**THERMOPHYSICAL PROPERTIES OF
FLUIDS AND FLUID MIXTURES**

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I. INTRODUCTION

This report covers research supported by DE-FG02-95ER-14509 during the period from December 15, 1994 through March 14, 2004.

A major goal of this project was to study the effects of fluctuations on the thermophysical properties of fluids. Long-range fluctuations appear in fluids because of the presence of critical phase transitions. In the first phase of the project we considered the effects of critical fluctuations on the thermodynamic properties and transport properties of molecular fluids and fluid mixtures. In the second phase of the project we extended the research to complex fluids where critical fluctuations may compete with a length scale associated with nano- or mesoscopic structures. Fluctuations in fluids in thermal nonequilibrium states have also been considered.

II. RESEARCH ACCOMPLISHMENTS

A list of publications supported by DOE Grant DE-FG02-95ER-14509 is presented in Section IIIA. Section IIIB gives a list of invited presentations and Section IIIC a list of contributed presentations related to the research project.

2.1. Critical fluctuations in molecular fluids

2.1.1. Thermodynamic properties

It has been well established that the thermodynamic properties of fluids in the near vicinity of critical points satisfy scaling laws with universal critical exponents and universal scaling functions [43,44]*. However, the correlation length of the critical fluctuations exceeds the short-range molecular interaction range in a sizable part of the phase diagram of fluids and fluid mixtures. As a result the thermodynamic properties (as well as the transport properties) are affected by the presence of critical fluctuations over a wide range of temperatures and densities. In one-component fluids near the vapor-liquid critical point the critical fluctuations are fluctuations in the density. More generally, in fluid mixtures both density and concentration fluctuations are present.

To deal with the effects of these fluctuations on the thermophysical properties we have developed a global approach to the treatment of critical fluctuations wherever they are significant. For this purpose one needs to account for a crossover from fluctuation-dominated behavior near the critical point to mean-field behavior far away from the critical point where the fluctuations have become negligibly small. Our approach to describe this crossover behavior of the thermodynamic properties of fluids is based on a transformed Landau expansion for the Helmholtz-energy density that includes the effects of critical fluctuations [4,11,31,43,44,50,52]. We have used this approach to formulate equations for the thermodynamic properties of a variety of fluids in the critical region such as sulfurhexafluoride [37], light and heavy steam [6,29,42,47,48], refrigerants like R152a [1] and ammonia [20,35].

* Numbers between square brackets refer to the publications listed in Section III.A.

We further developed a parametric version of the crossover equations of state with improved agreement with the theoretical universal values of the amplitudes and correlation-to-scaling amplitudes of the critical power laws [50,52].

Our crossover Landau expansion has also been used to represent the thermodynamic properties of some binary fluid mixtures that have a continuous locus of vapor liquid critical points, namely, mixtures of methane and ethane [10], mixtures of H_2O and D_2O [49,57] and aqueous solutions of NaCl [14,17,21,28,39].

We have generalized the principle of isomorphism of critical behavior to binary fluids with complex phase diagrams [3]. This encompasses from a unified point of view the asymptotic critical behavior near vapor-liquid critical points or plait points, near consolute points in incompressible liquid mixtures, near critical endpoints, near re-entrant critical points and near maxima or minima on critical loci. We have illustrated how the theory can be used to estimate the thermodynamic properties of mixtures of methane and *n*-hexane near their critical end points [15] and to describe closed solubility loops in partially miscible liquid-liquid mixtures [64]. We have also used the crossover theory to examine the effect of small impurities on the two-phase isochoric heat capacity near the critical point. In particular, the slope of the so-called Yang-Yang plots, that are used to relate the heat capacity to the second derivatives of pressure and chemical potential with respect to temperature, appears to be very sensitive to small levels of impurities [56].

In addition we have shown how the results of a crossover Landau expansion can be used to develop a procedure for incorporating the effects of critical fluctuations in simple classical equations of state [27,30,31,33,69]. Application of the procedure to the classical equation of state of Van der Waals yields a quantitative illustration of how critical fluctuations

lower the critical temperature, flatten the coexistence curve, strengthen the divergent behavior of the compressibility, and induce a singularity of the isochoric heat capacity [69].

The critical crossover behavior is governed by two physical parameters: a reduced coupling constant $\bar{u}$ which is related to the range of the molecular interactions and a reduced cutoff wave number Λ , related to the size of the microscopic structure of the system which for molecular fluids can be identified with the cube root of the molecular volume [52]. In applying a crossover Landau expansion to represent experimental property data, $\bar{u}$ and Λ are in practice used as adjustable parameters [4,19]. Recently, it has become possible to determine the susceptibility and the order parameter of the three-dimensional Ising model as functions of both the interaction range and the temperature from computer simulations. For the case of the Ising model, unlike the case of fluids, all system-dependent properties are known *a priori*, including the cutoff wave number (equal to the inverse of the cell size) and the coupling constant (inversely proportional to the fourth power of the range of interactions). Hence, we have been able to apply our crossover theory to the Ising model without any adjustable parameters [65]. In the one-phase region above the critical temperature excellent agreement was obtained with the numerical data for the susceptibility of the Ising model over eight decades in terms of the relevant reduced temperature variable. Below the critical temperature along the phase boundary some systematic deviations could be noticed, but they are still small compared to the accuracy with which the susceptibility (or, equivalently, the compressibility of fluids) and the order parameter along the phase boundary can be measured experimentally. This represents a major result that justifies the use of our crossover equation of state for representing thermodynamic-property data of fluids in the critical region. We quote from the report of the referee: "The present work is a true scientific highlight."

