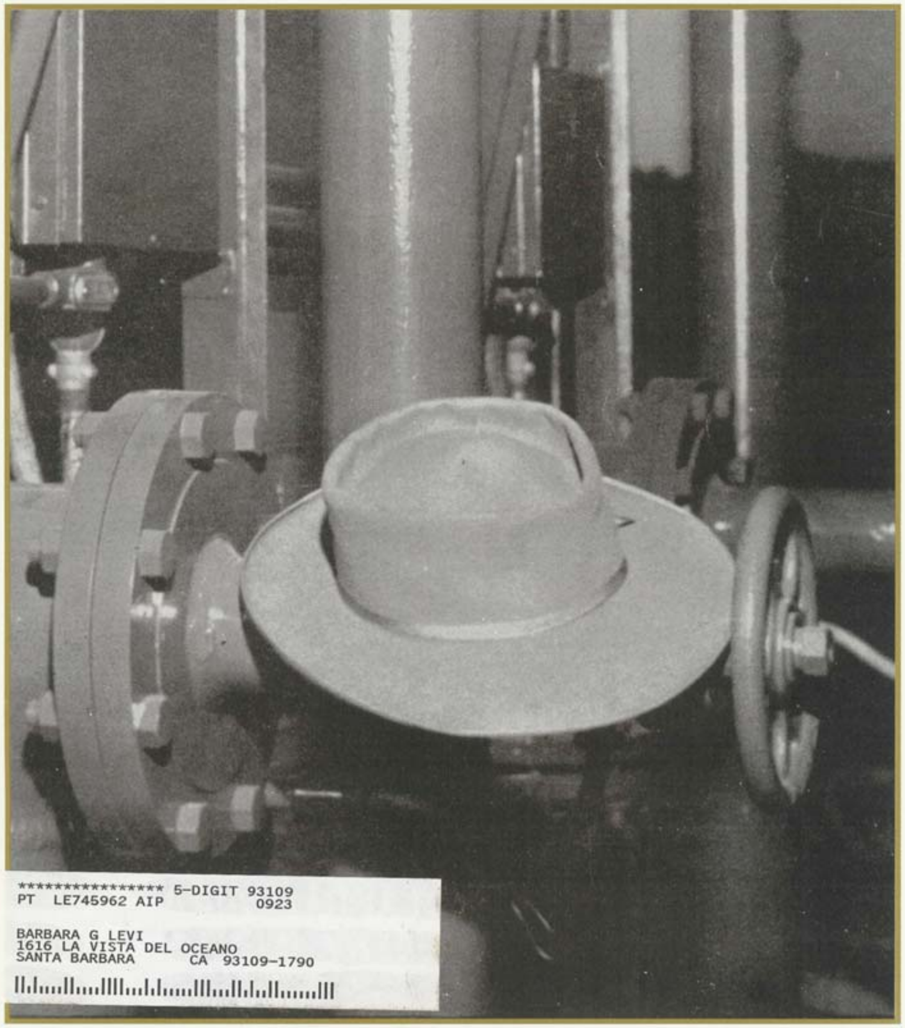
PHYSICS TODAY

MAY 1998



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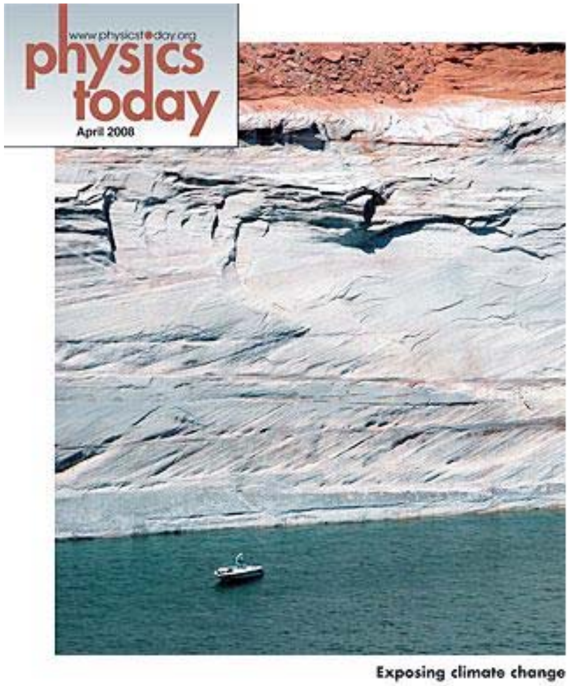
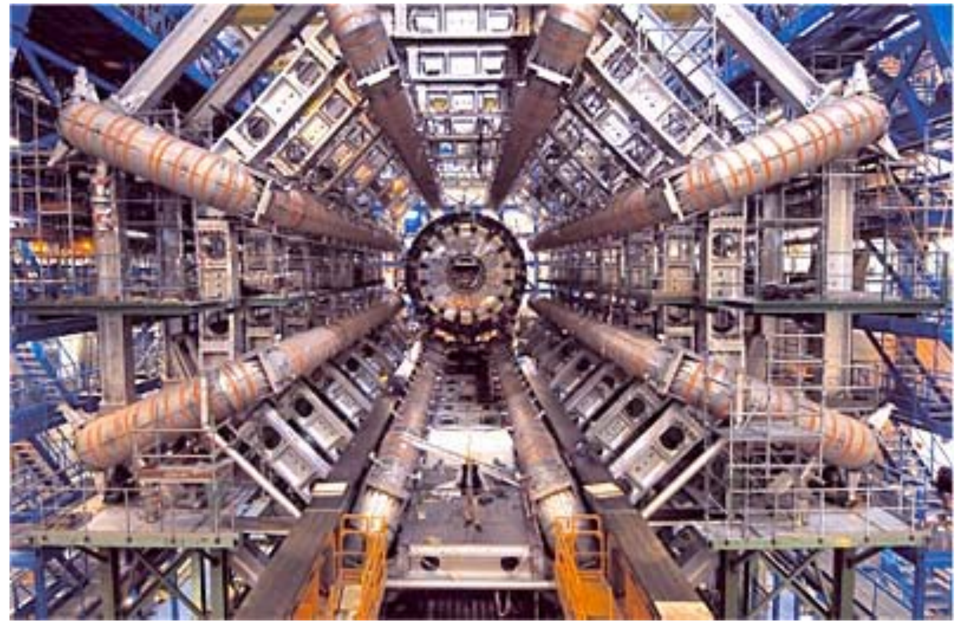
THE FIRST FIFTY YEARS

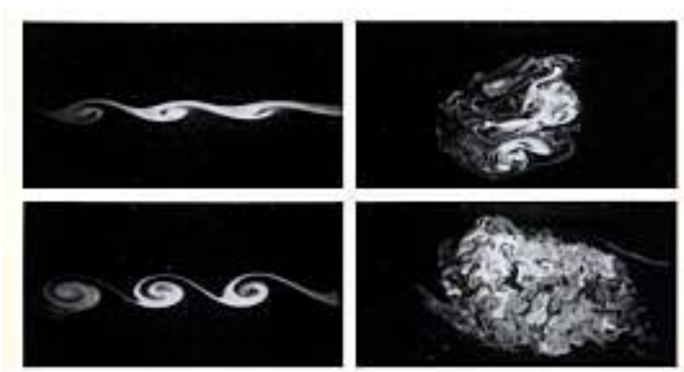
American Institute of Physics



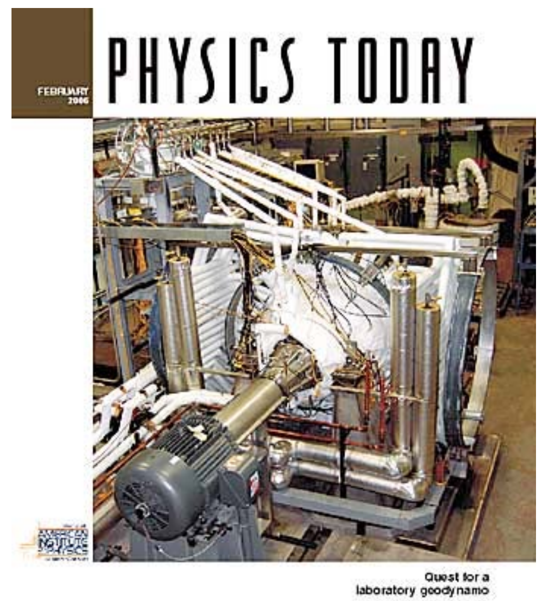
Western Hydrology April 2008



Eyes on the LHC September 2007



Hydrodynamic Turbulence April 2006
Gregory Falkovich & Katepalli Sreenivasan



Laboratory Geodynamo February 2006

Search and Discovery

- **Accuracy**
- **Fairness**
- **Balance**

The Challenges We Face

Competing Monthly: ***Physics Today or Yesterday ?***

“Reaching for the Top”

