In 2001, scientists assembled molecules into basic circuits, raising hopes for a new world of nanoelectronics

Molecules Get Wired

Computer chip technology and scientific breakthroughs have been marching in step for decades. Without computers, scientists couldn't track climate change, sequence the genomes of entire organisms, or image the human brain at work. But the ability to cram ever more circuitry onto silicon chips now faces fundamental limits. Ironically, it's now possible to make the innards of a circuit—the transistors, resistors, capacitors, and wires—so small they no longer function.

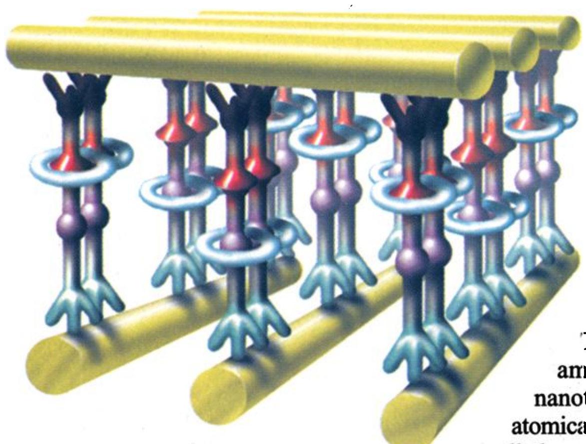
Breakthrough Online
For an expanded version of this section, with references and links, see www.sciencemag.org/content/vol294/issue5551/#special

In recent years, scientists have tried to get around these limits by going for the ultimate in shrinkage: turning single molecules and small chemical groups into transistors and other standard components of computer chips. It's a provocative idea, but many have doubted that researchers would ever manage to link such devices together into more complex circuits. Today, those doubts are diminishing. This year, researchers wired up their first molecular-scale circuits, a feat *Science* selects as the Breakthrough of 2001. If researchers can wire these circuits into intricate computer chip architectures, this new generation of molecular electronics will undoubtedly provide computing power to launch scientific breakthroughs for decades.

It's easy to see the allure of computing with molecules. Today's state-of-the-art computer chips pack some 40 million transistors onto a slab of silicon no bigger than a postage stamp. The smallest features in these miniature landscapes measure just 130 billionths of a meter, or nanometers, across. In another 10 years or so, chip engineers expect to shrink whole transistors—not just individual features—down to about 120 nanometers per side. Small as this seems, it's still gargantuan compared to molecules, which are some 60,000 times smaller. Chips made with components at that scale would harbor billions of devices.

Dreams of such unbridled computer power started soon after the dawn of the computer age itself. In 1974, Mark Ratner and Ari Aviram of IBM suggested building computers from the bottom up by turning individual molecules into circuit components. But their suggestion remained little more than a pipe dream until the advent of scanning probe microscopes in the 1980s, which gave researchers the tools to probe individual molecules and move them around at will. That led to a spate of studies in the late 1990s that showed that individual molecules could conduct electricity like wires or semiconductors, the building blocks of modern microprocessors.

Turning individual molecules into devices was not far behind. In 1997, groups led by Robert Metzger of the University of Alabama, Tuscaloosa, and Chong-Wu Zhou of Yale University created molecular diodes, one-way current valves that are among the most basic and essential elements in the chip designer's tool kit. In July 1999, another group led by James Heath and Fraser Stoddart of the University of California, Los Angeles (UCLA), created a rudimentary switch, a molecular fuse that carries current but, when hit with the right voltage, alters its molecular shape and stops conducting. Within months, still another team led by Yale University electrical engineer Mark Reed and Rice University chemist Jim Tour reported making molecular-scale devices that could control a current just as a transistor does.



Good connections. Molecules can now be crafted into working circuits. Constructing real molecular chips will be a big challenge.

ILLUSTRATION: C. SLAYDEN

By the end of 2000, researchers had amassed a grab bag of molecular electronic devices but no demonstrations of wiring them together. 2001 brought a world of difference, when five labs succeeded in hooking up these devices into more complex circuits that could carry out rudimentary computing operations. In January, a team led by Charles Lieber, a chemist at Harvard University, got the ball rolling. In the 26 January issue of *Science*, Lieber's team reported arranging indium-phosphide semiconducting nanowires into a simple configuration that resembled the lines in a ticktacktoe board. The team then used a technique called electron beam lithography to place electrical contacts at the ends of the nanowires in order to show that the array was electronically active. The tiny arrangement wasn't a circuit yet, but it was the first step, showing that separate nanowires could communicate with one another.