2.1.2. Transport properties

To deal with the global critical crossover behavior of the transport properties of fluids we have extended the mode-coupling theory originally developed for dealing with the effects of critical fluctuations on the dynamic behavior of fluids in the near vicinity of the critical point [2,7,8]. We have applied the theory to develop equations for the transport properties of R152a [9], of methane [12,13], of mixtures of ethane and carbon dioxide [8], and of mixtures of ethane and methane [12,18,25]. We have also elucidated the coupling between the decays of density fluctuations and concentration fluctuations in compressible fluid mixtures near the critical vapor-liquid critical line [23].

2.2. Critical and tricritical phenomena in polymer solutions

2.2.1. Crossover theory

While our earlier work focused on critical fluctuations in molecular fluids, subsequently we have made a concentrated effort toward understanding critical phase-separation phenomena in polymer solutions [19,36,45,58–60,71,77,78]. Unlike molecular fluids, polymer solutions contain not only a molecular length scale associated with the size of a monomer but also a mesoscopic length scale related to the radius of gyration. The presence of such a mesoscopic length scale has a major effect on the critical phase-separation behavior of polymer solutions [41,55]. As the polymer weight increases, so does this mesoscopic length scale. The locus of

critical points of phase separation, considered as a function of the molecular weight, ends at very large molecular weights in the Θ -point that is actually a tricritical point as originally pointed out by de Gennes. Hence, one needs to account not only for a crossover from critical fluctuation-induced behavior to mean-field behavior but also for a crossover from Ising-like criticality to tricriticality. We have also solved the latter problem, which was earlier identified by Widom as a major outstanding problem in the theory of phase transition.

It turns out that our crossover Landau theory for molecular fluids can be extended to include also crossover from criticality to tricriticality [36,45,59,77]. The difference with molecular fluids is that the cutoff parameter in the crossover theory now can be related to the appropriate mesoscopic length scale, which acts as a correlation length of a competing order parameter. As the Θ -point is approached, both the correlation length of the critical concentration fluctuations and the mesoscopic length scale related to the radius of gyration diverge leading to tricritical behavior. We quote from the report of the referee for Ref. [59]: “In this paper, Hager *et al.* studied the scaling and critical behavior of a polymer solution based on a renormalization-group treatment. The manuscript not only demonstrates the theoretical aspects of the importance of the problem, but also gives an analysis of experimental data. I have read the manuscript twice and I highly recommend this manuscript for publication in JCP.”

2.2.2. Light-scattering experiments in polymer solutions

When we developed a global theory for the effects of critical fluctuation on the thermophysical properties for molecular fluids, we could draw on an extensive body of experimental data to test the theoretical predictions. This is not the case for complex fluids where the amount of reliable experimental data for the properties and phase behavior is rather limited. Hence, for complex fluids we decided to supplement our theoretical pursuits with an experimental research program. For this purpose we used a light-scattering technique that is ideally suited for measuring fluctuations at the relevant nanoscales and mesoscales.

We have established two light-scattering facilities in our laboratory. One is a compact setup suitable for measuring the sizes of particles suspended in solutions in the range from 0.001 to 5 μm , even when suspended in optically nontransparent fluids. A second, rather sophisticated, setup with a multi-tau correlator is capable of yielding high-resolution static and dynamic light-scattering measurements in well-characterized solutions. Specifically, we measured the intensity and the decay rate of light scattered from polystyrene solutions in cyclohexane with polymer molecular weights ranging from 200,000 up to as large as 11.4×10^6 [58,71,77,78]. From the intensity of the scattered light and its dependence on the scattering angle one can deduce the susceptibility and the correlation length of the polymer solutions. The experiments clearly demonstrate that the effective susceptibility exponent crosses over from its Ising value $\gamma = 1.24$ to its (mean-field) tricritical value of unity. Similarly, the effective exponent for the correlation length crosses over from its Ising value $\nu = 0.63$ to its (mean-field) tricritical value 0.5. Moreover, in each sample the crossover takes place at a

temperature where the correlation length closely tracks the radius of gyration in accordance with the prediction of our theory for the crossover from Ising critical behavior to tricritical behavior. Furthermore, the experiments have provided a beautiful confirmation of the validity of the dependence of the amplitudes of the critical power laws on the molecular weight M in the tricritical limit, as predicted by de Gennes. Past attempts of researchers to verify de Gennes' scaling have been hampered by the problem that one did not know how to distinguish between effective and truly asymptotic values of the exponents associated with the molecular weight dependence for large M . Further details will be presented in a forthcoming publication [77].

The measurements of the time-dependent correlation functions show for the larger molecular polymer weights the appearance of two dynamic modes: a "slow" mode and a "fast" mode that result from a coupling between diffusive relaxation of critical concentration fluctuations and viscoelastic relaxation associated with self-entanglement of the polymer chains [58]. The coupling leads to the phenomenon of "avoided crossing" of the two modes. As a consequence, the presence of a viscoelastic relaxation mode causes an additional slowing down of the critical fluctuations on top of the slowing down expected in the absence of the viscoelastic relaxation. This additional slowing down has a dependence on the wave number opposite to that of the usual slowing down of the critical fluctuations. Using a theory of crossover behavior from Ising criticality to Θ -point criticality for both static and dynamic properties, we were able to present a quantitative description of the phenomenon and obtained a scaling of the viscoelastic parameters as a function of the polymer molecular weight. We have demonstrated that light scattering of fluctuations in macromolecular solutions provides a method for microrheology that does not require the use of probes that may effect the environment of the macromolecules in solutions [58,78].