Last minute insertion

May 1994

http:www.physicstoday.org

algae by Laurens Mets (of the University of Chicago's department of molecular genetics) and spread them on a mica surface. The researchers then did a simultaneous shear-force scan and near-field optical scan. The former provided a topographic image of the 7-nm-thick membrane fragments, while the latter revealed which regions were fluorescing. (See the figure on page 17.) Xie and his group have also performed separate scans of allophycocyanin and sulforhodamine 101 molecules dispersed on glass, with sensitivity and resolution sufficient to detect individual molecules. (Allophycocyanin is a six-chromophore light-harvesting protein that occurs in red algae, and sulforhodamine 101 is a single-chromophore laser dye.) After doing a scan they positioned their microscope tip over a bright region of the membrane or over a single sulforhodamine 101 molecule and took time-correlated photon counts, which revealed the fluorescence lifetime of that region or molecule. The field of fluorescence-lifetime imaging is very active, but most work uses confocal microscopy, which is diffraction limited.

Ultimately Xie's goal is to map the photosynthetic membrane spectroscopically and to study the many reactions involved in photosynthesis at the single-molecule level, including electron transfer, proton transfer, energy transfer and protein conformational changes.

His group has also made a movie of a 2-micron-square field of sulforhodamine 101 molecules fluorescing after being hit by a pulse of laser light. (Strictly speaking, the movie shows the temporal probability distribution of the fluorescence, since it is mapped out with a series of laser pulses.) Hollywood epics are not under challenge, however: The movie's 64 frames represent 6 nanoseconds of action.

In addition, Xie's group has studied the effect of the microscope tip itself on fluorescence. When the edge of the tip was close to a fluorescing molecule the aluminum in the tip quenched the fluorescence, reducing the lifetime in one experiment from about 3 nsec to about 1 nsec. When the center of the tip was over the molecule, however, the lifetime was close to the bulk lifetime (measured for a collection of molecules using far-field light), suggesting that the tip is not greatly influencing the results in that case.

Patrick Ambrose and collaborators at Los Alamos have also done time-resolved studies of single-chromophore molecules.[6] They saw individual molecules' fluorescence blinking out due to photobleaching and they also observed the effect of the tip on fluorescence lifetimes. In their experiments, using the dye rhodamine 6G on silica, they saw both lengthening and shortening of the fluorescence lifetime according to whether the molecule was centered under the tip or was near the edge of the tip, respectively. Ambrose attributes this effect to phenomena observed in the 1960s with molecular layers close to metal surfaces: As a molecule approaches the surface, radiation reflected from the metal suppresses or enhances the spontaneous emission rate, depending on the distance from the metal. Within 50 nm of the metal, direct energy transfer from the molecule to the metal can occur, quenching the fluorescence.

In the immediate future a rapidly growing body of researchers will likely be using fiber-probe scanners based on Betzig's design for increasingly detailed studies of small, delicate systems such as photosynthetic membranes and silicon clusters. When asked about his own future plans, Betzig only hints suggestively about the prospects for a near-field optical microscope with a molecule-sized tip. He and Trautman took out a general patent on such a concept a couple of years ago.

—Graham P. Collins

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Reaching for the Top

The uninitiated would have had difficulty explaining the excited crowd of physicists filling Fermilab's auditorium on 26 April—especially since the presenters were careful to disclaim an actual discovery. Yet even though skepticism remained the watchword, the excitement of even the most ardent critics was palpable. The multinational 440-member Collider Detector Facility group at Fermilab's Tevatron may have glimpsed the top quark—the long-sought partner of the bottom quark—at 174 ± 17 GeV. This would make the t quark the heaviest fundamental particle yet seen. Indeed, because the observed mass is so close to the mass at which electroweak unification becomes manifest, many speculate that the top quark may hold the secrets to the primordial breaking of vacuum symmetry that is thought to have given masses to elementary particles.

CDF spokesmen William Carithers and Melvyn Shochet discussed the t-quark candidates distilled from 10^{12} 1.8-GeV $p\bar{p}$ interactions that took place during the ten-month run beginning August 1992. Three analyses looking for different final states of t quarks decaying into a W boson and a b quark found a total of 12 candidates. Three of those events were seen independently by two of the analyses, adding to their credibility. Depending on the background estimates used, the statistical significance of the observation lay between 2.8 and 3.? standard deviations. The t-quark hypothesis is also supported by most subsequent analyses of the top sample. On the other hand, spokesmen for CDF and the other Fermilab collider experiment, D0 (which reports no significant signal, despite similar sensitivity), pointed out that limited statistics, inconsistencies in some backgrounds and event complexity (many events produce more than 100 charged particles) suggest caution. The CDF analyses are so complex that the paper submitted to *Physical Review D* on 22 April was 153 pages long. As CDF physicist Paul Tipton said, "If we'd had twice the signal or half the signal, it would have been a much shorter paper." The CDF and D0 teams hope that the 1994–95 data run will help them make an intriguing observation believable. —Ray Ladbury

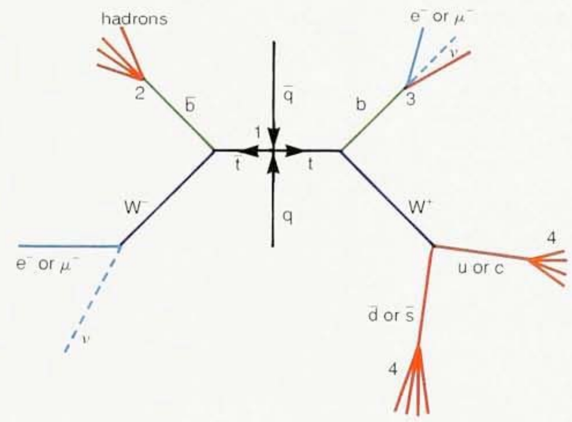
Full Story on the Top Quark

June 1994

SEARCH & DISCOVERY

FERMILAB TEVATRON COLLIDER GROUP GOES OVER THE TOP—CAUTIOUSLY

The evidence from Fermilab's Collider Detector Facility group for a 174-GeV/c^2 top quark (see PHYSICS TODAY, May, page 20) has been received with cautious enthusiasm by the particle physics community. Since most physicists still have not seen the 153-page preprint submitted on 22 April to *Physical Review D*, the demand for speakers on the result exceeds even CDF's abundant supply of experimenters. Still, it is unlikely that new developments will supplant CDF's present results before we've had time to digest them. The low top-production rate, the large backgrounds—events that mimic top decay—and the complicated topologies of t-quark decays all but ensure that the discovery



Top quark signature: $q\bar{q}$ annihilations (1) produce $t\bar{t}$ pairs. Each t quark decays into a W boson (purple) and a b quark (green). The W bosons decay hadronically (red), producing "jets" (4), or leptonically (blue). Hadronic (red) and semileptonic (blue and red) b-decays form detached vertices (2, 3).

