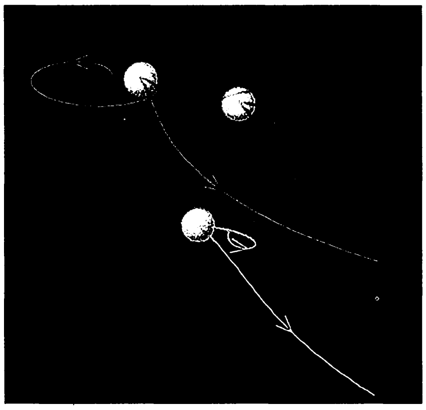
a puzzling phenomenon that, on the face of it, should be impossible.

The affront to scientific common sense turned up in the late 1980s. Scientists had long known that if you zap an atom with a photon, its electron can pick up a packet of energy that sends it into an excited state. Like a rock raised on high, the excited electron stores the energy. Eventually, it falls back to its ground state, releasing a photon that carries the spare energy away.

Zap an atom hard enough, however, and its electron flies free, like a rock boosted beyond Earth's escape velocity. So an electron in an atom should be able to store only so much energy, even if it is hit with a huge barrage of photons. "You would expect, wffft! The atom is ionized—nothing more would happen," says Pascal Salières, a physicist with France's Atomic Energy Commission in Gif-sur-Yvette.



Neoclassical. Electron orbits à la Newton can make quantum problems solvable.

Au contraire. A little more than a decade ago, scientists experimenting with lasers discovered that atoms could absorb hundreds of photons beyond their binding energy and could emit photons with much more energy than should be allowed. "By the 1990s, there was much confusion on how to describe these phenomena," says Gerhard Paulus, a physicist at the Max Planck Institute for Quantum Optics in Garching, Germany. "It was a big controversy."

Physicists were stymied because their usual quantum problem-solving methods broke down under the extreme conditions caused by the laser. But Caltech's Richard Feynman had already suggested a totally different approach that seemed to hold the answer. Most quantum theorists had tackled the problem by using the Schrödinger equation to find the distribution of electron wave functions—smeary particle-wave beasties that inhabit a large parcel of space all at one time. Feynman, on the other hand, treated electrons as ordinary point-particles that circle their nuclei just as planets orbit their star.

But quantum weirdness took its toll: To make the method work, physicists had to take *all* possible orbits into account simultaneously, rather than just one as in classical mechanics. Ordinarily, the infinite variety of possible orbits makes Feynman's method impractical. But on page 902, Salières, Paulus, and colleagues show that the method does indeed hold the key to solving the mystery of the superionized atoms.

CREDITS: (TOP) P. SALIÈRES *ET AL.*

Using a titanium-sapphire femtosecond laser, the team zapped a sample of xenon, sending the atoms' electrons into fits. Ordinarily, the electrons would take many different paths around their nuclei. But Salières and colleagues polarized their laser beam so that most of the electrons' paths cancel one another, leaving only a handful of possible orbits around the nuclei. For instance, one path sends the electron looping around, smashing back into the atom and scattering off into the distance. By summing up the contributions for the paths, the team figured out the energy of the electrons coming off the sample, as well as the high-energy light that gets released in the process—and it matched their observations admirably well. When they adjusted the laser to emphasize certain paths over others, the spectrum changed in just the way the Feynman path method predicted.

"The elliptical case is an interesting test of this [theory]. I don't think anyone's given a good demonstration before," says Ken Kulander, a physicist at Lawrence Livermore National Lab in California who helped formulate the Feynman-based theory behind the experiment. "It really shows that you have all the information about the system in a few paths." Kulander hopes that the theory will suggest a way to boost the number of high-energy photons coming from such laser-matter interactions, perhaps yielding powerful extreme-ultraviolet lasers.

—CHARLES SEIFE

TECHNOLOGY

Liquid Crystal Displays Rub Out the Rub

The sprinkle of black magic behind making liquid crystal displays (LCDs) may finally be ready for its own vanishing act. IBM researchers report in this week's issue of *Nature* that they've come up with a way to eliminate a cumbersome and little understood step of rubbing separate layers of plastic in a display to align liquid crystals placed in between. The advance could simplify and speed display manufacture, drop costs, and help LCDs fight off emerging competition from new flat displays made with light-emitting plastics.

