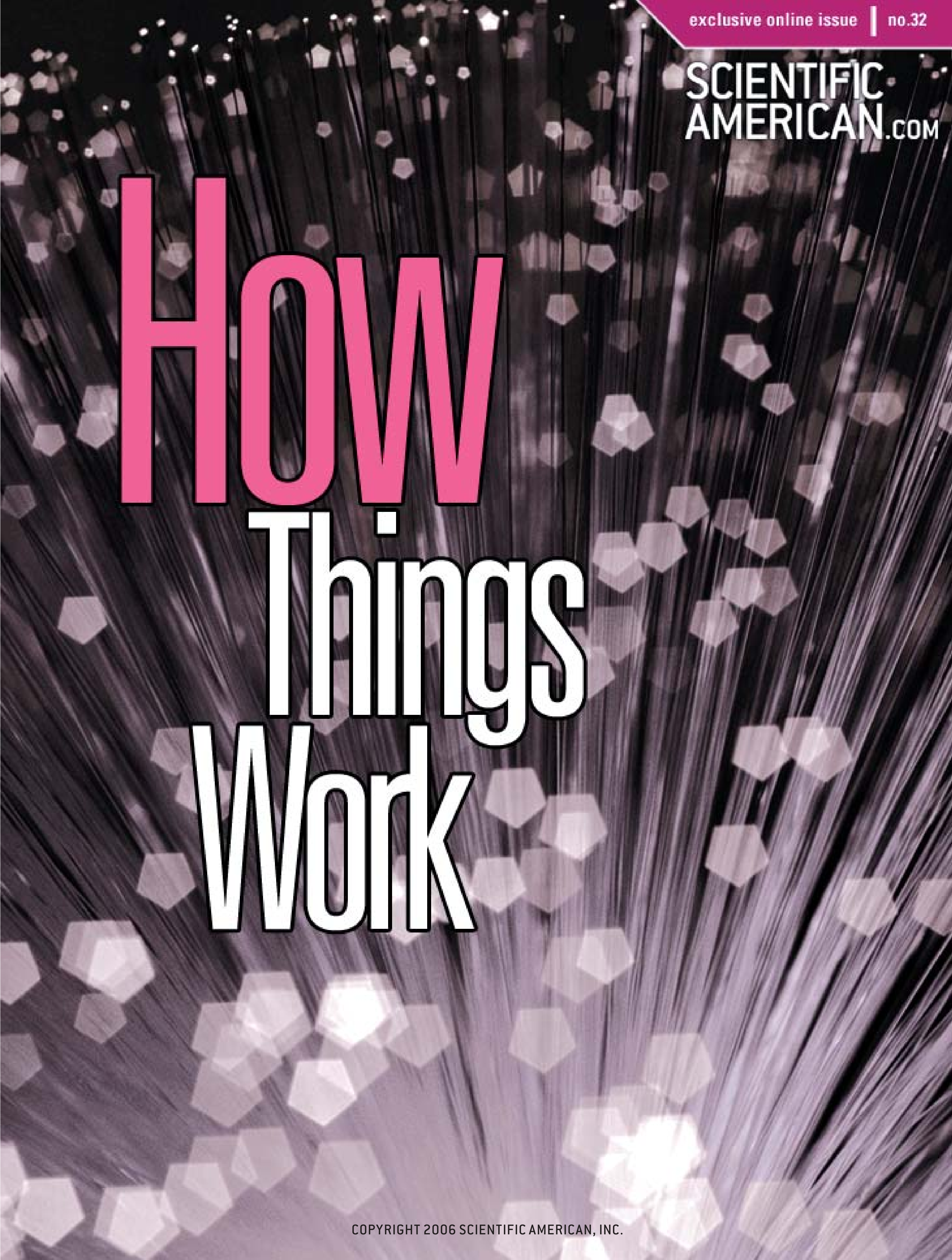

exclusive online issue | no.32

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How Things Work

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HOW THINGS WORK

ScientificAmerican.com
exclusive online issue | no. 32

From the touch screens we use at ATMs to the treatments that keep our canine companions flea-free, we often take for granted the science behind everyday technologies.

In this exclusive online issue, *Scientific American* editor Mark Fischetti explains the inner workings of 20 commonly used technologies. Learn how noise-cancelling headphones silence unwanted background noise and how digital cameras overcome shaky hands. Discover how crude oil is refined and how cochlear implants enable hearing. You'll also find out how radar guns spot speeders, how air traffic control systems minimize accidents in the sky, and how medical patches enable continuous drug delivery. --*The Editors*

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WORKINGKNOWLEDGE

IMAGE STABILIZATION

Steady Cam

"Hold still while I take your picture."

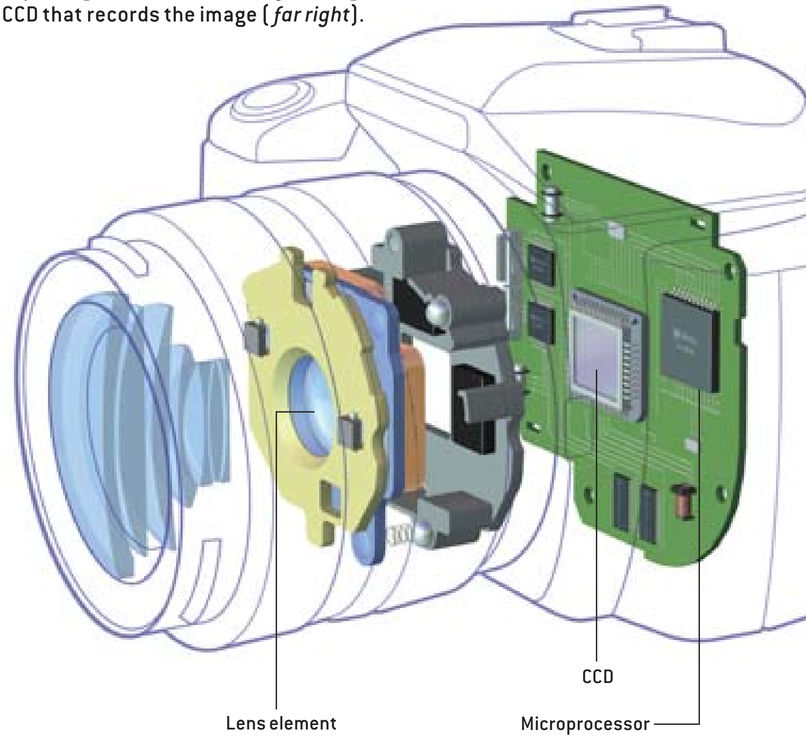
Photographers who instruct their subjects this way can still end up with a blurry image if they themselves move their hands even slightly when depressing the shutter, shaking the camera. The problem is so common among people who use digital cameras and camcorders, especially in low light when the shutter must stay open longer, that manufacturers are introducing image stabilization systems that automatically correct for human shudder. "The industry is moving toward cameras with higher megapixels, smaller size and longer zoom lenses that magnify shake," says Jay Endsley, manager of digital camera advanced development at Eastman Kodak Company in Rochester, N.Y. "So we're adding whatever we can to improve picture quality."

Digital cameras employ two different image stabilization hardware schemes. One system moves a segment of the lens to deflect incoming light, compensating for the direction of shake; the other moves the CCD—the sensor that captures the image [*see top illustrations*]. Engineers who favor the lens approach say moving the CCD complicates the recording of sharp images, especially when using a flash. Designers of the CCD method note that it works with every lens a user might attach to the camera, negating the need to buy different lenses.

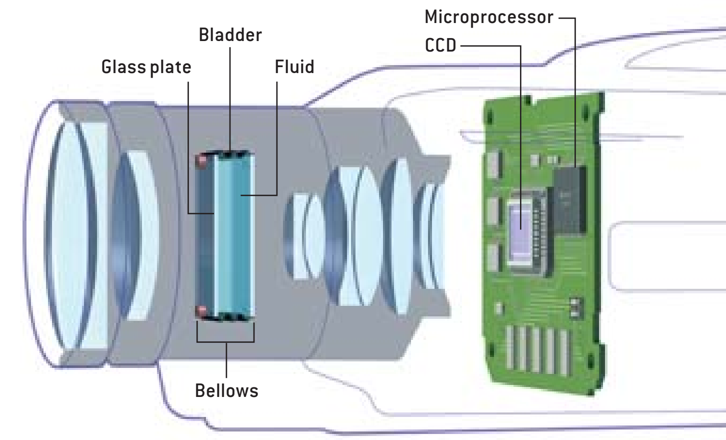
Correction inside camcorders also occurs in one of two ways: by moving a bellows inside the lens assembly or by digitally adjusting which CCD pixels record the incoming light [*see bottom illustrations*]. The latter method, sometimes called electronic image stabilization, is simpler and cheaper to implement but reduces the camcorder's field of view by 10 to 20 percent.

Developers are trying to devise digital processes for still cameras, but so far the approaches require much more processing power than current models carry. All the systems now deployed raise cost and add complexity. "Image stabilization began in high-end cameras because they had longer zooms and therefore needed greater shake compensation," says Chuck Westfall, who heads the technical information department at Canon USA in Lake Success, N.Y. "But 10× and even 12× optical zoom is moving down to less expensive cameras, so image stabilization must move down, too. It adds cost, but customers find it's worth it." —*Mark Fischetti*

DIGITAL CAMERA can offset blur from a shaky photographer's hand by rapidly adjusting a lens element or by moving the CCD that records the image (*far right*).



DIGITAL CAMCORDER contains a variable-angle prism, or bellows, that refracts light to offset shake. An alternative method, with no bellows, is digital stabilization (*far right*).