The Challenges We Face

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Physical Review Letters
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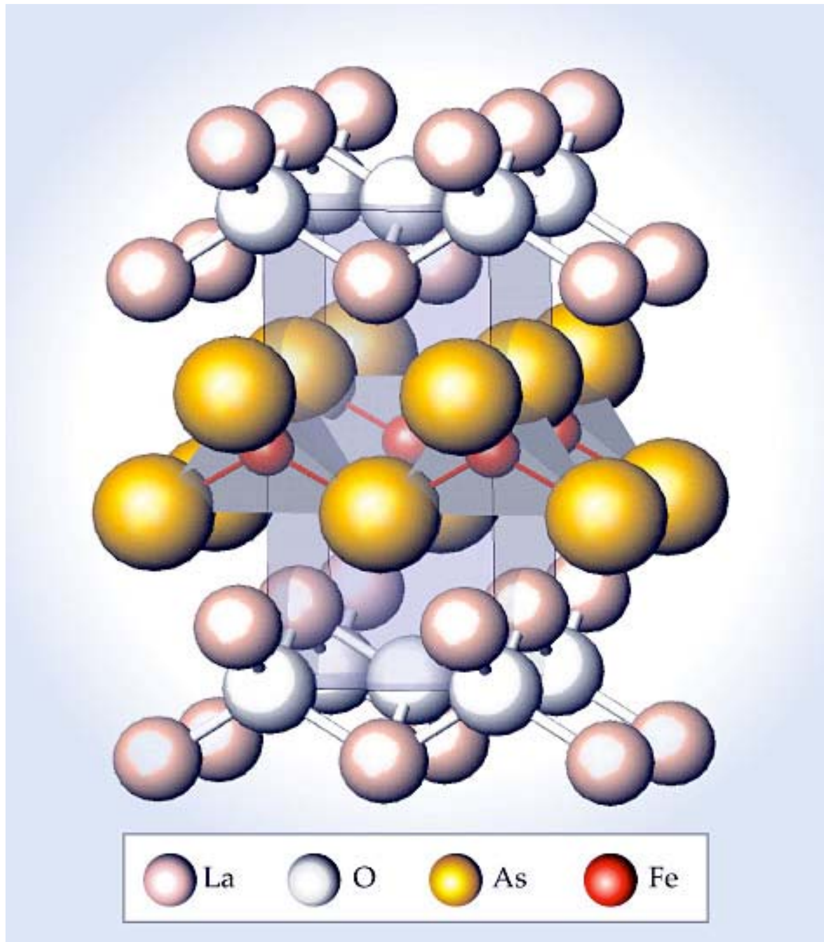
APS heads to the Big Easy for annual March Meeting

Weekly EurekAlert! Express Embargoed Release Notification for 11-May-2008

Journal Club for Condensed Matter Physics

New family of quaternary iron-based compounds superconducts at tens of kelvin



May 2008

The Challenges We Face

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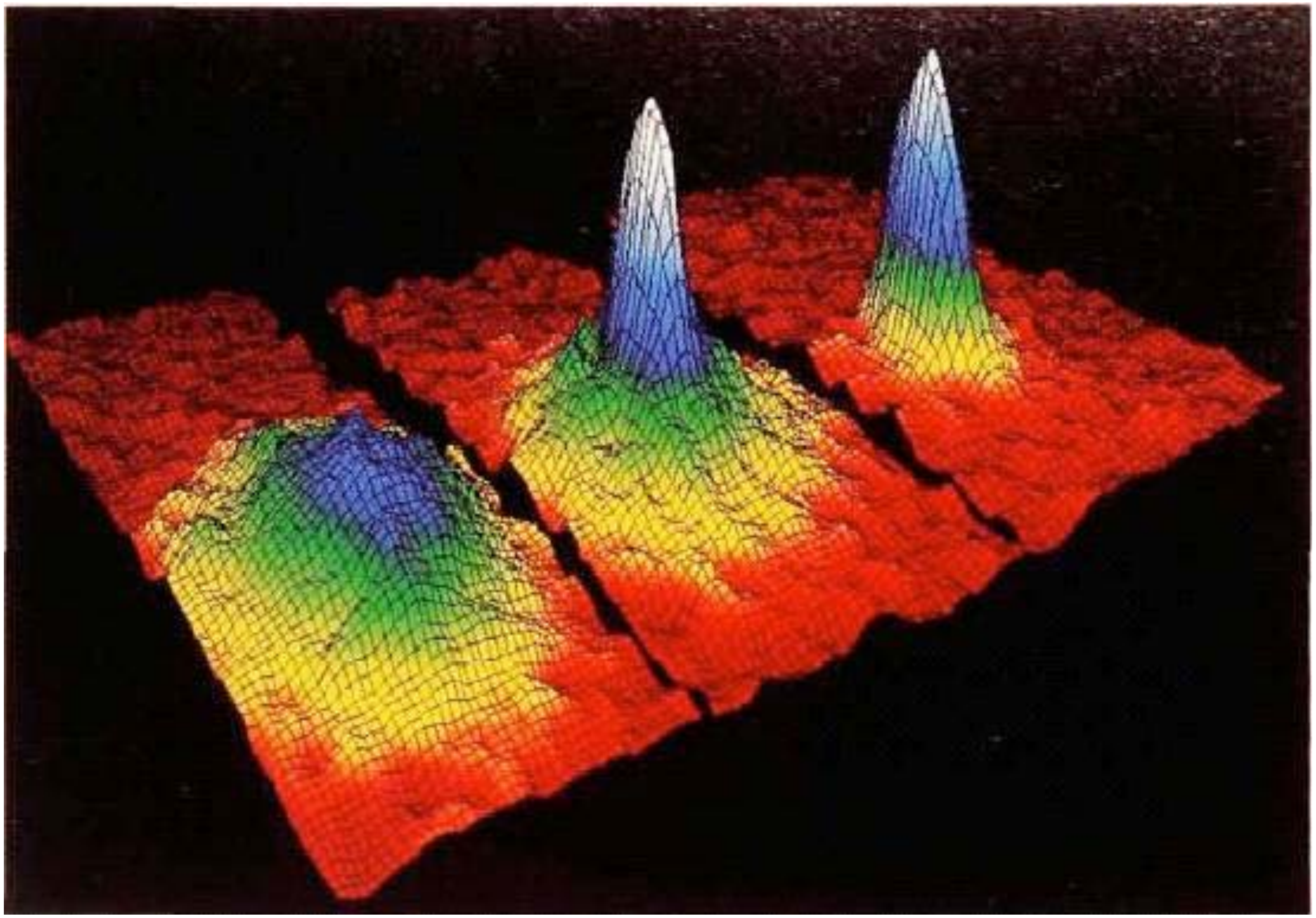
- **Getting a Lead:** ***Information Overload !***
- **Picking the Story:** ***Breakthrough or Breakdown ?***

SEARCH AND DISCOVERY

Gaseous Bose–Einstein Condensate Finally Observed



August 1995

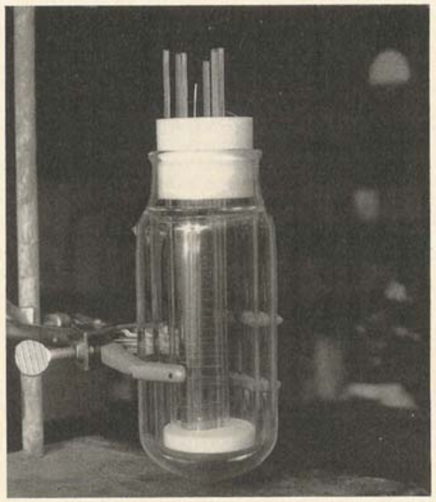
Cold Fusion

June 1989

DOUBTS GROW AS MANY ATTEMPTS AT COLD FUSION FAIL

All the world has been hoping for evidence that Martin Fleischmann of the University of Southampton, England, and Stanley Pons of the University of Utah are right. The pair claimed on 23 March that, inside a small cell containing a palladium cathode immersed in heavy water at room temperature, deuterium nuclei were fusing and producing heat at a rate four times higher than the input power. Two hectic months later scores of research groups were ready to confirm or deny that claim. Many reported at special sessions of the APS meeting in Baltimore and of the Electrochemical Society meeting in Los Angeles in early May. At the time of this writing the "nays" were outnumbering the "yeas." Although the final tally will not be taken until more experiments are done and all papers are published in peer-reviewed journals, the euphoria is quickly fading.

Still the variety of experimental results suggests some mystery regarding events—nuclear or otherwise—in systems with deuterium embedded in palladium. Fleischmann, Pons and graduate student Marvin Hawkins estimated in their paper[1] that neutrons and tritium were being released at rates that are a billion times slower than the fusion rate expected from the heat generated. In Los Angeles, Pons admitted to errors in the neutron results but still stands behind the heat measurements. In a cell with different materials, Steven Jones and his colleagues from Brigham Young University and the University of Arizona claim to see neutrons but not heat. The neutron count implies a fusion rate about ten thousand times smaller than the rate consistent with the neutron data reported by Fleischmann, Pons and Hawkins.



