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040001 **Editorial: Promoting Inclusive and Respectful Communications** Michael Thoennessen

041001 ***Colloquium*: Unusual dynamics of convection in the Sun** Jörg Schumacher, Katepalli R. Sreenivasan

The Sun, Earth's star, remains a source of many scientific mysteries. The motion in its interior is complex and involves physical phenomena at many scales, from nuclear to astronomical. In this Colloquium the unusual flow of mass and energy inside of our yellow star is discussed.

041002 ***Colloquium*: Statistical mechanics and thermodynamics at strong coupling: Quantum and classical** Peter Talkner, Peter Hänggi

The question of how classical systems approach thermal equilibrium is as old as the foundations of thermodynamics and statistical mechanics. How quantum systems decohere and thermalize is even more puzzling. This Colloquium provides an account of how the thermal equilibrium of a system is influenced by the presence of a thermal bath. It also gives a view of both classical and quantum aspects providing an understanding on the particularities of the quantum case. Moreover, a description of the challenges in the definition of heat from the perspective of fluctuating thermodynamical potentials is given. An old subject, perhaps, but definitely fundamental.

041003 ***Colloquium*: Quantum crystallizations of ^{4}He in superfluid far from equilibrium** R. Nomura, Y. Okuda

Bosonic helium is one of the most quantum mechanical materials ever studied in physics. It shows the famous Bose-Einstein condensation at extremely low temperatures. Although the equilibrium properties of boson liquids are now well understood, little is known about their nonequilibrium properties, especially the interfacial properties between superfluid and crystal phases far from equilibrium. In this Colloquium nonequilibrium crystal shapes in superfluid are discussed based on high-speed visualization techniques and the challenges related to the theoretical interpretation of the interfacial dynamics are presented.

045001 **APS Medal for Exceptional Achievement in Research: Topology and other tools in condensed matter physics** Bertrand I. Halperin

The 2019 APS Medal for Excellence in Physics was given to Bertrand I. Halperin. This contribution was invited in conjunction with this award. This article is an extended version of a talk given at the March 2019 meeting of the American Physical Society, summarizing the author's work in areas linked to topological aspects of classical and quantum physics.

045002 **Mechanical behavior of solid helium: Elasticity, plasticity, and defects**

John Beamish
Sébastien Balibar

At low temperatures, atoms in classical crystals are localized at lattice sites and can be regarded as distinguishable particles rendering quantum statistics unimportant. In solid helium, however, this situation is different: helium's small mass and weak interatomic potentials allow the exchange of neighboring atoms and the emergence of statistics dominated by quantum effects. This review covers the concepts and properties of solid helium and how crystalline properties are affected by structure, defects, vacancies, and dislocations. Recent experimental results on plastic deformation give promise to a new understanding of the mechanical properties of quantum solids.

045003 **Hadronic structure in high-energy collisions**

Karol Kovařík
Pavel M. Nadolsky
Davison E. Soper

Parton distribution functions quantify the nonperturbative QCD structure of protons and nuclei, expressed as probabilities for finding quarks and gluons, in high-energy collisions. Determined by applying advanced quantum field theory to precise experimental measurements using modern statistical techniques, parton distribution functions are crucial for interpreting the short-distance behavior of the standard model. This review presents the state of the art of this evolving subject.

045004 **Light rays, singularities, and all that**

Edward Witten

Starting from the 1960s, numerous results have been obtained on the global structure of solutions of Einstein's general relativity. These include the classic singularity theorems of Penrose and Hawking, which imply that under certain rather general conditions singularities are unavoidable. Light rays play an important role in the proofs of these theorems. This paper reviews the properties of light rays and surveys their implications for the occurrence of singularities in general relativity.

045005 **Large D limit of Einstein's equations**

Roberto Emparan
Christopher P. Herzog

Taking the limit of a large number of spatial dimensions is a familiar technique in statistical mechanics but, until recently, seldom used in gravity. In this review its use is described in black hole physics, and, through the anti–de Sitter/conformal field theory correspondence, in condensed matter physics and fluid mechanics.

045006 **Grand unified neutrino spectrum at Earth: Sources and spectral components**

Edoardo Vitagliano
Irene Tamborra
Georg Raffelt

The measured neutrino spectrum is essential in this epoch of multimessenger astronomy. To explore astrophysics and particle physics it is necessary to understand and quantify the known contributions to the grand unified neutrino spectrum. Only through a study of the expected neutrino backgrounds can we hope to detect new phenomena. This review summarizes the composition of the spectrum arising from the cosmic background, the remnants of nucleosynthesis, solar and terrestrial production, supernovae and cosmological phenomena, and even nuclear power plants.

045007 **Neutrinoless double-electron capture**

K. Blaum
S. Eliseev
F. A. Danevich
V. I. Tretyak
Sergey Kovalenko
M. I. Krivoruchenko
Yu. N. Novikov
J. Suhonen

Efforts to understand the character of the neutrino, and searches for physics beyond the standard model, motivate several ongoing experiments to detect neutrinoless double-beta decay. The complementary process of double-electron capture has received less attention. Currently the limits on capture measurements are not competitive with the limits on decay measurements. With a look to future experiments, this review covers the current status, emphasizes the significant enhancements that can occur when a resonance condition exists, and provides a road map for future progress.