GEORGE RETSECK; SOURCES: EASTMAN KODAK AND CANON USA

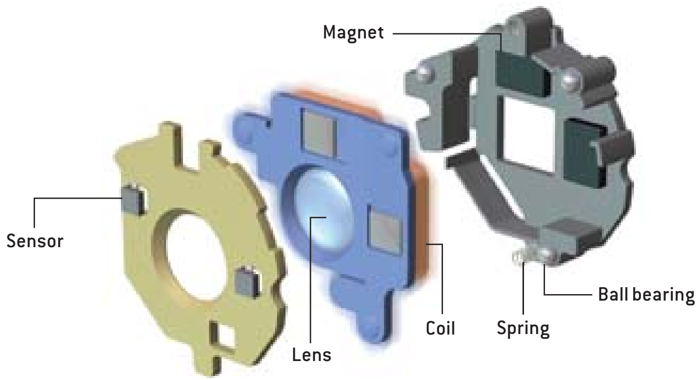
DID YOU KNOW...

PANNED: When shooting a movie, it is common to pan—move the camera to follow the action. But a stabilization system will try to counter that motion. Software can override the correction; if all the pixels are moving in harmony for more than a moment, the change is deemed to be a pan, not an accidental bump. No system can tell the difference during the first fractions of a second, however, so some cameras allow the operator to turn stabilization off.

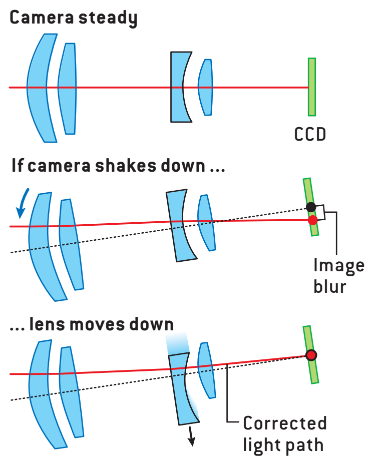
CELL PHONES: Image stabilization is hard to cram into cell phone cameras because there is so little space. "The phones also have to pass a drop test," Kodak's Jay Endsley notes, "which is tough for mechanical correction. Digital stabilization could work well, though."

BINOCULARS: Even the slightest hand shake will blur the image seen through strong binoculars, because the high magnification compounds the error. To compensate, Canon has inserted the same corrective bellows from camcorders into each cylinder of its high-end binoculars.

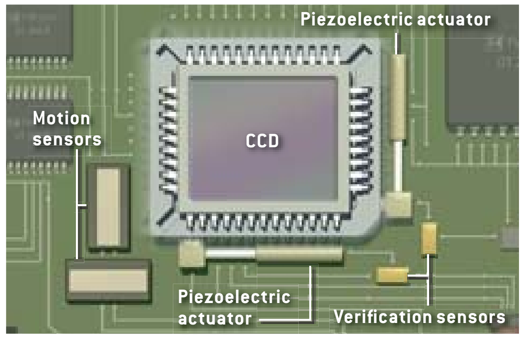
SPEEDY ANALOGY: Brochures espousing cameras with image stabilization tend to say that the system corrects up to two or three shutter-speed stops. The idea is that if, without correction, a user could not hold still enough to take a blur-free shot at a shutter speed slower than $^1/_{125}$ of a second, with correction he or she would in effect be steady down to $^1/_{60}$, $^1/_{30}$ and possibly $^1/_{15}$ of a second.

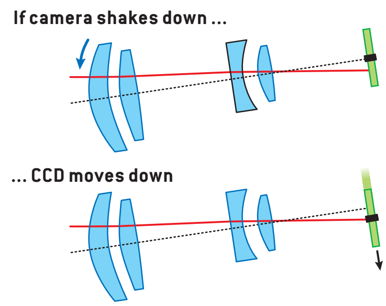


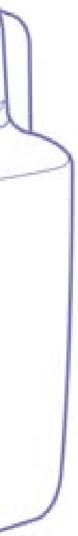
LENS ELEMENT shifts freely on ball bearings—up, down, left or right—inside a housing, when magnets induce attached coils to move. (Other designs nudge the lens with piezoelectric rods.) Sensors detect the direction and speed of camera jitter, signaling a microprocessor that controls the magnets. For example, if the camera tips down, the microprocessor instructs the lens element to drop, refracting the incoming light upward. A spring anchors the lens in a home position.

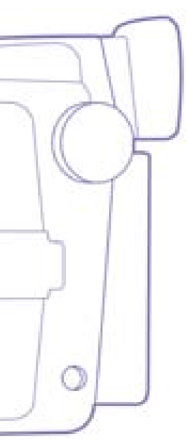


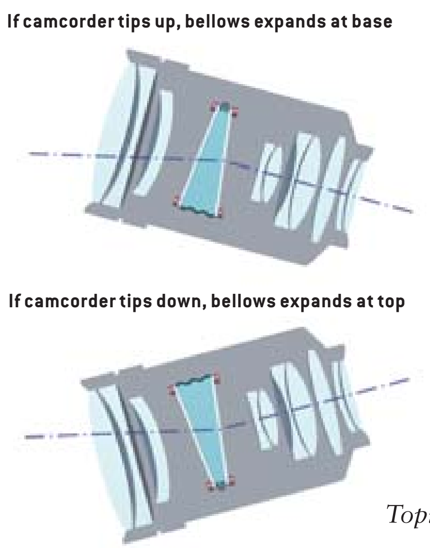
CCD is moved up, down, left or right by piezoelectric actuators when directed by a microprocessor, if motion sensors indicate the camera is jiggling. Verification sensors confirm that the CCD has shifted properly. If the camera tips down (*below*), the CCD drops so light stays centered.



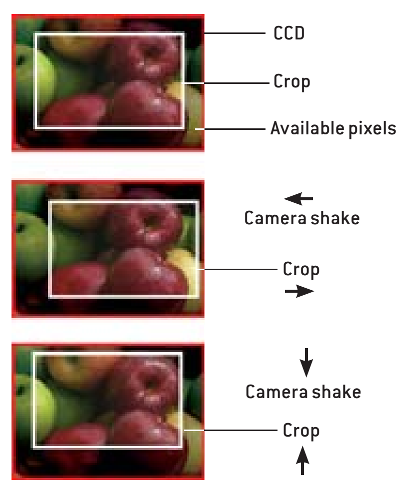








DIGITAL STABILIZATION requires no moving parts. Software crops the incoming image so it covers only 80 to 90 percent of the CCD's pixels. If electronics sense that the camera shakes left, the software adjusts the crop to the right (over available pixels); if it shakes down, the crop moves up.



Topic from reader William Phillips. Send ideas to workingknowledge@sciam.com

ORIGINALLY PUBLISHED IN JUNE 2006

OIL REFINERIES

Carbon Hooch

Heating oil, gasoline, jet fuel, kerosene and plastics. These products and more are derived from crude oil in one big fuming silo, siphoned off and fine-tuned through a bewildering maze of pipes.

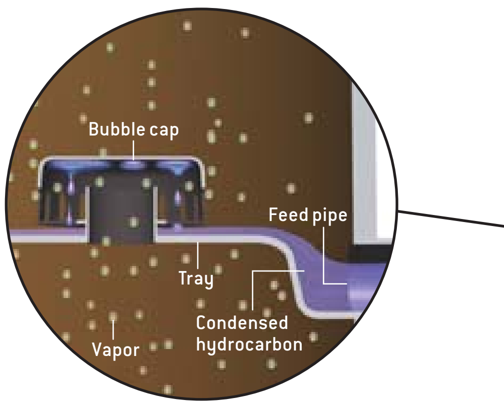
Crude oil contains hundreds of different hydrocarbons. Yet U.S. refineries convert half of all crude into gasoline—a blend of fuel stocks, particularly 2,2,4-trimethylpentane (eight carbon atoms chained together) and heptane (seven carbon atoms). The more complex the chain, the more the molecule can be compressed before it ignites spontaneously, allowing an engine to operate at a higher compression ratio—greater power output. The test mixture by which a gasoline's octane rating is judged combines 2,2,4-trimethylpentane and heptane (87 to 13 percent for "87 octane").

Refiners have tried additives over time to boost octane rating. Tetraethyl lead worked in "leaded" gasoline but was phased out because it spoiled catalytic converters. Producers switched to methyl tertiary butyl ether (MTBE), but it has been implicated in contaminating groundwater, and state governments are banning it. An alternative increasingly being used is ethanol, which has an octane rating of 108 or 110; gasoline with 10 percent ethanol is marketed as gasohol.

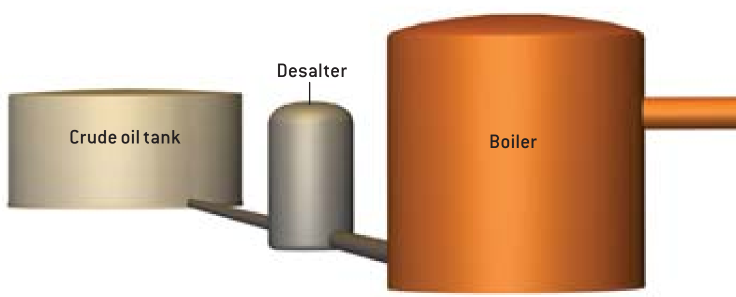
No new U.S. refineries have been built for 30 years because of "not in my backyard" public opposition and environmental permitting hurdles. Although some existing operations have been expanded, refineries nationally are running beyond 90 percent utilization, according to Harold Schobert, professor of fuel science and director of the Energy Institute at Pennsylvania State University. "So if one or two facilities go down, as they did during Hurricane Katrina," he says, "there will be refining shortages, and pump prices will go up."