UNIVERSITY OF UTAH

Electrolytic cell, originally used in experiments at the University of Utah. Similar cells have now been studied in many labs around the world. In the cell a palladium cathode is surrounded by a platinum wire anode. The whole cell is then filled with heavy water and lithium deuteroxide salts. In such a simple device Fleischmann, Pons and Hawkins claimed in March to see signs of fusion—neutrons, tritium and excess heat.

Fusion in an electrolytic cell

The techniques for possibly achieving fusion borrow from extensive research over the years on metal hydride systems. It has long been known that certain metals such as palladium and titanium have a particularly large capacity for storing hydrogen: The lattice spacing is large enough and the atomic size small enough that there are regions of low electron density where hydrogen atoms can readily sit. The hydrogen can be attracted into the lattice either by high pressures or by the electric fields in an electrochemical cell. One can get a ratio of somewhat less than one hydrogen to every palladium or nearly two hydrogens to every atom of titanium.

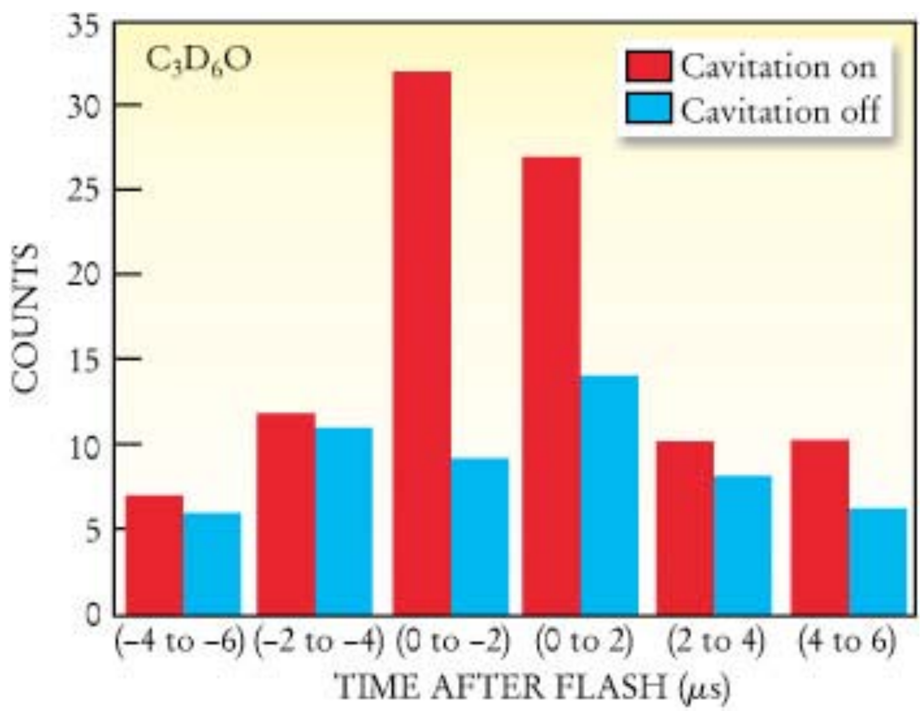
Fleischmann, Pons and Hawkins filled a small cell with a solution of lithium deuteroxide salts and 99.5% deuterium oxide, or heavy water.[1] (See the photo above.) They surrounded a 10-cm-long palladium cathode with a platinum wire anode and ran the cell with current densities as high as 516 mA/cm^2. They studied the cell behavior with cathodes ranging in diameter from 1 to 4 mm, and found that the heat released increased markedly as a function of both cathode volume and current density.

Fleischmann, Pons and Hawkins report that they generated heat in excess of their input energy at a rate of more than 10 watts per cm^3 of Pd for longer than 120 hours. During another trial, the experimenters came in one morning to find the cathode melted and part of the experiment housing destroyed. They calculated the heat output from temperature differences between the cell and a surrounding water bath. They used three different methods for calculating the power output as a percentage of the breakeven, where breakeven is the point at which power in just equals power out. The excess heat ratios are significantly greater than 100% only for one of these methods.

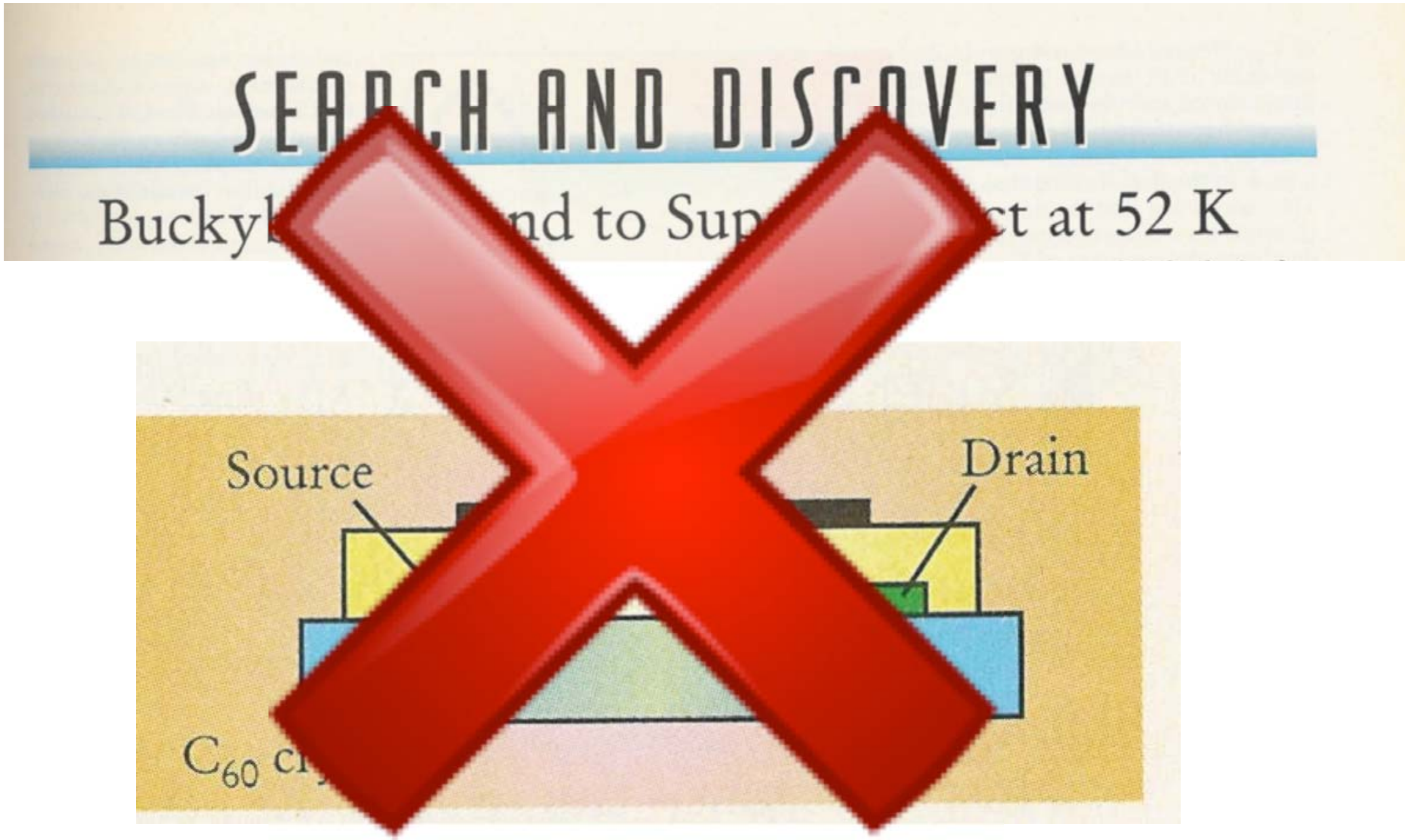
The heat output reported by Fleischmann and Pons is so large that it is hard to imagine what besides nuclear processes could be the source. Cheves Walling of the University of Utah told us that the heat released is larger than what one would get if all the hydrogen in a fully saturated palladium cathode recombined with oxygen. However, heat generation alone does not prove that fusion has occurred. Confirmation requires evidence for at least one of the two common modes of deuter-

Skepticism Greets Claim of Bubble Fusion

Researchers report evidence that fusion has occurred within collapsing bubbles of deuterium-containing vapor. Critics would like to see more definitive proof.