The next step came at the American Chemical Society meeting in April. Heath and his colleagues at UCLA reported making semiconducting crossbars. But in this case, Heath's team placed molecules called rotaxanes, which function as molecular transistors, at each junction. By controlling the input voltages to each arm of the crossbar, the scientists showed that they could make working 16-bit memory circuits.

But molecular crossbars were only part of the success story. Researchers also made heady progress with their favorite nanomaterial, carbon nanotubes. These tiny straws of carbon are among the hottest materials in the nanotech world because they have an atomically perfect structure, resembling a rolled-up sheet of chicken wire. Depending on how these carbon sheets are rolled—so that chains of carbon atoms circle or spiral around the tubes—the nanotubes' electrical properties can be engineered to serve as either conductors or semiconductors.

In the 26 August online edition of *Nano Letters*, a team led by Phaedon Avouris of IBM reported making a circuit out of a single semiconducting nanotube. By draping the nanotube over a pair of electrodes and independently controlling their behavior, the team coaxed the device to work like a simple circuit called an inverter, another basic building block for more complex circuitry.

In addition to carrying out rudimentary processing, the IBM circuit demonstrated another key advantage: "gain," the ability to turn a weak electrical input into a stronger output,

The Year of Living Dangerously

When the World Trade Center towers collapsed on 11 September, seismographs recorded an impact equivalent to that of a mild earthquake. The aftershocks for the international science and engineering community, however, could be of much greater magnitude—from reshuffled budgets to new restrictions on research, information-sharing, and international collaboration. Indeed, some scientists say the terrorist assaults, and the subsequent anthrax mail attacks, could mark the beginning of a sobering new era of scientific soul-searching, akin to that which followed the development of the atom bomb.

The new landscape "will present some scientists with opportunities and others with obstacles," says Lewis Branscomb, a science policy specialist at Harvard University, who is helping lead a U.S. National Academies study of what scientists can do to respond to terrorism.

Shake-up. Twin Tower and anthrax attacks have rattled the science community.

The immediate consequences of the attacks were far-reaching. Engineers analyzed why the towers fell—and debated what should be done to make skyscrapers safer. Gene researchers scrambled to cobble together a DNA-testing system capable of generating and handling the cascade of data needed to identify the thousands of crushed and incinerated victims. Public health specialists struggled to identify and treat those threatened by anthrax. Microbiology sleuths took to their labs, hoping to finger the deadly strain's origin.

The U.S. Congress, meanwhile, passed sweeping new security laws requiring everything from the installation of new security technology at airports to criminal background checks for scientists working with deadly biological agents. It debated barring foreign students from studying certain sensitive scientific topics at U.S. universities. And lawmakers pumped billions of new dollars into developing ways of detecting biowarfare agents—and creating new vaccines that could render them harmless. Other nations, such as the United Kingdom, launched similar initiatives.

The shake-up is far from over. Economic damage caused by the attacks has erased a U.S. government budget surplus, raising fears that some research spending might be trimmed next year to pay for the war against terrorism. Universities are reconsidering research programs involving potential bioweapons in light of increased regulation and community concerns. Journal editors, research funders, and scientists have begun debating whether some information—such as the genomic details of candidate bioweapons—is just too sensitive to be released publicly. "If the scientific literature is no longer used for the good it was intended, we will be left with no choice but to restrict information access at a cost to human health," *The Lancet Infectious Diseases* warned in a 1 December editorial.

Many researchers hope such crackdowns can be avoided. But they are again pondering how to work for good while keeping the fruits of their labors from being used for evil. –DAVID MALAKOFF

which is a necessary feature for sending signals through multiple devices. Circuits with even stronger gain came just over 2 months later in a pair of reports in the 9 November issue of *Science*. The first, by Cees Dekker's team at Delft University of Technology in the Netherlands, also relied on carbon nanotubes. In 1999, Dekker's group was the first to report making a nanotube-based transistor. His team then wired up a range of logic circuits with nanotube-based transistors. By carefully controlling the formation of metal gate electrodes, Dekker's group was able to create transistors with an output signal 10 times stronger than the input. Lieber's group at Harvard, meanwhile, constructed circuits with their semiconducting nanowires, in this case made from silicon and gallium nitride.

Finally, in a report published online by *Science* on 8 November, a group led by physicist Jan Hendrik Schön of Lucent Technologies' Bell Laboratories in Murray Hill, New Jersey, reported similar success in crafting circuits from transistors made from organic molecules that chemically assemble themselves between pairs of gold electrodes.