Still, refineries cannot be blamed—as they have been—for the relentless rise in prices. According to the U.S. Energy Information Administration, the refining step accounts for only 18 percent of the final price (47 percent comes from crude oil, 23 percent from taxes, and 12 percent from distribution and retail dealers). Schobert says that refinery margins are only a few cents per gallon, too. Low profits, plus public resistance, give companies little incentive to invest the $2 billion or more needed to build a new plant. —*Mark Fischetti*

REFINERY boils crude oil, and the vapors enter a distillation column, where they rise and condense as they cool below their boiling points. Long, complex hydrocarbon chains, or fractions, condense at high temperatures near the bottom; shorter, simpler hydrocarbons condense at lower temperatures toward the top. Secondary processes such as cracking and reforming further refine products.



PERFORATED TRAYS allow vapors to bubble up into caps, where they condense, flowing into feed pipes.



GEORGE RETSECK

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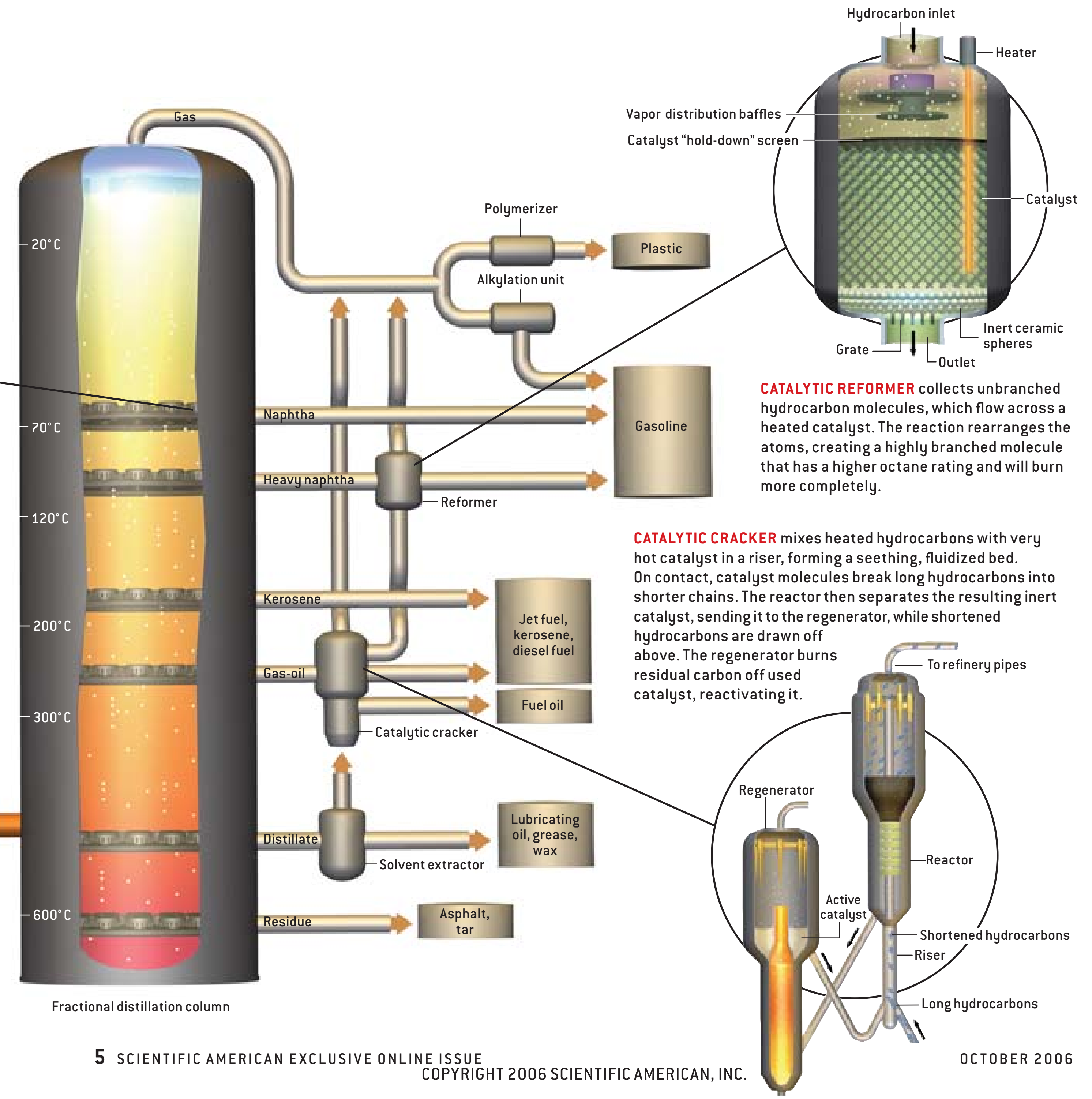
DID YOU KNOW...

NUISANCE: As whale oil for lamps became scarce in the 1850s, Canadians converted seeping ground oil into kerosene. Russia had dug trial oil wells, but the industry ignited in 1859, when American industrialist George Bissell contracted Edwin Drake to drill a well near Oil Creek, Pa. It produced paraffin, readily distilled into kerosene. Gasoline, a by-product, was discarded as a nuisance.

ONE WORD—PLASTICS: Some crude oil contains dissolved propane and butane that is tapped at the top of the distillation column. Propane is later converted to propylene for use in textiles, food packaging and automotive components. Butane is converted to butadiene for synthetic rubber. Most ethylene—the base for polyethylenes found in plastic containers and packaging—is refined in a high-temperature, low-pressure "thermal" cracker. "The cracker unzips the hydrocarbons, one pair of carbon atoms at a time," explains Penn State's Harold Schobert. "Each double-bonded pair is an ethylene molecule."

OPEC AGAIN: Refining capacity is expanding substantially in OPEC countries. Plants under way include a 600,000-barrel-per-day (bpd) operation in Kuwait and a 450,000-bpd site in Saudi Arabia. India, China and South Korea also plan vast growth. Arizona Clean Fuels has proposed a 150,000-bpd refinery outside Yuma, but it has not yet completed funding or agreements.



CATALYTIC REFORMER collects unbranched hydrocarbon molecules, which flow across a heated catalyst. The reaction rearranges the atoms, creating a highly branched molecule that has a higher octane rating and will burn more completely.

CATALYTIC CRACKER mixes heated hydrocarbons with very hot catalyst in a riser, forming a seething, fluidized bed. On contact, catalyst molecules break long hydrocarbons into shorter chains. The reactor then separates the resulting inert catalyst, sending it to the regenerator, while shortened hydrocarbons are drawn off above. The regenerator burns residual carbon off used catalyst, reactivating it.

ORIGINALLY PUBLISHED IN MAY 2006

WORKINGKNOWLEDGE

ROBOT MOWERS

Cutting Work

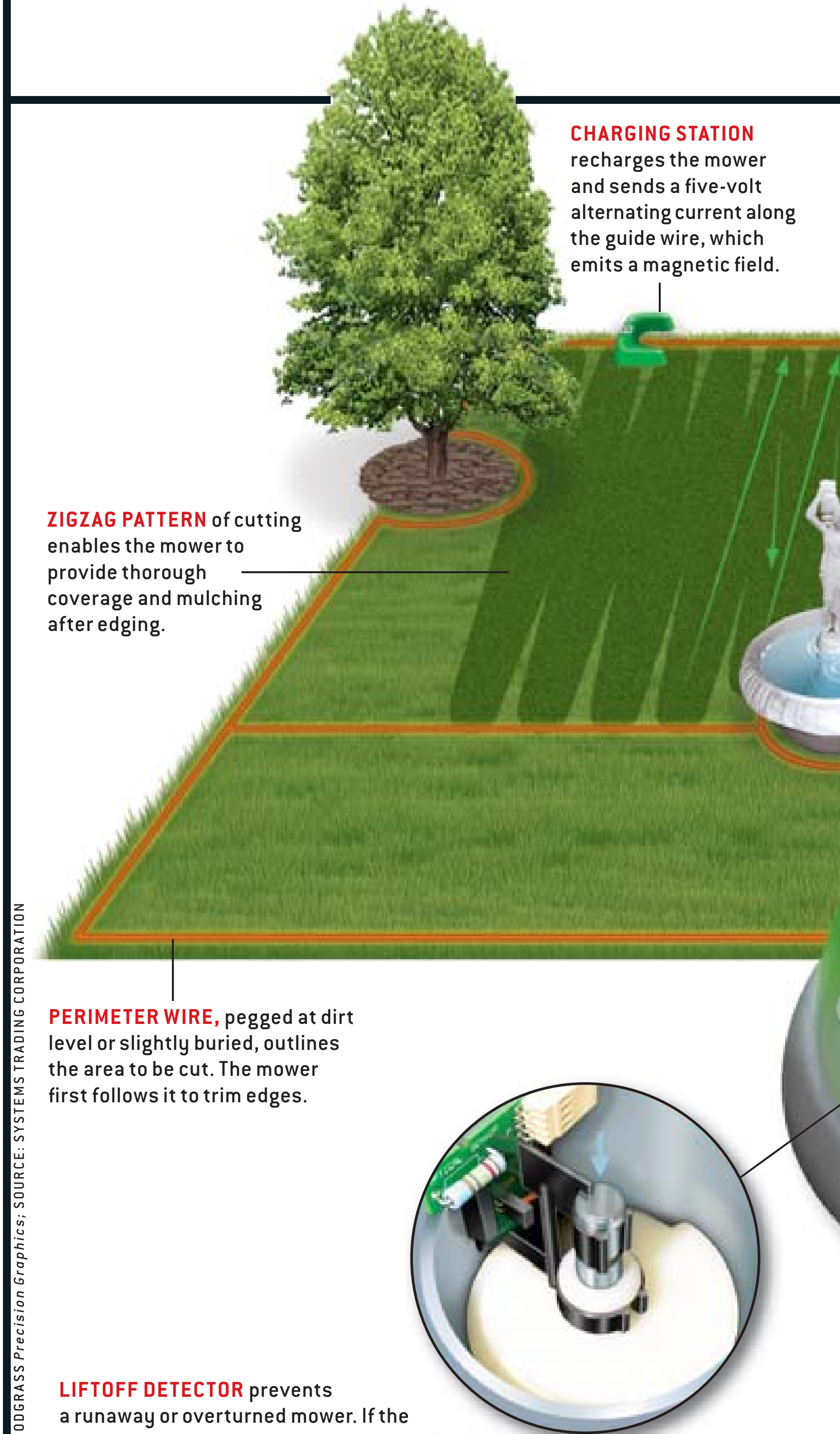
Autonomous lawnmowers have been around for several years, but after improving through hard knocks (some of them into trees), the newest generation is gaining popularity.

