In this issue

Nonequilibrium statistical systems

When a system with many interacting constituents is driven to a state far removed from equilibrium, it often behaves in a new and unusual way. The interplay of drive and interactions brings in nonequilibrium effects, often of a collective character, which put a distinctive stamp on the spatial and temporal properties of the state. Nonequilibrium states and their static and dynamic properties are the subject of the special section in this issue.

One reason for the interest in nonequilibrium states is their ubiquity. They arise not only in physical systems in the laboratory, but also in nature and in everyday life. Thus, for instance, current-carrying steady states describe not only the flow of carriers in a semiconductor or submicron particles sedimenting in a fluid, but also traffic flow on a highway. And the phenomena of coalescence and reconstitution are as relevant to the formation of aggregates in a polymeric solution, as to mergers and splits of companies in the financial market. Nor are these examples idle armchair analogies. Methods of statistical physics are being used increasingly in analysing problems of vehicular traffic. And econophysics has emerged as a growing area, as witnessed by the demand for physics Ph Ds on Wall Street, though not yet on Dalal Street. Closer home, in the sciences, nonequilibrium statistical physics today influences and is influenced by its interactions with soft condensed matter physics, materials science, fluid mechanics, geology, chemistry and biology.

One may distinguish between three broad types of nonequilibrium states. Recall that the state of a statistical system involves many microscopic configurations, and is specified by giving the probability, time-dependent or steady, of each configuration. If the driving force is turned off, an out-of-equilibrium system may return to the equilibrium state via a sequence of *time-varying* nonequilibrium states, though this return may be slowed down due to cooperative effects or conservation laws. On the other hand, the system may get stuck in a long-lived *arrested* state, unable to evolve towards equilibrium because of kinetic barriers which cannot be overcome over laboratory time scales. Finally, if the external drive continues to act, the system may settle into a nonequilibrium *steady state*.

In equilibrium statistical mechanics, there is a well laid-out general formalism going back to Boltzmann and Gibbs on how to compute properties of bulk systems starting from a microscopic description requiring knowledge only of the Hamiltonian. But for nonequilibrium states, there is no such general prescription, not even for steady states, and the theoretical description must grapple with the dynamics. Nevertheless, there have been some striking advances in the field, both conceptual and technical, over the past couple of decades. For instance, the description of large-distance, long-time properties by scaling functions, which first arose in the context of equilibrium critical phenomena, is a recurring theme in nonequilibrium systems; surprisingly many such out-of-equilibrium systems are found to exhibit slow decays characterized by power laws, in space and time. The dynamical renormalization group provides a calculational and conceptual framework for describing scaling properties. It leads to the idea of universality classes, which refer to sets of different systems with the same scaling behaviour, and this has become a useful way of classifying nonequilibrium systems. The demarcation of universality classes is very much a part of the current agenda in the field.

Some important new concepts of broad applicability have emerged over the past couple of decades. One of these is the notion of self-organized criticality, which addresses the widespread occurrence of slow decays of correlation functions in natural systems. Examples range from the Richter's law of distributions of earthquake intensities, to power laws which describe the areas of river basins. The scenario is that this happens because the dynamics of a wide class of nonequilibrium systems generically leads to a steady state attractor which is critical. Then power laws are inevitable, rather than being a result of fine tuning, as in equilibrium critical phenomena. Another, quite separate, new notion that has emerged is that of persistence, namely the question of how long an initial condition can survive locally in a coupled system. This is interesting because it is a natural question which probes non-Markovian aspects of systems which may be evolving under Markovian dynamics. Remarkably, explicit analytical solutions have been obtained for some models of both self-organized criticality and persistence, and these have been supplemented by many numerical and approximate analytical studies of a wider class of models. Experimental tests have been carried out as well, in systems ranging from rice piles to liquid crystals, to test these ideas.

As in much of theoretical physics, progress has been achieved by studying simple models which embody only the bare bones of the physical phenomenon under study. Often, the dynamics is taken to be explicitly dissipative and noisy, retaining however the key feature of interactions between particles, so that the many-body aspect of the problem remains. In the analysis of the models and prediction of large-scale behaviour, a two-pronged approach has proved very useful: first, analysis of lattice models by probabilistic and algebraic methods; and second, field-theoretic studies of continuum models which can be thought of as coarse-grained versions of the discrete models. Further insight into the dynamical mechanisms at work, and often, evidence for scaling behaviour, comes from direct numerical simulations of the models under study. With advances in high-speed computing and graphics, computational statistical physics has become a major subfield, and has greatly enlarged the scope of problems for which reliable answers can be obtained.

