cryomodules of the linac of the SNS, ORNL laboratory, Oak Ridge, USA. Between 2009 and 2011 he worked at the ITER thermonuclear fusion project, Cadarache, France, in the vacuum pumping group. He then joined the Vacuum Surfaces and Coatings group at CERN, where he is now Senior Applied Physicist. He is mostly known for the development of the ray-tracing monte-carlo codes Molflow+ and SYNRAD+, the latter being used for synchrotron radiation studies. He was the original developer of non-evaporable getter vacuum chambers on light sources since the year 1999. He has been and still is member of the machine advisory committee of 7 light sources, and reviewer for other accelerator projects.

Experimental characterization of the gas-surface interaction.

Relations between theoretical and experimental approaches. Experimental data analysis.