Of course, a human must set the stage, by outlining a yard with a dirt-level guide wire and by programming the robot with dates and times for cutting. After that, though, the electric mowers will start themselves, cut and return to base for recharging as needed, all on their own. Contrary to myth, they do not store maps of the territory or consult the Global Positioning System; they simply track where they are in relation to the guide wire [*see illustrations*].

Batteries are a key factor. Most units use lead-acid technology because it can provide the high power output needed for thick grass and is inexpensive. But the best mowers still cover only about 6,000 square feet per charge; half an acre will take four sessions. The machines also need two to three hours to complete those 6,000 square feet, crisscrossing and doubling back over their own paths to ensure they do not miss spots and for thorough mulching. That means the mower is on the lawn a lot, "but you're not out there pushing it, so why do you care?" notes Roy Tamir, technical expert at Systems Trading Corporation in Dallas. The company manages the RoboMower line, the biggest U.S. seller, made by Friendly Robotics in Israel.

Some prospective customers with large lawns balk at a bot mowing almost every other day to keep up. But the routine requires a change in mind-set; instead of a person shoving a mower through high grass and raking every weekend, the bots venture out more frequently and therefore only have to snip the tips of blades each time, which, turf experts add, leads to a healthier lawn. Despite all the activity, manufacturers say recharging costs only a few dollars a month.

Homeowners may find the frequent forays a nuisance (although the bots can cut at night). Owners may have to push a mower into tight corners or use the robot's manual controller. And they do still have to pick up sticks and debris that can ruin any mower's blades. Then there's the price: $1,500 or more. But busy people may be willing to pay for extra hours of free time. And the dog may make a new friend. —*Mark Fischetti*



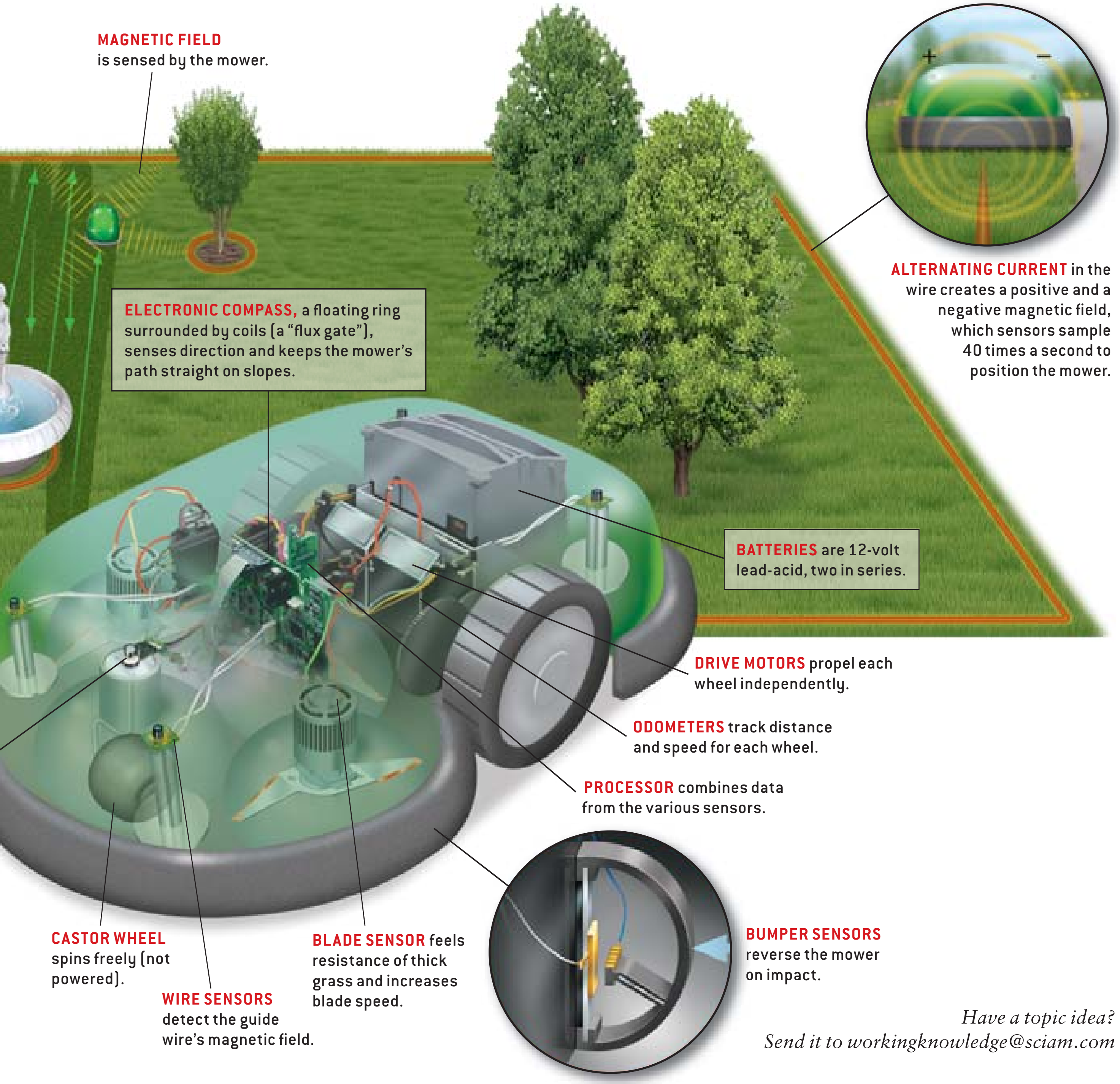
KENT SNODGRASS *Precision Graphics*; SOURCE: SYSTEMS TRADING CORPORATION

DID YOU KNOW...

NEW ANGLE: Robot mowers follow a counterintuitive pattern of zigzags to cover a lawn [*see illustration on opposite page*]. Manufacturers made prototypes that cut rows, back and forth, as most people do. But the inability of the compass to determine a perfectly parallel path, and slippage on slopes or wet grass, left islands undone. The course follows a precessing triangle scheme that eventually covers all spots several times over.

VACUUMS, TOO: Small robot vacuums that clean floors or short-pile carpet can be programmed ahead of time, return and dock for recharging on their own, and follow byzantine coverage patterns. There is no guide wire, though; to navigate, they reflect infrared or ultrasound beams off walls, objects and floors (the last to sense a stairway). Most look like a four-inch-thick Frisbee on wheels and underneath have a beater brush, spinning wand (for wall edges) and a suction slit. Models sell for $200 to $1,700. Some makers offer similarly styled units that wash floors.

SITTIN' BY THE POOL: Automatic pool cleaners resemble a large, hard-shell bowling ball bag that crawls along the pool floor and walls, sweeping up sand, pebbles, leaves and scum. Powered by an electric cord, an impeller draws water through a filter while rotating scrub brushes scour surfaces. Other models have water jets that expel debris through a hose to the pool's filter system.



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LEVEES

Into the Breach

Hurricane Katrina hit Louisiana on early Monday morning, August 29, 2005, and by Monday night levees and flood walls were bursting across New Orleans. Since then, four teams have investigated what happened.

The American Society of Civil Engineers (ASCE) inspection team was led by Peter G. Nicholson, a civil and environmental engineer at the University of Hawaii at Manoa. In his November 2 testimony to the U.S. Senate, Nicholson said his group observed "a number of different failure mechanisms" that led to "dozens of breaches" throughout the levee system.

The three most common failure modes [*see illustrations*] are similar for big earthen levees along rivers and lakes and for concrete flood walls along shipping and drainage canals. The mechanisms have caused the majority of levee failures worldwide; one way or another, water weakens the barrier's base until the barrier topples or collapses.

A robust foundation is key. Levees are needed in floodplains, where soils tend to be wet and can change every 100 yards along a proposed route. The exact path chosen "depends on which types of soil are where, their strength," and local water pressure, notes Francisco Silva-Tulla, a soil mechanics consultant in Boston who is on the ASCE team.

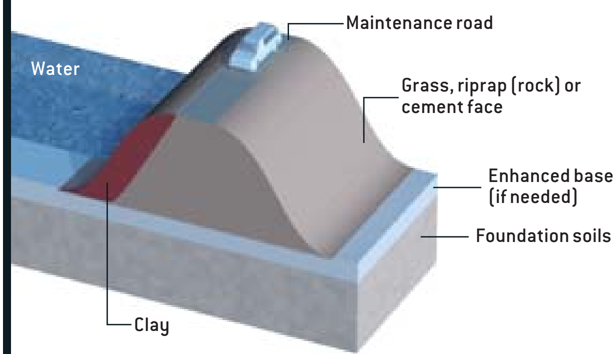
Building begins after field surveys and borings characterize the soils. Engineers then typically dig out shallow trenches or pits along the path to obtain earth for the levee. Their biggest concerns are preventing seepage under or through the embankment, stabilizing the slopes, and overbuilding to counteract settling, which can be up to 5 percent for soils compacted during construction and 15 percent for uncompacted material. New levees must usually settle for one to two years before the surface is finished.

