Reviews of Modern Physics

Volume 91 **Number 2** **April–June 2019**

021001 ***Colloquium*: Many-body localization, thermalization, and entanglement**

Dmitry A. Abanin, Ehud Altman, Immanuel Bloch, Maksym Serbyn

The route of a physical system toward equilibrium and thermalization has been the subject of discussion and controversy since the time of Boltzmann. This Colloquium reviews the recent progress in understanding many-body localization, a phase of matter in which quantum mechanics and disorder conspire to prohibit thermalization altogether. Many new phenomena emerge in lieu of conventional statistical mechanics and may be observed in systems of ultracold atoms, superconducting qubits, and certain quantum materials.

021002 ***Colloquium*: Physical constraints for the evolution of life on exoplanets**

Manasvi Lingam, Abraham Loeb

Since the 1990s over 4000 exoplanets have been discovered: which of them could also develop and harbor life? It is posited that the planet must have liquid water, a surrounding atmosphere, and must be both biocompatible and possess the bioessential elements to be habitable. This Colloquium explores what features of the central star are conducive to these requirements with an eye toward optimizing our search for extraterrestrial life.

021003 ***Colloquium*: Fractional electromagnetism in quantum matter and high-energy physics**

Gabriele La Nave, Kridsanaphong Limtragool, Philip W. Phillips

Electromagnetism is one of the most important theories in all of the sciences since it describes the fundamental phenomenon of how electromagnetic radiation propagates and interacts with matter. However, in certain exotic situations, such as in the interior of a superconductor, strange metals, or horizons of black holes, electromagnetism can be modified due to the complexity of the environment. In this Colloquium the authors discuss such a case and the mathematical complexities associated with it.

021004 ***Colloquium*: Ionic phenomena in nanoscale pores through 2D materials**

Subin Sahu, Michael Zwolak

Porous two-dimensional materials are a new area of research in membrane science and technology. In addition to applications such as water filtration and energy harvesting, ion transport in nanoscale pores through these membranes is unique due to the geometric confinement that balances strong ion-water and other interactions and the relevancy of atomic details. This Colloquium reviews theoretical and experimental aspects of ionic phenomena in membranes.

025001 **Quantum resource theories**

Eric Chitambar
Gilad Gour

This review introduces a new development in theoretical quantum physics, the "resource-theoretic" point of view. The approach aims to be closely linked to experiment and to state exactly what result you can hope to achieve for what expenditure of effort in the laboratory. This development is an extension of the principles of thermodynamics to quantum problems; but there are resources that would never have been considered previously in thermodynamics, such as shared knowledge of a frame of reference. Many additional examples and new quantifications of resources are provided.

025002 **Exploring astrophysics-relevant magnetohydrodynamics with pulsed-power laboratory facilities**

S. V. Lebedev
A. Frank
D. D. Ryutov

Supernovae shocks, accretion disks, and collimated jets are astrophysical phenomena thought to be dominated by hydrodynamical and magnetohydrodynamical effects. Their spatial and temporal extent cover an enormous range of scales, from tens of kilometers to many parsecs, and from a fraction of second to a million years. What they all share is the importance of strong magnetic fields. In this article the progress and challenges are reviewed of laboratory-based, pulsed-power devices with high currents and voltages as platforms for studying scaled versions of these fascinating outer space plasma phenomena.

025003 **Electronic coarse graining: Predictive atomistic modeling of condensed matter**

F. S. Cipcigan
J. Crain
V. P. Sokhan
G. J. Martyna

The potentials and forces that govern the interaction of atoms and molecules with each other, and with their environment, are crucial for understanding and simulating complex condensed matter systems. At the same time, they are complicated and hard to describe at a microscopic level. This review gives a pedagogical introduction to a method for treating these interactions in an effective manner that can be used for simulations of noble gas fluids and solids, as well as water, and has potential for applications to more complicated systems.

025004 **Mesoscopic simulations at the physics-chemistry-biology interface**

Massimo Bernaschi
Simone Melchionna
Sauro Succi

The complex phenomena emerging at the interface of physics, chemistry, and biology encompass a wide range of scales in both length and time. The quantitative description of motions or flows across multiple scales has been possible with the development of the lattice Boltzmann method in conjunction with mesoscale particle methods. This article reviews how the lattice Boltzmann method leverages parallel processing in high-performance computing. With this, we can see the dawn of mesoscale physics-informed computational physiology and medicine.

025005 **Ultrastrong coupling regimes of light-matter interaction**

P. Forn-Díaz
L. Lamata
E. Rico
J. Kono
E. Solano

In the ultrastrong coupling regime, light and matter can no longer be distinguished: their coupling strengths are as large as their own energy scales. Even for simple two-level systems, this represents a new regime to explore within the quantum Rabi model. There has been considerable theoretical and experimental progress on the physics of these systems in recent years, as presented in this review. Key experimental results are discussed in a set of current platforms arising in quantum information research, including superconducting and semiconducting devices and other hybrid quantum systems.

025006 **The modern era of light kaonic atom experiments**

Catalina Curceanu
Carlo Guaraldo
Mihail Iliescu
Michael Cargnelli
Ryugo Hayano
Johann Marton
Johann Zmeskal
Tomoichi Ishiwatari
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Kaonic atoms are exotic atomic systems where an electron is replaced by a negatively charged kaon which also experiences the strong interaction with the nucleus. Precision spectroscopy of kaonic atoms represents an excellent tool to study the strong interaction of particles with strangeness. This work reviews progress and prospects in the modern era of kaonic atom experiments and discusses constraints on low-energy theories of the strong interaction in the strangeness sector.