

autoimmune response in humans, providing a potential candidate for treatment. Arif and colleagues found that insulin-reactive lymphocytes from diabetics appeared to have a destructive nature; they release molecules that are harmful to β -cells. Insulin-reactive lymphocytes from healthy individuals, however, seemed mostly to have a regulatory function, given the signalling molecules that they secrete. The idea that self-reactive lymphocytes can have different functions is therapeutically interesting in that it suggests two principal pathways to mitigate the effects of autoimmune lymphocytes: wipe out the aggressive cells, or ensure that more of the cells end up with a regulatory function^{11,12}. Indeed, recent work indicates that inducing such a change in the function of autoreactive lymphocytes from aggressive to regulatory might be possible, not only in mice, but also in some diabetic patients¹³.

So, we will not only have to learn which proteins and peptides are recognized by autoreactive lymphocytes, but we will also have to see whether this recognition elicits a regulatory or a destructive state. Dysregulation of such responses might ultimately lead to autoimmune diseases such as type I

diabetes, for example, if lymphocytes switch from a regulatory to an aggressive state. The identification of a high proportion of insulin-A-specific lymphocytes in human pancreatic lymph nodes gives us a valuable population of autoimmune lymphocytes to study, and highlights the importance of recovering cells directly from human target organs. ■

Matthias von Herrath is in the Immune Regulation Laboratory, La Jolla Institute for Allergy and Immunology, San Diego, California 92121, USA. e-mail: matthias@liai.org

1. Nakayama, M. *et al. Nature* **435**, 220–223 (2005).
2. Kent, S. *et al. Nature* **435**, 224–228 (2005).
3. Wegmann, D. R., Norbury-Glaser, M. & Daniel, D. *Eur. J. Immunol.* **24**, 1853–1857 (1994).
4. Wong, F. S. *et al. Nature Med.* **5**, 1026–1031 (1999).
5. Tian, J. *et al. Immunol. Rev.* **164**, 119–127 (1998).
6. Lieberman, S. M. *et al. Proc. Natl Acad. Sci. USA* **100**, 8384–8388 (2003).
7. Yoon, J. W. *et al. Science* **284**, 1183–1187 (1999).
8. Jaeckel, E., Lipes, M. A. & von Boehmer, H. *Nature Immunol.* **5**, 1028–1035 (2004). Errata: **5**, 1190 (2004); **6**, 219 (2005).
9. Jaeckel, E., Klein, L., Martin-Orozco, N. & von Boehmer, H. *J. Exp. Med.* **197**, 1635–1644 (2003).
10. Arif, S. *et al. J. Clin. Invest.* **113**, 451–463 (2004).
11. Homann, D. *et al. Immunity* **11**, 463–472 (1999).
12. von Herrath, M. G. & Harrison, L. C. *Nature Rev. Immunol.* **3**, 223–232 (2003).
13. The Diabetes Prevention Trial — Type I Study Group. *Diabetes Care* doi:28.05.05.dc04–1693 (2005).

High-energy physics

An emptier emptiness?

Frank Wilczek

Temperatures similar to those reached an instant after the Big Bang can be created in collisions of gold atoms. The resulting fireballs may allow us a glimpse of a world that is more symmetrical than our own.

The concept that what we ordinarily perceive as empty space is in fact a complicated medium is a profound and pervasive theme in modern physics. This invisible, inescapable medium alters the behaviour of the matter that we do see. Just as Earth's gravitational field allows us to select a unique direction as up, and thereby locally reduces the symmetry of the underlying equations of physics, so cosmic fields in 'empty' space lower the symmetry of these fundamental equations everywhere. Or so theory has it. For although this concept of a symmetry-breaking aether has been extremely fruitful (and has been demonstrated indirectly in many ways), the ultimate demonstration of its validity — cleaning out the medium and restoring the pristine symmetry of the equations — has never been achieved: that is, perhaps, until now.

In a new paper, Cramer *et al.*¹ claim to have found evidence that — for very brief moments, and over a very small volume — experimentalists working at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory in New York have

vaporized one symmetry-breaking aether, and produced a more perfect emptiness. This pioneering attempt to decode the richly detailed (in other words, complicated and messy) data emerging from the RHIC experiments is intricate², and it remains to be seen whether the interpretation Cramer *et al.* propose evolves into a consensus. In any case, they've put a challenge on the agenda, and suggested some concrete ways to tackle it.

But what exactly is this underlying symmetry of nature that is broken by the aether? How is it broken, and how might it be restored? The symmetry in question is called chiral symmetry, and it involves the behaviour of quarks, the principal constituents of the protons and neutrons in atomic nuclei (among other things).