A levee's height, the depth of its foundation or pilings, the quality of its materials, the degree of compaction (done by driving heavy machinery over the layers), and the type of slope finish depend greatly on the money approved for a project. When finalized, the investigation reports will clarify whether bad design, improper construction or simple failure to erect sufficiently large levees drowned New Orleans and the Gulf Coast.

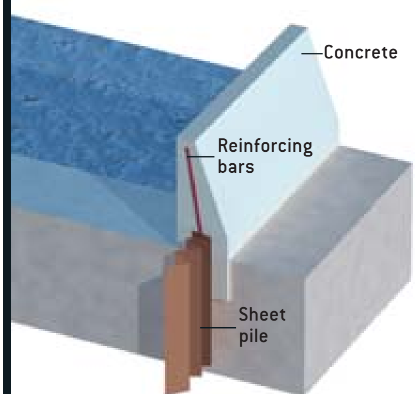
—Mark Fischetti

LEVEES are earthen embankments. Sandy soils are strong but are permeable to water; clays are weaker but are more impervious to water. Although designs vary widely, ideally strong soil forms the foundation and clay lines the water side. Slopes are finished with grass, riprap (rock) or soil cement, each of which, respectively, provides increasing protection against erosion.

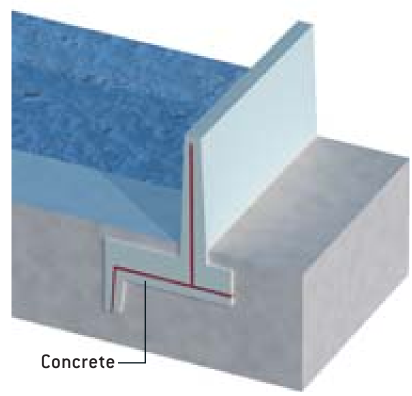
STANDARD LEVEE



I-WALL



INVERTED T-WALL



BRYAN CHRISTIE DESIGN

FLOOD WALLS may be built directly along canals or atop levees to add height when there is no space to enlarge them. I-walls are anchored by steel sheet piling. Inverted T-walls are anchored with a concrete footing that can provide greater resistance to lateral forces and reduce foundation erosion. I-walls failed much more frequently than T-walls did in New Orleans.

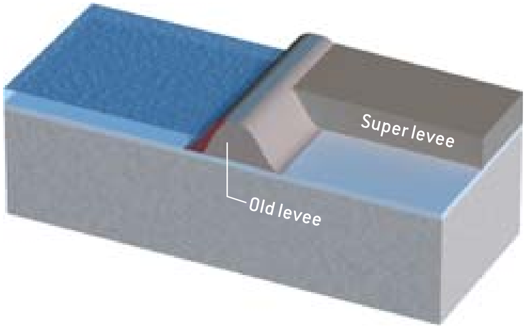
DID YOU KNOW. . .

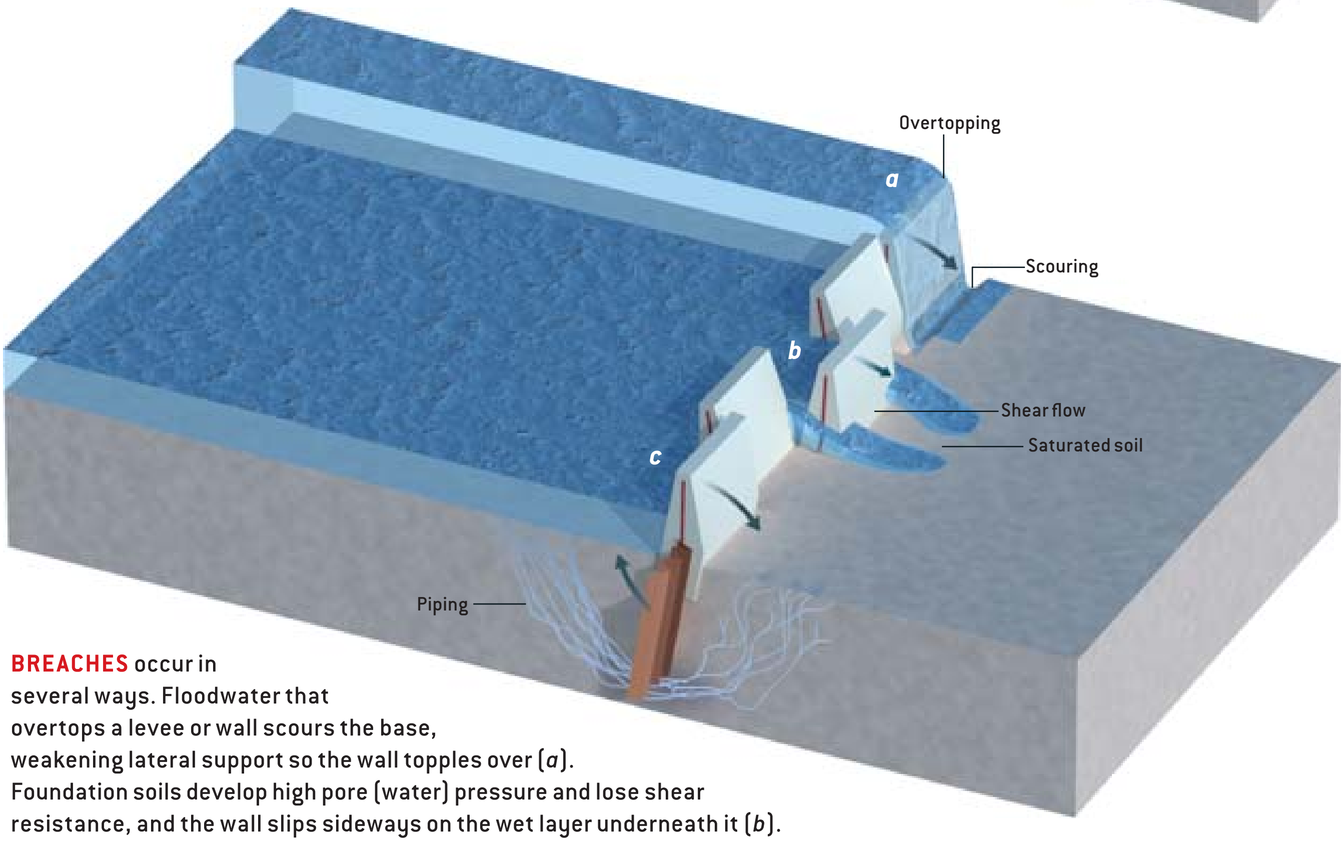
LIQUEFACTION: Earthquakes can shake a levee loose, especially if the foundation is sandy or silty and becomes waterlogged. The tremors liquefy the soggy layer like a blender, and the levee or wall can surf laterally for tens of yards, tearing the structure apart.

TRANSITION ISSUES: A number of breaches in New Orleans occurred where an earthen levee met a concrete flood wall and rising water scoured the joint and pushed through. "Transitions are a big problem; they are weak points," says ASCE team member Francisco Silva-Tulla. Transitions commonly occur when levees meet flood walls, floodgates, bridge abutments, or a different levee design and benefit from extra strengthening.

EARLY WARNING: If maintenance crews and emergency officials knew a section of levee was weak, they could shore it up or order timely evacuations. Kane GeoTech in Stockton, Calif., has wired several "smart levees" on Tyler Island, part of the Sacramento River Delta in California. Piezometers, which measure water pressure, are inserted on the river side and inside the levee at its center line and landward toe. Coaxial cable sensors are also laid. All the instruments lead to a computer at an exposed meter box; a technician can read the data, or it can be broadcast. Readings can be taken every few minutes. Changes in piezometer pressure indicate possible piping (*see "Breaches" diagram below*), and coaxial sensors can tell if a levee is beginning to shift; either can presage a breach.

SUPERLEVEES offer superior protection. They are being built in Japan to shore up conventional levees that might shake apart during an earthquake. They are so wide (30 times the levee height) that many existing buildings have to be demolished to make room—unless a storm has already cleared the way.





BREACHES occur in several ways. Floodwater that overtops a levee or wall scours the base, weakening lateral support so the wall topples over (*a*). Foundation soils develop high pore (water) pressure and lose shear resistance, and the wall slips sideways on the wet layer underneath it (*b*). Seepage driven by high water pressure creates "pipes" in erodable soil that tunnel below the wall, undermining the foundation so the wall collapses (*c*).

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ORIGINALLY PUBLISHED IN NOVEMBER 2005

WORKINGKNOWLEDGE

NUTS

Case Cracked

"How are nuts shelled commercially?" asks *Scientific American* reader Bill Lush. "Every time I struggle with a Brazil nut or a pecan I wonder. It must be tough, since we're dealing with a natural product that varies in size and shape. And don't tell me it's done by hand—I would be soooo disappointed."

Lush's note expresses a frustration many people share during Thanksgiving and the December holidays—the stressful attempt to crack a nut just enough to open it without crushing the prize inside. Production plants can process 30 to 60 tons of nuts a day, smashing fewer than one tenth of 1 percent.

