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Editorial: Oscillations, waves and patterns in the physical and life sciences

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Editorial on the Research Topic
Oscillations, waves and patterns in the physical and life sciences

This special issue of *Frontiers in Physics* explores the vast field of nonlinear dynamical phenomena, manifested notably by oscillatory behavior and exotic pattern formation, both periodic and aperiodic. The contributions treated a broad variety of problems from physics, chemistry, biology, economics, engineering and medicine.

The development of wave mechanics continues to lie at the basis of quantum physics and chemistry. Frontiers research spans a wide range of wave studies encompassing gravitational, magnetic, convective waves, touching on the physics of dark matter, and black holes, and ranging from subatomic axions to new (HFR) waves discovered in the Sun. The physics of particles is visited here in a number of contributions, with a focus on interactions, collisions, undulatory swimming as well as mechano-chemical effects. "Liquid particles" or droplets have widely and tremendously important industrial applications and usages. Their study is also of pivotal importance to prevent or control infection and disease spread (such as the recent Covid-19 pandemic), whenever they are contaminated and harmful. The motion of droplets and clusters of droplets is treated here, considering mechanical, dynamic and thermodynamic aspects.

Oscillations in biology are ubiquitous and their applications fall in a broad spectrum of categories. From attractive patterns on butterflies and the pelt of many animals, to the dynamics of populations evolution, to the cycle of sleep (circadian), and to a huge multitude of biochemical processes in living organisms, the study of biological/biochemical oscillations lies at the heart of the understanding of various aspects of life on our planet.

In chemistry, over 300 chemical oscillators (oscillating chemical reactions) are known and classified. Oscillations are dynamic, but the resulting patterns can often be locked in space, such as in periodic precipitation (Liesegang) patterns and, typically, the geological stratigraphic scenery. We conclude with a study of oscillations in the economy and complex market systems. Besides this diversity across those disciplines, the richness of the contributions also lies in a harmonious balance between theory and experiment.

The quantum world is the central area in physics for the study of oscillations, spanning the properties of light waves with a wide spectrum of applications. In a paper by Choi, quantum light waves studied formerly by the same author in a static environment in the q-quadrature space were extended to an investigation in the p-quadrature space, along with an inquiry of the coupling between the two. The conjecture of nonstatic waves can be applied to interferometers, gravitational-wave detection, quantum information processing, high-precision measurements, and nano-quantum dots.

From light waves to the Physics of particles, objects and droplets. Two articles analyze the evolution of the motion of self-propelled objects. Kitahata and Koyano reported a mathematical approach to uncover fundamental behaviors of a cluster of two or three self-propelled particles. One of the common self-propelled particle changes its surrounding chemical concentration profile and succeeds to get driving force.

Mechano-chemical effects were studied by Fujita et al. in a nonlinear science context. Self-propelled objects in nonlinear multi-dimensional motion on an aqueous surface exhibit a so-called undulatory "swimming". Experimental implementation was tested on two systems: a filament on water and a floating camphor disc.

The filament exhibits periodic pendulum motion horizontally with an oscillation phase propagated in the opposite direction of the motion, a regime (or module) coined undulatory swimming. In a camphor disc on a water surface submerged with a nervonic acid condensed fluid phase layer, different modes of motion were determined, with both lateral and vertical oscillations at the air-water interface.

Polo et al. analyzed mechanical forcing transferred to a milling ball within two reactors with slightly different geometries: rectangular with flat bases, and rectangular with semi-circular bases. The oscillations amplitude, the number of collisions and the mean square velocity per collision were monitored by varying two essential parameters: the disc radius and the restitution coefficient. Those parameters critically control the transition from periodic to chaotic regimes *via* period doubling-like routes. The geometry of the reactor governs the dynamics of the milling body and hence the powder dragging and mixing, and the transfer of mechanical energy.

The present special issue extrapolates the interest in the motion of solid particles, to the study of liquid droplets and their clustering properties.

Itatani and Nabika reported novel chemical systems in which droplets spontaneously moved with interfacial chemical reaction. They carefully measured interfacial tension depending on the concentration of surfactant and related to the droplet motion, in particular movement length.

