Reviews of Modern Physics

Volume 96 **Number 2** **April–June 2024**

020001 **Editorial: Coauthor! Coauthor!**
Randall D. Kamien
Daniel Ucko

021001 ***Colloquium*: Magnetotactic bacteria: From flagellar motor to collective effects**
M. Marmol
E. Gachon
D. Faivre

Magnetotactic bacteria have a built-in compass, in the form of a magnetosome chain made up of magnetic biominerals, that allows them to passively align along terrestrial magnetic field lines. They also sense oxygen gradients and swim using at least one flagellum. Hence, these bacteria are self-propelled active matter capable of displaying flocking behavior. This Colloquium explains the physics behind these various capabilities, as well as their interactions and biological significance.

021002 ***Colloquium*: Topologically protected transport in engineered mechanical systems**
Tirth Shah
Christian Brendel
Vittorio Peano
Florian Marquardt

Artificially engineered mechanical systems, sometimes called metamaterials, offer many promising applications on length scales ranging from macroscopic systems to the nanoscale. A topic of particular interest is the existence of topologically protected phononic edge states in such systems that are analogous to the electronic edge states that give rise to the quantum Hall effect. This Colloquium gives an introduction to topologically protected transport in metamaterials and its applications for controlling acoustic transport.

021003 ***Colloquium*: Spin-orbit effects in superconducting hybrid structures**
Morten Amundsen
Jacob Linder
Jason W. A. Robinson
Igor Žutić
Niladri Banerjee

In many solids, the spin-orbit interaction is only a small effect. However, in certain classes of materials it leads to new phenomena, for instance, helical magnetism in noncentrosymmetric lattices. This Colloquium reviews the role of spin-orbit interaction in hybrid superconducting structures, where it can lead to exotic states such as spin-triplet pairing, topological superconductivity, and the superconducting diode effect. These are both of fundamental interest and of importance for applications, including spintronics and quantum computing.

025001 **Single-molecule scale magnetic resonance spectroscopy using quantum diamond sensors**
Jiangfeng Du
Fazhan Shi
Xi Kong
Fedor Jelezko
Jörg Wrachtrup

Nitrogen-vacancy centers in diamond are sensitive to magnetic fields, and a single center permits detection of electron and nuclear spins and imaging of single molecules in its vicinity. This article reviews the achievements of advanced methods to obtain spectral and spatial resolution and it points to technical problems that remain to be solved for widespread and multi-disciplinary adoption of single-molecule magnetic resonance spectroscopy.

025002 **When superconductivity crosses over: From BCS to BEC**

Qijin Chen
Zhiqiang Wang
Rufus Boyack
Shuolong Yang
K. Levin

The theory of unconventional superconductors continues to provide profound puzzles. The crossover between the weakly coupled Bardeen-Cooper-Schrieffer (BCS) state and the strong-pairing Bose-Einstein condensate (BEC) provides a useful perspective on how to address these questions. This paper describes a self-consistent framework for thinking about the crossover regime in between these two limits. The Review discusses to what extent this BCS-BEC theory applies to a range of classes of superconducting materials including the cuprates, iron pnictides, twisted bilayer graphene, and interfacial superconductivity among others.

025003 **Fluorescence microscopy: A statistics-optics perspective**

Mohamadreza Fazel
Kristin S. Grussmayer
Boris Ferdman
Aleksandra Radenovic
Yoav Shechtman
Jörg Enderlein
Steve Pressé

For centuries, human fascination with the living world motivated the development of tools for visualizing life's events at the spatiotemporal scales beyond our visual range. While all optical microscopes use light to probe the object of interest, fluorescence microscopes can discern between the object and background at the molecular scale. At this scale, the stochastic properties of light are fundamental to interpreting fluorescence microscopy data. Accordingly quantitative methods that enable such interpretation necessitate stochastic perspective and the use of statistical concepts. The physical-optical principles governing the formation of fluorescent images and modeling tools interpreting these images while accounting for the stochasticity of light and measurements are reviewed.

025004 **Neutrinos from dense environments: Flavor mechanisms, theoretical approaches, observations, and new directions**

M. Cristina Volpe

Neutrinos can change flavors due to their nonzero masses and mixings as well as their interactions with matter and other neutrinos. In dense astrophysical environments, such as core-collapse supernovae or neutron star mergers, the problem of neutrino flavor evolution becomes very complex. Connections to other domains such as quantum information theory have been uncovered. Understanding the neutrino flavor evolution in dense environments can shed light on the dynamics of massive star explosions and the origin of heavy elements in the Universe and is important for future observations of supernova neutrinos.

025005 **Catalysis in quantum information theory**

Patryk Lipka-Bartosik
Henrik Wilming
Nelly H. Y. Ng

A branch of quantum information is concerned with transformations that are possible given certain resources: for example, quantum teleportation moves a quantum state from one place to another, aided by entanglement and classical communication. Certain other tasks are provably impossible. But, as surveyed in this review, a surprising fact is that some tasks become possible if another quantum state is present, even if this state is returned untouched at the end of the task. This "quantum catalysis" enables a large variety of interesting tasks, with applications ranging from cryptography to thermodynamics.