Most nuts are harvested by shaking their trees with a bulldozerlike contraption. The jewels are scooped up from the ground along with dirt, grass, leaves, sticks and stones. Screens and shakers sieve this mess to leave a reasonably junk-free bin of nuts, which are then mechanically sorted by size. To handle the size variations, a processing plant operates a number of cracking machines in parallel, each one accepting nuts of a specified size—for almonds, say, 8/16 inch wide, 9/16, 10/16 and so on. Pecans are typically sifted into five size ranges, peanuts into six. "The more precise the match, the less damage to the kernel," says Bill Hoskins, director of quality assurance at Blue Diamond Growers in Sacramento, Calif.

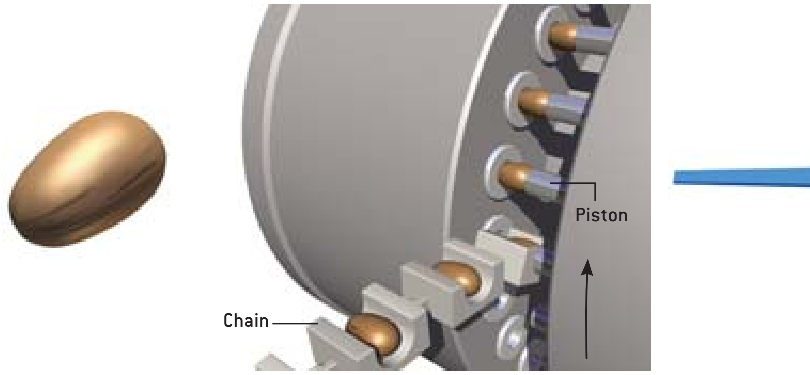
Although machines are tailored to each nut type, a few basic techniques—screen impurities, tear off shells and aspirate both away—underlie the processes [*see illustrations*]. "The most important objective is to keep cleaning the product flow," says Lewis Carter, Jr., chairman of Lewis M. Carter Manufacturing in Donalsonville, Ga., which makes a large share of American machines.

The technology has evolved slowly for decades. For example, "the almond industry has adapted much of its machinery from the peanut industry," Hoskins says. Similar equipment and procedures are used for grains and beans, too.

A few nuts pose unique challenges. Black walnut shells are so hard they require special crackers. Brazil nuts are actually seeds that grow in groups of eight to 24 inside a small coconutlike pod that must itself be cracked. —*Mark Fischetti*

SOFT-SHELL NUTS, such as almonds (*shown*), are separated from harvest debris and sorted by size through a series of perforated pans. Nuts of similar diameter fall between a pair of rollers spaced slightly closer than that diameter. One 10-inch-diameter roller rotates faster than the other, creating a shearing action that tears the shell away from the kernel. In contrast, peanuts are pushed through sharp gates that slice off the shell.

HARD-SHELL NUTS, such as pecans (*shown*) and hazelnuts, are submerged in water at 190 degrees Fahrenheit for three to 12 minutes, which softens (and pasteurizes) them. Once they are extracted, the shell hardens within minutes, but the meat remains pliable. The nuts settle into a chain that pulls each one past a piston, which strikes the shell at 35 to 45 pounds per square inch, cracking it; the soft core remains intact.



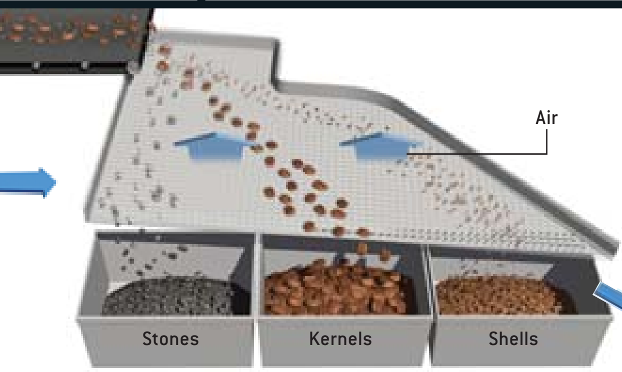
GEORGE RETSECK

DID YOU KNOW. . .

FRESH COLD ONE: Peak U.S. harvests are in the autumn, but processing continues year-round. Almonds can be stored for six to eight months at 32 to 60 degrees Fahrenheit before shelling. Pecans can keep in freezers for two to three years; they are 80 percent oil, which remains very stable when frozen, says Brenda Lara, plant manager at Green Valley Pecan Company in Sahuarita, Ariz.

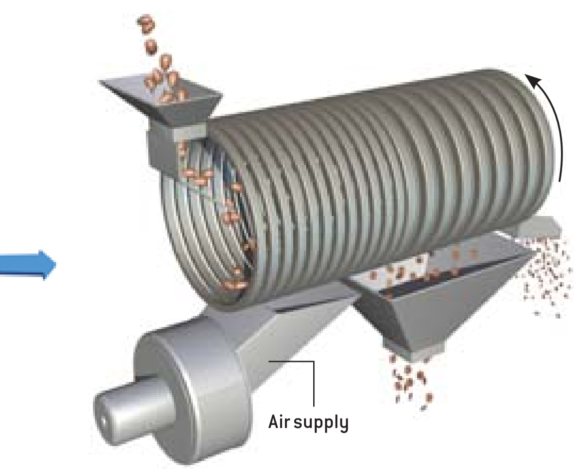
SQUIRREL MANIA: Ninety-nine percent of U.S. hazelnuts are grown in the Willamette Valley of Oregon. In the past, the shells were burned as fuel; the hot market today is for mulch. Because the shells absorb very little moisture, they drain quickly yet block sun from drying the soil underneath, and they decompose slowly. They are also dense, preventing weed seeds from germinating. But the scent drives squirrels nuts—no kernels to be found.

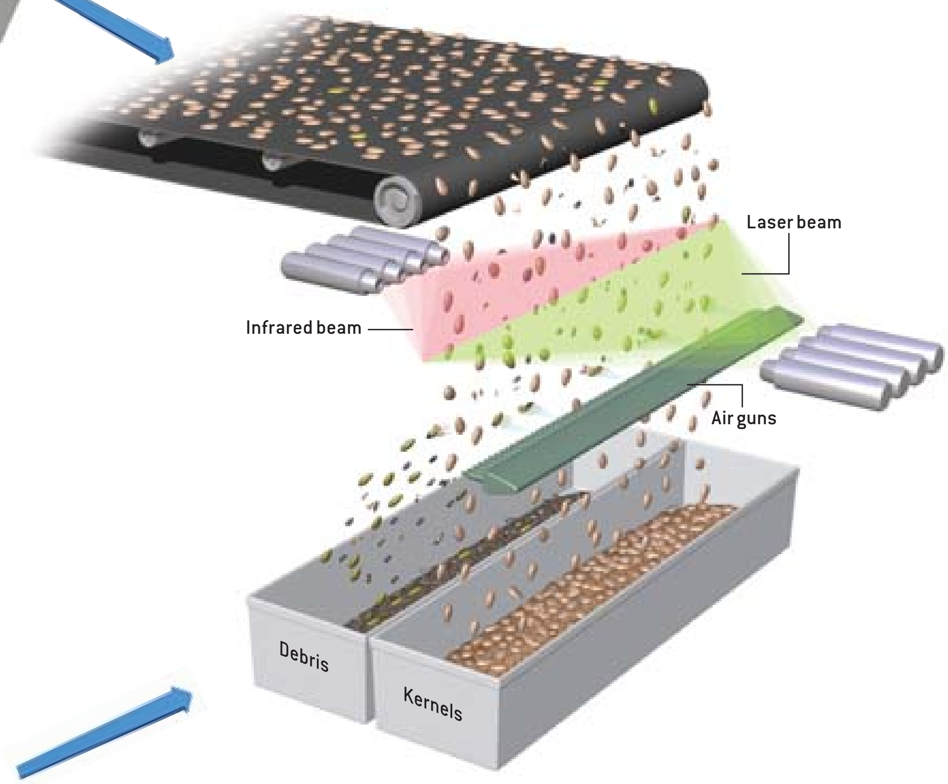
TOUGH NUT TO CRACK: Many of the world's cashews are cultivated in India, Malaysia, Indonesia and eastern Africa. Each nut grows inside a small, pear-shaped peduncle—a false fruit. In developing countries workers often tear the fruit away by hand. Oil on the nutshell surface is toxic and corrosive to human skin, so the nut is dried and roasted to extract the oil and to make the shell brittle. Most shells are cracked by hand, too; workers dust their fingers in wood ash or linseed or castor oil, for protection. Gradually, machinery is being deployed.



INCLINED GRAVITY TABLE oscillates and vibrates as air is blown up through the screen tray. The material stratifies within a fluidized bed: shell fragments (low specific gravity) float down to one end and are drawn off. Heavier, whole kernels migrate to the central part of the screen. Dense objects (stones) climb to the high end and are combed away.

SHELLER DRUM rotates as cracked nuts are conveyed inside, drawn through the cylinder by negative air pressure. Rings strike the nuts, knocking the cracked shells free.





FOR MOST NUTS, kernels and remaining impurities fall through a scanner. Infrared or laser beams reflect off each object to check for poor shape (partial kernel) or bad color (rotten kernel). An air gun blows a suspect nugget out of the four-foot-wide stream. Production workers spot-check whole kernels before packaging.

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ORIGINALLY PUBLISHED IN JULY 2005

WORKINGKNOWLEDGE

RAPID PROTOTYPING

Make It Quick

Before manufacturing a new product, companies craft models or prototypes to check designs, assess appearance, test fit and function with other parts, or fine-tune molds and dies for the production line. For decades, prototypes have typically been made by hand from drawings, a slow and expensive exercise. But in recent years, various rapid-prototyping techniques that automatically produce three-dimensional parts from computer-aided-design data have reduced the time from weeks to days or hours.