Particle physics using a coarse-grained model could be extended to biological systems, notably that autonomous oscillatory dynamics are ubiquitous at every level in biology. At the cellular level, one of the most relevant and well-characterized examples of periodic behavior is the cyclic assembly and disassembly of actomyosin networks. Hernández-Del-Valle et al. recently proposed that this cyclic behavior arises as a system's property from the competition between the cooperative assembly and the tension-induced disassembly of actin networks. In their contribution to this special issue, the authors perform experiments and simulations to characterize the properties of the actomyosin oscillations and how they depend on different features of the system.

This research collection touches on widely diverse aspects and perspectives of applications of nonlinear dynamics in biology and medicine. The behavior of ant colonies, the formation of Turing patterns on zebra fish and the diagnosis of schizophrenia.

Yamanaka et al. clearly showed characteristic collective behavior of ants, namely ants use two different tactic behaviors. One is to follow pheromone and the other is to use visual information. To show such complex behaviors, they prepared a circular-shaped pheromone road connecting between nest and food and observed much amount of ants' behaviors. Stochastic analysis of the data indicated that ants switched between the two different tactic behaviors. This paper provides a biological strategy for the special issue. It is expected to inspire chemical and physical experimentalists of nonlinear sciences.

In the paper by Nakamasu, pattern formation on a zebrafish skin was mathematically investigated by introducing a three-variable nonlinear reaction–diffusion model. The main objective of this study was to link the parameters in the reaction–diffusion model and connexin (gap junction protein in the cells) functions during the Turing pattern formation. Higher diffusivity of the chemical species was implemented by using channels in the membranes of pigment cells.

Bose and Gorecki describe a method that can be used in the diagnosis of schizophrenia based on the analysis by networks of chemical oscillators. The networks were constructed by using a 2-variable mathematical model (Oregonator), which describes the kinetics of the Belousov-Zhabotinsky reaction. The overall accuracy of schizophrenia diagnosis can be improved when using the majority decision from a network consisting of three oscillators.

The experimental and theoretical characterization of some novel properties discovered in the well-known Belousov-Zhabotinsky oscillating chemical reaction, was also the focus of two further contributions. Okamoto et al. exploited the nonlinear behavior of the Belousov-Zhabotinsky reaction to relate the degree of homogeneity of a reactive mixture with the characteristics of the travelling waves that may form in a reaction-diffusion system. In particular, they found that the wavelength and the wavenumber of a BZ pulse-train depend on the mixing state of the solution.

Wodlei et al. thoroughly reinvestigated the transient chaotic dynamics generally observed in unstirred Belousov-Zhabotinsky media. They discovered that periodic bulk motions, in form of convective cells, appeared during the aperiodic regime. Single and double convection cells were observed and they were found to be related to the duration of the chaotic transient.

Precipitation patterns are perhaps the earliest observed manifestation of self-organization in chemical systems after the discovery of the Liesegang phenomenon in 1896. Hayashi explored a wide diversity of such patterns with the Prussian blue (PB) reagent and its analogs (PBA) in agarose hydrogel as the supporting anion, and a variety of metal cations in the presence of an applied electric field (both constant and alternating voltages). A wealth of colorful patterns is obtained and displayed, along with the generation of Liesegang bands in the cyclic voltage mode experiments with the Cu–Fe PBA system.

The coupling of simple chemical reaction schemes to transport and hydrodynamic effects can result in complex behavior engendering oscillations. Tiani and Rongy, describe a mechanism for the emergence of spatial and temporal oscillations of the surface tension and of the velocity field in a bimolecular system ($A+ B \rightarrow C$ reaction-type) with no chemical instability involved. Such oscillations emerge as the result of the interplay between differential diffusion of chemical species and chemically driven Marangoni stresses at the air/liquid interface.

Last but not least, nonlinear dynamics and chaos theory transcended beyond the natural sciences reaching out to the social sciences, notably in population dynamics and the study of uncertainty in economic systems.

Economy and market are prototypical complex systems that influence (and are influenced by) life styles, well-being and behaviors of human societies all over the world. In their contribution, Yesiltas et al. constructed an economic index based on data from social media (Twitter) to track out and somehow predict market fluctuations and economic risks at a country level. By using macroeconomic modeling techniques, the authors developed a set of key financial indicators for tracking financial developments in Turkey, the country chosen as a benchmark.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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