nucleus has a mass number of 238.

If we added protons to uranium, the heaviest naturally occurring element, then we would produce new elements. (In fact, we would need to add protons and neutrons, to avoid reaching the border of proton stability). The resulting nuclei would be progressively less stable to spontaneous fission because of Coulomb repulsion in their interiors. Nuclei become totally unstable towards fission at about $Z = 106$, in the absence of quantum effects.

But nuclei consisting of certain 'magic' numbers of protons and neutrons are especially stable by comparison with their neighbours. Superheavy nuclei that have nearly magic numbers of protons and neutrons form islands of relatively long-lived nuclei surrounded by a sea of short-lived nuclei. A pair of magic numbers in the superheavy region (114 protons and 184 neutrons) was predicted[7–10] in the 1960s. The centre of this island has not been reached experimentally, and the ways to reach it are debated[11]. However, elements up to $Z = 118$ have been synthesized[5,12]. The existence of the island unambiguously follows from these results, but the data do not indicate where the top of the island is, nor how long-lived the nuclei at the top would be. No consensus on this topic has been reached from theoretical considerations.

Are there other islands of stability? Probably, yes. But different theories of nuclear stability diverge from each other when extrapolated into remote domains of nuclei, so the opposite answer cannot be excluded. One hypothesis proposes that very heavy nuclei do not have a 'normal', nearly uniform distribution of nuclear matter, but a bubble-like distribution. This should substantially suppress the Coulomb forces and increase nuclear stability. Some theories predict bubble-like structures in the vicinity of the first island of stability of superheavy nuclei — in which case, massive, long-lived nuclei might have rather exotic structures. ■

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1. Bohr, N. *Phil. Mag.* **26,** 1–25 (1913).
2. Indelicato, P., Santos, J. P., Boucard, S. & Desclaux, J.-P. *Eur. Phys. J. D* **45,** 155–170 (2007).
3. Indelicato, P., Bieroń, J. & Jönsson, P. *Theor. Chem. Acc.* **129,** 495–505 (2011).
4. Ackad, E. & Horbatsch, M. *Phys. Rev. A* **78,** 062711 (2008).
5. Oganessian, Y. T. *et al. Phys. Rev. C* **74,** 044602 (2006).
6. Pohl, R. *et al. Nature* **466,** 213–216 (2010).
7. Mosel, U., Fink, B. & Greiner, W. in *Memorandum zur Errichtung eines gemeinsamen Ausbildungszentrums fuer Kernphysik der Hessischen Hochschulen* (1966).
8. Mosel, U. & Greiner, W. *Z. Phys.* **222,** 261–282 (1969).
9. Meldner, H. *Ark. Fys.* **36,** 593 (1967).
10. Sobiczewski, A., Gareev, F. A. & Kalinkin, B. N. *Phys. Lett.* **22,** 500–502 (1966).
11. Zagrebaev, V. I., Karpov, A. V., Greiner, W. *J. Phys. Conf. Ser.* **420,** 012001 (2013).
12. Oganessian, Y. T. *et al. Phys. Rev. Lett.* **104,** 142502 (2010).
13. de Marcillac, P., Coron, N., Dambier, G., Leblanc, J. & Moalic, J.-P. *Nature* **422,** 876–878 (2003).

HIGH-TEMPERATURE SUPERCONDUCTIVITY

The sound of a hidden order

Ultrasound measurements in a copper oxide superconductor have revealed an exotic phase of matter, composed of loops of spontaneous quantum currents, that has hitherto excelled at evading observation. **SEE LETTER P.75**

JAN ZAANEN

Rigid things are obvious in the human world, but nature allows for circumstances in which hardness gets a quantum-physics twist. The electron systems formed in copper oxide compounds became famous with the discovery in 1986 that these materials become superconductors at high temperature. But this turned out to be only the tip of the iceberg: the intensive research that ensued revealed surprise after surprise. It became clear that the strongly interacting electrons of these systems form the building blocks of a plethora of exotic phases of matter that are shaped by the weirdness of quantum mechanics[1]. On page 75 of this issue, Shekhter *et al.*[2] present conclusive evidence for the existence of one such phase — one that breaks 'quantum-spookiness' records. Driven by a quantum effect known as zero-point motion, the electrons in this phase organize themselves into patterns formed from spontaneous current loops, and the phase transition in which this electronic order sets in leaves an unambiguous mark on the sound waves travelling through the copper oxide lattice.