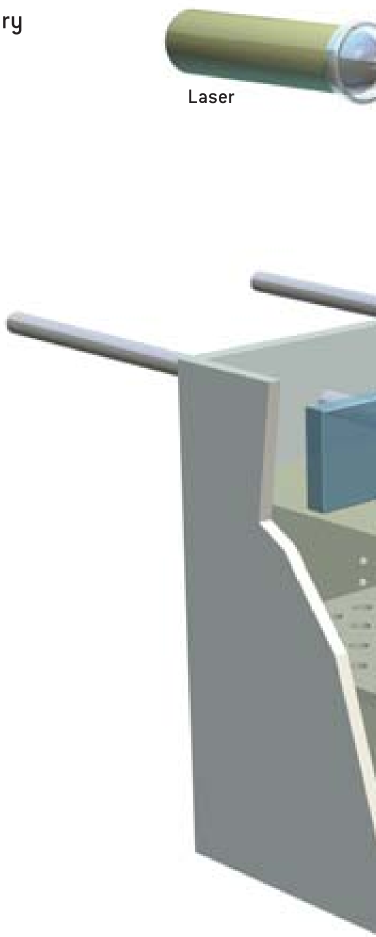
Automotive, consumer-products and medical-device engineers are among the most avid users, along with service providers that make models for clients. Objects are built additively as a series of very thin layers of resin, extruded plastic or powder that are hardened [*see illustrations*].

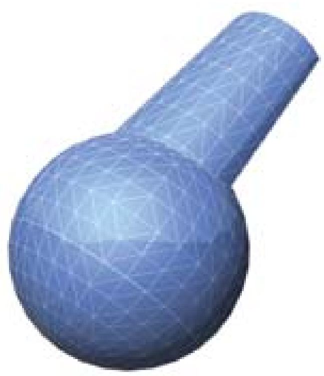
Stereolithography was the first process and is now the most widely employed. "Maybe 30 other processes have been attempted, but only five or six" have prevailed, says Ron Barranco, owner of Stereolithography.com, a service in Palo Alto, Calif. Among the alternatives are fused deposition modeling and so-called 3-D printers, which can crank out pieces quickly and inexpensively, although they may be a bit less accurate and long-lasting. Stereolithography machines may range from $180,000 to more than $500,000, whereas 3-D printers can cost $25,000 to $60,000.

Object size is typically less than 24 inches along the *X*, *Y* and *Z* axes, but larger machines are emerging. Some can build commercial goods directly, eliminating the need for molds, dies and machining, but most products still struggle to match the mechanical, thermal, durability or low-cost properties achieved by traditional manufacturing. Nevertheless, "if production cost is high, volume is low and the object's shape is complex," then rapid prototyping can excel, says Terry Wohlers, president of Wohlers Associates, prototyping consultants in Fort Collins, Colo. For example, most in-ear hearing aids are made this way, because each piece must be custom-fit to each patient's ear canal.

The rapid-prototyping market is growing fast. Proponents say rapid manufacturing is the next step, as tougher materials and still greater precision are demonstrated. —*Mark Fischetti*

STEREOLITHOGRAPHY: Software translates design data for an object into a series of very thin cross sections. A perforated platform in a vat of liquid photosensitive polymer rises to the surface. The fluid bubbles up through the platform, and a blade sweeps across, leaving a film. An ultraviolet laser beam, directed by a mirror, traces out the first cross section, converting precise portions of the coating into a solid. The platform drops slightly,and the blade smoothes the liquid just over the solidified area. The laser hardens the second layer on top of the first, and so on, building up the structure. Support columns are added as needed and are later removed.





COMPUTER-AIDED-DESIGN software may define an object as a series of triangles, in part to encode a designer's raw solid-modeling data. A stereolithography machine would then redefine the model as layers for fabrication.

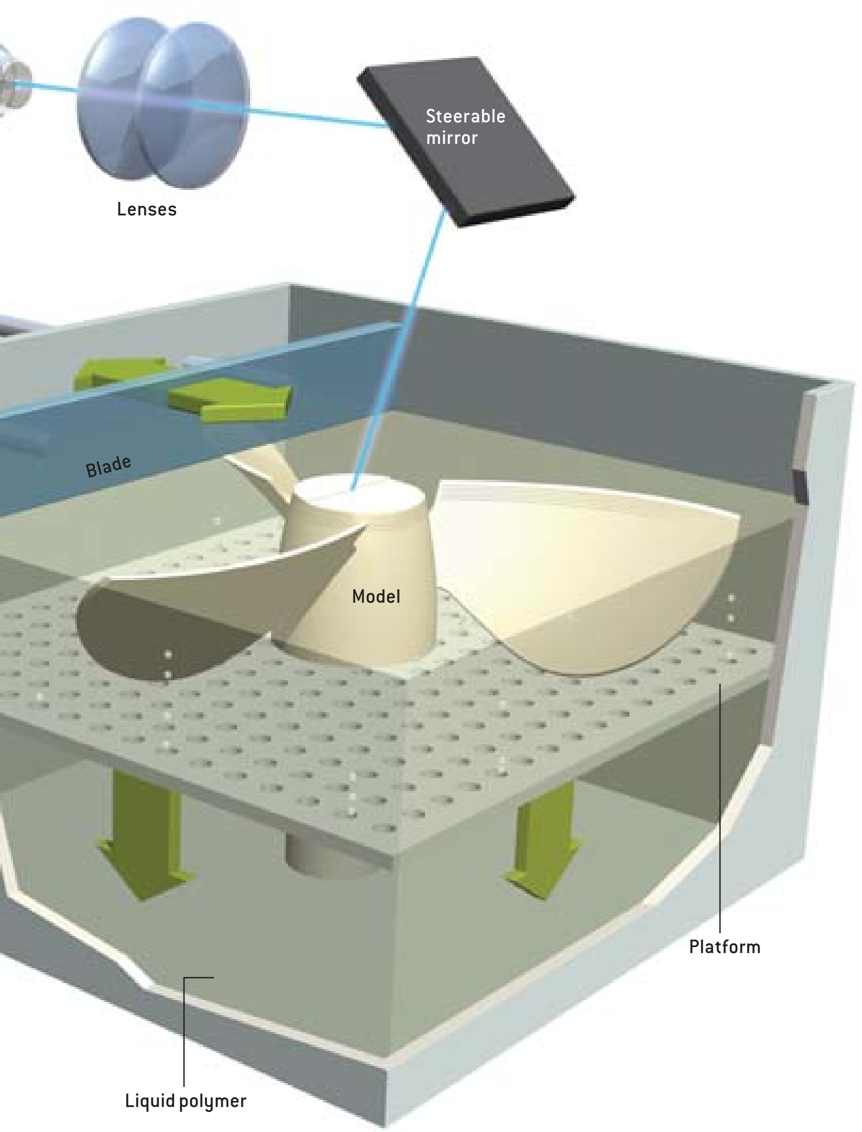
GEORGE RETSECK

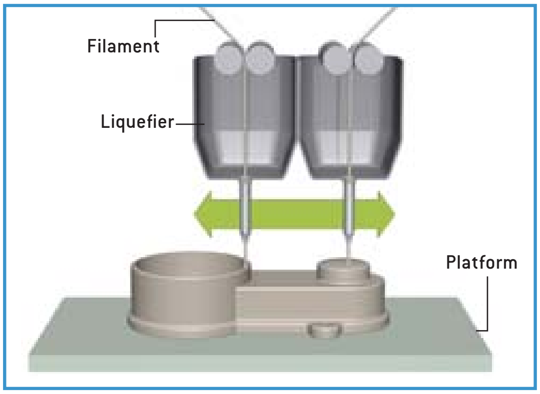
DID YOU KNOW. . .

JUST ADD HEAT: So-called selective laser sintering is growing in use. A laser forms layers by fusing heat-sensitive nylon or metal powder that is spread on a platform like that employed in 3-D printing. The process creates end products, typically those that must be custom-made for each buyer, such as hearing aids. Other goods include air ducts for Boeing's F-18 fighter jet and parts for the U.S. space shuttle and the International Space Station.

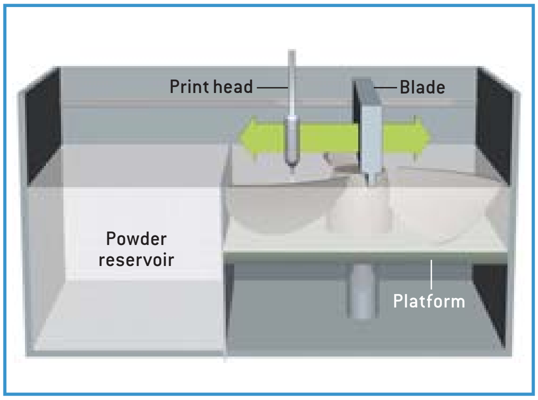
3-D AT HOME: Enthusiasts say homeowners could someday construct their own kitchenware or parts for the car with a rapid-prototyping machine in their basement, from design data sent online by a service provider. But Terry Wohlers of Wohlers Associates thinks that scenario is unlikely "when they could go to Wal-Mart" and buy the item inexpensively. Engineers might do such work from home, but the real market, Wohlers says, will be kids: "The computer design game SimCity, for example, uses 3-D data; a 3-D printer could make all the items. In 10 years, if printer prices drop to $300, just imagine the school projects kids could do."

SOLID, NOT GAS: Despite the many materials employed in stereolithography, Ron Barranco of Stereolithography.com says the key factor in improving quality and reducing cost has been the switch from gas lasers to solid-state lasers. "The gas lasers were less accurate and wore out," he explains.





