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021001 ***Colloquium*: Quantum limits to the energy resolution of magnetic field sensors** — Morgan W. Mitchell, Silvana Palacios Alvarez

Magnetometry, that is, the measurement of magnetic fields, has applications that range from brain imaging to exploration of the outer Solar System. The best magnetometry technologies achieve a sensitivity close to Planck's constant, the number that appears in the Heisenberg uncertainty relation. This Colloquium reviews what is known about quantum mechanical limits on field sensing, and identifies new sensing approaches that may break the current impasse in magnetic sensitivity.

021002 ***Colloquium*: Bell's theorem and locally mediated reformulations of quantum mechanics** — K. B. Wharton, N. Argaman

Quantum mechanics and relativity are two of the most profound theoretical developments of the 20th century. In 1964, John Bell proposed a test for quantum mechanics that shocked the theoretical community, showing that quantum mechanics implies a violation of locality, that is, action at a distance beyond the light-speed limits of relativity. In this Colloquium this fundamental problem is reviewed in a framework wider than the usual hidden-variable formulation, indicating an allowable "continuous action" option in addition to the standard action-at-a-distance approaches.

021003 ***Colloquium*: Spintronics in graphene and other two-dimensional materials** — A. Avsar, H. Ochoa, F. Guinea, B. Özyilmaz, B. J. van Wees, I. J. Vera-Marun

Controlled spin transport in graphene and other two-dimensional materials has become increasingly promising for applications in devices. Of particular interest are custom-tailored heterostructures, known as van der Waals heterostructures, that consist of stacks of two-dimensional materials in a precisely controlled order. This Colloquium gives an overview of this developing field of spintronics and outlines the experimental and theoretical state of the art.

025001 **Theoretical perspectives on biological machines** — Mauro L. Mugnai, Changbong Hyeon, Michael Hinczewski, D. Thirumalai

By operating out of equilibrium, nanoscale biological machines execute many functions that do not take place in abiotic systems. Statistical physics, physical chemistry, and polymer physics principles are needed in elucidating the rules and constraints governing large-scale structural changes that occur when metabolizing molecular fuel. This paper reviews the advances in theories rooted in coarse graining the complex systems while reminding us that molecular details must be an integral part of a deeper understanding of processes in living systems.

025002 **Secure quantum key distribution with realistic devices**

Feihu Xu
Xiongfeng Ma
Qiang Zhang
Hoi-Kwong Lo
Jian-Wei Pan

Some years ago quantum hacking became popular: devices implementing the unbreakable quantum cryptography were shown to have imperfections which could be exploited by attackers. Security has been thoroughly enhanced, as a consequence of both theoretical and experimental advances. This review gives both sides of the story, with the current best theory of quantum security, and an extensive survey of what makes quantum cryptosystem safe in practice.

025003 **Strong-field nano-optics**

Péter Dombi
Zsuzsanna Pápa
Jan Vogelsang
Sergey V. Yalunin
Murat Sivis
Georg Herink
Sascha Schäfer
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When electromagnetic fields impinge on nanoscale structured materials, optical field concentrations can occur that enhance the field strength up to 2 orders of magnitude. The strong-field interaction physics enabled by these nano-optical building blocks probes highly nonlinear phenomena that can pave the way toward unique probes of matter such as ultrafast electron imaging and spectroscopy and ultrahigh frequency transistor concepts that are preludes to light-wave electronics. This article reviews the fundamentals and applications of these phenomena.

025004 **Nuclear effective field theory: Status and perspectives**

H.-W. Hammer
Sebastian König
U. van Kolck

Effective field theory has revolutionized the theory of nuclear forces by providing a systematic expansion for strong interactions at low energies based on the symmetries of quantum chromodynamics. This paper reviews layers of effective field theories used in the description of nuclei and their reactions, and in broader applications to hadron structure and fundamental symmetries.