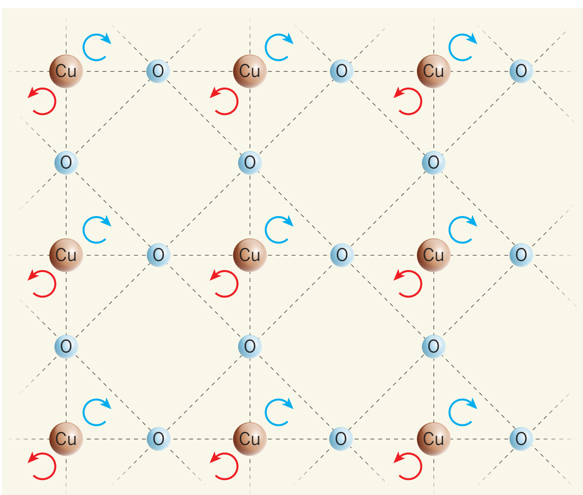

Figure 1 | Electronic order. Shekhter *et al.*[2] demonstrate an electronic order in a copper oxide compound (Cu, copper; O, oxygen) which consists of countercirculating currents (arrows) within the unit cells of the compound's atomic lattice.

The discovery of a phase of matter formed from spontaneous quantum currents is stunning in itself: this 'hidden order' has been playing hide-and-seek for a long time[1]. The first indications of it came from neutron-scattering experiments[3,4]. However, to qualify as a phase of matter, such an electronic order must set in suddenly at a critical temperature. Measuring thermodynamic quantities such as the specific heat is the standard way to detect such phase transitions, because at the critical temperature these quantities should show singularities — sharp cusps in their temperature dependence. These singularities have not been detected, but it was argued[4] that, given its special symmetry, this order could conceal itself completely even in this regard.

Much like the vibrating strings of a violin produce sound waves, the vibrations of the ions in copper oxide compounds also generate sound waves. At high (ultrasound) frequencies, such 'phonons' lose their energy to the electron system, and when the electrons undergo a phase transition, their 'boiling' markedly increases their capacity to damp the phonons. This is precisely what Shekhter *et al.* observe in their ultrasound measurements of the copper oxide compound $YBa_2Cu_3O_{6+\delta}$: at the critical temperature, the onset of the current-loop order in this material causes sharp changes in both the speed and the lifetime of the phonons. These changes reveal the thermodynamic singularities demonstrating that the currents form a macroscopic phase of matter.

What is the origin of this form of spontaneous-current order? Although details remain to be settled, theorists have played a key part in guiding experimentalists to look in the right places, indicating that the underlying theory is trustworthy at least to a certain degree. The physics behind the current loops is counterintuitive, arising in the brew of quantum mechanics and strong interactions[1]. The chemistry of the copper oxides causes the electrons to repel each other so strongly, while their density is high, that they impede each other's motion. An appropriate metaphor is to view these systems as traffic jams, with the difference being that an electron's urge to move comes from the demand of eternal quantum motion.

Resting on the mathematical theory describing such quantized traffic jams, the idea was born[5] in the 1980s that the electrons might organize into a state with spontaneous currents, and in 1997 it was proposed[6] that the currents might form a pattern of counter-circulating flows inside the unit cell of the copper oxide lattice (Fig. 1) — which now seems to be confirmed by Shekhter and colleagues' measurements. This particular pattern of currents was inspired[6] by the state's capacity to hide, because the only symmetry it breaks is the eerie reversal of time[7,8].

This current order is sturdy: at low levels of hole (the absence of an electron) doping, at which the electronic traffic jam effects are particularly strong, the order sets in at quite high temperatures, whereas it gradually weakens when the doping increases, and disappears when superconductivity is strongest[1,4]. Could this order be the cause of superconductivity? It can be argued that the severe quantum fluctuations that develop when the current order disappears altogether as a function of doping might 'glue' electrons into Cooper pairs[4] — a key ingredient in superconductivity. But a lot goes on in the copper oxides besides loop currents and superconductivity[1]. The idea of exotic orders started in the 1990s with the observation of electronic stripes, a form of spatial self-organization of the electronic traffic jam[9], and since then claims of several other exotic ordering phenomena have been made[1].

The simultaneous presence of all of these different ordering tendencies in the copper oxides is not at all understood, and the mystery deepens further when the electrons are heated to temperatures well above the critical temperatures of the current order and of superconductivity. Here, all this complexity disappears, and instead a 'strange metal' phase is observed experimentally, which completely confounds the present understanding of quantum many-body theory[1]. Recent attempts to unleash the mathematics of string theory, in which particles are described by extended entities called strings, seem to shed light on this mystery. These 'AdS/CFT' calculations predict strange metals that are quite like those seen in the laboratory: at low temperatures, they turn into several competing orders, including superconductivity[10].