Chiral symmetry is easiest to describe if we adopt the slight idealization that the lightest quarks, the up quark (u) and down quark (d), are massless. (In reality their masses are small, on the scale of the energies in play, but not quite zero.) According to the equations of quantum chromodynamics (QCD), the theory that describes quarks and their interactions via the strong nuclear

force, the possible transformations among quarks are very restricted. One rule is that u-quarks and d-quarks retain their 'flavour' — that is, a u never converts into a d, nor a d into a u. Quarks also, like the more familiar photons, have an intrinsic spin. If the spin axis is aligned with the direction of motion, then the sense of the rotation defines a handedness, known as chirality, rather like a left- or right-handed screw. The two possible states of chirality of a quark, left and right, are essentially the same concept as left and right circular polarization for photons. The fundamental interaction between quarks and gluons, to which we ultimately trace the strong nuclear force, conserves chirality as well as flavour. Thus a u-quark with left-handed chirality (written u_L) never converts into a right-handed u_R , and so on. But these extra conservation laws, which follow from the symmetry of QCD's equations, are too good to be true. In reality, one finds that although the rule forbidding changes of flavour holds true, there is no additional conservation law for chirality — chiral symmetry is broken.

The accepted explanation for this mismatch blames a form of aether. The idea is that there is such a powerful attractive interaction between u_L -quarks and \bar{u}_R -antiquarks (every quark has an antiquark with the opposite charge), and likewise between d_L -quarks and \bar{d}_R -antiquarks, that the energy gained from their attraction outweighs the cost of creating the particles in the first place. Thus, perfectly empty space, devoid of quarks, is unstable. One can lower the energy of the vacuum by filling it with bound u_L - \bar{u}_R and d_L - \bar{d}_R pairs (and their antiparticles, \bar{u}_L - u_R , \bar{d}_L - d_R). Physicists call this process the formation of the chiral condensate. In the stable state that finally results, the conservation of chirality is rendered ineffective, as space itself has become a reservoir containing, for example, an indefinite number of u_L -quarks. (Because each u_L - \bar{u}_R pair contains both a quark and an antiquark, net conservation of flavour still holds good.) This extraordinary picture has experimental consequences: the lightest strongly interacting particles, the π -mesons, can be identified as collective oscillations of the chiral condensate. This identification provides clues to the unusual properties and interactions of the π -mesons, notably their small masses compared with those of other strongly interacting particles.

At the RHIC, collisions between heavy ions — gold nuclei with a total of 197 protons and neutrons each — create a fireball in which temperatures exceeding 1.5×10^{12} kelvin are achieved (Fig. 1). Impressive evidence has accumulated that a qualitatively new state of matter has been created, a liquid-like plasma of quarks and gluons^{3–6}. Could something even more dramatic — a qualitative change in the properties of empty

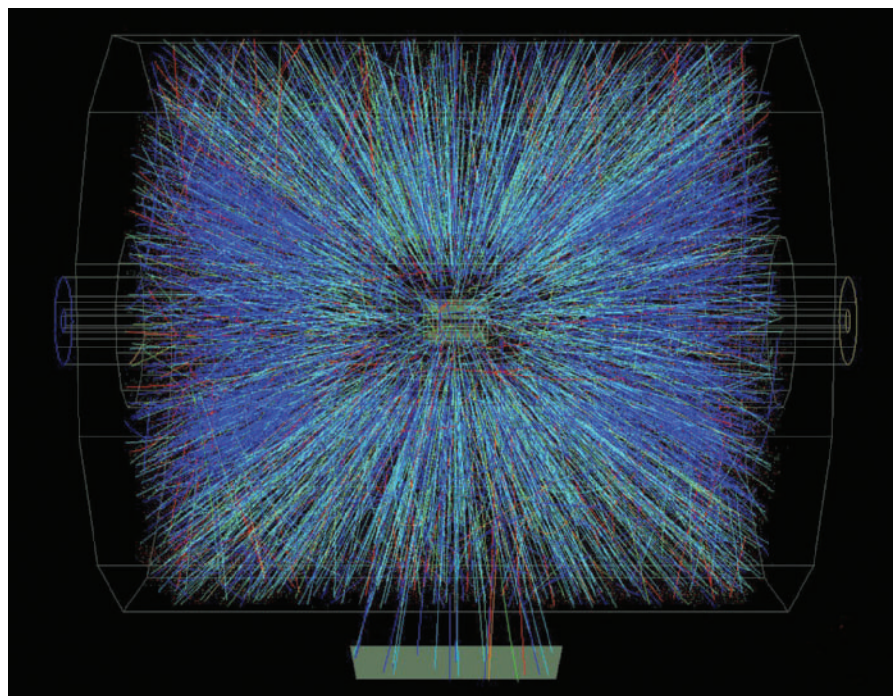


Figure 1 Gold dust. A side view of one of the first high-energy collisions captured by the Solenoidal Tracker of the STAR detector at the Relativistic Heavy Ion Collider (RHIC). The initial head-on collision of two gold ions, each consisting of a total of 197 protons and neutrons, occurs at the mid-point of the central tube (running across the image from right to left). The tracks indicate the paths taken by thousands of subatomic particles created in the fireball of energy set free in these collisions. Several layers of detectors, arranged concentrically around the central tube, and encased in a powerful magnet, allow the identification of these particles. (Courtesy of Brookhaven National Laboratory, STAR collaboration.)

space — be occurring as well? Theoretical calculations indicate that at such temperatures the pairs that make up the chiral condensate will break apart. When the condensate vaporizes, the full underlying chiral symmetry of QCD becomes operative. This change in the properties of ‘empty’ space last occurred throughout the Universe in the early moments after the Big Bang, when temperatures were as high as those reached in the RHIC fireball. This and similar vaporizations of other condensates at higher temperatures play an important role in modern cosmological thinking. Such an event might, for example, have triggered an epoch of inflation — a period of accelerated growth in which the horizon of the Universe expanded, temporarily, much faster than the speed of light.

