experiments are hard to do is only a temporary excuse; it does not scratch the logical itch. Bergman and Siegal's work makes it more plausible that capacitance effects will be found. Yet there are at least three reasons why their results are not yet sufficient to convince a sceptic that capacitance is real.

First, in their simulations the authors looked only at gene expression (the 'transcriptome'), rather than at anything approaching the complexity of whole-organism phenotype. So their results leave us uncertain about what might happen in between. Variation in gene expression might in fact lead to canalization at the whole-organism level, if appropriately regulated transcriptome variation is part of the mechanism that canalizes whole-organism traits.

Second, variation released in the transcriptome could also produce changes in reproduction and mortality rates, which determine the strength of natural selection. If increased genetic variation were accompanied by reduced variation in reproductive success, or by reductions in the correlation between variation in traits and variation in reproductive success, the rate of evolution would not necessarily change. In fact, if the effects were strong enough, the rate of evolution might even decrease.

Third, Bergman and Siegal's analysis of yeast data reveals an increase in phenotypic, not genetic, variation when genes are knocked out at random. Yet capacitance requires that the increased variation be, at least in part, genetic. It has been asserted[7,8] that increased phenotypic variation implies increased genetic variation in such circumstances. But it might not.

So the existence and importance of evolutionary capacitance remain uncertain. But if canalization does turn out to be a pervasive property of genetic networks — one that evolves rapidly and serves as an evolutionary capacitor — a key feature of the genotype–phenotype connection will have been clarified. And that would stimulate further questions. One is how part of the organism's response to environmental change remains canalized while others become 'plastic', or flexible. Also, how do the genetic networks that might be producing canalization as a by-product interact with the mechanisms that determine plasticity (if they interact at all)? Does evolutionary capacitance explain the periods of stasis and rapid change that are seen in experimental studies of evolution — or perhaps even in the fossil record? The answers to such questions may seem beyond reach, but in fact we can start right now with evolutionary experiments on the functional genomics of microorganisms. ■

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1. Wagner, A. *Evolution* **50,** 1008–1023 (1996).
2. Wagner, G., Booth, G. & Baghieri-Chiachian, H. A. *Evolution* **51,** 329–347 (1997).
3. Siegal, M. L. & Bergman, A. *Proc. Natl Acad. Sci. USA* **99,** 10528–10532 (2002).
4. Rutherford, R. L. & Lindquist, S. *Nature* **396,** 336–342 (1998).
5. Quietsch, C., Sangster, T. A. & Lindquist, S. *Nature* **417,** 618–624 (2002).
6. Bergman, A. & Siegal, M. L. *Nature* **424,** 549–552 (2003).
7. Stearns, S. C., Kaiser, M. & Kawecki, T. J. *J. Evol. Biol.* **8,** 539–557 (1995).
8. Meiklejohn, C. D. & Hartl, D. L. *Trends Ecol. Evol.* **17,** 468–473 (2002).

Condensed-matter physics

Singular behaviour

Zachary Fisk

Quantum fluctuations at absolute zero may push a system into a different phase or state. The 'quantum critical point' at which this happens in certain materials has now been probed in greater detail.

More than a century of probing the physics of magnetism has only served to heighten its interest for physicists. Over the past decade, a new focus has evolved — the behaviour of magnetic materials at a 'quantum critical point'. Critical points are perhaps more familiarly associated with phase transitions such as those between water, steam and ice. But at zero temperature there are quantum phase transitions, fluctuations between different states of a phase diagram that are governed by Heisenberg's uncertainty principle. In certain magnetic materials, the temperature at which the system takes on a magnetically ordered state can be tuned, either chemically or through some external influence, towards absolute zero, the transition point being a quantum critical point[1]. The question is, at a quantum critical point, do we see something new that does not occur in classical systems? On page 524 of this issue, Custers *et al.*[2] go some way towards an answer, through the closest approach yet to a quantum critical point in a 'heavy-fermion' material.