2.3. Aqueous electrolyte solutions

We have shown how our theory of crossover critical phenomena can account for the crossover behavior of the susceptibility of ionic solutions [4,11,34,75]. A sensitive test for checking crossover critical behavior is based on considering an effective crossover susceptibility exponent γ_{eff} , which is related to the third derivative of the Helmholtz-energy density. While in simple fluids γ_{eff} decreases gradually from its asymptotic value ($\gamma = 1.24$) upon increasing distance from the critical point [4], in aqueous electrolyte solutions this behavior is sharper and nonmonotonic. We attribute this phenomenon to strong short-range interactions related to hydrogen bonding.

There are some major outstanding issues concerning the nature of critical behavior of aqueous electrolyte solutions. Sometimes Ising-like fluctuation-induced behavior has been found and sometimes mean-field critical behavior, even for nominally the same systems depending on the sample sources. We have made an extensive study of the effect of salt as a solute in aqueous mixtures of 3-methylpyridine. Specifically, we have performed light-scattering measurement in critical samples with various concentration of NaBr. In this study, we paid attention to the achievement of thermodynamic equilibrium, hysteresis effects, aging and prehistory of the samples, and a possible role of impurities [75]. We have concluded that properly aged, equilibrium samples of aqueous solutions of 3-methylpyridine and NaBr exhibit Ising-like critical behavior with a nonmonotonic crossover to mean-field behavior similar to that observed in other aqueous solutions. However, we have also observed mesoscopic

nonequilibrium aggregates that are even more persistent in aqueous solutions without salt. This phenomenon appears to be reminiscent of anomalous behavior in aqueous solutions observed by other investigators. It is plausible that the energy landscape in aqueous solutions of 3-methylpyridine is such that states with nonequilibrium supramolecular structures can exist during time periods longer than the ordinary times for conducting light-scattering experiments. Further studies of the physical and chemical variables that govern the appearance of long-living nonequilibrium structures would be highly desirable.

2.4. Fluctuations in other complex fluids

In addition to studying polymer solutions and aqueous electrolyte solutions we have investigated critical fluctuations in liquid crystals [22,76], crossover kinetics of asphaltene aggregation in hydrocarbon solutions [24], and dynamics of gel formation and breakage in a biopolymer gel [66]. We have elucidated the nature of the mysterious blue-phase-III-isotropic critical point in a chiral liquid crystalline solution and shown that this critical point belongs to the same universality class as ordinary critical points in fluids [22]. The universality is revealed if one properly identifies the relation between the physical variables and the theoretical scaling fields.

We have also investigated pretransitional fluctuations in the isotropic phase of a lyotropic chromonic liquid crystal, an aqueous solution of cromolyn. By combining light-scattering and viscosity measurements we have determined the correlation length and relaxation time of the orientational order-parameter fluctuations and shown that the pretransitional fluctuations are accompanied by elongation of the cromolyn aggregates [76].

Using dynamic light scattering we have monitored the aggregation kinetics of asphaltene particles in hydrocarbon solutions and observed crossover from the reaction limited kinetics to the diffusion limited kinetics; this effect is associated with a coupling between processes of particle aggregation and molecular micellization in solution [24]. We have also performed a dynamic-light-scattering monitoring of formation and destruction of a transient gel formed by chitosan and gelatin [66]. The experiment has revealed an intrinsic symmetry in the kinetics of formation and destruction of the gel as a function of time provided that a proper temporal scale is used.

2.5. Nonequilibrium fluctuations

Long-range dynamic fluctuations caused by mode-coupling effects also appear in fluids in nonequilibrium states. Specifically, we have considered fluctuations in fluid layers subjected to a stationary temperature gradient [53,54,61,62,70,72]. In simple liquids the long-range fluctuations appear as a result of a coupling between temperature fluctuations and viscous fluctuations through the temperature gradient. In liquid mixtures and polymer solution long-range fluctuations are also caused by a coupling of concentration fluctuations and viscous fluctuations through the concentration gradient induced by the Soret effect [54].

It turns out that long-range dynamic fluctuations are ubiquitous in both classical and quantum statistical mechanics. During the reporting period we completed an analysis of the analogies between long-range dynamic fluctuations in classical nonequilibrium systems and similar phenomena in quantum statistical mechanics [63].

The above-mentioned fluctuations refer to fluids in thermal nonequilibrium states far away from any convective instability, *i.e.*, to fluid layers with a large negative Rayleigh number [54]. We have extended the theory to include the effects of gravity and of the boundary conditions for fluid layers confined between two parallel horizontal walls [53,61,62,70,72]. This extension of the theory enabled us to describe fluctuations of fluids in stationary nonconvective thermal nonequilibrium states with positive values of the Rayleigh number close to the appearance of the Rayleigh-Bénard convective instability. We predict that close to the Rayleigh-Bénard instability the nonequilibrium structure factor as a function of the wave number q will exhibit a crossover from a $1/q^4$ dependence for larger wave numbers to a q^2 dependence for very small wave number [53,61,70]. This prediction is a new one and goes beyond the implications of the generally accepted Swift-Hohenberg theory for fluctuations in fluids near the convective instability [61].

Finally we investigated the long-time behavior of the trajectories of Brownian particles in molecular fluids [51]. The experiments showed that Brownian motion exhibits a positive dynamic entropy consistent with the modern concept of microscopic chaos.

