

REVIEWS of MODERN PHYSICS

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011001 *Colloquium: Synthetic quantum matter in nonstandard geometries*

This Colloquium presents ways to implement fractal lattices, curved spaces, and higher dimensions in atomic, photonic, and electronic systems. The study of quantum many-body physics in these exotic geometries permits simulation of phenomena from topology in condensed matter to models of gravity and cosmology.

Tobias Grass
Dario Bercioux
Utso Bhattacharya
Maciej Lewenstein
Hai Son Nguyen
Christof Weitenberg

015001 *Using gravitational waves to see the first second of the Universe*

Gravitational waves open a unique window on the earliest times in cosmology because the dense primordial plasma, impenetrable to light or neutrinos, is transparent to gravitational waves up to the instant of the birth of the Universe. This review discusses the possible signals from the phase transitions, topological defects, and other cosmological sources, as well as a range of strategies for detection of the stochastic gravitational waves produced by the earliest events in the history of the Universe.

Rishav Roshan
Graham White

015002 *Macroscopic stochastic thermodynamics*

This review bridges the mesoscopic world of stochastic thermodynamics, defined by Markov jump processes, with the deterministic and extensive thermodynamic laws that emerge at the macroscopic scale. Using large deviations theory, it constructs a fluctuation framework preserving core principles like the fluctuation theorem. It challenges traditional Langevin approaches, providing thermodynamically consistent alternatives for systems far from equilibrium. From chemical reaction networks to electronic circuits and Potts models, this work elucidates the dynamics of rare fluctuations, attractor transitions, and entropy production principles, offering a robust theoretical foundation for understanding nonequilibrium phenomena across disciplines.

Gianmaria Falasco
Massimiliano Esposito

015003 *Massive quantum systems as interfaces of quantum mechanics and gravity*

The authors review theories and experimental state-of-the-art efforts to study the effects of gravity on massive quantum systems. Classical gravity is the least precisely tested natural force and may be addressed via precision quantum probes. Experiments testing whether the quantum nature of gravity causes decoherence and collapse of matter-wave functions and whether it can mediate entanglement between separate massive particles are underway, and their results will guide the theoretical description of gravity effects on a laboratory scale.

Sougato Bose
Ivette Fuentes
Andrew A. Geraci
Saba Mehsar Khan
Sofia Qvarfort
Markus Rademacher
Muddassar Rashid
Marko Toroš
Hendrik Ulbricht
Clara C. Wanjura

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| 015004 | Wrinkles, creases, and cusps in growing soft matter | Martine Ben Amar |
| | <p>The buckling of a material surface subject to compression or growth is a ubiquitous phenomenon, arising in materials science contexts such as the swelling of gels as well as in biological contexts such as morphogenesis and embryogenesis. A complete understanding of the creases and sharp cusps that commonly accompany buckling requires nonlinear elasticity theory. This review presents a modern treatment of the Biot instability, integrating many standard techniques of nonlinear physics and solid mechanics, such as bifurcation theory, conformal mapping, and J and M integrals.</p> | |
| 015005 | The need for optoacoustic microscopy | Ludwig Englert
Dominik Jüstel
Vasilis Ntziachristos |
| | <p>Advanced imaging methods are essential for providing biological and clinical insight into cells and biological tissues. Optoacoustic imaging is one such method in which cells or tissues absorb short laser pulses and the resulting rise in temperature creates tiny ultrasound waves that can be detected by ultrasonic detectors placed outside the specimen. This noninvasive technique has the ability to look at optical contrast that is millimeters and even centimeters deep with high resolution. This review discusses the basic physics, how the method impacts biological and clinical research, and the latest developments in multi-modal microscopy and imaging combining optical and optoacoustic techniques.</p> | |
| 015006 | Quantum-information methods for quantum gravity laboratory-based tests | Chiara Marletto
Vlatko Vedral |
| | <p>It is conceptually possible that gravity is a force of nature that is not describable with a classical theory, but is also not described by a conventional quantum theory. Information-theoretic approaches make it possible to address this general idea in a concrete way, with thought experiments that would constrain the scope of whatever new theory emerges. This review gives the status of these new theoretical approaches, with an emphasis on proposed experiments that look for gravitationally induced entanglement (GIE) between two probes for which quantum theory is known to be applicable. Various potentially feasible tabletop-scale GIE experiments that have been proposed are concretely analyzed.</p> | |
| 015007 | Self-aligning polar active matter | Paul Baconnier
Olivier Dauchot
Vincent Démery
Gustavo Düring
Silke Henkes
Cristián Huepe
Amir Shee |
| | <p>What if active units could align—or even antialign—their orientation with their own velocity? This intriguing self-alignment property unlocks a spectrum of fascinating behaviors, from single self-propelled particles orbiting in harmonic traps to transformative collective phenomena like synchronized motion in dense or solid elastic assemblies. Unlike systems where units simply mimic their neighbors, self-alignment fundamentally reshapes how motion emerges, paving the way for groundbreaking discoveries in biology, smart materials, and robotics. This review uncovers the hidden power of self-alignment in active systems, introduces a unified mathematical and conceptual framework, explores existing models of self-alignment, and highlights its transformative impact on the study and real-world applications of active systems.</p> | |