Heavy-fermion materials, a class of so-called correlated-electron materials, are metallic compounds with a chemically ordered lattice of magnetic ions, in which conduction electrons interact antiferromagnetically with the local magnetic moments on the atoms. In other words, the conduction electrons have a slight preference energetically to have their spins oriented in the opposite direction to that of the magnetic moments localized on the atomic sites in the lattice. As the temperature falls below the value that characterizes this ordering preference, the local atomic moments become progressively screened and the entropy associated with the local magnetic degeneracy 'dresses' the conduction electrons, dramatically increasing their effective masses and making them into 'heavy fermions'. This reduction of atomic moments drives down the magnetic ordering temperature, and as the local interaction between magnetic moment and conduction electron becomes stronger, the moment and the magnetic ordering temperature simultaneously drop to zero — this is the quantum critical point.

Much of the interest in quantum critical physics stems from its relevance to the physics of phenomena that involve correlated behaviour of electrons — the prime example here being heavy-fermion superconductivity, the resistance-less flow of current at very low temperatures. Discovered[3] in 1979, this particular variant of superconductivity demanded a new understanding of the nature of heavy-fermion materials, as their magnetic character had been thought to be hostile to the occurrence of superconductivity. In the 1990s, it became clear that the systematic appearance of superconductivity in some heavy-fermion materials happens in the vicinity of what has since been recognized as a quantum critical point[4]. Although this is not true for all heavy-fermion materials (including $YbRh_2Si_2$, studied by Custers *et al.*[2]), the tantalizing link between superconductivity and quantum critical points has driven efforts to understand both phenomena.

Classically, critical phenomena are narrowly confined to the region around a critical point, but, in contrast, the influence of a quantum critical point spreads through the phase diagram, well away from the point itself. The effects are many and can be parametrized through properties that vary with a power of temperature, such as electrical resistivity, magnetic susceptibility and specific heat. In their experiments, Custers *et al.*[2] have traced the variation of such properties as they tuned their heavy-fermion material, $YbRh_2Si_2$, into a quantum critical point by applying magnetic fields.

In these experiments, to probe the quantum critical point more deeply, the authors 'doped' their samples of $YbRh_2Si_2$, replacing some of the silicon atoms with germanium. Germanium atoms are slightly larger than silicon ones, and so increase the pressure in the atomic lattice and drive down the strength of the magnetic field at the critical point to almost zero. Custers *et al.* have now provided the most complete study so far of the heavy-fermion quantum critical point, combining chemical doping and magnetic-field measurements to very low temperatures. Chemical doping, however, introduces inhomogeneities in the material that might easily confuse the interpretation of experiments. But in this case the results for the germanium-doped material overlap convincingly with those of the pure compound. This overlap is by no means a foregone conclusion: magnetic field and chemical (or here, size) doping are not in general interchangeable. But the singular nature of the quantum critical point is revealed in these measurements: the mass of the 'dressed' electrons diverges towards infinity.

The temperature dependence of physical properties, in particular how these quantities scale with an exponent of temperature, is a useful diagnostic close to the quantum critical point. This scaling behaviour — of specific heat, electrical resistivity and magnetic susceptibility — is used in attempts to model quantum critical behaviour, and to describe the physics of the fluctuations. Custers *et al.*[2] have uncovered a linear temperature-dependence of electrical resistivity over a remarkably large range, from 10 mK to 10 K (as shown in Fig. 1 on page 524). Moreover, the new data reveal that, as the temperature changes and the system moves away from the quantum critical point, temperature is the only energy scale necessary to describe the evolution. Similarly, when the magnetic field is varied, that quantity sets the energy scale for variations in the material's properties.

There is obvious danger in drawing conclusions from such power-law fits, which can only be suggestive, but our modern understanding requires that if there is a critical point, there should be scaling. Theoretical work[5,6] has shown that it is reasonable to think of quantum phase transitions as classical phase transitions in higher dimensions, but the question remains whether the highly developed scaling concepts of classical critical phenomena can be simply borrowed here.

The measurements made by Custers *et al.*[2] show just how strongly the phase diagrams of heavy-fermion materials are organized by their singularities, the quantum critical points. The goal is to understand the nature of this organization at a deeper level; the dream is that some essentially new ground state may be found in the quantum-critical-point regime. ■

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1. Sachdev, S. *Science* **288,** 475–480 (2000).
2. Custers, J. *et al. Nature* **424,** 524–527 (2003).
3. Steglich, F. *et al. Phys. Rev. Lett.* **43,** 1892–1896 (1979).
4. Mathur, N. D. *et al. Nature* **394,** 39–43 (1998).
5. Hertz, J. A. *Phys. Rev. B* **14,** 1165–1184 (1976).
6. Millis, A. J. *Phys. Rev. B* **48,** 7183–7196 (1993).

