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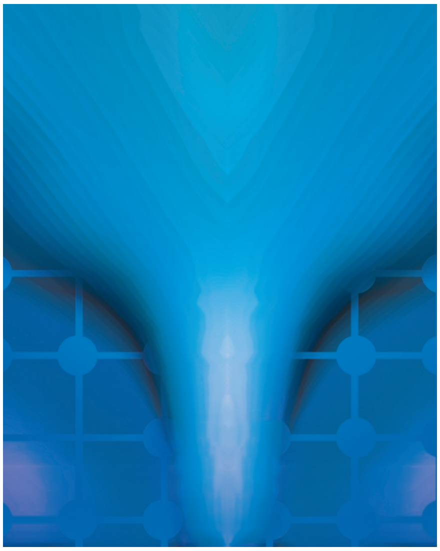
Transitions in focus

In this month's issue, we present our first 'Focus' — a collection of specially commissioned review and opinion pieces — on the topic of quantum phase transitions.

The most familiar examples of phase transitions involve temperature changes, such as water boiling when heated, or a snowflake melting on a warm hand. But there are many more control parameters in the laboratory besides temperature — pressure, uniaxial stress, chemical substitution, magnetic field and so on — all of which can induce a change in matter from one state to another.

Particularly interesting are phase transitions at zero temperature, or quantum phase transitions. Often there are many competing interactions (repulsive or attractive, say) in the vicinity of a quantum critical point between phases, so that minute changes in the control parameter will favour one type of order over another. Fluctuations between these states are quantum fluctuations, which influence surprisingly large areas of the phase diagram, as compared with thermal fluctuations. An example is the compound $CePd_2Si_2$ (ref. 1). At low temperature and ambient pressure, the prevailing order is antiferromagnetic, but applied hydrostatic pressure can suppress the dominant antiferromagnetic interactions. However, just before all of the magnetism disappears at the quantum phase transition, a bubble of superconductivity appears. It's a competing state that can only exist if the magnetism is sufficiently weakened, but the spin fluctuations associated with the antiferromagnetic state seem to be helping the electrons to form pairs in the superconducting state, which is a very exotic form of superconductivity.

The existence of these sorts of exotic states is hard to predict. Given the difficulty in solving a system of three particles, it's impossible to tackle a real system from first principles. So how does a physicist go about finding new states of matter? On page 167, Paul Canfield[2] shares his own experience in searching for new materials: in general, there are some rules of thumb, but a large dose of luck never hurts! Then, on page 170, David Broun[3] addresses the debate regarding one of the most exotic materials — the high-temperature superconductor. Is there a quantum critical point in the phase diagram for such materials? Perhaps.



The Focus also includes three Review articles. The first provides a clear overview of quantum magnetism and quantum criticality (page 173). Subir Sachdev[4] explains how quantum mechanics and entanglement affect magnetic insulators, as well as superconductors and exotic metallic states that defy our standard theories. There is even a connection to black-hole physics.

Heavy-fermion compounds are so-called because the localized *f* electrons hybridize with the conduction electrons; the effective masses of the resulting quasiparticles can reach a thousand times the mass of the bare electron. For an introduction to this class of compounds — of which $CePd_2Si_2$ is one — turn to page 186. Philipp Gegenwart and co-authors[5] show how quantum fluctuations lead to novel ground states in heavy-fermion systems, including unconventional superconductivity and other unexpected states.

Finally, on page 198 is a review of Bose–Einstein condensation in magnetic insulators. Bose–Einstein condensation has received much attention recently thanks to advances made by the community of physicists working with ultracold atoms, but the phenomenon occurs in many bulk systems, including liquid ^4He and quantum antiferromagnets. In a magnetic material, a quantum of magnetic excitation is called a magnon, which is a boson. Thierry Giamarchi *et al.*[6] review how magnons condense when their density is tuned using an applied magnetic field.

We do hope you enjoy reading this Focus on quantum phase transitions, as well as our regular array of papers on cold atoms and molecules, granular matter, graphene and more. There are, of course, many other topical areas in physics that deserve to be highlighted in this way — look out for more *Nature Physics* Focuses to come.

References

1. Mathur, N. D. *et al. Nature* **394,** 39–43 (1998).
2. Canfield, P. C. *Nature Phys.* **4**, 167–169 (2008).
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5. Gegenwart, P., Si, Q. & Steglich, F. *Nature Phys.* **4**, 186–197 (2008).
6. Giamarchi, T., Rüegg, C. & Tchernyshyov, O. *Nature Phys.* **4**, 198–204 (2008).