Reviews of Modern Physics

Volume 95 **Number 3** **July–September 2023**

030001 **Editorial: To Review Is to Be** Randall D. Kamien

030501 **Nobel Lecture: Multiple equilibria** Giorgio Parisi

The 2021 Nobel Prize for Physics was shared by Syukuro Manabe, Klaus Hasselmann, and Giorgio Parisi. This paper is the text of the address given in conjunction with the award.

031001 ***Colloquium*: Quantum and classical discrete time crystals** Michael P. Zaletel, Mikhail Lukin, Christopher Monroe, Chetan Nayak, Frank Wilczek, Norman Y. Yao

The spontaneous breaking of time translational invariance, which leads to time crystals, is harder to achieve than that of other continuous symmetries, including spatial translational invariance. In recent years it has become clear that ergodicity breaking is crucial for the stabilization of time crystals. This Colloquium explains the concepts behind time crystals, as well as recent theoretical and experimental advances in this exciting field.

031002 ***Colloquium*: Unconventional fully gapped superconductivity in the heavy-fermion metal $CeCu_2Si_2$** Michael Smidman, Oliver Stockert, Emilian M. Nica, Yang Liu, Huiqiu Yuan, Qimiao Si, Frank Steglich

The heavy-fermion compound $CeCu_2Si_2$ has long been known to be an unconventional superconductor with *d*-wave symmetry. Ordinarily, this would imply that the gap function has nodes on the Fermi surface. This Colloquium explains that recent experiments have shown that the gap is nonzero everywhere, if small where a single-band wave gap would vanish. The Colloquium discusses theoretical scenarios to explain these observations, as well as the implications for other unconventional superconductors.

031003 ***Colloquium*: Anomalous statistics of laser-cooled atoms in dissipative optical lattices** Gadi Afek, Nir Davidson, David A. Kessler, Eli Barkai

The standard central limit theorem does not apply to sums of many random variables with heavy-tailed probability distributions. The anomalous statistics for such sums have exotic properties and they are applied phenomenologically across the natural sciences, economics, and the social sciences. This Colloquium reviews how anomalous statistics can be derived from first principles and how they govern the observed diffusive motion of ultracold atoms in laser fields.

035001 **Computational advantage of quantum random sampling**

Dominik Hangleiter
Jens Eisert

Quantum computers have improved and recent experiments have claimed quantum advantage—completion of a computational task that is evidently hard for any conventional computer. The problem solved is that of obtaining samples, by quantum measurement, from a certain probability distribution. This review shows in what precise way quantum random sampling can be seen as a computation. It explains what that computation solves, in what way it outperforms classical computations, and what methods of verification are available. Quantum random sampling becomes a first test of the presumed exponential computational advantage of quantum computers over classical ones.

035002 **Long-range interacting quantum systems**

Nicolò Defenu
Tobias Donner
Tommaso Macrì
Guido Pagano
Stefano Ruffo
Andrea Trombettoni

Many-body quantum physics with long-range interactions of variable range and strength can be studied in experiments with Rydberg atom arrays, dipolar systems, trapped ions, and cold atoms in cavities. This review identifies common and universal features induced by the long-range interactions such as the extensive or nonextensive character of the total energy and features that deviate from the case of short-range interactions. A comparison with the corresponding results for classical systems is presented.

035003 **Weak gravity conjecture**

Daniel Harlow
Ben Heidenreich
Matthew Reece
Tom Rudelius

The weak gravity conjecture, at the simplest level stating that "gravity is the weakest force," has motivated many recent works aiming to understand quantum gravity and to put constraints on field theories that can be coupled to quantum gravity, including the one describing the real world. This review surveys the motivation, historical development, and recent advances related to this conjecture.

035004 **Quantitative theory of magnetic interactions in solids**

Attila Szilva
Yaroslav Kvashnin
Evgeny A. Stepanov
Lars Nordström
Olle Eriksson
Alexander I. Lichtenstein
Mikhail I. Katsnelson

Magnetic moments in solids become useful and interesting due to the interatomic exchange that causes them to align. Developments in calculations of the electronic structure of solids have led to the ability to predictively compute these interactions in many materials. This review describes the development of these calculations and their application in describing the behavior of materials including technologically important hard and soft magnetic materials, novel two-dimensional magnets, elemental solids, alloys, antiferromagnets, noncollinear magnets, and magnetic molecules containing hundreds of atoms.

035005 **The physics of fast radio bursts**

Bing Zhang

Fast radio bursts, milliseconds-duration radio bursts predominantly originating from cosmological distances, figure among the unsolved puzzles of contemporary astrophysics. The rapid accumulation of observational data has generated an equally intense theoretical activity toward the understanding of the physical processes at the origin of these events. This review presents a thorough survey of the current knowledge about fast radio bursts, starting with the generic constraints that can be placed on theoretical models based on current observations and plasma physics considerations, then moving to a critical discussion of coherent radiation mechanisms and source models currently debated in the scientific community.

035006 **Atom counting with accelerator mass spectroscopy**

Walter Kutschera
A. J. Timothy Jull
Michael Paul
Anton Wallner

Accelerator mass spectrometry (AMS) is a mass-spectrometric method using entire accelerator systems to measure ultralow traces of long-lived radioisotopes. AMS spectrometers produce an ion beam from a sample of interest and separate ions according to their magnetic, electric, and atomic characteristics. It is thus possible to identify both the mass number and the atomic number of a very rare radioisotope, and count it atom by atom. The review describes the 45-year history since the discovery of AMS, detailed technical aspects, and a wide range of research fields.