April 2002

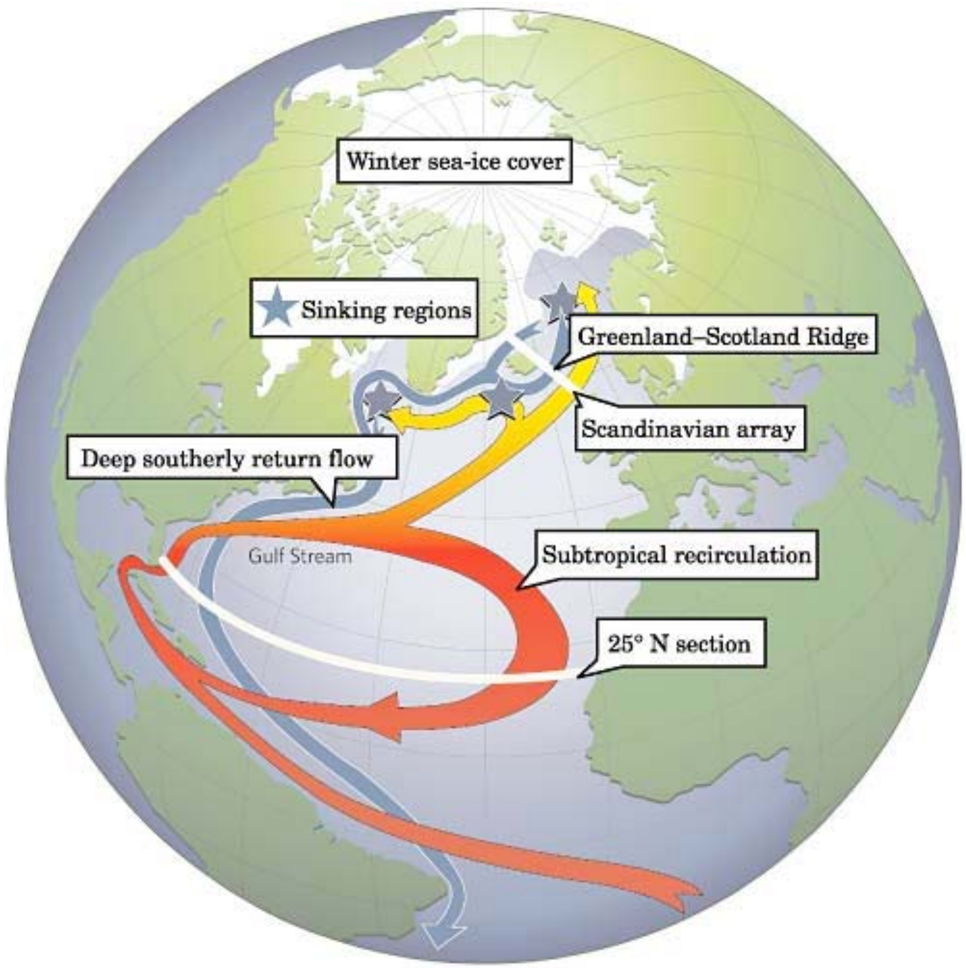


January 2001

Is there a Slowing in the Atlantic Ocean's Overturning Circulation?

A shift in the pattern of ocean currents might signal a long-term trend, or it might simply reflect large, natural fluctuations.

Search and Discovery



April 2006

The Challenges We Face

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- **Learning the Physics:** ***Jargon Jungle !***

D-branes ?

Dirichlet boundary conditions ?

Minkowski space ?

Anti-de-Sitter space ?

N D3 branes ?

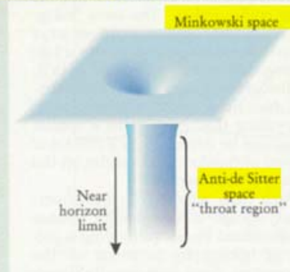
Multidimensional Hyperboloid ?

Duality Demonstrated on D-Branes

Juan Maldacena made clear the duality between two very different types of theories by formulating them both in terms of strange topological structures known as D-branes. D-branes are a subset of a larger class of objects known as *p*-branes (*p* is the object's spatial dimension), which are distortions of spacetime geometry, rather like dislocations in a crystal. If $p = 2$, the *p*-brane is an ordinary two-dimensional sheet, or membrane; if $p = 1$, it's a string and if $p = 0$, a point particle.

D-branes can have any dimension, but it may be easiest to visualize them as sheets. They are distinguished from other *p*-branes by being, loosely speaking, surfaces where the ends of open strings get stuck. (The strings that end on D-branes must satisfy Dirichlet boundary conditions; hence the name of these sheets.) The open strings give rise to particles whose dynamics take place on the brane. Joseph Polchinski (University of California, Santa Barbara) discovered that each D-brane carries a charge and hence is associated with a gauge potential, much as an electric charge is. On a single D-brane, one can formulate a one-color gauge theory, represented by the symmetry group U(1): Stacking *N* such D-branes gives a U(*N*) Yang–Mills theory.

To get a gauge theory in four dimensions, one needs three-dimensional (D3) branes, which can be embedded in ten-dimensional spacetime. In general, the gauge fields on these branes will interact with the gravity field in the surrounding space, but for low enough energies, the gauge field on the D3 brane is decoupled from gravity. Thus, for the gauge field side of his duality, Maldacena took *N* D3 branes.



REGION OF SPACETIME similar to a black hole, formed by stacking a large number of three dimensional hypersurfaces known as D-branes. The flat portion of the surface resembles Minkowski space, and the cylindrical portion (the throat region) is an anti-deSitter space, described by five-dimensional spheres with negative curvature. According to a new duality, the ten-dimensional spacetime deep in the throat, near the horizon of the black hole, is related to a four-dimensional gauge theory, which can be thought of as existing on the very remote boundary of the throat region.

These same D-branes can be viewed as a spacetime gravity solution that is similar to certain types of charged black holes. For the supergravity side of the duality, Maldacena used the curved spacetime around *N* D3 branes—the same configuration used by Klebanov and company for their cross sectional calculations. The metric around this stack takes the form shown in the figure above. Much of the hypersurface is nearly flat, and resembles Minkowski space. But a portion descends into a throatlike region, which continues indefinitely. One can think of this throat as leading to the horizon of a black hole; particles descending into it steadily lose potential energy, as they would were they to fall into a black hole. In ten dimensions, the metric there is described—formidably—as the product of five-dimensional anti–de Sitter (AdS) space and a five-dimensional sphere. AdS space is analogous to a sphere with negative curvature, rather like a multidimensional hyperboloid. The product of AdS space with a five-sphere is considered maximally symmetric. (John Schwarz, who with Michael Green invented the type of superstring theory in which D-branes arise, pointed out in 1983 that it admits this type of solution.[9])

Maldacena's contribution was to look at the supergravity solution deep in the throat region, where the energy is low. It turns out that, in this AdS space, the radius of curvature is proportional to $N^{1/4}$. *N* is the number of D3 branes, but it is also the number of colors in the gauge theory. That's the amazing part. The supergravity solution can be trusted the most when *N* is very large, and that translates precisely to the strong-coupling limit for the gauge theory. Maldacena points out that for large *N*, the supergravity in the bulk region (toward the center of the throat) is not influenced by the remote boundary, just as the gauge theory on the brane is not affected by gravity in the space around it.

The Challenges We Face

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- **Learning the Context:** ***Fine Lines and Land Mines !***

Debate over the Pairing Symmetry in High Tc

May 1993

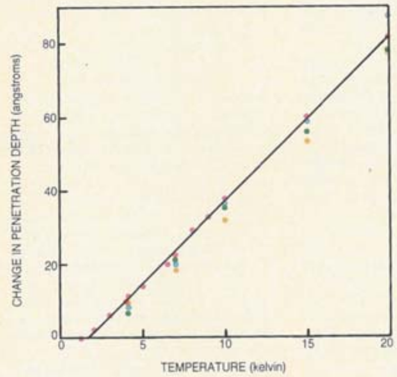
IN HIGH-T_c SUPERCONDUCTORS, IS d-WAVE THE NEW WAVE?