Backed by this string of accomplishments, molecular electronics is rapidly moving from blue-sky research to the beginnings of a technology. Experts in the field have few illusions, however, that molecular electronics will replace conventional silicon-based computing anytime soon, if ever. Researchers now face the truly formidable task of taking the technology from demonstrations of rudimentary circuits to highly complex integrated circuitry that can improve upon silicon's speed, reliability, and low cost. Reaching that level of complexity will undoubtedly require a revolution in chip fabrication. But as chip designers race ever closer to the limits of silicon, pressure will to extend this year's breakthroughs in molecular electronics will only intensify. –ROBERT F. SERVICE

THE RUNNERS-UP

Science celebrates nine other areas in which important findings were reported this year, from subatomic to atmospheric and beyond.

First runner-up: RNA ascending. RNA molecules, long viewed as little more than couriers shuttling messages or amino acids around the cell, are turning out to be remarkably versatile. In 1995, researchers showed that small pieces of RNA could shut down genes in the nematode *Caenorhabditis elegans*, a phenomenon very similar to gene silencing, which was known to occur in plants. Molecular biologists realized that this RNA interference (RNAi) could be a boon to studies of gene function, and now interest in RNA has exploded. This year, they discovered that RNAi can quell gene activity in mouse and human cells as well.

Structure solved. RNA-building enzyme revealed.

Short RNAs clearly play important biological roles. Dozens of the

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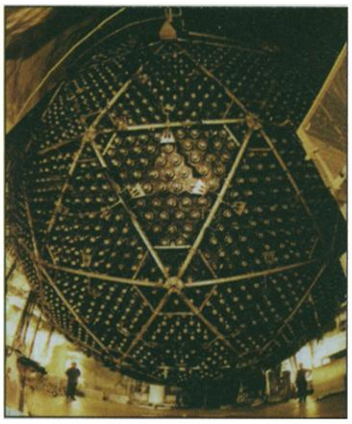
molecules are now known to exist in the nematode and fruit fly. The coding for these molecules is contained in the DNA sequence. Some 100 of these tiny RNA "genes" have been found in the gut bacterium *Escherichia coli*, and some 200 were uncovered in DNA from mouse brain tissue. In the nematode and fruit fly, they seem to be involved in development; in *E. coli*, they may facilitate rapid responses to environmental change and could serve similar functions in mammals.

The process by which the more familiar messenger RNA (mRNA) is generated also gained new respect in 2001. During transcription, mRNAs are built to match the sequence of the active gene, and they then instruct the cell's protein factory, the ribosome, how to build a protein. The discovery of key proteins involved in splicing together mRNA's coding regions added details to this scenario. Also, in June, high-resolution pictures captured the yeast RNA polymerase II—which builds the mRNA based on the gene's sequence—in action. During transcription, the polymerase opens and closes to bring DNA in and pump newly made RNA out, all through the same opening.

Another set of small nuclear RNAs turns out to play a surprising role. These RNAs combine with proteins to form the spliceosome, which removes noncoding sequence from nascent mRNA. Researchers discovered this year that spliceosome RNAs, not the proteins, control the removal of unwanted sequence. This has spawned a new field, "ribozymology," aimed at clarifying and harnessing RNA's enzymatic potential. In one experiment, researchers forced RNA enzymes, or "ribozymes," to evolve by selecting for those that are able to replicate RNA. These results help show that RNA could have preceded proteins in the earliest life-forms.



Case closed. Sudbury observatory finally nabbed missing neutrinos.

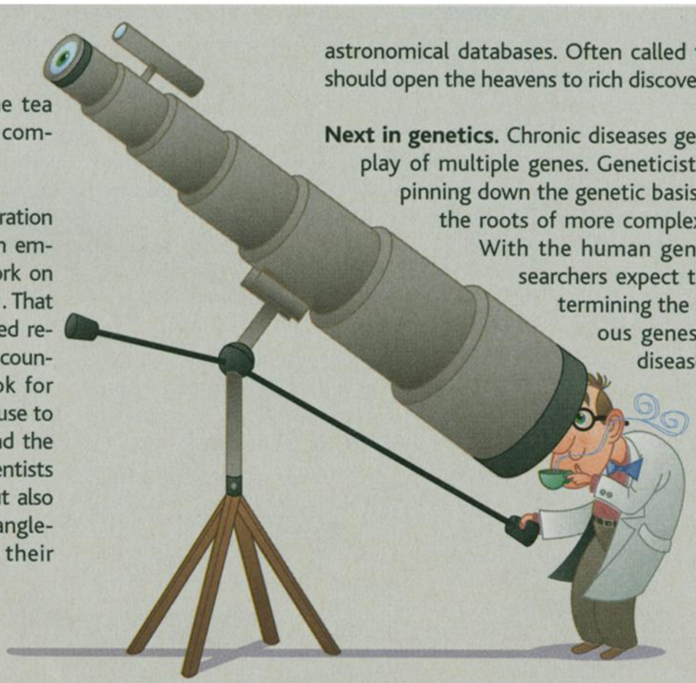
So what's neu? With nearly no mass, it's amazing that anyone noticed that they were missing. But this year, the 30-year-old case of the missing solar neutrinos was cracked.

