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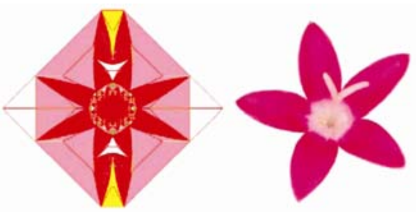
Condensed matter physics

This issue of *Current Science* brings out a special section on 'condensed matter physics' to highlight the advances made in this area that has contributed to the development of other sciences.

It is a common observation that as a baby animal grows, different parts of the body grow, to the first approximation, at the same rate. This property is called proportionate growth. How this is achieved is an interesting problem in biology, and is not well-understood. Proportionate growth requires some communication and coordination between different growing parts. If the growth in different parts were independent, differences due to fluctuations would grow in time and expected to lead to much larger variation than what is actually seen.



The mechanism that regulates growth in animals involves many chemical agents that are in turn produced and degraded in a complex chain of reactions, finally orchestrated by the genetic program stored in the animal's DNA. While some of these chemical agents and pathways have been identified, this mostly deals with the hardware aspect of the regulation.

Sadhu and Dhar (**page 512**) have discussed a simple model that does not invoke the full complexity of DNA, but achieves proportionate growth with simple evolution rules. They note that none of the growing structures studied by physicists so far, e.g. snowflakes, or crystals forming from melt, or coagulating chemicals, have this property. They discuss a simple cellular automaton model with simple local evolution rules that gives rise to patterns which show proportionate growth.

In the model, one starts with a simple periodic background on a lattice and adds particles at one site. There is a relaxation rule that distributes particles to neighbouring sites if there are too many particles at any site. Depending on the initial periodic state, and the precise relaxation rule, one gets different patterns. Some of these patterns, produced with very simple rules, generate features at several length scales, having striking similarity to the natural ones (as seen in the accompanying pictures).

The quantum physics of many particle systems underlies many of the exciting developments in materials science. These include high temperature superconductivity, the 'colossal magnetoresistance' effect, and metal–insulator transitions in a host of materials. While the effects are spectacular, a deep understanding, and our ability to manipulate the materials, requires advances in condensed matter theory. The starting point, a many particle Schrödinger equation, is well known but controlled solutions are difficult to obtain. Tiwari and Majumdar study (**page 518**) one of the simpler problems in this class, the metal–insulator transition with increasing interaction strength in the half-filled Hubbard model. This 'Mott' transition has relevance to a wide variety of oxide materials and organics. Much of the recent work on the Mott transition, and on many particle physics in general, employs what is called 'dynamical mean field theory' (DMFT). This powerful method maps the many electron system to a single site in a self-consistent bath. The resulting problem retains local quantum effects accurately but, by construction, misses out on spatial fluctuations. Nevertheless, much of our current understanding comes from such DMFT (or cluster DMFT) studies. Tiwari and Majumdar use a complementary approach, based on original suggestions of Hubbard himself, which maps the interacting electron problem onto that of electrons coupled to auxiliary magnetic moments. The resulting model is then solved via a Monte Carlo method in real space. This approach captures many of the crucial effects associated with the Mott transition, and, most importantly, allows some degree of visual intuition about otherwise opaque many particle systems. With further refinement this could be a useful tool in low dimensional or frustrated systems.

Advances in atomic physics and optics have made possible the creation of 'artificial materials' – cold atomic systems that mimic real materials – that allow for unprecedented tenability and control. These developments promise to provide clues to solving some of the key open problems of condensed matter physics such as high temperature superconductivity. A rapidly evolving area of cold atom research is study of systems with synthetic gauge fields. Shenoy *et al.* discuss (**page 525**) their recent theoretical work on interacting fermions in synthetic non-Abelian gauge fields which produce a generalized Rashba spin–orbit coupling. They show that, with increasing strength of the spin–orbit coupling (gauge field strength), a superfluid of weakly attracting fermions is transformed to a Bose–Einstein condensate (BEC) of a new kind of boson, the rashbon, whose properties are determined solely by the gauge field. The rashbon BEC is shown to have a transition temperature of the order of the Fermi temperature of the system, suggesting clues to produce high temperature superfluids by tuning spin–orbit interaction. They also demonstrate a novel feature of the rashbon BEC – the rashbon–rashbon interaction is independent of the interaction between the constituent fermions! The authors show that a synthetic non-Abelian gauge field used in conjunction with an external potential can be used to tailor novel Hamiltonians, such as that associated with a magnetic monopole, useful in quantum computing.