Vaporization of the chiral condensate affords by far our best opportunity to access a phase transition of empty space in a controlled terrestrial experiment. The difficulty arises not so much in creating the necessary extreme conditions, but in reconstructing from the ashes available to us what happens during the initial stages of the experimentally created fireballs. Cramer *et al.*¹ use correlations between observed π -mesons to reconstruct properties of the medium through which they travelled. Previous models have had difficulty in dealing with these correlations, resulting in what has been

called the ‘HBT puzzle’⁷. Only by allowing for the possibility that the medium significantly alters the properties of the π -mesons, in the way expected if that medium were free of the chiral condensate^{8,9}, do Cramer *et al.* achieve a satisfactory fit to the data they consider. Thus, they may both resolve an old puzzle and open a new vista. Whether their model can be extended successfully to cover additional phenomena, and whether models based on other ideas can be equally successful, are questions sure to receive considerable attention in the near future. ■

Frank Wilczek is at the Center for Theoretical Physics, Massachusetts Institute of Technology, 77 Massachusetts Avenue 6-305, Cambridge, Massachusetts 02139-4307, USA.
e-mail: wilczek@mit.edu

1. Cramer, J., Miller, G., Wu, J. & Yoon, J.-H. preprint at www.arxiv.org/nucl-th/0411031 (2004).
2. Kolb, P. F. & Heinz, U. in *Quark Gluon Plasma* Vol. 3 (eds Hwa, R. C. & Wang, X.-N.) (World Scientific, Singapore, 2004); preprint at www.arxiv.org/nucl-th/0305084 (2003).
3. Adcox, K. *et al.* (The PHENIX collaboration) *Nucl. Phys. A* (submitted); preprint at <http://arxiv.org/nucl-ex/0410003> (2005).
4. Adams, J. *et al.* (The STAR collaboration) *Nucl. Phys. A* (submitted); preprint at <http://arxiv.org/nucl-ex/05010095> (2005).
5. Back, B. B. *et al.* (The PHOBOS collaboration) *Nucl. Phys. A* (in the press); doi:10.1016/j.nuclphysa.2005.03.084 (2005).
6. Arsene, I. *et al.* (The BRAHMS collaboration) *Nucl. Phys. A* (in the press); doi:10.1016/j.nuclphysa.2005.02.130 (2005).
7. Heinz, U. W. & Kolb, P. F. preprint at www.arxiv.org/hep-ph/0204061 (2002).
8. Son, D. T. & Stephanov, M. A. *Phys. Rev. D* **66**, 076011 (2002).
9. Son, D. T. & Stephanov, M. A. *Phys. Rev. Lett.* **88**, 202302 (2002).



100 YEARS AGO

A description of the large diamond found recently in the Premier Mine, Transvaal, is given in the *Geological Magazine* (April) by Dr. F. H. Hatch and Dr. G. S. Corstophine, with reproductions of four photographs which represent the diamond in its actual size from four different points of view... The stone is bounded by eight surfaces, four of which are faces of the original crystal, and four are cleavage surfaces, which are distinguished from the original octahedral faces by greater regularity and smoothness. For a large stone the crystal is of a remarkable purity... The stone, which has been named the Cullinan diamond, weighs 9600.5 grains troy, or 1.37 lb. avoirdupois; this is more than three times the weight of the largest diamond previously known.

ALSO:

In proposing the toast of “The Japan Society” at its annual dinner on May 3, Sir Frederick Treves referred to the medical and surgical ability of the Japanese. Nothing astounded him more, he said, in his recent visit to Japan than the way in which the Japanese have inquired into the medicine and surgery of the western world and the marvellous thing they are making of it... The Japanese have all the qualities of a surgeon. They have infinite patience and infinite tenderness. Sir F. Treves is confident that not many years hence there will be seen in Japan one of the most progressive schools of medicine the world has ever known. From *Nature* 11 May 1905.

50 YEARS AGO

In 1947, Evans and Guild described a technique for the quantitative extraction of earthworms. This consisted of treating a known area with a solution of potassium permanganate (1.5 gm. per litre) at the rate of 6.8 litres per sq. metre. The method was said to recover a high proportion of the total population... I found, however, that population estimates obtained by the permanganate technique were considerably lower than those suggested when a more laborious hand-sorting method was employed. In order to measure the relative efficacy of these techniques, permanent pasture on light soil of alluvial origin was sampled by both methods contiguously... While the fifty soil cores... produced 639.5 worms, the permanganate samples... produced only 350 worms. J. A. Svendsen
From *Nature* 14 May 1955.