REVIEWS of MODERN PHYSICS

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1041 **Quantum interface between light and atomic ensembles**

Klemens Hammerer
Anders S. Sørensen
Eugene S. Polzik

In future quantum communication networks atoms would be used to store quantum information and photons to transmit it from one place to another. An interface between atoms and photons will be required. The interface should be able to reliably transfer the quantum state of the atoms into the photons and vice versa. This paper reviews the methods proposed so far to build interfaces between ensembles of atoms and propagating light beams, as well as the latest experimental achievements.

1095 **Baryon spectroscopy**

Eberhard Klempt
Jean-Marc Richard

Understanding the fundamental structure of matter requires knowledge of how quarks and gluons are assembled to form baryons: the family of strongly interacting particles containing three valence quarks. While about 120 baryons and baryon resonances are known and their spectroscopy has provided essential clues that led to the development of a theory of the strong interaction, quantum chromodynamics, it has also left many puzzles. This article surveys the field of baryon spectroscopy, with an emphasis on issues, open question, and prospects in this field.

1155 **Introduction to quantum noise, measurement, and amplification**

A. A. Clerk
M. H. Devoret
S. M. Girvin
Florian Marquardt
R. J. Schoelkopf

The concept of quantum noise is of fundamental importance for problems related to quantum measurements, and quantum information in general. This review gives a pedagogical overview of this important topic, including a thorough discussion of the quantum limit of linear amplifiers.

1209 ***Colloquium*: Quantum networks with trapped ions**

L.-M. Duan
C. Monroe

Quantum computation remains one of the most challenging problems in science. In recent years there have been many developments, theoretical and experimental, in this active area of research. In this Colloquium the issue of quantum networks in the context of information exchange between trapped ions by photons is discussed. Advances in this area can have huge impacts in communication and computation.

1225 **Feshbach resonances in ultracold gases**

Cheng Chin
Rudolf Grimm
Paul Julienne
Eite Tiesinga

A Feshbach resonance is a scattering resonance that occurs when the energy of an unbound state of a two-body system matches the energy of an excited state of the compound system. Recognized long ago as an important feature in nuclear, atomic, and molecular scattering, and in photoionization and photodissociation, Feshbach resonances have assumed new importance in ultracold atomic systems. In these systems the energies of the colliding atoms can be brought into resonance with a high-lying molecular state by applying a magnetic field or by other means, providing unprecedented control over the collision dynamics. By allowing precise control of the interactions, Feshbach resonances thus open a new door to the study of many-body physics. This review summarizes the theoretical background of Feshbach resonances and their application to Bose-Einstein condensates, Fermi gases, and ultracold molecular physics.

1287 ***Colloquium*: Looking at a soliton through the prism of optical supercontinuum**

Dmitry V. Skryabin
Andrey V. Gorbach

This Colloquium provides a consistent description of the established theoretical picture of the supercontinuum generation and expansion through nontrivial scenarios of the interaction between solitons and radiation in optical fibers. These processes are of particular importance for the design of new schemes for frequency conversion, short pulse generation, and high speed optical communication.

1301 **Vortices on curved surfaces**

Ari M. Turner
Vincenzo Vitelli
David R. Nelson

Curved surfaces are common in soft condensed matter and in biological systems, and the curvature can be important for the functionality. This review demonstrates that geometric properties can also influence quantum mechanical degrees of freedom, using vortices on curved superfluid films as an example.

1349 **Nonperturbative QCD simulations with 2+1 flavors of improved staggered quarks**

A. Bazavov
D. Toussaint
C. Bernard
J. Laiho
C. DeTar
L. Levkova
M. B. Oktay
Steven Gottlieb
U. M. Heller
J. E. Hetrick
P. B. Mackenzie
R. Sugar
R. S. Van de Water

A number of developments have allowed for improved numerical studies of quantum chromodynamics using discrete lattice techniques, including improved lattice formulations, new algorithms, and increased computing power. This article reviews an improved formulation and presents results for the quark masses, the hadron spectrum, the heavy quark potential, weak matrix elements, and other quantities.

