superconductivity requires that this occur at k_F. Kanigel and co-workers observed that the back-bending above T_c occurs at the same k as below T_c. But at the antinode, their claim of particle–hole symmetry is not strong because k_F is uncertain: even below T_c the pseudogap state may alter the antinodal back-bending momentum from the k_F that would be expected for pure superconductivity. Their experiment doesn't go above T^* for an independent measure of k_F in the normal state.

Hashimoto and co-workers provide a more thorough glimpse into the pseudogap state — choosing the lower T_c compound $Bi_2Sr_{2-x}La_xCuO_{6+\delta}$ (Bi2201) to allow measurements from below T_c = 34 K up through T^* = 125 K. The authors found that below T^*, at the antinode, the back-bending momentum is not k_F. This particle–hole symmetry breaking implies that something other than simple superconducting pairing is responsible for the pseudogap at the antinode. Furthermore, a dramatic broadening of the spectra exactly as the temperature drops through T^* confirms that one of the short-range ordered states imaged at lower T by scanning tunnelling microscopy[6,7] is probably the pseudogap state.

It is important to emphasize that all of the experiments mentioned here are indirect tests of pairing. The existence of a gap could signify any ordered state. The symmetry of the gap is more telling — a superconducting state is the only one known to produce a particle–hole symmetric gap tied to the Fermi momentum. But just because the gap is not symmetric at the antinode (the only region measured in the experiment of Hashimoto *et al.*) doesn't rule out pairs at lower energies nearer the nodes. A number of experiments such as measurements of the Nernst effect[4], diamagnetism[11], tunnelling[12], and quasiparticle interference[13] do suggest incoherent pairs in some range above T_c (although none all the way up to T^*). ARPES experiments such as this one[2] should be repeated in momentum space approaching the node, to detect the boundary between pairing and non-pairing behaviour. Ultimately, we should hold out hope for an experiment that directly measures the charge of a carrier above the superconducting dome all the way up to the pseudogap line — is it e or $2e$? ❐

Jennifer E. Hoffman is in the Department of Physics, Harvard University, 17 Oxford Street, Cambridge, Massachusetts 02138, USA.
e-mail: jhoffman@physics.harvard.edu

References

1. Corak, W. S., Goodman, B. B., Satterthwaite, C. B. & Wexler, A. *Phys. Rev.* **96,** 1442–1444 (1954).
2. Hashimoto, M. *et al. Nature Phys.* **6,** 414–418 (2010).
3. Renner, Ch., Revaz, B., Genoud, J. Y., Kadowaki, K. & Fischer, Ø. *Phys. Rev. Lett.* **80,** 149–152 (1998).
4. Xu, Z. A., Ong, N. P., Wang, Y., Kakeshita, T. & Uchida, S. *Nature* **406,** 486–488 (2000).
5. Emery, V. J. & Kivelson, S. A. *Nature* **374,** 434–437 (1995).
6. Wise, W. D. *et al. Nature Phys.* **4,** 696–699 (2008).
7. Kohsaka, Y. *et al. Nature* **454,** 1072–1078 (2008).
8. Kondo, T. *et al. Nature* **457,** 296–300 (2009).
9. Yang, H. B. *et al. Nature* **456,** 77–80 (2008).
10. Kanigel, A. *et al. Phys. Rev. Lett.* **101,** 137002 (2008).
11. Wang, Y. *et al. Phys. Rev. Lett.* **95,** 247002 (2005).
12. Bergeal, N. *et al. Nature Phys.* **4,** 608–611 (2008).
13. Lee, J. *et al. Science* **325,** 1099–1103 (2009).

ENERGY CONSERVATION

In two minds

During the present economic turmoil it may be tempting to make an analogy between energy and money — not least as a reminder that neither can be generated arbitrarily. Few physicists nowadays would use such a comparison to explain the fundamental principle of energy conservation, but in the second half of the nineteenth century scientists would often do so, and try to explore its ramifications. Such anthropomorphic references, however, have long since given way to firm, quantitative descriptions. Daan Wegener now describes the 'de-anthropomorphizing' of energy and energy conservation by considering the cases of the Austrian physicist and philosopher Ernst Mach (pictured) and his German colleague, and opponent, Max Planck (*Studies in History and Philosophy of Modern Physics* doi:10.1016/j.shpsb.2010.02.001; 2010).

The relationship between Mach and Planck is typically discussed in the context of their disagreement about the reality of atoms, which Mach was reluctant to accept. Planck heavily criticized Mach's view that atoms are merely theoretical constructs, and Planck would of course be proven right. However, that victory, Wegener argues,

© ÖSTERREICHISCHE NATIONALBIBLIOTHEK

does not imply a defeat of Machian philosophy altogether.

In his analysis of their views on the law of energy conservation, Wegener has spotted a range of similarities between Planck and Mach, starting from both men's belief that the law is valid and fundamental, to their scepticism towards philosophical speculations (and both found analogies between energy and money not to be useful). But whereas Mach and Planck both aimed at a "de-mystification and purification of the basic concepts of science, such as energy", they phrased the law of energy conservation in slightly different ways, Wegener finds.

These differences, subtle as they are, highlight the fundamentally different outlooks on science that Mach and Planck had. Planck's motivation was mainly to establish theoretical physics as a profession of its own, distinct from metaphysics (and mathematics). He avoided any reference to "human or technical perspectives", and considered the laws of nature to be valid independent of human existence. In contrast, the view of Mach — the "philosopher, historian and sociologist of science" — must be seen in a much broader context, Wegener argues, in which science interacts with society and industry. For Mach, conservation of energy followed from a principle of causality (an argument that is free of anthropomorphic elements) and empirical meaning could come only through the actual practice of science and in the context of historical developments.

ANDREAS TRABESINGER