2.6. Reviews

As part of this project we completed a number of scholarly reviews on crossover critical phenomena in molecular fluids [43,44] and in complex fluids [41,55,74], on transport properties of fluids in the critical region [7], on the near-critical behavior of aqueous systems at high temperatures [73], and on nonequilibrium concentration fluctuations in liquid mixtures [54].

2.7. International collaborations

The research on the thermodynamic properties of H_2O and D_2O and of mixtures of H_2O and D_2O , as well as the critical behavior of aqueous systems at high temperature, is part of an international research program coordinated by the International Association for the Properties of Water and Steam (IAPWS). Our equation for the critical locus of aqueous solution of sodium chloride [39] was adopted as a Guideline by IAPWS. The research on transport properties of fluids is part of a research program coordinated by the International Union of Pure and Applied Chemistry (IUPAC) and of the International Association for Transport Properties (IATP).

2.8. Ph.D. and M.S. degrees

Eleni Sakonidou, Ph.D., physics, 1996

Anoop Singh, M.S., chemical engineering, 1998

Thomas A. Edison, Ph.D., chemical engineering, 1998

Anna Kostrowicka Wyczalkowska, Ph.D., physics, 1998

Vakhtang A. Agayan, Ph.D., chemical physics, 2000

Yingtao Wang, M.S., chemical engineering, 2002

Sarvin Moghaddam, Ph.D., chemical engineering, 2003

2.9. Awards

During the reporting period the PI and the Co-PI received a number of awards based on research supported by DOE:

Jan V. Sengers

Citation Award for advancement of the engineering profession in the field of utility and industrial steam generation, ASME Research and Technology, Committee on Water and Steam in Thermal Power Systems	1996
Elected Fellow of American Society of Mechanical Engineers	1996
Elected Fellow of American Institute of Chemical Engineers	1999
Elected Honorary Fellow of the International Association for the Properties of Water and Steam	2000
Elected Fellow of the World Innovation Foundation	2002
Elected Academician Emeritus of the International Academy of Refrigeration of the Russian Federation	2002
Elected Fellow of International Union of Pure and Applied Chemistry	2004

Mikhail A. Anisimov

Elected Fellow of American Physical Society	1998
Elected Fellow of American Association for the Advancement of Science	2002
Elected Academician of International Academy of Refrigeration (Ukrainian Division)	2004

III.A. PUBLICATIONS SUPPORTED BY DOE GRANT DE-FG02-95ER-14509

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10. A. A. Povodyrev, G. X. Jin, S. B. Kiselev, and J. V. Sengers, "Crossover equation of state for the thermodynamic properties of mixtures of methane and ethane in the critical region", *Int. J. Thermophys.* **17**, 909-944 (1996).
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15. H. Y. Cheng, M. A. Anisimov, and J. V. Sengers, "Prediction of thermodynamic and transport properties in the one-phase region of methane+n-hexane mixtures near critical end points", *Fluid Phase Equilibria* 128, 67-96 (1997).
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65. Y. C. Kim, M. A. Anisimov, J. V. Sengers, and E. Luijten, "Crossover critical behavior in the three-dimensional Ising model", *J. Stat. Phys.* 110, 591-609 (2003).

66. A. H. Krall and J. V. Sengers, "Simultaneous measurement of viscosity and density with an oscillating disk instrument: The effect of fixed plates", *Int. J. Thermophys.* **24**, 337-359 (2003).
67. S. Moghaddam, Finite-Discretized Lattice Models", Ph.D. Thesis (Department of Chemical Engineering, University of Maryland, College Park, MD, 2003).
68. A. F. Kostko, T. Chen, G. F. Payne, and M. A. Anisimov, "Dynamic light-scattering monitoring of a transient biopolymer gel", *Physica A* **323**, 124-138 (2003).
69. A. Kostrowicka Wyczalkowska, J. V. Sengers, and M. A. Anisimov, "Critical fluctuations and the equation state of Van der Waals", *Physica A* **334**, 482-512 (2004).
70. J. Oh, J. M. Ortiz de Zárate, J. V. Sengers, and G. Ahlers, "Dynamics of fluctuations in a fluid below the onset of Rayleigh-Bénard convection", *Phys. Rev. E* **69**, 021106 (2004), 13 pp.
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72. J. M. Ortiz de Zárate and J. V. Sengers, "On the physical origin of long-ranged fluctuations in fluids in thermal nonequilibrium states", *J. Stat. Phys.* **115**, 1363-1381 (2004).
73. M. A. Anisimov, J. V. Sengers, and J. M. H. Levelt Sengers, "Near-critical behavior of aqueous systems", in *Aqueous Systems at Elevated Temperatures and Pressures: Water, Steam and Hydrothermal Solutions*, D. A. Palmer, R. Fernández-Prini, and A. H. Harvey, eds. (Elsevier, Amsterdam), pp. 29-71.
74. M. A. Anisimov, "Thermodynamics at the meso- and nanoscale", in *Encyclopedia of Nanoscience and Nanotechnology* (Marcel Dekker, New York, 2004).
75. A. F. Kostko, M. A. Anisimov, and J. V. Sengers, "On the nature of criticality in aqueous solutions of 3-methylpyridine and sodium bromide", *Phys. Rev. E*, submitted.
76. Yu. A. Nastishin, H. Liu, S. V. Shiyanovskii, O. D. Lavrentovich, A. F. Kostko, and M. A. Anisimov, "Pretransitional fluctuations in the isotropic phase of a lyotropic chromonic liquid crystal", *Phys. Rev. E*, to be submitted.
77. A. F. Kostko, M. A. Anisimov, and J. V. Sengers, "Crossover from critical to tricritical behavior in polymer solutions I: Statics", in preparation.
78. A. F. Kostko, M. A. Anisimov, and J. V. Sengers, "Crossover from critical to tricritical behavior in polymer solutions II: Dynamics", in preparation.