Not long ago, LCDs were themselves an emerging technology. The screens got their start at the now-defunct RCA Labs in the late

ScienceScope

More Is Better Marine scientists say federal officials are being too cautious when it comes to planning the future of the aging U.S. oceanographic fleet.

The government's Ocean Research Advisory Panel last week reviewed a draft plan that recommends that the United States aim for a smaller but more capable fleet of large research vessels over the next 2 decades. The U.S. currently operates 16 vessels longer than 40 meters. A discussion paper drafted by the National Science Foundation (NSF) and other agencies suggests that researchers could get by with as few as 10 new ships in light of funding constraints and the rise of buoy- and satellite-based data collection systems.

But the University-National Oceanographic Laboratory System (UNOLS), which represents ship users, says planners should recommend a "prudently larger" fleet. In a 30 March letter to NSF, UNOLS chair Robert Knox of Moss Landing Marine Laboratories in California urged fleet planners to be "realists but not defeatists. ... If ever there was a time to make strong cases for ... basic oceanographic research, it is now."

NSF's Mike Reeve says officials hope to have a revision within a couple of months "that will reflect a workable agreement."

Resigned Harvard University astronomer Margaret Geller (right) ended a 4-year tenure battle this week by submitting her resignation. Geller will remain employed by the Smithsonian at the joint Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts, but she plans to stop teaching at Harvard after 1 July.

A member of the National Academy of Sciences, Geller was offered a Harvard chair but not tenure in 1997, an unprecedented arrangement (*Science*, 12 November1999, p. 1277). She held out for tenure or a salary guarantee, suspecting sex discrimination as the reason for the unusual offer. University officials rejected her request, however, saying that they would be forced to make the same deal with other Smithsonian employees.

1960s and soon found their way into simple numeric displays on wristwatches and calculators. Now married with powerful silicon electronics, LCDs have grown into a $21-billion-a-year business fashioning screens for everything from laptop computers to cell phones.

The devices use a panel of transistors to control the ability of light to shine through an array of filters. In a typical LCD cell, light enters through a polarizing filter at the bottom of the cell and is twisted 90 degrees by liquid crystalline molecules so that it can exit through a similar filter at the top that is oriented perpendicular to the first. Ordinarily, the rod-shaped liquid crystalline molecules between the filters would stack atop one another all pointing in the same direction. But displaymakers alter that tendency with the help of layers of transparent plastic that sandwich the liquid crystal molecules. During manufacturing, they rub the two plastic layers in perpendicular directions with a velvet roller. This aligns the plastic molecules and causes the liquid crystals near them to line up in the same direction. Because the liquid crystal molecules at opposite ends of the cell are now oriented perpendicular to one another, intervening molecules stack slightly askew, creating what looks like a spiral staircase. This staircase twists light as it passes through, enabling it to emerge from the top polarizing filter. But when an electric voltage reorients the liquid crystal molecules, the light is no longer twisted and so cannot thread its way through both filters. The pixel goes dark. When the voltage is turned off, the liquid crystal relaxes to its original shape.

Cheaper, clearer. Ion treatment may yield better liquid crystal displays.

Although the rubbing step works, it has numerous drawbacks, says Mahesh Samant, a chemist at IBM's Almaden Research Center in San Jose, California. Not only can it damage the transistors on the panel, but the rolling process can introduce tiny contaminants onto the screen and create streaks across it. Both problems regularly force manufacturers to toss out batches containing hundreds of damaged screens.

In hopes of reducing such waste, Samant and his colleagues at IBM's Thomas J. Watson Research Center in Yorktown Heights, New York, set out to develop a noncontact method for aligning their liquid crystals. Four years ago, they tried bombarding various thin surfaces with ions. The technique worked: The ions created tracks in the films that caused liquid crystals layered on top to orient along the same direction.