1419 **Track and vertex reconstruction: From classical to adaptive methods**

Are Strandlie
Rudolf Frühwirth

As the number of particles created in high-energy collisions increases with collision energy and the rate of interactions is expected to increase substantially, the task of reconstructing the momenta and angles of individual particles at their point of production and the task of estimating the location of the production vertex have become challenging. Adaptive methods have been developed to meet these challenges, ranging from neural networks and deformable templates to robust stochastic filters with annealing. They are presented in this review and compared to classical approaches.

1459 ***Colloquium*: Failure of molecules, bones, and the Earth itself**

Markus J. Buehler
Sinan Keten

The structural stability of materials is not only a topic of fundamental relevance for human life but also shows up in many less obvious situations in the microscopic world. In this Colloquium article the problem of material failure in a large number of situations in nanotechnology, biochemistry, and medicine as well as the theoretical aspects of the problem, the importance of computer simulations, and possible ways to improve the resistance of materials is discussed. It is expected that this field might lead to a new generation of tailored materials that have unimaginable structural stability.

1489 **Exciton-polariton Bose-Einstein condensation**

Hui Deng
Hartmut Haug
Yoshihisa Yamamoto

The achievement of Bose-Einstein condensation (BEC) in exciton systems is balked by the short lifetime of excitons. However, by employing polaritons rather than excitons, and using concepts of cavity quantum electrodynamics, the possibilities for BEC are vastly improved. Using a two-dimensional planar geometry, a quantum degenerate polariton gas has been observed within the BEC region. This review describes the theory of semiconductor microcavity polaritons, including polariton superfluidity. Experimental progress is reported and a number of novel experimental possibilities are discussed including condensation in lattices and room temperature condensation.

1539 **Anomalous Hall effect**

Naoto Nagaosa
Jairo Sinova
Shigeki Onoda
A. H. MacDonald
N. P. Ong

The anomalous Hall effect occurs in solids with broken time reversal symmetry, typically a ferromagnetic phase, as a consequence of spin-orbit coupling. This review summarizes experimental and theoretical studies on specific materials and then distinguishes the differences between intrinsic, skew scattering, and side-jump contributions. The emphasis is on providing a global view of the anomalous Hall effect by elucidating the link between semiclassical and microscopic theory.

1593 ***Colloquium*: Time-resolved scanning tunneling microscopy**

Arie van Houselt
Harold J. W. Zandvliet

Scanning tunneling microscopy (STM) is one of the most powerful techniques to study materials at the molecular and atomic scale. Besides being used as a way to manipulate atoms, or studying local spectroscopic properties of materials, STM even reveals motion on the atomic scale. This technique also opens up the door to the possibility for real-time studies of chemical reactions on surfaces. In this Colloquium the field of time-resolved STM is reviewed and its newest developments are discussed.

1607 **Dynamics of filaments and membranes in a viscous fluid**

Thomas R. Powers

Soft matter—liquids, colloidal crystals, and in general objects that are thin in one or two dimensions like bacterial flagella, actin filaments, and cell membranes—is easy to deform. The physics behind deformation is directly connected to understanding the shapes of the deformed systems and hence to the question of how curves and surfaces behave under the influence of external forces. The present article addresses this problem from the point of differential geometry for such curves and surfaces—filaments and membranes—in a viscous fluid and illustrates the formalism with two simple case studies.

1633 **First-principles theory of dilute magnetic semiconductors**

K. Sato
L. Bergqvist
J. Kudrnovský
P. H. Dederichs
O. Eriksson
I. Turek
B. Sanyal
G. Bouzerar
H. Katayama-Yoshida
V. A. Dinh
T. Fukushima
H. Kizaki
R. Zeller

Dilute magnetic semiconductors are of immense interest for both fundamental and practical reasons. This review provides an overview of methods for understanding their properties from first principles, using *ab initio* calculations, Monte Carlo simulations, and density functional theory.