Theorists trying to explain the mechanism for superconductivity in the copper oxide materials may not agree on much, but they all do believe it involves the coupling of electrons of opposite spin. Paths quickly diverge when it comes to the angular momentum of the pair. Is it a BCS-like s-wave (with $l = 0$)? A d-wave? Or something else? The answer is linked to the mechanism that couples the electrons. Although early experiments seemed consistent with an s-wave pairing, recent measurements suggest that the pairing state is at least not isotropic. If the experiments can further delineate the symmetry of the pairing state, they might help narrow the field of contending theories.

How does the angular momentum of the pairing state manifest itself? For one, it determines the wavevector dependence of the energy gap that develops at the Fermi surface when a substance goes superconducting: This gap is the energy needed to break the electron pairs in the superconducting state. If the electrons were paired in an ideal s wave, the energy gap would have the same value at all points on the Fermi surface. More realistically, s-wave pairing gives rise to an energy gap that has the same symmetry as the crystal. But if the electron pairs have a form of d-wave pairing called $d_{x^2-y^2}$, the shape of the gap in k space resembles a four-leaf clover, and is described by the function $\cos(k_x a) - \cos(k_y a)$ (or, in real space, by $x^2 - y^2$ for points (x,y) on a circle). For $d_{x^2-y^2}$-wave pairing, the superconducting gap is positive in some directions in k space and negative in others, and it goes through zero in between. Because of these zeros, the hallmark of this type of pairing is the appearance of "nodes in the gap." There are other possible forms of anisotropic pairing states, but they do not necessarily have nodes.

Evidence of anisotropic pairing has surfaced in nuclear magnetic resonance measurements and, more recently, in studies of angle-resolved photoemission and measurements of the microwave penetration depth in a crystal. Hints of anisotropy have also been seen in nuclear quadrupole resonance studies, Raman scattering and neutron scattering. But, perhaps because the data come from different techniques applied to a variety of copper oxides, the details of the results are not all consistent with one another. Many researchers are now designing new experiments as well as going back to look more critically at old data.

Noting that lots of first-rate experiments are now focused on this fundamental question of the pairing symmetry, Malcolm Beasley (Stanford University) remarked, "It's great that the experiments once again have a lot to tell us."

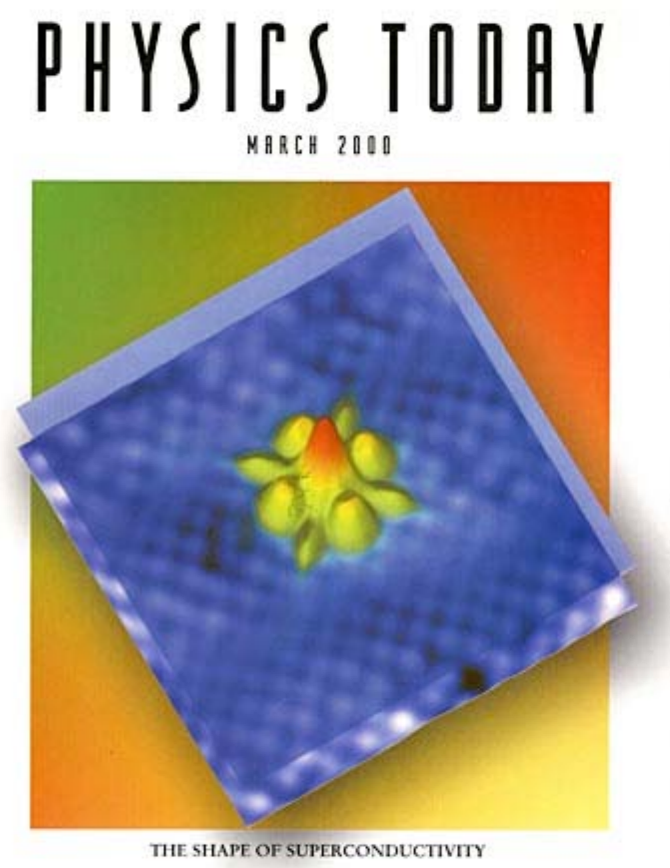


Penetration depth of microwaves in a high-T_c crystal, compared to some reference value, is predicted to vary linearly with temperature at low temperatures if the electrons in the superconductor are paired in a particular type of d-wave state. That theoretical prediction is compared here to recent measurements on four different crystals. (Adapted from ref. 6.)

Evidence from nmr

Nuclear magnetic resonance studies probe the local magnetic field around an atom and hence reflect the susceptibility of the material. They have been of special interest for the high-T_c materials because many researchers have wondered whether spin correlations might play a role in the mechanism of superconductivity: When copper oxides are in their insulating state—that is, before they are doped—the electron spins associated with the copper atoms in the copper oxide have an antiferromagnetic ordering, with the spin of each copper atom opposite to those of all its nearest neighbors. In the metallic, or doped, state this order disappears, but the copper spins still exhibit short-range antiferromagnetic spin fluctuations, with the spins ordering themselves fleetingly over a fairly short distance. Those theories that postulate a role for the spin fluctuations in superconductivity predict d-wave pairing. But there are also predictions of $d_{x^2-y^2}$-wave pairing that are not based on spin fluctuations.

Nmr measurements of the resonance frequency on $YBa_2Cu_3O_7$ indicated several years ago that electrons in the copper oxide superconductors are paired in spin-singlet states. This indication came from the behavior of the Knight shift, the frequency shift



D-Wave Seen by STM

March 2000

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- **Learning the Context:** ***Fine Lines and Land Mines !***
- **Writing the Story:** ***In 2000 Words or Less***

Specialized Topics!

The Energy Gap in the Normal Phase of Underdoped High-Temperature Superconductors

Evidence for a Luttinger Liquid in a Quantum Hall Edge State Formed by a Cleaved Overgrowth Technique

The Longitudinal Resistivity of a Two-Dimensional Electron Gas Exhibits a Strong Anisotropy at Filling Factors of 9/2 and 11/2

The Challenges We Face

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- **Writing the Story:** ***In 2000 Words or Less***
- **Checking the Story:** ***Super Sensitivities***

Box to Accompany a

Debate over the SALT II Treaty

Debaters were

Wolfgang Panofsky

&

Edward Teller

SALT II—the terms of the Treaty

The Strategic Arms Limitation Talks aim to limit the escalation both in numbers and in types of strategic nuclear delivery systems. Reflecting the view that SALT is an ongoing process, the proposed SALT II agreement is organized in three parts, each corresponding to a different duration of enforcement. The Treaty would remain in effect until 1986; the Protocol would last about three years and the Joint Statement of Principles would establish guidelines for future negotiations.

The SALT II Treaty would subject both parties equally to quantitative and qualitative restrictions, including the following:

- A ceiling of 2400 on the aggregate number of strategic nuclear delivery vehicles, to be lowered to 2250 by 1982
- A limit of 1320 on launchers of ballistic missiles equipped with multiple, independently targetable reentry vehicles (MIRV's) and on heavy bombers equipped for long-range cruise missiles
- A lid of 1200 on the number of MIRV'd ballistic missiles alone
- A ceiling of 820 on MIRV'd, land-based intercontinental ballistic missile (ICBM) launchers
- A prohibition against any increase in the number of reentry vehicles (RV's) carried by existing types of ICBM's. The number of warheads on existing type of ICBM's will be frozen at the maximum with which that missile type has been tested. New types of ICBM's will be limited to 10 RV's and new types of SLBM's to 14.
- A ban on the construction of additional fixed ICBM launchers and on any increase in the number of heavy ICBM launchers, defined as those larger than the Soviet SS-19 missile
- A restriction to one new type of ICBM during the lifetime of the Treaty
- A ban on certain new types of strategic offensive systems such as ballistic missiles on surface ships
- A ban on the development of the Soviet SS-16 missile for the Treaty's duration
- An exchange of data on the weapons systems that are limited by the Treaty