One of the great triumphs of science in the past century has been understanding how stars burn nuclear fuel, yet physicists quickly discovered that something was wrong. Expected products of the stellar fireball—neutrinos of a particular type called "electron" neutrinos—were not nearly as abundant as required by the straightforward theory.

In 1998, physicists presented evidence that seemed to explain the discrepancy: They showed that neutrinos "oscillate" from one

Peering Into 2002

Science's editors once again read the tea leaves for hot research areas in the coming year.



Stem cells abroad. The Bush Administration has limited federal support for human embryonic stem (ES) cell research to work on cell lines derived before 9 August 2001. That still leaves the door open for unfettered research in privately funded labs and in countries with less restrictive rules. Look for progress in translating results from mouse to human ES cells as governments around the world clarify their rules and more scientists gain access to the human cell lines. But also watch for legal and commercial entanglements as companies race to stake their claims in the wide-open field.

Proteomics. Genes tell cells what proteins to make, so figuring out how proteins interact is vital for leveraging genetic knowledge in medicine and biotech. It's a tough assignment: Although there might be as few as 35,000 genes, there might be millions of proteins. But the will is there: Biotech companies and funding agencies are pouring hundreds of millions of dollars into untangling the proteome. Next year could see the first protein-based drug targets from biotech proteomics.

Eyes on the sky. Early in 2002, the second of the Gemini project's 8-meter telescopes will be dedicated in Chile, following its sibling, which saw first light in Hawaii 2 years ago. The Very Large Telescopes (also in Chile), now fitted with new "adaptive optics," reportedly see as well as the Hubble Space Telescope. Next year, big sky efforts such as the Sloan Digital Sky Survey should continue to produce solid results. Also on the horizon is the Virtual Observatory, a vast network of astronomical databases. Often called the World-Wide Telescope, it should open the heavens to rich discoveries in coming years.

Next in genetics. Chronic diseases generally result from the interplay of multiple genes. Geneticists have made much progress pinning down the genetic basis of single-gene disorders, but the roots of more complex diseases have been elusive. With the human genome sequence in hand, researchers expect to make clear progress in determining the relative contributions of various genes to problems such as heart disease, cancer, and diabetes.

Optical clocks and constants. Because they're based on higher frequency visible light waves rather than microwave radiation, optical clocks are an order of magnitude more accurate than previous instruments. They should lead to more precise global positioning systems and a new generation of experiments to test and challenge the fundamental constants of nature. In 2002, expect an increasing pace of research as optical clocks become the gold standards by which to judge other important measurements.

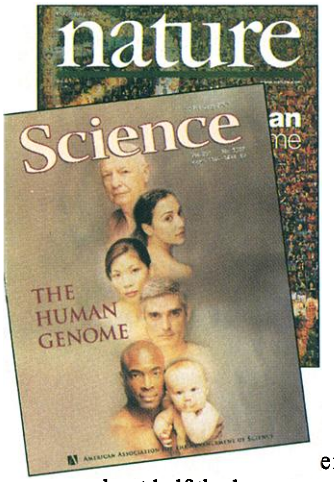
Visualization of complex systems. New imaging technology and ever-faster computers will come together to allow a closer look at biological molecules and their interactions. Recent lab successes with electron cryomicroscopy and electron microscope tomography are merging with computer simulation to create new views of how proteins work with each other. And labeling techniques for tagging proteins, lipids, and other biomolecules are evolving rapidly toward the goal of watching cell signaling as it occurs in space and time.

CREDITS: (TOP TO BOTTOM) SNO; ILLUSTRATION: TERRY E. SMITH flavor (such as the electron neutrino) to another (such as the muon or tau neutrino). If the electron neutrinos turned into another variety as they streamed away from the sun, that would explain the shortfall of electron neutrinos. But there was still no direct evidence that neutrino oscillations are to blame for the solar neutrino paradox.

This June, all that changed, thanks to the Sudbury Neutrino Observatory (SNO), a 1000-ton sphere of heavy water 2 kilometers below Earth's surface in Sudbury, Ontario. After some delay, SNO scientists announced that they had found the missing solar neutrinos—and they were, indeed, changing flavor.

