50 & 100 YEARS AGO

50 YEARS AGO

The problem of the 'Abominable Snowmen' is discussed by S. V. Obruchev ... beginning with Waddell's report of 1898 about the hairy wild man called 'Yeti' by the Tibetans. In the Soviet Press during 1957–59 there appeared a number of articles on this subject, especially on the possible presence of the 'Snowman' in the Pamirs. In 1958 a special expedition sent to the Pamirs to study this problem reported negatively ... At the same time, numerous recent finds of teeth of a huge anthropoid ape—*Gigantopithecus*—in China suggest that the Tibetan 'Yeti' and the legendary 'Snowman' of the Pamirs and Mongolia may all refer to the former, or present-day but rare, presence of this type of ape in the high-altitude regions of the Himalayas and the Pamirs.

From *Nature* 13 August 1960.

100 YEARS AGO

'Wild plants on waste land in London' — The waste ground between Aldwych and the Strand has been colonised by a variety of plants, most of which show luxuriant growth. Many of the colonists have fruits or seeds adapted to wind distribution, as in the case of the winged fruit of the sorrel (*Rumex acetosa*), and of the plumed seeds of the hairy willow herb (*Epilobium hirsutum*) and French willow, or rose bay (*E. angustifolium*), by far the most conspicuous plant on the ground. It is of interest that *E. angustifolium*, which is absent in many of the waste places of London, occurs in the garden of Fountain Court, near the Strand ... A probable auxiliary exists in the sparrow, through the alimentary canal of which various seeds and fruits no doubt pass, and it is not unlikely that others become attached to its feet by means of the sticky London mud. It will be remembered that Darwin in the "Origin of Species" describes eighty-two plants as springing from the feet of a single partridge ... The above list is by no means exhaustive.

From *Nature* 11 August 1910.

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other elements, freezing in random positions when the samples are cooled. Fratini *et al.*[3] report on page 841 a direct observation, using a novel synchrotron-light microdiffraction technique, of how this 'oxygen dirt' is structured on the micrometre scale in the La_2CuO_{4+y} superconductor.

The result turns out to be surprisingly beautiful: the oxygen interstitials form geometrical patterns that look the same on different scales, ranging from a micrometre up to fractions of a millimetre. Although such fractals are ubiquitous elsewhere in nature, it comes as a complete surprise that crystal defects can accomplish this feat. Even more stunningly, Fratini *et al.* demonstrate that this fractal organization directly promotes the superconductivity: T_c increases when the fractality is more complete. This finding hints at a possible relation with the mysterious quantum-matter side of high-T_c superconductors: the 'quantum-critical' property of the cuprate electrons, referring now to a scale invariance that governs the quantum physics[4].

The experiment of Fratini *et al.* is conceptually straightforward, but it needs the big machines installed at synchrotrons: it amounts to measuring X-ray diffraction on micrometre-sized patches of the sample and combining the results into real-space maps. Zooming in on the diffraction peaks associated with an ordering of the oxygen interstitials in a nanometre-scale 'superlattice' (see Fig. 1c of the paper on page 841), they find that this superlattice order varies considerably in space. Both its magnitude and spatial distributions show power-law behaviour (Fig. 2 on page 842) — the unique fingerprint of scale invariance. This fractal-defect structure is astonishing, and there is nothing in the textbooks even hinting at an explanation.

An obvious alley to explore is dynamical-systems theory, a subject offering insights into fractal phenomena as diverse as the shapes of fern leaves, the 'fat tails' of option pricing in the financial markets and the Gutenberg–Richter earthquake law[5]. The focus in those cases is on the way that things evolve over time, but where is this motive in the case of oxygen interstitials? The fractal patterns actually originate in a rapid quench of the sample from a high temperature, at which the oxygen atoms are highly mobile, to liquid-nitrogen temperature. I suspect that some novel form of 'turbulence' is responsible and is at work when the oxygen 'liquid' formed in the crystal freezes out rapidly.

To demonstrate that the quality of fractal organization promotes the superconductivity, the authors[3] prepared, using different quenching protocols, two samples of La_2CuO_{4+y} that are similar except for the scale at which the fractality comes to an end — 400 or 180 micrometres, respectively. Accordingly, they find that the superconductor deteriorates, from a muscular form at $T_c = 40$ kelvin, to a messy, inhomogeneous one at $T_c = 32$ kelvin. This is hard to comprehend given the conventional understanding of superconductivity. The transition to a superconducting state is driven by the binding of electrons in pairs, and the length scales of relevance for this process (pair size and electronic mean free path) are supposed to be on the nanometre scale. Why should the pairing mechanism be sensitive to subtle changes in the crystalline disorder happening on a length scale that is more than a factor of 1,000 larger?

Is this a sign of the strangeness of the cuprate electron matter? In conventional metals and superconductors, the electrons form a weakly interacting quantum gas, and they go, in the first instance, their own way. But not so in high-T_c superconductors, in which the electrons form poorly understood, highly collective quantum states[2]. The few things that we condensed-matter physicists know about these systems follow from phenomenological analysis of experimental information. A highlight in this regard is that, in superconductors such as those studied by Fratini *et al.*, one finds fingerprints of scale invariance in measurements of the materials' electronic behaviour but in a quantum-physical incarnation[4]. In this 'quantum-critical state', the electrons form collective patterns that look the same regardless of scale. However, this fractal trait is now present on scales both in space and in time, because the electrons are in a state of perpetual quantum motion[6,7].

Could there be some profound relation between the static scale invariance in the defect structure and this quantum criticality, explaining why superconductivity is so sensitive to the former? All along, the problem faced by condensed-matter physicists has been the lack of a general mathematical theory capable of describing quantum-critical metals. But, very recently, help has arrived from an unexpected side. It turns out that the 'anti-de-Sitter space/conformal field theory correspondence', a mathematical highlight of string theory, is encoding the physics of states that look remarkably like the cuprate metals in — *nota bene* — the properties of special black holes[8]. This theory insists that quantum-critical metals have a destiny that they cannot escape: they have to turn into superconductors[9,10]. Hence, quantum criticality is good for superconductivity, but it could of course be that quantum criticality itself is disrupted by crystalline disorder. It is, however, a speciality of things that are scale invariant that they care less about influences that by themselves are also scale invariant. In this sense, the fractal defect structure could be good news, eventually even for superconductivity. But does this quantum-criticality hypothesis explain the sensitivity of superconductivity to changes occurring in the oxygen dirt on fractions of a millimetre? Even the strange worlds described by string theory might not be strange enough to explain this remarkable fact, which will undoubtedly inspire exciting future research. ■

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1. 'Materials for electronics' spec. sect. *Science* **327,** 1595–1611 (2010).
2. Editorial *Nature Phys.* **2,** 133 (2006).
3. Fratini, M. *et al. Nature* **466,** 841–844 (2010).
4. Zaanen, J. *Nature* **430,** 512–513 (2004).

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