The SALT II Treaty would continue the verification provisions of SALT I. (The SALT I Interim Agreement expired in October 1977, but the US and USSR have unilaterally stated their intents not to take any actions contrary to that accord as long as SALT II negotiations continue in good faith.) Under the verification arrangements of that earlier treaty, each side is to confirm by national

	US	Soviet Union
Strategic nuclear warheads	9000+	5000+
Land-based missiles (ICBM's)	1054	1400
Heavy bombers	350	150
SLBM launchers	656	950

The Challenges We Face

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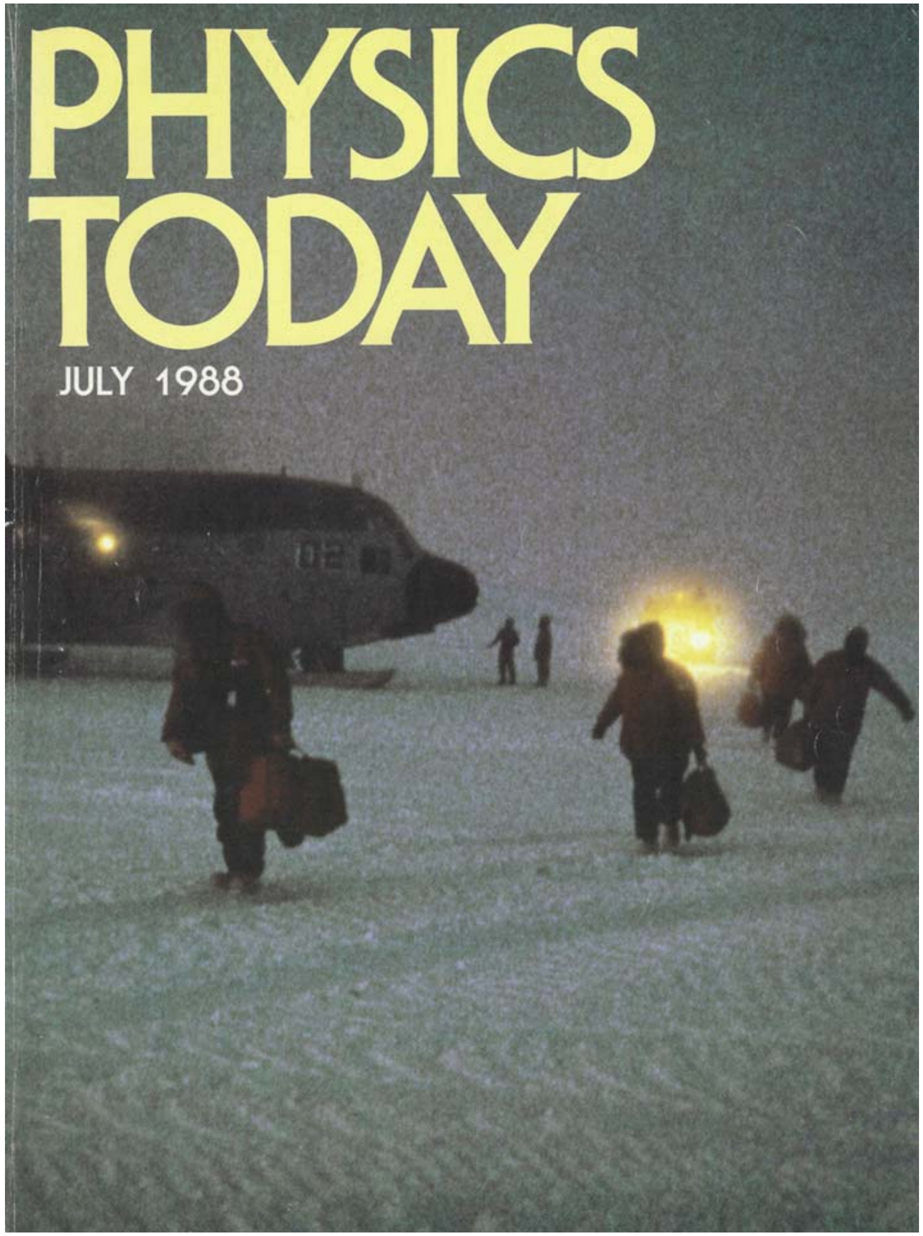
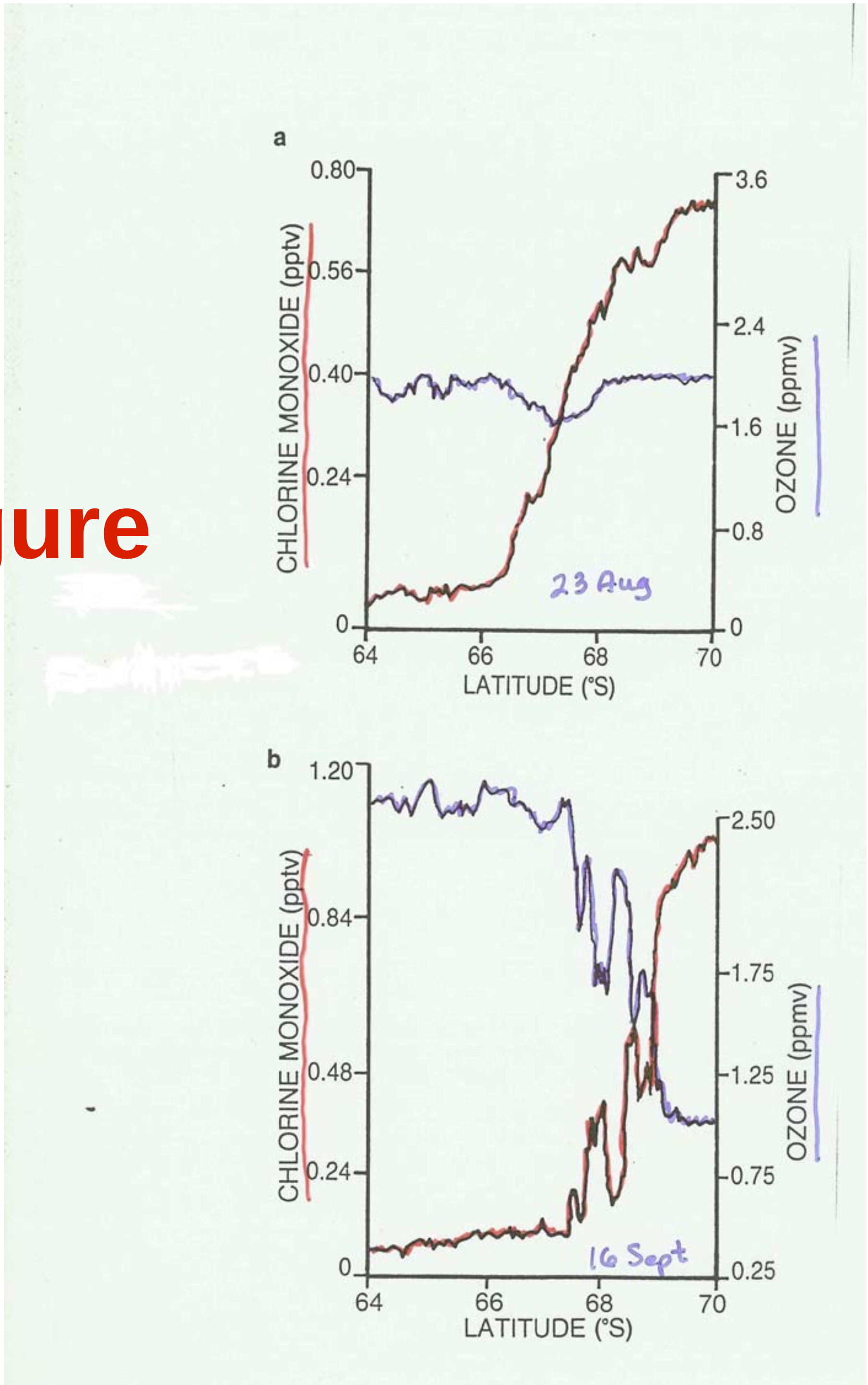
- **Checking the Story:** ***Super Sensitivities***
- **Avoiding Errors:** ***Bloopers***