1691 **Genetic demixing and evolution in linear stepping stone models**

K. S. Korolev
Mikkel Avlund
Oskar Hallatschek
David R. Nelson

Populations of organisms change over time, since individuals which are more fit are selected over others. Populations also change by random genetic drift. Even in a population of different types of individuals with equal fitness, the frequencies of types change from generation to generation due to random fluctuations. This review article applies the tools of nonequilibrium statistical mechanics to show how the effects of the evolutionary forces of selection and genetic drift vary dramatically depending on whether the population is well mixed or segregated into spatial patterns.

1719 ***Colloquium*: Identifying the propagating charge modes in doped Mott insulators** — Philip Phillips

The problem of strongly interacting electrons close to a Mott insulating state is one of the most challenging theoretical problems in condensed matter physics. In this Colloquium article the problem is analyzed under a new light, both theoretically and experimentally. By focusing on the nature of the actual propagating charge modes of these complex systems, a compelling case is drawn for the need of a new theoretical framework that can describe the unusual excitations in materials such as cuprate superconductors.

1743 ***Colloquium*: Transport in strongly correlated two dimensional electron fluids** — B. Spivak, S. V. Kravchenko, S. A. Kivelson, X. P. A. Gao

Two-dimensional electron liquids are quintessential quantum mechanical systems where quantum fluctuations allied to strong interactions lead to unusual electronic phases. In this Colloquium the experimental and theoretical results associated with systems with particular attention to the controversial problem of the metal-insulator transition in the two-dimensional electron gas are presented. Also discussed are the various open issues in this important field of condensed matter research.

1767 ***Colloquium*: Gripped by light: Optical binding** — Kishan Dholakia, Pavel Zemánek

Macroscopic objects can interact with each other by exchanging light. This interaction can have unexpected effects such as the formation of structures with high degree of organization. In this Colloquium this emerging field of optical binding is reviewed from the theoretical as well as experimental perspective.

1793 **Laser-driven nonlinear cluster dynamics** — Th. Fennel, K.-H. Meiwes-Broer, J. Tiggesbäumker, P.-G. Reinhard, P. M. Dinh, E. Suraud

Clusters are nanometer-sized objects of atoms or molecules with a finite number of particles and represent a special state of condensed matter. Their adjustable size and high local density provides for detailed analysis of ultrafast laser-matter interactions in many-particle systems. The electron and ion dynamics as well as their complex interrelation is explored for various excitation regimes ranging from single-photon absorption up to the strong-field domain. This article reviews laser-cluster interactions, providing an understanding of key phenomena in relation to the interactions regimes in which they prevail.

1843 **The physical and chemical properties of heteronanotubes** — Paola Ayala, Raul Arenal, Annick Loiseau, Angel Rubio, Thomas Pichler

The modification, doping, and general formation of single-walled heteronanotubes which contain carbon, boron, and nitrogen are of great interest to scientists working in different fields for fundamental and applied reasons. This review focuses on the theoretical concepts and experimental approaches embracing the gamma from nanotubes of C with low B or N doping to BN nanotubes and the new physics behind them.

1887 **Long range interactions in nanoscale science**

Forces that reach beyond the length of an interatomic bond dominate the organization of matter at the scale of nanometers. This review describes long range electrodynamic, electrostatic, and polar interactions. The basic physics is illustrated with instructive examples drawn from a diverse array of topics, including carbon nanotubes, DNA, interfaces and surfaces, and suspensions. The review concludes with a survey of how long range interactions at the nanoscale can be manipulated for practical use.

Roger H. French
V. Adrian Parsegian
Rudolf Podgornik
Rick F. Rajter
Anand Jagota
Jian Luo
Dilip Asthagiri
Manoj K. Chaudhury
Yet-ming Chiang
Steve Granick
Sergei Kalinin
Mehran Kardar
Roland Kjellander
David C. Langreth
Jennifer Lewis
Steve Lustig
David Wesolowski
John S. Wettlaufer
Wai-Yim Ching
Mike Finnis
Frank Houlihan
O. Anatole von Lilienfeld
Carel Jan van Oss
Thomas Zemb

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Thomas R. Powers

Forthcoming articles