IIIB. INVITED PRESENTATIONS

J. V. Sengers, "Universality of Critical Phenomena in Fluids and Fluid mixtures", University of Amsterdam, The Netherlands, March 15, 1995.

J. V. Sengers, "Fluctuations in Dissipative Liquid Systems Subjected to a Stationary Temperature Gradient", Oak Ridge National Laboratory, Oak Ridge, TN, April 10, 1995.

J. V. Sengers, "Critical Phenomena in Fluids and Fluid Mixtures", Department of Chemical Engineering, University of Tennessee, TN, April 11, 1995.

J. V. Sengers, "Light Scattering of Nonequilibrium Fluctuations in Liquid Mixtures and Polymer Solutions", Department of Chemical and Biochemical Engineering, University of Maryland, Baltimore County, MD, May 1, 1995.

J. V. Sengers, "Course on Critical Phenomena", 8 lectures, Delft University of Technology, Delft, The Netherlands, June 6-9, 1995.

J. V. Sengers, "Fluctuations in Dissipative Liquid Systems Subjected to a Stationary Temperature Gradient", Department of Chemical Engineering, Princeton University, Princeton, NJ, November 29, 1995.

J. V. Sengers, "Fluctuations in Liquids and Polymer Solutions in Stationary Nonequilibrium States", Department of Chemical Engineering, Howard University, Washington, DC, January 26, 1996.

J. V. Sengers, "Nonequilibrium Fluctuations in Liquids and Polymer Solutions Subjected to a Stationary Temperature Gradient", Department of Chemistry, Clemson University, Clemson, SC, March 28, 1996.

J. V. Sengers, "Nonequilibrium Fluctuations in Liquids and Polymer Solutions Subjected to a Stationary Temperature Gradient", Department of Chemical Engineering, West Virginia University, Morgantown, WV, October 29, 1996.

J. V. Sengers, "Nonequilibrium Fluctuations in Liquids and Polymer Solutions Subjected to a Stationary Temperature Gradient", Department of Chemical Engineering, University of Pennsylvania, Philadelphia, PA, November 4, 1996.

J. V. Sengers, "Thermal Nonequilibrium Phenomena in Polymer Solutions", Department of Chemical Engineering, University of Maine, Orono, ME, November 22, 1996.

J. V. Sengers, Invited Lecturer, 26th Winter Meeting on Statistical Physics, Cuernavaca, Mexico, January 15-17, 1997.

J. V. Sengers, "Can Science or Engineering Fulfill Your Dreams", ASHRAE Chapter, Department of Mechanical Engineering, University of Maryland, College Park, MD, March 14, 1997.

J. V. Sengers, Invited Seminar, Department of Chemical Engineering, Carnegie-Mellon University, March 18, 1997.

- J. V. Sengers, "Nonequilibrium Fluctuations in Liquids and Polymer Solutions", Chemical Physics Seminar, University of Maryland, College Park, MD, April 2, 1997.
- J. V. Sengers, "Rayleigh Scattering in Liquids and Polymer Solutions", Symposium in honor of R. D. Mountain, National Institute for Standards and Technology, Gaithersburg, MD, April 10-15, 1997.
- J. V. Sengers, "Nonequilibrium Concentration Fluctuations in a Polymer Solution Subjected to a Temperature Gradient", 13th Symposium on Thermophysical Properties, Boulder, CO, June 22-27, 1997.
- J. V. Sengers, "Nonequilibrium Fluctuations in Simple and Complex Fluids", Symposium in honor of J. M. J. van Leeuwen, Institute Lorentz for Theoretical Physics, Leyden, The Netherlands, September 5, 1997.
- J. V. Sengers, "Fluctuations in Liquids and Polymer Solutions Induced by a Temperature Gradient", Statistical Physics Seminar, University of Maryland, College Park, MD, September 9, 1997.
- J. V. Sengers, "Nonequilibrium Fluctuations in Liquids and Polymer Solutions Subjected to a Stationary Temperature Gradient", Department of Chemical Engineering, University of Florida, Gainesville, FL, September 15, 1997.
- J. V. Sengers, Invited Seminar, Department of Chemical Engineering, City College of New York, October 6, 1997.
- J. V. Sengers, "Fluctuations in Liquids and Polymer Solutions Subjected to a Temperature Gradient", Department of Chemical Engineering, Massachusetts Institute of Technology, Cambridge, MA, October 13, 1997.
- J. V. Sengers, "Transport Properties of Supercritical Fluids", Keynote Lecture, International Conference on Heat Transfer Issues in National Refrigerants, University of Maryland, College Park, MD, November 6-7, 1997.
- J. V. Sengers, Member Panel on Computational Thermodynamics, 8th International Conference on Properties and Phase Equilibria for Product and Process Design, Delft, The Netherlands, April 26-May 1, 1998.
- J. V. Sengers, "Crossover from Ising-Like to Mean-Field Critical Behavior of Simple and Complex Fluids", Symposium in honor of J. W. Cahn, Rutgers University, May 17, 1998.
- J. V. Sengers, "Crossover Critical Phenomena in Simple and Complex Fluids", Chemical Science and Technology Laboratory, National Institute of Standards and Technology, Boulder, CO, June 30, 1998.
- J. V. Sengers, Invited Lectures on Crossover Critical Phenomena in Fluids and Fluid Mixtures: I. Thermodynamic Properties; II. Transport Properties, NATO Advanced Study Institute on Hypercritical Fluids, Kemer, Turkey, July 12-24, 1998.
- J. V. Sengers, Panel Member, NATO Advanced Study Institute on Supercritical Fluids, Kemer, Turkey, July 12-24, 1998.
- J. V. Sengers, "Crossover Critical Phenomena in Simple and Complex Fluids", Statistical Physics Seminar, University of Maryland, College Park, MD, September 8, 1998.