100 YEARS AGO

The additions to the Zoological Society's Gardens during the past week include a Sooty Mangabey (*Cercocebus fuliginosus*) from West Africa, presented by Mrs. Watkins; a Ring-tailed Lemur (*Lemur catta*) from Madagascar, presented by Mr. H. P. Jacques; a Suricate (*Suricata tetradactyla*) from South Africa, presented by Captain C. P. Harvey; two Kinkajous (*Cercoleptes caudivolvulus*) from South America, presented by Miss C. Wallace Dunlop; a Himalayan Whistling Thrush (*Myiophoneus temmincki*), a Blue-winged Siva (*Siva cyanouroptera*), a Lesser Blue-winged Pitta (*Pitta cyanoptera*) from the Himalayas, presented by Mr. E. W. Harper; … two Wanderoo Monkeys (*Macacus silenus*) from Malabar, a Common Crowned Pigeon (*Goura coronata*), a Sclater's Crowned Pigeon (*Goura sclateri*) from New Guinea… two Indian Rollers (*Coracias indica*), three Pond Herons (*Ardeola grayi*), five Scarlet-backed Flower-peckers (*Dicaeum cruentatum*), two Two-banded Monitors (*Varanus salvator*) from India, deposited.

From *Nature* 30 July 1903.

50 YEARS AGO

Traité de zoologie Anatomie, systématique, biologie. Publié sous la direction de Prof. Pierre-P. Grassé. Tome 1, Fascicule 1: Phylogénie; protozoaires, generalités; flagellés. (Paris: Masson et Cie., 1952.) 9,600 francs. This is another volume of the now well-known "Traité de Zoologie", issued under the editorship of Prof. Pierre-P. Grassé, of the Sorbonne. While the seventh to appear, it is in fact the first fascicle of the first volume of the series and is in every way worthy of its predecessors. Its 1,071 pages are provided with 829 illustrations (there is no Fig. 285), 694 in line-drawings, 116 in half-tone from wash drawings, 18 in half-tone of photographs and 1 in line and colour… The present volume deals only with the general introductory matters and the sub-phylum Flagellata. The introductory accounts of the structure, physiology, nuclear behaviour, life-cycle and biology of the various categories form a valuable part of the work. Under the systematics of each class there is, wherever possible, a section dealing with its fossil members, a reminder of the present interest in microfossils. It is regrettable that the exigencies of the times are reflected in the price, for this highly commendable book should be readily accessible to every zoologist.

From *Nature* 1 August 1953.

Cell biology

Moving inside membranes

Katsuyoshi Mihara

The mechanism that inserts proteins into the membranes of cellular organelles was thought to be well understood. But studies in yeast reveal that this process is sometimes more complicated than had been suspected.

Rather like the organs of the human body, the 'organelles' of plant, animal and yeast cells are specialized compartments that fulfil specific functions. Each organelle is bounded by a lipid membrane, which contains 'translocase complexes' that ferry proteins from outside the compartment to the inside. But organelle membranes are more than just barriers; besides the translocase complexes, they contain many other proteins, which often adopt intricate configurations within the membrane itself. The prevailing view is that these proteins are sorted and assembled in the membrane by the same translocase complex that transports proteins across the membrane to the organelle interior. But on page 565 of this issue, Wiedemann *et al.*[1] report an unexpected finding from their studies in yeast mitochondria. They show that additional machinery, besides the translocase complex, is required to sort and assemble mitochondrial outer-membrane proteins that have a complicated conformation — including the translocase proteins themselves.

Mitochondria, the powerhouses of the cell, are bounded by not one, but two membranes. Some mitochondrial proteins reside in one of these membranes, some occur in the space between the membranes, and yet others are at the heart of the mitochondrion (Fig. 1, overleaf). All of these proteins are synthesized as precursor proteins (preproteins) inside the cell and are shuttled across the membranes by TOM and TIM complexes — preprotein translocases of the outer and inner membranes, respectively[2]. The TOM complex forms a channel in the outer membrane, called the general insertion pore, through which nearly all mitochondrial preproteins pass. The channel is made by the protein Tom40. This protein chain spans the membrane many times, forming an intricate pore-shaped structure. The entire TOM complex, however, is composed of many