SNO was able to count the number of electron neutrinos coming from the sun and compare it to the total number. The number of electron neutrinos was still too small to match nuclear physicists' theories, in agreement with past experiments. However, the total number of incoming neutrinos matched expectations: The predictions were correct, but the neutrinos were swapping identities on the way to the detector.

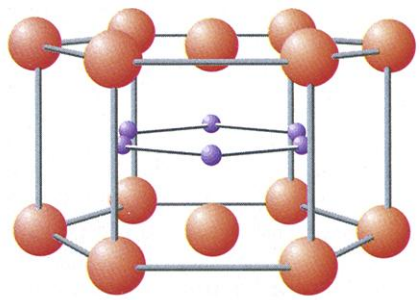
Genomes take off. Barely 3 years ago, researchers were edging hesitantly to the starting gate in the race to sequence the human genome. But egged on by competition, a private effort and an international public consortium galloped into the home stretch early this year, achieving the first publications of draft coverage of the 3.3 billion bases that define our species. The drafts cover the gene-containing portions of our DNA but have gaps of varying sizes. The big surprise when the drafts were revealed: Our genetic code contains only about 35,000 genes, not even twice as many as the lowly worm *Caenorhabditis elegans*. (By year's end, however, the number began creeping upward.) All told, genes account for less than 2% of the DNA, the rest consisting of repetitive stretches of sequence or mobile genetic elements that have inserted themselves into our chromosomes.



These drafts only fueled the hunger for more sequence. By the end of the year, about half the human genome sequence was put into final finished form. And now the sequences of more than 60 other organisms are done. Most are those of microbes, such as nitrogen-fixing bacteria, human pathogens, or organisms that cause food poisoning. A draft sequence of the Japanese puffer fish genome—the most compact genome of all vertebrates—is now in the public databases. The sequencing of the rat, mouse, zebrafish, a freshwater puffer fish, a malaria mosquito, the fungus *Neurospora crassa*, and fission yeast is proceeding at full speed, with the last two virtually done. Similarly, private companies announced that they have rough copies of the rice and mouse genome sequences.

Superconductor surprises. Visions of resistance-free electricity transmission tantalized researchers this year, as two teams discovered vastly different superconductors at higher than expected temperatures.

Hopes ran high in January, when researchers announced that one of the simplest compounds in the chemistry stockroom—magnesium diboride—becomes a superconductor at 39 kelvin. Although still chilly, it



Simple superconductor. A metal compound—MgB_2—set a new record.

CREDITS: (TOP TO BOTTOM) CRYSTAL BALLS: TERRY E. SMITH; ANN ELLIOTT CUTTING; ILLUSTRATION: C. SLAYDEN

Scorecard 2000

In which the editors face the music and polish their crystal balls.

Infectious diseases. There were few breakthroughs in drug development for the world's major killers—HIV, tuberculosis, and malaria—and new vaccine candidates have only recently entered the testing phase. On the other hand, interest in tackling infectious diseases kept surging—especially after the 11 September attacks and the spate of anthrax letters.

New views of the ocean. A satellite called SeaWiFS provided the first multiyear, global picture of photosynthesis on both land and sea and detected a burst in ocean plant growth during an El Niño–La Niña shift. SeaWiFS also revealed how large "planetary" waves pump nutrients to the ocean surface. However, data from NASA's Terra satellite, which will add ocean fluorescence to the picture, are still awaiting validation.

RNA surveillance. It has been a banner year for RNA interference (RNAi) (see Runners-Up, p. 2443). 2001 has seen the identification of the enzyme, appropriately called Dicer, that kicks off the whole RNAi process by chopping up double-stranded RNA precursor molecules into small RNAs. Dicer also has been implicated in the control of gene expression by small RNAs during development. Just last month, the RNAi field took another leap forward with the finding that the cell can boost RNAi by amplifying the number of small RNAs through the action of a cellular-directed RNA polymerase.

Follow the money. With the exception of the National Institutes of Health, presidential candidate George W. Bush's support for research during the campaign was AWOL this spring in his first proposed budget. But legislators repaired much of the damage, giving several science agencies more than they had requested. At the same time, research budgets in most of Europe and Asia were protected from the worst effects of a global downturn, because governments continue to see science and technology as a good way to bolster their long-term economic prospects.