The researchers didn't rush to tell the world until they had found out whether the technology would work in a manufacturing setting. The Almaden and Watson groups, together with colleagues at IBM's display and engineering business units in Japan, used the new technique to make 15-inch and 22-inch LCD displays that team member James Lacey calls "sharper and crisper" than today's models. The company is now considering using the new process to make all its LCDs.

"It's certainly interesting," says Kimberly Allen, who directs technical and strategic research at Stanford Resources, a company that analyzes display technology and markets. LCD prices have plummeted over the past 6 months as manufacturers have upped their output. That's left LCD makers scrambling for ways to recover their costs, says Allen: "If a new manufacturing step can show even a little bit of cost reduction, that would be helpful to them."

By reducing costs, the new approach could also help LCDs fend off emerging competition from novel technologies, such as organic light-emitting devices (OLEDs), which emit light from thin layers of plastics and other organic materials. If OLEDs can beat back nagging problems with quick burnout, they have the potential to dethrone LCDs as the flat screens of choice. But as the IBM group's work proves, LCD makers aren't sitting around and waiting for the competition to catch up.

–ROBERT F. SERVICE

DIGITAL SECURITY

Music Industry Strikes Sour Note for Academics

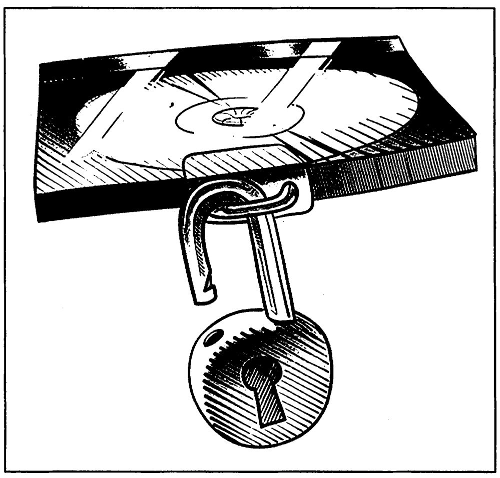
Flush from a courtroom victory over the music-trading network Napster, the music industry is targeting another band of rabblerousers: scientists studying ways to crack digital security technologies. It's following in the footsteps of the motion picture industry, which has sued a magazine for publishing information that could defeat its technology to protect digital videos. At the heart of both cases is the question of freedom of expression under the 2-year-old Digital Millennium Copyright Act (DMCA).

In 1998, some 200 companies banded together to seek a technological fix for the problem of digital music piracy. Their answer consisted of a kind of watermarking, in which a faint digital signature is overlaid on audio bits to mark it as an original and not a copy. Last September, that consortium, the Secure Digital Music Initiative (SDMI), announced a contest to test its copy-protection schemes. Although some hackers and computer science researchers boycotted the contest and its $10,000 prize, saying they didn't want to help the music industry strengthen its copy protection or offer their services so cheaply, Princeton computer science professor Edward Felten and his colleagues at Rice University in Houston and the Xerox Palo Alto Research Center in California accepted the challenge. Last fall, they announced they had succeeded in stripping off the signature without degrading the audio quality (*Science*, 3 November 2000, p. 917).

Forgoing the money, they decided instead to write up the results for presentation last week at the Information Hiding Workshop in Pittsburgh. That's when the music industry's lobbyists moved in. "I sent a courtesy copy to someone at Verance [a company that supplied one of SDMI's watermark technologies]," says Felten, "and a day or two later I got a letter from Matthew Oppenheim, a vice president at RIAA [Recording Industry Association of America]." So did the conference program chair and all of their employers.

The RIAA letter said that any disclosure by Felten and his colleagues would violate a "click through" agreement that was part of the contest. "Any disclosure of information gained from participating in the Public Challenge," Oppenheim added, "could subject you and your research team to actions under DMCA." Oppenheim urged the authors to pull their paper, destroy their data, "and avoid a public discussion of confidential information."

Negotiations proved futile, says Felten, who minutes before his 26 April talk announced that he was pulling out because of a threatened lawsuit "if we proceeded with our presentation or the publication of our paper." That evening, Oppenheim posted his own



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