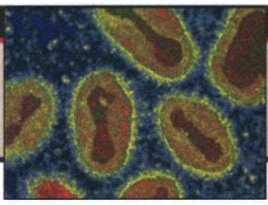

PAGE 1383
Official reprieve for smallpox

1383
Dry spell for U.K. environmental research

RESEARCH INTEGRITY

Pioneering Physics Papers Under Suspicion for Data Manipulation

Recent discoveries at Bell Laboratories—the research arm of Lucent Technologies in Murray Hill, New Jersey—said to be of Nobel quality suddenly became mired in questions last week. Outside researchers presented evidence to Bell Labs management on 10 May suggesting possible manipulation of data involving five papers published in *Science*, *Nature*, and *Applied Physics Letters* over 2 years. In response, Bell Labs officials said that they are forming a committee of independent researchers to investigate. Their conclusions may not be known for months, but scientists who have seen the data are already saying that the potential fallout from the investigation could be devastating.

The Bell Labs papers describe a series of different experiments with organic conductors, but portions of the figures seem almost identical, according to the physicists who raised suspicions. Particularly puzzling, they say, is the fact that two graphs show a pattern of "noise" that looks identical, although it should vary randomly.

Bell Labs physicist Jan Hendrik Schön is lead author on the papers in question and the only author whose name appears on all five. Among his most frequent co-authors are two colleagues from Murray Hill, Bertram Batlogg—a former Bell Labs physicist who has since moved to the Swiss Federal Institute of Technology in Zurich—and Bell Labs chemist Christian Kloc. Schön told *Science* he stands behind his data and says it's not surprising that experiments with similar devices produce similar-looking data. "We are trying as hard as we can to repeat those measurements," Schön says. "I am convinced they will show I haven't done anything wrong." Co-authors on the five papers either declined public comment or could not be reached.

Many scientists have reacted with disbelief. "I'm shocked," says James Heath, a chemist at the University of California, Los Angeles, and director of the California NanoSystems Institute: "It's hard to understand. I know these people. Most of them are good, careful scientists." "It's a little overwhelming," adds Lydia Sohn, a Princeton University physicist who helped bring some of the discrepancies to light. "It's just disturbing, and disappointing, and sad." The noise pattern is particularly disturbing, says Charles Lieber, a chemist and nanoscience expert at Harvard University in Cambridge, Massachusetts: "It's virtually impossible for me to believe that some of this wasn't made up."

Schön himself acknowledges that the similar noise pattern is "difficult to explain." But others affiliated with Bell Labs suggest privately that a systematic artifact in the measurement equipment might account for the similar noise trace, and that in the other cases, computer files containing similar data could have been mixed up.

In happier times. Bell Labs scientist Jan Hendrik Schön (left) with co-authors Christian Kloc and Bertram Batlogg.

Still, Lieber and others say the concerns are so serious that the authors should immediately withdraw the papers in question. "They should be retracted until they can be duplicated," Lieber says. But Cherry Murray, who heads physical sciences research at Bell Labs, says the company won't take any action until the external review committee reaches its conclusion. "We are not rushing to judgment," Murray adds. *Science*'s editor-in-chief, Donald Kennedy, says that's the right course of action. "Until one completes an investigation, it's premature to make any decisions about the papers," he says.

Until last week, most physicists viewed Schön and his collaborators with something between envy and awe. Schön joined Bell Labs as a postdoc in 1998 to work with Batlogg and Kloc, setting out to study the way electrical charges conduct through organic crystals. They soon propelled Bell Labs beyond all competition in the nascent field of organic transistor research.

In a series of groundbreaking papers—most of which are not directly implicated in the current inquiry—the researchers showed that they could use devices called field effect transistors (FETs) to inject large numbers of electrical charges into organic materials. By changing the concentration of charges, they could tune the electronic properties of the materials to behave in any number of ways—as an insulator or semiconductor, a metal or superconductor—exhibiting a malleability that had never been seen before.

The group also reported that organic FETs displayed superconductivity at a temperature higher than had ever been seen in an organic material, revealed quantum signatures never before seen in organics, and could be made to act as lasers and novel superconducting switches. Physicist Art Ramirez of Los Alamos National Laboratory in New Mexico, praising the work in an interview prior to the recent revelations, says "the string of papers is really outrageous" in its success. "I don't know of anything like it." Heath says he was equally impressed: "I saw Batlogg talk about [the team's results] a year ago at a meeting in Venice. I was blown out of my chair. I thought, 'These guys are going to Stockholm.'"

The astounding results prompted groups around the world to attempt to replicate the work. But to date, although other researchers have made some progress, no one has reported duplicating any of the high-profile results. That troubled many in the community, says Cornell University physicist Paul McEuen, the first to notice the apparent duplication of data.

Some physicists grew more concerned last fall when Schön published a pair of papers on a different topic in *Nature* and *Science* with Bell Labs colleagues Hong Meng and Zhenan Bao. In the first, published in the 18 October 2001 issue of *Nature*, the researchers reported making a novel type of transistor in which the key charge-

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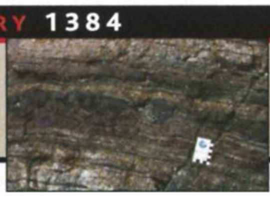