Quark soup. In 2001, scientists at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory in Upton, New York, saw evidence of "jet quenching": a sign that nuclear particles might have melted into their component parts, creating a quark-gluon plasma. Although the results are still open to interpretation, and theorists are talking about new concepts such as "colored glass" states, it has been a good year in quark-gluon plasma research. If all goes well at RHIC, next year will be even better.

Cellular asymmetry. Although 2001 has been a quiet year for asymmetry—how a cell tells its left from its right and up from down—the asymmetric distribution of messenger RNAs (mRNAs), proteins, and stem cells in the developing *Drosophila* embryo has been mapped. Also, in developing flies the distribution of Wingless mRNA and stardust proteins was found to be important for establishing epithelial cell polarity.

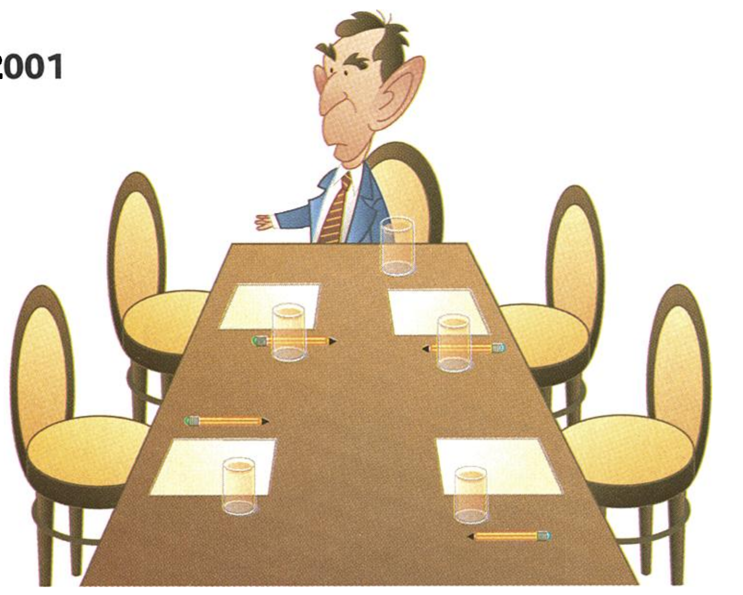
beat the previous record metallic transition temperature by a factor of 2.

But the big question was whether MgB_2 is kin to the high-temperature ceramic superconductors discovered 15 years ago or more like conventional metal superconductors. The answer could shed light on how the high-temperature superconductors work—a riddle still without a solution.

By March, the theoretical questions were settled: MgB_2 is an interesting but conventional superconductor. Although not the paradigm-shifter researchers had hoped, it proved that simple compounds can still generate surprises. The second surprising superconductor may be more promising. C_{60} molecules—popularly called buckyballs—had long been known to superconduct at 18 K when "doped" with alkali metals. Last year, physicists pushed the transition temperature to 52 K. In August, researchers announced that when they stuffed organic molecules into a crystal of C_{60}, the distance between the buckyballs increased and the transition temperature rocketed to 117 K. If they can spread out the C_{60}s even more, the researchers hope the material might even superconduct at room temperature, opening new possibilities for superconducting molecular electronics.

Breakdowns of 2001

Bush Mystery Science Theater. Never has a modern president tackled so many hot scientific issues with so little help. In his first year, Bush laid out new policies, from stem cells and missile defense to climate change and the amount of arsenic that should be allowed in drinking water. Then came anthrax. Through it all, many of the appointees who might normally be expected to offer technical advice—from the White House science adviser to the heads of the National Institutes of Health (NIH) and the Food and Drug Administration (FDA)—were invisible. It took a record 10 months to install science adviser John Marburger in his post, and the NIH and FDA positions remained unfilled in mid-December. The lackadaisical pace drew criticism, but White House officials pointed to an increasingly onerous appointments process, while thorny politics made recruiting for some jobs difficult.

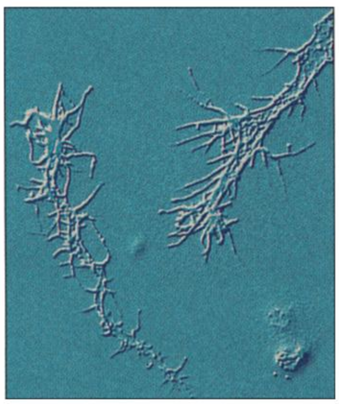


An early meeting of the new president and his science team.

Where no budget has gone before. Spacewalkers continue to build the international space station in orbit. But on the ground, the research facility seems to get smaller and smaller. Frustrated by cost overruns on the program, the White House earlier this year ordered NASA to make drastic cuts, and the result has infuriated researchers. They argue that the crew will spend the vast majority of its time keeping the station operating rather than doing science. A blue-ribbon panel in November backed a strong research effort but called for the space agency to prove it can finish building the modest version before it completes the more ambitious design. Those findings, however, triggered a revolt among the international partners, who say that the smaller version would leave their own research programs high and dry.