J. V. Sengers, Invited Seminar, Department of Physics, Keio University, Yokohama, Japan, December 8, 1998.

J. V. Sengers, Invited Seminar, Department of Chemical and Biological Engineering, Gunma University, Gunma, Japan, December 9, 1998.

J. V. Sengers, "Nonequilibrium Fluctuations in Liquids and Polymer Solutions", Second ICRS International Symposium, Tohoku University, Sendai, Japan, December 10-11, 1998.

J. V. Sengers, Invited Seminar, Department of Chemical Engineering, Kyushu University, Japan, December 14, 1998.

J. V. Sengers and M. A. Anisimov, "Crossover Critical Phenomena in Aqueous Solutions", 13th International Conference on the Properties of Water and Steam, Toronto, Canada, September 12-16, 1999.

J. V. Sengers, "Thermal Nonequilibrium Phenomena in a Polymer Solution", Polymer Division, NIST, Gaithersburg, MD, November 24, 1999.

J. V. Sengers, "Properties of Fluids in the Critical Region", Workshop on Vapor Compression with the Critical Point in Mind", University of Maryland, College Park, MD, February 10-11, 2000.

J. V. Sengers, "Thermal Nonequilibrium Phenomena in a Polymer Solution", Department of Chemical Engineering, North Carolina State University, Raleigh, NC, February 22, 2000.

J. V. Sengers, "Changes with Time: Thermal Nonequilibrium Phenomena in Polymer Solutions", Symposium in honor of Matthieu Ernst's Contribution to Nonequilibrium Statistical Mechanics, Utrecht University, The Netherlands, June 15-16, 2000.

J. V. Sengers, "Mesoscopic Dynamics in Fluids", Touloukian Memorial Lecture, 14th Symposium on Thermophysical Properties, Boulder, CO, June 25-30, 2000.

M. A. Anisimov, "Universality, Scaling, and Crossover in Polymer Solutions", 14th Symposium on Thermophysical Properties, Boulder, CO, June 25-30, 2000.

R. W. Gammon and J. V. Sengers, "Light Scattering from Nonequilibrium Fluctuations in Liquids and Polymer Solutions", OSA Conference on Photon Correlations and Scattering, Whistler, British Columbia, Canada, August 21-23, 2000.

J. V. Sengers, "Thermal Nonequilibrium Fluctuations in Simple and Complex Fluids", Plenary lecture, Fourth International Meeting on Thermodiffusion, Bayreuth, Germany, September 11-14, 2000.

J. V. Sengers, "Light Scattering from Nonequilibrium Fluctuations in Liquids", Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany, September 15, 2000.

J. V. Sengers, "Crossover Critical Phenomena in Complex Fluids", three lectures presented at a Summer School on Complex Fluids, Bayreuth, Germany, September 18-29, 2000.

J. V. Sengers, "Mesoscopic Dynamics in Fluids", Max-Planck-Institut für Polymer Forschung, Mainz, Germany, September 22, 2000.

J. V. Sengers, "Mesoscopic Dynamics in Fluids: 40 Years of Nonequilibrium Statistical Physics", Conference in honor of L. Garcia-Colin Scherer, UAM Iztapalapa, Mexico City, November 29-30, 2000.

J. V. Sengers, "Nonequilibrium Fluctuations in Liquids and Polymer Solutions", University of Sevilla, Spain, March 21, 2001.

J. V. Sengers, "Critical Phenomena and Phase Behavior in Complex Fluids and Electrolyte Solutions", Complutense University of Madrid, Spain, March 23, 2001.

J. V. Sengers, "Nonequilibrium Fluctuations in Simple and Complex Fluids", University of Valladolid, Spain, March 22, 2001.

J. V. Sengers, "Crossover Critical Phenomena and Phase Behavior in Aqueous Electrolyte Solutions", Conference on Thermodynamics and Statistical Mechanics with Industrial Applications, University of Bristol, UK, April 4-6, 2001.

J. V. Sengers, "Critical Phenomena and Phase Behavior in Polymer Solutions and Electrolyte Solutions", Fluid Science; a Symposium in honor of M. R. Moldover, National Institute of Standards and Technology, Gaithersburg, MD, April 18, 2001.

A. Wyczalkowska, "Impurity Effects on the Heat Capacities of Near-Critical Fluids", Statistical Physics Seminar, University of Maryland, College Park, MD, April 24, 2001.

M. A. Anisimov, "Order-Disorder Phase Transitions in Isotropic Fluids: Beyond Fluid-Fluid Separations". NATO Advances Research Workshop on New Kinds of Phase Transitions: Transformations in Disordered Substances, Moscow, Russia, May 17-21, 2001.

J. S. Hager, "Logarithmic Corrections near Tricritical Points", Statistical Physics Seminar, University of Maryland, College Park, MD, June 5, 2001.

J. V. Sengers, "Critical Phenomena and Phase Behavior in Aqueous Electrolyte Solutions", Applied Statistical Physics Molecular Engineering Conference, Cancun, Mexico, July 23-27, 2001.