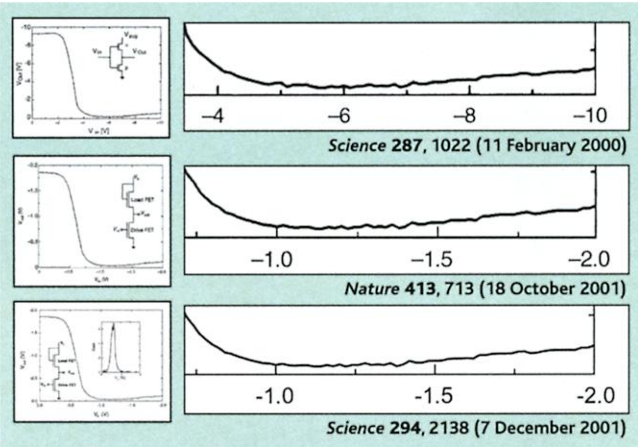
conducting layer was composed of a single layer of an organic conductor. In the *Science* paper, published in the 7 December issue (p. 2138), they reported diluting that charge-conducting layer with nonconducting insulating molecules, allowing them to track the electrical conductivity in a transistor through a single molecule. Together, the results received international press attention as a triumph of molecular-scale electronics. But McEuen says the papers puzzled researchers because, despite the novel architecture of the devices, they seemed to conduct current in a manner similar to traditional FETs.

Last month, a more troubling aspect came to light: Researchers noted that figures describing the conductivity in the two papers appeared identical, even though the measurements were supposedly done at temperatures different enough to affect the results. According to Princeton's Sohn, several Bell Labs researchers pointed out the identical figures to her, McEuen, and others. "Collectively, people at Bell [Labs] were nervous," says Sohn, although she declines to identify who tipped her off. Word of the duplicate figures began to spread. And late last month, Lieber and Harvard physicist Charles Marcus contacted manuscript editors at *Science* and *Nature* informing them of the apparent problem.

A few days later, even before he had heard from *Science*, Schön e-mailed *Science* associate editor Ian Osborne to say there had been a mix-up and that the wrong figure had mistakenly been incorporated in the *Science* paper. Schön also sent along a new figure, which appears as a correction on page 1400 of this issue.

But Sohn says the mix-up explanation just didn't sit well with her or McEuen. "Paul said, 'Lydia, I'm just going to look at the data, the figures,' " says Sohn. And on Thursday, 9 May, McEuen stayed up much of the night looking through Schön's *Science* and *Nature* papers and found what he calls two "disturbing" coincidences.

The first involves the same duplicate figures that prompted the heads-up from Lieber and Marcus. McEuen noticed a close resemblance with yet another figure, this one in the 11 February 2000 issue of *Science* (see figures above). The figures show how changes in an electrical voltage applied to a control electrode called a gate alter the ability of charges to conduct through a simple circuit of two FETs. The devices in the 11 February 2000 *Science* paper reportedly contain different materials in the key charge-conducting channel in each FET and a different physical geometry, both of which should cause these devices to conduct current differently from devices described in the other papers, says McEuen. But when McEuen resized the figures and overlaid the data, he found that the seemingly uninteresting background data on the right portion of the figures looked similar. "The noise looks almost identical, bumps and all," McEuen says. "This is very confusing and disturbing. They should be vaguely similar, maybe roughly similar. But certainly the noise shouldn't be the same," McEuen says. "This knocked me for a loop."



Striking resemblance. Published data from studies of different devices revealed a similarity in recorded "noise." Schön says the bottom figure was sent to *Science* by mistake (see correction, p. 1400).

He quickly got another shock. McEuen noticed that the same 11 February 2000 *Science* and 18 October 2001 *Nature* papers contained another similar figure, which also closely resembled a figure in a third paper, from the 28 April 2000 issue of *Science*. All three papers describe different organic conductors. Yet, if one ignores the labels, several of the data traces appear very similar. "There is no physical reason why they should be so similar," McEuen says.

The next day, 10 May, McEuen says he and Sohn were concerned enough that they contacted Schön, Batlogg, managers at Bell Labs, and manuscript editors at *Science* and *Nature*. He says that all involved expressed deep concern.

A couple of days later, Sohn found another uncomfortable coincidence. In this case, six data traces in a figure in the 3 November 2000 issue of *Science* appear virtually identical to ones in the 4 December 2000 issue of *Applied Physics Letters* (*APL*). But, whereas the *Science* paper tracked the conductivity of a light-emitting organic material known as α-6T in a FET, the *APL* paper followed the conductivity in a non–light-emitting FET made with an organic compound called perylene. Moreover, whereas the FETs in the α-6T figure are "n-channel" devices, which conduct negatively charged electrons, those in the perylene figure are "p-channel" devices, which conduct positive charges. According to McEuen, most physicists believe that should cause the devices to conduct current in a slightly different manner. "They overlap, noise and all," says McEuen. "They are identical," except that the labels on the axes referring to the voltages applied to the devices have an opposite sign, he adds.

Taken together, the three examples are deeply troubling, says Leo Kouwenhoven, a physicist at Delft University of Technology in the Netherlands. "I think that it is very worrisome," Kouwenhoven says. "I can imagine you switch one figure by mistake. It's hard to imagine how you switch 10 figures."

Schön says that because his papers report the conductivity in FETs, "I would expect them to be very similar." He declines to comment on other specific issues. Bell Labs' Murray declines to comment on specifics as well, but adds: "I am very concerned. … This deserves a full and complete investigation."

A five-member committee headed by Stanford University physicist Malcolm Beasley began an investigation last Friday. Beasley says he cannot estimate how long it will take or whether it will be broadened to look at data presented in other papers. Schön has been the first author on 17 papers in *Science* and *Nature* alone in the last 2.5 years and a co-author on dozens elsewhere. Beasley says: "We are hoping for something by the end of summer."

McEuen, for one, believes Bell Labs is taking the proper first step. "Beasley has great stature in the community. … Everybody wants to get to the truth."

–ROBERT F. SERVICE