It might be that much will also be learned in this regard from Shekhter and colleagues' ultrasound measurements. Sound-wave propagation is affected by fluctuations in the electron system not only at the phase transitions that occur in these materials but over the whole range of doping and temperature in which the competing orders and the strange-metal phase occur. These data indicate that this electronic stuff is, in this whole regime, fluctuating under the influence of heat in a way that is utterly different from boiling matter in our everyday world. It may be that further analysis of these ultrasound data may unlock some of the deepest secrets of this mysterious 'quantum matter'. ■

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1. Zaanen, J. in *100 Years of Superconductivity* (eds Rogalla, H. & Kes, P. H.) Ch. 2.4, 92–117 (Chapman & Hall, 2011); preprint at http:/arXiv.org/abs/1012.5461.
2. Shekhter, A. *et al. Nature* **498,** 75–77 (2013).
3. Fauqué, B. *et al. Phys. Rev. Lett.* **96,** 197001 (2006).
4. Varma, C. M. *Nature* **468,** 184–185 (2010).
5. Affleck, I. & Marston, J. B. *Phys. Rev. B* **37,** 3774 (1988).
6. Varma, C. M. *Phys. Rev. B* **55,** 14554–14580 (1997).
7. Kaminski, A. *et al. Nature* **416,** 610–613 (2002).
8. Xia, J. *et al. Phys. Rev. Lett.* **100,** 127002 (2008).
9. Zaanen, J. *Nature* **440,** 1118–1119 (2006).
10. Liu, H. *Phys. Today* **65**(6), 68–69 (2012).

IMMUNOLOGY

An innate regulatory cell

The finding that innate lymphoid cells can control the activity of CD4$^+$ T cells reveals another potential form of immune-system regulation, and may help to explain how the body distinguishes resident from pathogenic bacteria. **SEE LETTER P.113**

MARCO COLONNA

The lining of our intestines is a border zone at which our own cells peacefully coexist with resident bacteria. Cells of the immune system patrol this area to prevent infiltration by invasive pathogenic bacteria. However, in some individuals, the immune system mistakenly targets the benign commensal bacteria, triggering an inflammatory process that damages the intestinal mucosa and leads to inflammatory bowel disease[1,2]. In a report on page 113 of this issue, Hepworth *et al.*[3] identify a mechanism that could be crucial for preventing an overly exuberant immune response to commensal bacteria. Intriguingly, this mechanism relies on the ability of a rare type of immune cell — innate lymphoid cells — to control T cells of the adaptive immune system.

Innate lymphoid cells (ILCs) are classified into three groups, depending on their expression of and developmental dependence on certain transcription factors and secreted molecules. Hepworth and colleagues studied group 3 ILCs, which reinforce the intestinal barrier against pathogenic bacteria by producing the soluble molecules IL-22 and IL-17A. These cytokines augment the capacity of epithelial cells to produce antimicrobial peptides and also recruit other immune cells, such as granulocytes[4,5].

The development of group 3 ILCs is driven by the transcription factor RORγt (ref. 6), and so these cells are absent from RORγt-deficient mice. Hepworth *et al.* noted that RORγt-deficient mice had symptoms that were characteristic of immune activation: their spleens were enlarged and contained activated T cells expressing the CD4 receptor (CD4$^+$ T cells). Moreover, the serum of the mice contained antibodies that bind to commensal bacteria, suggesting specific immune activity against these bacteria. Consistent with this, the authors could ameliorate the CD4$^+$ T-cell activation by using antibiotic treatment to eliminate the commensal bacteria. The researchers saw a similar effect when they depleted the group 3 ILCs in normal mice, confirming that these cells are essential for controlling CD4$^+$ T-cell activation.

But how does this regulation occur? Although group 3 ILCs produce IL-22 and IL-17A, mice that lacked these cytokines did not have symptoms of immune activation. To gain more insight, Hepworth and colleagues turned to analysis of the transcriptome — a cell's complement of RNA molecules. This revealed that the genes that encode MHC class II proteins are highly expressed by a subset of group 3 ILCs called lymphoid tissue inducer (LTi)-like cells. LTi-like cells appear after birth in the intestinal mucosa, in which they promote the generation of post-natal lymphoid tissue by recruiting B cells to form isolated lymphoid follicles[7]. MHC class II molecules capture