Guide me home. How do the neural projections called axons find their way to the correct destination during embryo development? Several studies over the past year helped sort out this finely tuned neuronal traffic control system.

In the 1990s, researchers identified four major families of molecular signals that tell wandering axons to either "come hither" or "shove off." At about the same time, researchers identified the receptors on the developing axon's surface that respond accordingly. And it turned out that axons could turn receptors on and off sequentially—allowing an axon to be attracted to the spinal cord initially, say, but then become repelled by it as the axon continues its voyage across the body.



Whither? These axon tips are testing the waters for guidance cues such as netrin and Slit.

Simple stop-and-go signals aren't enough to generate complex neural circuitry, though; somehow the growing tip of the axon, called the growth cone, integrates conflicting signals. At the very end of last year, researchers reported that three different receptors for one guidance molecule, called Slit, could combine in various ways to guide axons to either close, distant, or intermediate paths. A study this year showed that, when presented with conflicting signals (one stop and one go), growth cones don't get confused. At the cell surface, a receptor for Slit latches onto and "silences" a receptor for a different signal, called netrin.

Additional studies this year focused on how the message received at the axon's surface translates into axon movement. It turns out that the signals activate regulators that instruct the actin cytoskeleton to build up the axon in one direction or another.

Ultimately, understanding how the developing axon finds its way could help repair adult nervous systems. Human axons don't regrow once severed because something stops them. Modifying those signals could lure damaged axons—which do have growth cones—to grow back to where they're needed.

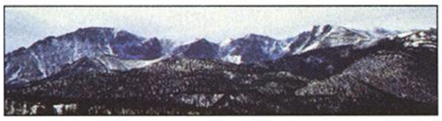
Climatic confidence. A major milestone was reached in January when the United Nations–sponsored Intergovernmental Panel on Climate Change (IPCC) officially declared that "most of the observed warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations." But the panel was vaguer than ever about future warming.

A better understanding of climate change finally allowed IPCC to pin much of the blame for rising temperatures on human activities. With better computer models and more data, it has become clear that even a combination of volcanic debris, solar flickering, and the natural jostlings of the climate

CREDITS: (TOP TO BOTTOM) ILLUSTRATION: TERRY E. SMITH; E. STEIN AND M. TESSIER-LAVIGNE

system could not explain the 0.6°C warming of the past century. An impressive new line of evidence came from the compilation of temperature records extracted from tree rings and other climate proxies. From a millennial perspective, the 20th century stands out as unnaturally warm.

The new scientific consensus spurred on negotiators working out the implementation of the Kyoto Protocol for the control of greenhouse gas emissions, with the notable excep-



All the elements. Extreme weather, melting snow, and gathering clouds may signify global warming.

tion of those from the United States. President George W. Bush pulled the United States out of the Kyoto process, citing high costs, an unfair advantage for developing countries, and remaining scientific uncertainties. The latter were evident in the IPCC's projections of possible warming by the end of the century, which ranged as high as a sizzling 5.8°C. Part of that increased uncertainty arose from unresolvable technological and socioeconomic uncertainties, but much lies in scientists' inability to pin down climate's sensitivity to increasing greenhouse gases. That uncertainty hasn't been narrowed in 20 years.

Cancer in the crosshairs. Thirty years after President Richard Nixon and the U.S. Congress declared a "War on Cancer," a new breed of cancer drugs is entering the clinic. This year, the U.S. Food and Drug Administration (FDA) approved a drug called Gleevec for use in treating one kind of leukemia. It's a milestone because Gleevec is the first small-molecule drug that works by targeting the specific biochemical defect that causes the cancer.

Gleevec's development is an outgrowth of 3 decades' search for genetic changes that lead to cancer. For example, in chronic myeloid leukemia (CML)—the cancer treated with Gleevec—the fusion of two genes, called *BCR* and *ABL*, produces an abnormally active kinase enzyme that fuels the growth of the cancer cells. Because Gleevec inhibits that kinase, it is very effective against CML, particularly in the leukemia's early stages.