J. S. Hager, "Phase Diagrams of One-Dimensional Driven Lattice Gases with Open Boundary Conditions", Informal Workshop on Driven Lattice and Continuum Models, Virginia Tech, Blacksburg, VA, August 8, 2001.

M. A. Anisimov, "Novel Phase Behavior in Isotropic Fluids: Beyond Liquid-Liquid Demixing", 76th International Bunsen Discussion Meeting on Global Phase Diagrams, Walberger, Germany, August 19-22, 2001.

M. A. Anisimov, "Light Scattering and Crossover to Tricriticality in Polymer Solutions", Universität Essen, Germany, August 23, 2001.

M. A. Anisimov, "Light Scattering and Crossover to Tricriticality in Polymer Solutions", Forschungszentrum Jülich, Germany, August 24, 2001.

J. V. Sengers, "Crossover Critical Phenomena in Molecular and Complex Fluids", Plenary Lecture, 7th European Days on Contemporary Thermodynamics, Mons, Belgium, August 27-31, 2001.

M. A. Anisimov, "Beyond Fluid-Fluid Phase Separation", Statistical Physics Seminar, University of Maryland, College Park, MD, November 20, 2001.

J. V. Sengers, "Critical Phenomena in Fluids with Competing Order Parameters", Statistical Mechanics Conference in honor of M. E. Fisher, Rutgers University, New Brunswick, NJ, December 16-18, 2001.

J. V. Sengers, "Fluctuations in Fluids in Thermal Nonequilibrium States Below the Convective Rayleigh-Bénard Instability", Dynamics Days 2002, Baltimore, MD, January 3-7, 2002.

M. A. Anisimov, "Coupled Dynamics in Near-Critical Polymer Solutions", Oil and Gas Research Institute of the Russian Academy of Sciences, Moscow, January 10, 2002.

J. S. Hager, "Droplet Condensation and Crystal Shapes in Two Dimensions", Statistical Physics Seminar, University of Maryland, College Park, MD, March 12, 2002.

J. V. Sengers, "Mesoscopic Dynamics and Fluids: 40 Years of Nonequilibrium Statistical Physics", Symposium in honor of J. R. Dorfman, University of Maryland, College Park, MD, May 30-31, 2002.

M. A. Anisimov, "Impurity Effects on the Two-Phase Heat Capacity and Yang-Yang Dilemma", Jet Propulsion Laboratory, Pasadena, CA, July 22, 2002.

M. A. Anisimov, "Mesoscopic and Nanoscale Thermodynamics", Moscow State Academy for Oil and Gas, Moscow, Russia, January 9, 2003.

M. A. Anisimov, "Trends in Engineering Education in the USA", Moscow State Academy of Oil and Gas, Moscow, Russia, January 16, 2003.

A. F. Kostko, "Competition of Mesoscales in the Static and Dynamic Behavior of Polymer Solutions", Special IPST Seminar on Interdisciplinary Problems in Chemistry and Physics, University of Maryland, College Park, MD, February 5, 2003.

M. A. Anisimov, "Competition of Mesoscales in Polymer Solutions", Department of Chemical Engineering, Colorado School of Mines, Golden, CO, February 13, 2003.

M. A. Anisimov, "Competition of Mesoscales and Coupled Critical Dynamics in Polymer Solutions", Physical and Chemical Properties Division, National Institute of Standards and Technology, Boulder, CO, February 14, 2003.

J. V. Sengers, "Thermal Nonequilibrium Fluctuations in Fluid Layers Below the Rayleigh-Bénard Convective Instability", Statistical Physics Seminar, University of Maryland, College Park, MD, May 6, 2003.

M. A. Anisimov, "Competition of Mesoscales in Complex Fluids", NATO Advanced Research Workshop on Nonlinear Dielectric Phenomena in Complex Fluids, Ustron-Jacowjec, Poland, May 10-14, 2003.

J. V. Sengers, "Thermal Nonequilibrium Fluctuations in Fluid Layers Below the Convective Rayleigh-Bénard Instability", Statistical Mechanics Conference in honor of E.G.D. Cohen, Rutgers University, NJ, May 18-20, 2003.

J. V. Sengers, "Thermal Nonequilibrium Fluctuations", Polymer Division, National Institute of Standards and Technology, Gaithersburg, MD, May 29, 2003.

J. V. Sengers, "Thermodynamics of Critical Fluctuations in Molecular and Complex Fluids", Centennial Conference of the Spanish Royal Societies of Physics and Chemistry, Madrid, Spain, July 7-11, 2003.

M. A. Anisimov, "Mesoscopic and Nanoscale Thermodynamics: Fundamentals for Emerging Technologies", Plenary Lecture, 15th Symposium on Thermophysical Properties, Boulder, CO, June 22-27, 2003.

M. A. Anisimov, "Competition of Mesoscales and Critical Dynamics in Polymer Solutions", 3rd International Workshop on Nonequilibrium Thermodynamics and Complex Fluids, Princeton, August 17, 2003.

M. A. Anisimov, "Competition of Mesoscales and Coupled Critical Dynamics in Polymer Solutions", International Applied Statistical Physics: Molecular Engineering Conference, Puerto Vallarta, Mexico, August 25-29, 2003.

M. A. Anisimov, "Dynamics of Polymers at Nanoscale", Department of Chemical Engineering, Purdue University, Lafayette, IN, October 30, 2003.

M. A. Anisimov, "Resolving the Yang-Yang Dilemma", Jet Propulsion Laboratory, Pasadena, CA, February 5, 2004.

J. V. Sengers, "Critical Phenomena in Simple and Complex Fluids", Department of Physics, Kansas State University, Manhattan, KS, March 8, 2004.