PHYSICS TODAY

JULY 1988



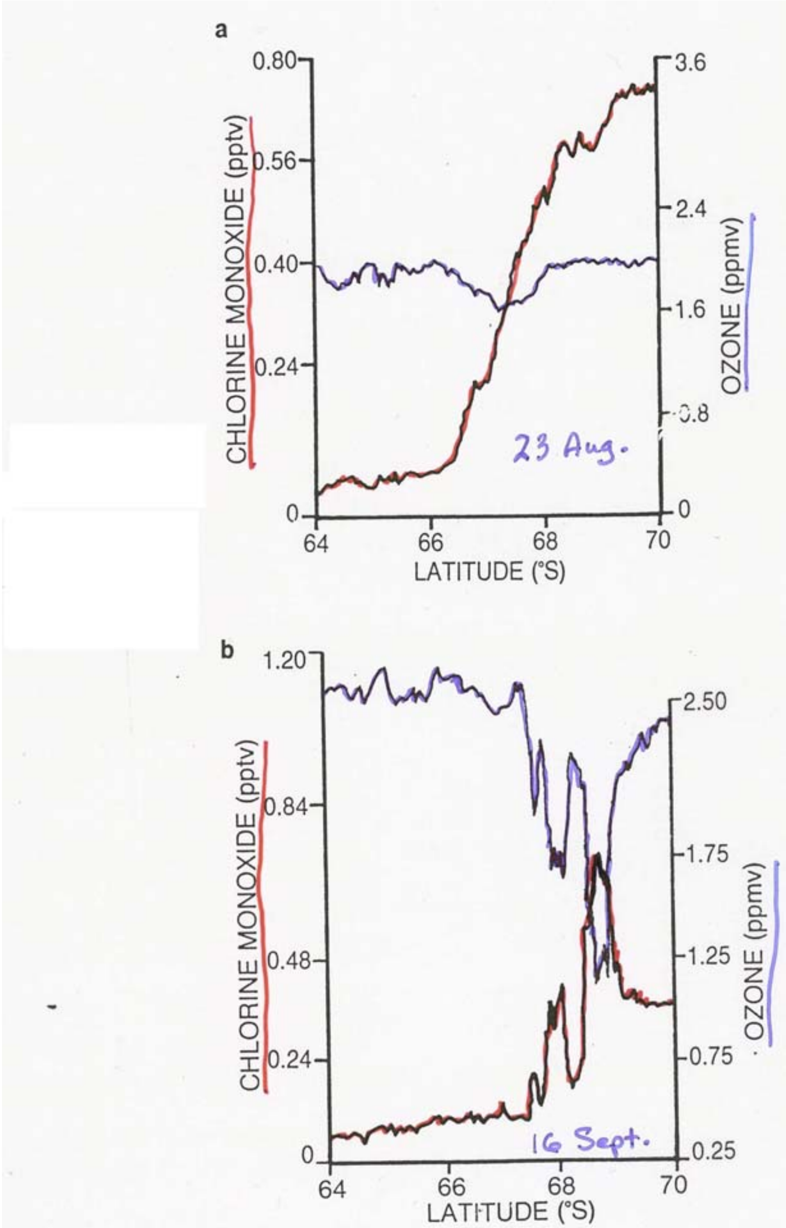
Key Figure

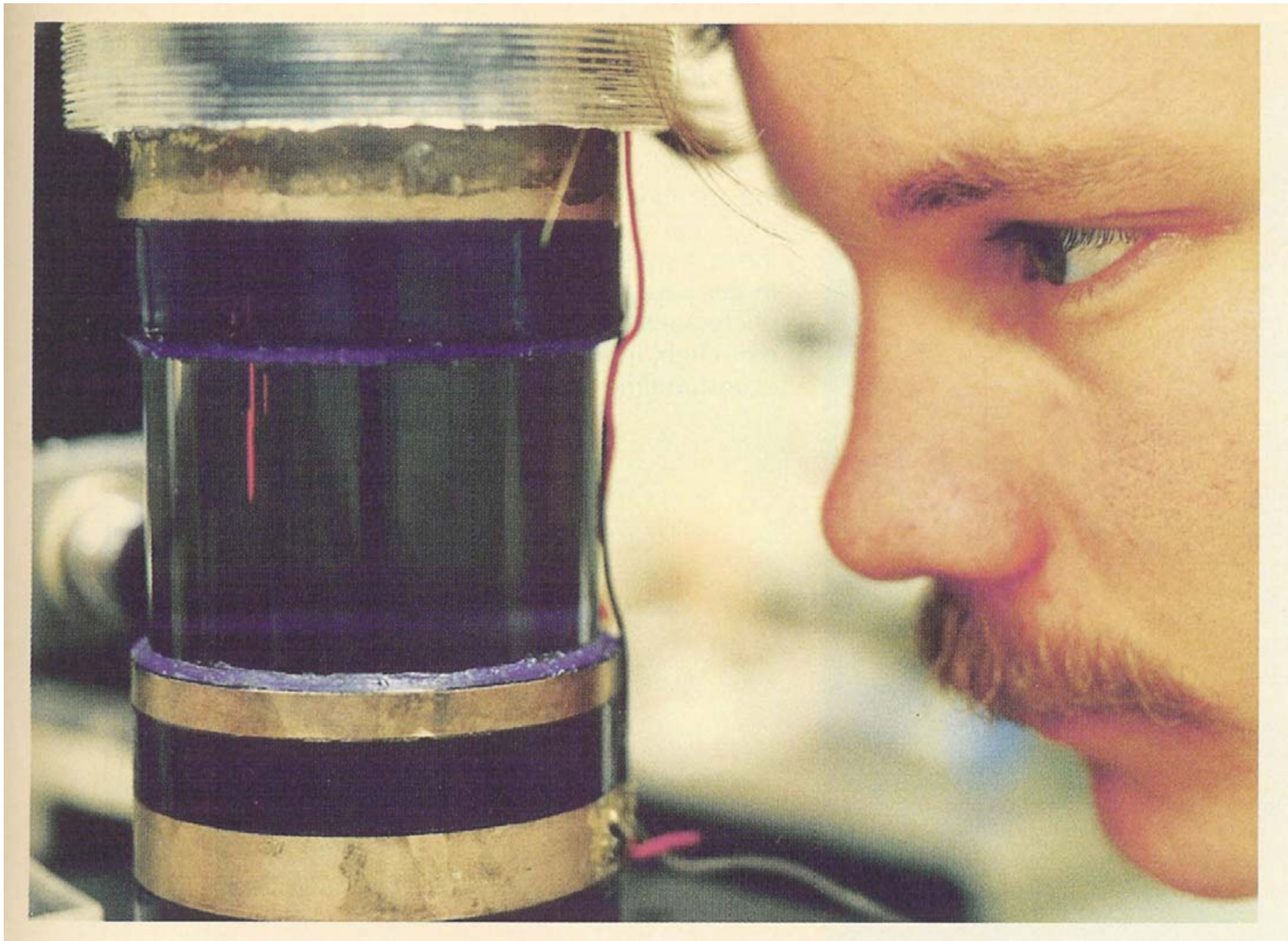

a
0.80
0.56
0.40
0.24
0
CHLORINE MONOXIDE (pptv)
3.6
2.4
1.6
0.8
0
OZONE (ppmv)
23 Aug
64
66
68
70
LATITUDE (°S)
b
1.20
0.84
0.48
0.24
0
CHLORINE MONOXIDE (pptv)
2.50
1.75
1.25
0.75
0.25
OZONE (ppmv)
16 Sept
64
66
68
70
LATITUDE (°S)

Key Figure

As published

OOPS !!





Graduate student Sean Cordry watches the blue sonoluminescence from a cavitation bubble in an acoustic resonator.

Where's the sonoluminescing bubble?

Levitation at ISTEC, the International Superconductivity Technology Center in Japan. Improvements to the bulk ceramic form of $Y_1Ba_2Cu_3O_7$ at ISTEC's Superconductivity Research Laboratory have allowed increases in the weight that can be lifted by a magnet mounted above the cooled superconductor. Last October the laboratory's director, Shoji Tanaka, was levitated. The lab is supported by many Japanese companies and a few from the United States.

Last October, the director of ISTEC was levitated.

LAST SLIDE