New ideas, new techniques, and new vistas of interdisciplinary applications have combined to make the field of interacting nonequilibrium systems grow rapidly worldwide. Within India, there are several groups which have made a strong impact in the field, and there is a growing community drawn from the physical sciences, mathematics and engineering. There is a definite need for a larger experimental effort within the country. A positive point about the area is that it is possible to do front-line experiments without necessarily requiring enormous resources.

The articles in the special section in this issue discuss several aspects of non-equilibrium statistical systems. In brief:

Satya N. Majumdar (**page 370**) reviews recent efforts to understand and quantify *persistence*, the ability of a local fluctuation to last without change in a statistical system of interacting particles or spins. Methods of calculating the persistence exponent are described for several problems including spin dynamics and diffusion.

Sanjay Puri (**page 376**) discusses the kinetics of *phase ordering*, the way a nonequilibrium homogeneously mixed initial state evolves towards a final state which is phase separated. Conservation laws in the dynamics are shown to have an important effect on the morphology and scaling properties of domains of each phase.

Madan Rao and Surajit Sengupta (**page 382**) discuss the nature of long-lived *arrested states* of solids formed by quenching rapidly across a phase boundary. A nonequilibrium theory for the solid–solid martensitic transition is developed, focusing on the morphology and growth of droplets and the emergence of scale-invariant microstructures.

S. S. Manna (**page 388**) discusses *self-organized criticality*, the notion that the dynamics of many nonequilibrium systems naturally lead them to critical states with slow power law decays of correlations in space and time. A sandpile model, which is a paradigm in this field, is discussed with a focus on the distributions of avalanches.

Sutapa Mukherji and Somen Bhattacharjee (**page 394**) discuss the scaling properties of roughness variations in a *driven growth front*. A model with a quadratic nonlinearity describes an important universality class and provides a point of departure for a discussion of the effects of quenched disorder, nonlocal interactions, and the presence of a crystalline lattice.

Sriram Ramaswamy (**page 402**) reviews the intriguing properties of *nonequilibrium suspensions* of particles in viscous fluids. Unusual collective effects are found in models of colloidal crystals which melt when they are sheared, or which clump together as they sediment, both systems of experimental relevance.

Debashish Chowdhury *et al.* (**page 411**) review the nature of the steady state and the evolution of fluctuations in *vehicular traffic* flow. Cellular automata models with simple driving rules can be treated analytically and numerically, and help understand the microscopic mechanisms underlying large-scale phenomena such as traffic jams.

Sitabhra Sinha and Bikas Chakrabarti (**page 420**) review *neural network* models of collective computation and argue that nonequilibrium models, rather than conventional static approaches, are better caricatures of neurobiological networks. These models show interesting collective behaviour such as stochastic resonance and a transition to an intermittently interrupted synchronized state.

I believe that these articles give a sense of the breadth of the subject and its vitality. I thank all the authors for agreeing to write, and Avinash Khare for mooting the idea of this special section in the first place.

Mustansir Barma

Pollution and health

The fact that urban air quality is deteriorating is undisputed. Choked roads and polluted air are the most visible testimonials to our economic growth. Even as tens of thousands of vehicles spew out oxides of nitrogen and sulfur and the more visible 'suspended particulate matter' in our major cities, there is very little activity on measures to control pollution. Diesel as a relatively economic fuel has contributed to the worsening situation. In a commentary on urban air pollution in this issue (**page 334**), a group of biomedical researchers draw attention to the many (and dismaying) physiological consequences of prolonged breathing of polluted air. Even more importantly, they call attention to the important problem of carrying out 'comprehensive epidemiological studies to show how ambient air pollution is affecting peoples health'. The fact that many international studies have already been carried out, which conclusively relate pollution to many chronic ailments, suggests that purposeful measures to control air quality are an immediate necessity. The authors conclude by pointing out that 'preventive action is critical for good public health management. Commercial profit and public good have to become mutually compatible and reinforcing'.

P. Balaram