CREDITS: (TOP TO BOTTOM) NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION; KATHLEEN BROWN/CORBIS; W. KETTERLE *ET AL.*/MIT

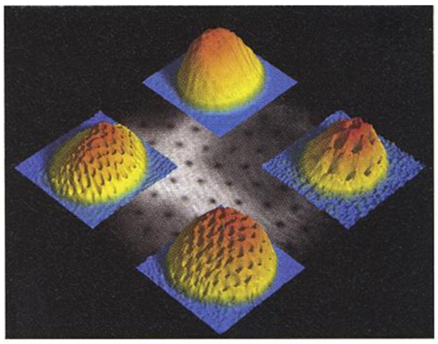
Growth-regulatory kinases such as BCR-ABL are a prominent target of the new wave of anticancer agents. Indeed, 3 years ago FDA approved a monoclonal antibody called Herceptin for treatment of metastatic breast cancer. Herceptin binds to and blocks a growth factor receptor, which is also a kinase and whose activity is thought to foster the growth of some breast tumors. Other drugs directed at kinases, including both small molecules and monoclonal antibodies, are now in preclinical and clinical trials against various cancers, as are a variety of drugs aimed at correcting other cancer-fostering defects. Dozens of clinical trials are now under way worldwide to test the efficacy of targeted cancer drugs.

Banner year for Bose-Einstein. Cooled atoms that march in quantum lockstep were big news in 1995, and this past October that work garnered physics Nobel honors for their discoverers. But the field hasn't rested on its laurels.

In March, two groups figured out how to make Bose-Einstein condensates (BECs) of metastable helium, a state in which high energy is stored in the atom's electrons. Each metastable atom is like a tiny bomb waiting to explode, so the result might one day lead to laserlike beams of atoms for carving nanocircuits out of silicon.

Researchers got their hands on other new condensates as well this year. One team cooled a mixture of lithium isotopes to create a kind of quantum pressure between atoms, similar to the force that keeps white dwarfs and neutron stars from collapsing. And in October, another group wrestled potassium atoms into a BEC. Both experiments ignited hope that even more members of the periodic table could join the club, leading to BECs with wholly new properties.

Scientists this year also acquired new skills in manipulating the condensates. They observed a kind of atomic supernova, dubbed a "bose nova," in a BEC, as part of the atomic vapor collapsed on itself, throwing off a miniature shock wave of atoms akin to the blast from a collapsing star.

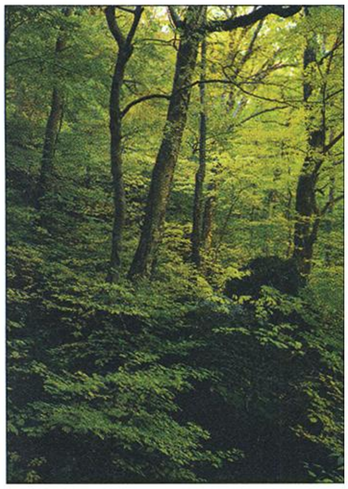


Atomic vortex. Superfluid swirls were another BEC triumph this year.

Lasers and BECs also made a good mix as researchers learned how to form a BEC using light alone, with no magnetic fields. Similarly, physicists trapped arrays of BEC bunches to create the first "squeezed" states of atomic matter, perhaps one route to future ultraprecise measurements.

Carbon consensus. Researchers who had been puzzling over how much carbon dioxide is absorbed by U.S. forests and fields have finally reconciled their conflicting results. The outcome will help hone estimates of how much the planet may warm in future years.

A "missing sink" had to exist: Even after scientists accounted for known carbon sinks, such as the oceans, less than expected of the CO_2 from burning fossil fuel remains in the atmosphere. Three years ago, researchers who put atmospheric CO_2 measurements into computer models concluded that North America is a humongous sink—big enough that plant ecosystems seemed to be sopping up most CO_2 emissions. Researchers tallying carbon uptake with land surveys, however, found a much smaller sink.



Big sponge. Researchers pinned down how much carbon is being absorbed by U.S. forests.

This summer, the two camps published a joint study in which their results finally match up. New atmospheric analyses modeling a bigger time period—all of the 1980s—found a slightly smaller sink than before in the lower 48 U.S. states. And a more thorough ground-based tally of where the carbon goes—one that included overlooked pieces of the sink, such as decaying wood and forest soils, sediments in reservoirs, and exported wood and grains—yielded a bigger number. The result is a sink of about 0.5 petagram per year, or about one-third of current U.S. emissions.

With the U.S. carbon sink firmed up, researchers now hope a similar approach will pinpoint carbon uptake in other regions, such as the tropics, where it seems to fluctuate most. The bad news: Because much of the U.S. sink is due to ecosystems recovering from past exploitation, this sponge is steadily shrinking and will taper off within 100 years.

—THE NEWS AND EDITORIAL STAFFS