J. V. Sengers, "Thermal Nonequilibrium Fluctuations in Fluids", Department of Physics, Kansas State University, Manhattan, KS, March 9, 2004.

M. A. Anisimov, "Mesoscopic and Nanoscale Thermodynamics: Fundamentals for Nanotechnology", Los Alamos National Laboratory, Los Alamos, NM, March 9, 2004.

M. A. Anisimov, "Mesoscopic and Nanoscale Thermodynamics: Where the Second Law Fails", Rice University, Houston, TX, March 17, 2004.

J. V. Sengers, "Thermal Nonequilibrium Fluctuations", Laboratory for Aero- and Hydrodynamics, Technical University Delft, The Netherlands, March 25, 2004.

J. V. Sengers, "Thermodynamics of Critical Fluctuations", Laboratory for Physical Chemistry and Molecular Thermodynamics, Technical University Delft, The Netherlands, March 31, 2004.

M. A. Anisimov, "Mesoscopic and Nanoscale Thermodynamics: Complex Fluids", Princeton University, Princeton, NJ, May 10, 2004.

M. A. Anisimov, "Thermodynamics at the Nanoscale: Coupled Fluctuations", Cavendish Laboratory, Cambridge University, UK, June 4, 2004.

M. A. Anisimov, "Mesoscopic and Nanoscale Thermodynamics: Coupled Fluctuations in Complex Fluids", Physics Department, University of Edinburgh, UK, May 31, 2004.

M. A. Anisimov, "Light Scattering in Aqueous Solutions", Physics Department, University of Bremen, Germany, June 12, 2004.

M. A. Anisimov, "Criticality versus Tricriticality in Polymer Solutions", Max-Planck Institut für Polymerforschung, Mainz, Germany, June 17, 2004.

M. A. Anisimov, "Near-Critical Aqueous Systems at Nano- and Meso Scales", 14th International Conference for the Properties of Water and Steam, Kyoto, Japan, August 29 - September 4, 2004.

IIIC. CONTRIBUTED PRESENTATIONS

A. A. Povodyrev, M. A. Anisimov, V. D. Kulikov, and J. V. Sengers, "Crossover Behavior of the Susceptibility in the Critical Region of Fluids and Fluid Mixtures", Meeting of the American Physical Society, Washington, DC, April 18-21, 1995.

M. A. Anisimov, V. D. Kulikov, A. A. Povodyrev, and J. V. Sengers, "Effects of Impurities on Relaxation Processes in Near-Critical Fluids", Meeting of the American Physical Society, Washington, DC, April 18-21, 1995 (poster).

M. A. Anisimov, A. A. Povodyrev, and J. V. Sengers, "Universality versus Non-Universality in Near-Critical Binary Mixtures: What we can learn from the shape of the critical line", Gordon Conference on the Chemistry and Physics of Liquids, Holderness, NH, August 7-11, 1995 (poster).

J. V. Sengers, "Light Scattering in Polymer Solutions", Polymer Science and Engineering Review, University of Maryland, College Park, MD, September 28-29, 1995.

J. V. Sengers, A. van Pelt, and G. X. Jin, "Critical Scaling Laws and Classical Equations of State", Annual Meeting of the American Institute of Chemical Engineering, Miami Beach, FL, November 12-17, 1995.

M. A. Anisimov, "Research Program of Sengers and Coworkers at the University of Maryland", 11th Mid-Atlantic Thermodynamics Conference, Johns Hopkins University, Baltimore, MD, March 18, 1996.

T. A. Edison and J. V. Sengers, "Thermodynamic Properties of Ammonia in the Critical Region", 11th Mid-Atlantic Thermodynamic Conference, Johns Hopkins University, Baltimore, MD, March 18, 1996 (poster).

A. A. Povodyrev, M. A. Anisimov, and J. V. Sengers, "Nature of Crossover between Ising-Like and Mean-Field Critical Behavior in Fluids and Fluid Mixtures", 11th Mid-Atlantic Thermodynamics Conference, Johns Hopkins University, Baltimore, MD, March 18, 1996 (poster).

A. A. Povodyrev, M. A. Anisimov, and J. V. Sengers, "Critical Phenomena in Aqueous Solutions of Sodium Chloride", Gordon Conference on the Physics and Chemistry of Water and Aqueous Solutions, Holderness, NH, August 3-9, 1996 (poster).

A. A. Povodyrev, M. A. Anisimov, J. V. Sengres and J. M. H. Levelt Sengers, "Scaling Crossover Description of Near-Critical Vapor-Liquid Equilibria in Aqueous Solutions of Sodium Chloride", Meeting of the American Physical Society, Washington, DC, April 18-21, 1997.

M. A. Anisimov, V. A. Agayan, A. A. Povodyrev, J. V. Sengers and E. E. Gorodetskii, "Two-Exponential Decay of Dynamic Light Scattering in Near-Critical Fluid Mixtures", Meeting of the American Physical Society, Washington, DC, April 18-21, 1997.

A. Wyczalkowska, M. A. Anisimov and J. V. Sengers, "Crossover between Singular Critical Behavior and Classical Behavior in a van der Waals Fluid", Meeting of the American Physical Society, Washington, DC, April 18-21, 1997.

- I. K. Yudin, G. L. Nicolaenko, V. I. Kosov, V. A. Agayan, M. A. Anisimov and J. V. Sengers, "A Compact Photon-Correlation Spectrometer for Research and Education", 13th Symposium on Thermophysical Properties, Boulder, CO, June 22-27, 1997.
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