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040001 **Editorial: A Welcoming Home for Applied Science** — Jessica Thomas, Michael Thoennessen

041001 ***Colloquium*: Atomtronic circuits: From many-body physics to quantum technologies** — Luigi Amico, Dana Anderson, Malcolm Boshier, Jean-Philippe Brantut, Leong-Chuan Kwek, Anna Minguzzi, Wolf von Klitzing

Atomtronics refers to the use of ultracold atoms for building circuits that rely on the coherent propagation of matter waves in waveguides. While still in its infancy, this new quantum technology is promising both for applications and for probing the correlated atomic matter itself. This Colloquium explains the current state of the field and discusses possible applications.

041002 ***Colloquium*: Planckian dissipation in metals** — Sean A. Hartnoll, Andrew P. Mackenzie

Relaxational processes for conduction electrons in metals come with characteristic temperature dependences; classic examples at low temperatures are the $1/T^2$ law for the relaxation time in a Fermi liquid, and the Bloch $1/T^5$ law for electron-phonon scattering. The strange metal phase of cuprate superconductors is governed instead by the Planckian time, which is given in terms of fundamental constants only. This Colloquium discusses the concept of such a fundamental timescale and the degree to which it provides a lower bound for relaxation times, and illustrates these ideas with examples from conventional and unconventional metals.

041003 ***Colloquium*: Cavity-enhanced quantum network nodes** — Andreas Reiserer

Quantum computing has seen much progress recently, but networks of quantum processors still face substantial challenges. At the same time they have extraordinary promise for both applied and fundamental purposes. This Colloquium explains how optical resonators can be used to achieve the necessary specifications in a variety of systems, bringing global quantum computing networks within reach.

045001 **Charged particle motion and radiation in strong electromagnetic fields** — A. Gonoskov, T. G. Blackburn, M. Marklund, S. S. Bulanov

Ultrastrong electromagnetic fields occur not only in astrophysical settings but also in dense lepton bunches, special crystals, and at the focus of high peak power lasers. For fields of sufficient magnitude including quantum electrodynamics effects becomes essential. Electron-positron pair creation and interaction of these pairs with the fields results in fascinating phenomena. In this review these particle dynamics are analyzed and shown to exhibit complex behavior including chaotic motion with strange attractors and limit cycles, as well as cascades where the vacuum "explodes" and acts back on the strong fields. An overview of planned experiments points to new discoveries which will challenge long-held theoretical expectations.

045002 **Laser melting modes in metal powder bed fusion additive manufacturing**

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Additive manufacturing, called 3D printing, has become ubiquitous in classrooms, laboratories, and research centers. While printing with plastics has revolutionized prototyping and modeling, it is now possible to fabricate metal parts and devices directly from computer models by fusing metal particles together with high-intensity lasers. This review focuses on the flow of heat and material in the high temperature environment, the instabilities that arise, and the tools to control them.

045003 **Implications of gauge freedom for nonrelativistic quantum electrodynamics**

Adam Stokes
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This article reviews the meaning of gauge freedom in quantum electrodynamics and emphasizes its consistency with examples and analyses. It thus demonstrates that ambiguities and recent controversies are resolved by proper identification of physically relevant observables of field and matter subsystems. Since these observables differ for different gauges, light and matter subsystems can only be defined relative to the choice of gauge, with implications for the identification of effective few-dimensional models, entanglement, phase transitions, and cavity quantum electrodynamics effects beyond weak-coupling regimes.

045004 **Ultrafast electron diffraction: Visualizing dynamic states of matter**

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Understanding the structure and function of both energy and matter is a fundamental goal in science. Various spatiotemporal probes have been developed from electromagnetic waves spanning the entire range of the spectrum to neutrons and charged particles such as electrons. With the development of highly controlled, shorter electron bunches, retrieving dynamic structural information from solid-state and gas-phase samples is now possible at timescales that resolve atomic motion and length scales that resolve atomic positions in even the lightest elements. In this review advances in the generation, manipulation, and characterization of ultrashort electron beams are described.

045005 **Mesoscopic physics of nanomechanical systems**

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Recent technological advances allow nanomechanical vibrational systems to be fabricated with small dimensions, large oscillation frequencies, and long vibrational lifetimes. Novel physical behavior occurs in the mesoscopic regime which applies only to studying individual systems and not to solid-state ensemble systems probed with molecular or vibrational spectroscopies. This review addresses the experimental work on physical phenomena in vibrational systems, including fluctuations in the nonequilibrium regime, relaxations, nonlinearities, dynamics both conservative and dissipative, and mode couplings and their interplay.

045006 **Nonequilibrium boundary-driven quantum systems: Models, methods, and properties**

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Systems whose boundaries are in contact with heat baths at different temperatures allow for the realization of nonequilibrium steady states (NESS) characterized by distribution functions that are still time independent, yet different from the equilibrium distributions. Such states have interesting properties even in classical statistical mechanics, but recently their quantum analogs have received attention, for both fundamental and applied reasons. This review provides an account of recent progress in this field. It introduces various models to describe the rich NESS phenomenology and covers analytic and numerical methods for analyzing them.

045007 **Kochen-Specker contextuality**

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Adán Cabello
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Matthias Kleinmann
Jan-Åke Larsson

A realization that came gradually in physics is that the "elements of reality" of Einstein, Podolsky, and Rosen are provably nonexistent. Specker initiated a line of thinking in 1960, observing that the outcomes of quantum measurements cannot reveal preexisting properties that are independent of which other measurements are performed. This review discusses the diverse current thinking on the problem of contextuality. The possibilities and problems with experimental verifications are discussed, and the violation of Bell inequalities can be viewed as a special case of contextuality.

045008 **Engineering quantum states and electronic landscapes through surface molecular nanoarchitectures**

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Surfaces of solid-state materials can be manipulated to fashion quantum dots and bespoke electronic properties. This review provides an overview of the work done to shape surface 2D electron gasses by means of patterning with molecule-based networks formed via supramolecular self-assembly or atomistic manipulation protocols, giving rise to distinct phenomena in the quantum regime. A vision of applying and engineering these techniques to achieve control over surface electron quantum states for many systems is presented.