FUSED DEPOSITION MODELING: Filaments of thermoplastic are warmed and liquefied. An extrusion head deposits a thin bead of material onto a platform, tracing out the object's first layer, like a baker decorating a cake. The platform is kept cool so the plastic sets quickly. After the platform lowers, a second layer is extruded, and so on.



3-D PRINTING: A blade brushes a thin layer of composite, ceramic or casting powder across a platform, and a print head, like that in an inkjet printer, sprays a fine pattern of binder fluid that hardens the powder where needed to form the object's initial layer. The platform lowers, more powder is spread, binder makes the second tier firm, and so on. Excess powder is later blown away. Wax or resin can be impregnated into final parts to enhance durability.

Topic suggested by readers Carl Groat and Yang Zhou. Send ideas to workingknowledge@sciam.com

ORIGINALLY PUBLISHED IN FEBRUARY 2005

WORKINGKNOWLEDGE

NOISE-CANCELING HEADPHONES

Reducing a Roar

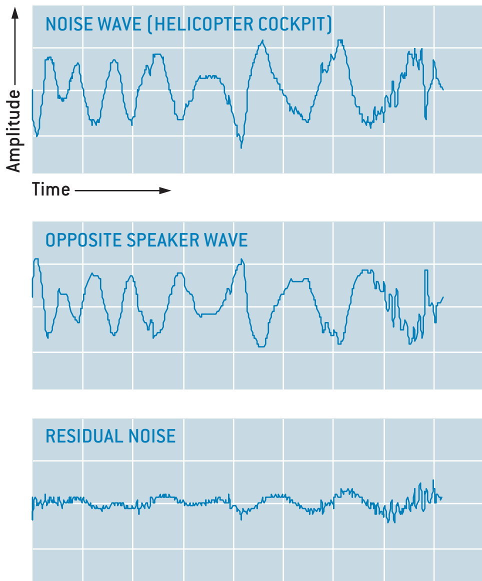
Whining jet engines pummel airline passengers with a mind-numbing 75 to 80 decibels of noise. Subways, trains and speeding cars also assail riders with a relentless howl. Putting on simple headphones and cranking up a compact-disc player to drown out the din just adds to the ear-pounding volume.

Deep earplugs or earmuffs like those worn by factory workers typically reduce the racket by 15 to 25 decibels, but they are uncomfortable and do not allow wearers to hear the audio from an airplane movie, music channel or their own music player. Noise-reduction headphones can help. The most advanced models, priced around $300, are made from structural materials that passively block higher-frequency noise (above about 200 hertz). They employ electronics and a speaker to actively cancel lower-frequency sounds, which are otherwise difficult to stop. A microphone inside each muff senses sound waves that make it through the outer ear cup, and a speaker creates pressure waves that cancel them. If desired, music can then be piped in at a comfortable level.

The best models passively reduce noise by 15 to 25 decibels; turning on the active circuitry can cut another 10 to 15 decibels of low-frequency tones. The interior microphone, circuitry and speaker—which constitute a feedback system—must create opposing waves fast and loud enough to almost match the sound in real time. Coming within 25 degrees of the needed 180-degree phase shift can cut noise by 20 decibels. Headphones that react more slowly provide less cancellation.

The electronics can also attack some mid-frequency sounds that seep through, "so the headset can be lighter or less tight, making it more comfortable," says Dan Gauger, noise-reduction research manager at Bose Corporation, a leading maker in Framingham, Mass. But actively attenuating frequencies higher than 500 to 1,000 hertz remains difficult, Gauger explains, because the hardware has less and less time to generate the opposing waves. (For reference, typical female speech is around 225 hertz.) "Feed-forward" systems that pick up noise outside the earpiece and pipe in the opposing signal are also available but require complex electronics. *—Mark Fischetti*

PRESSURE WAVE from noise is canceled by destructive interference; the speaker creates a wave that is 180 degrees out of phase and of similar amplitude. Many frequencies are present in the noise.



SAMUEL VELASCO; SOURCE: BOSE CORPORATION

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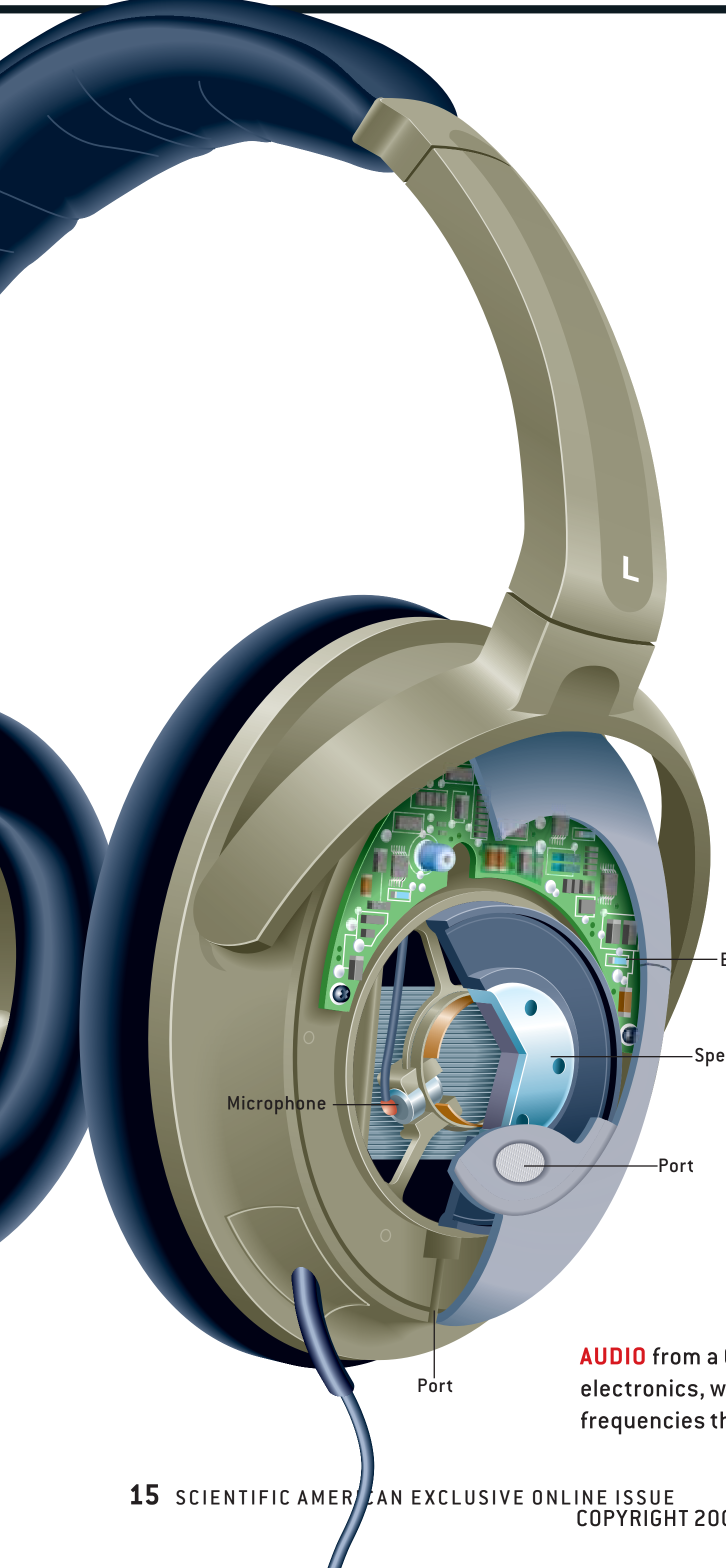
DID YOU KNOW . . .

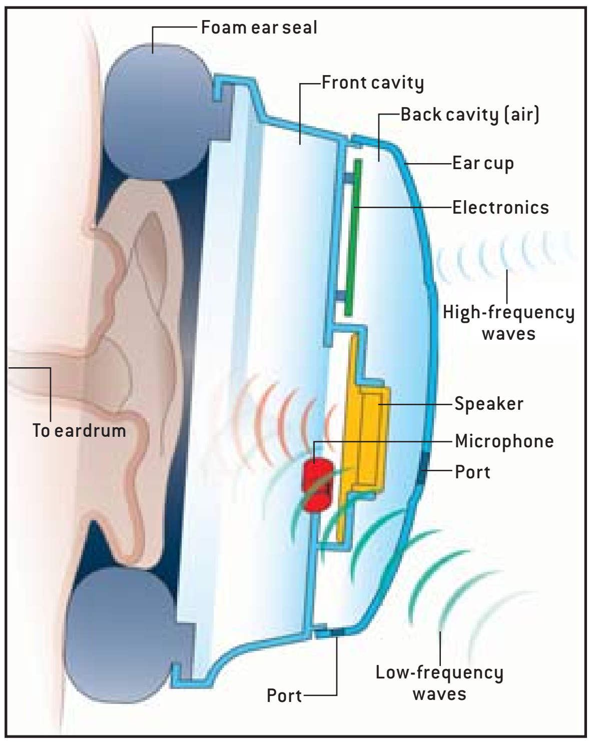
FRAZZLED FLIER: Bose Corporation founder Amar Bose was prompted to craft noise-canceling headphones during an aggravatingly loud plane flight from Europe in 1978. The U.S. Air Force had tried active-cancellation headphones in the 1950s, but invention in the 1970s of the tiny, low-power electret microphone would make possible much lighter gear. Bose worked with air force clients and began selling commercial sets in 1989.

WHAT?!: The National Institute for Occupational Safety and Health says that sustained exposure to sound exceeding 85 decibels can harm human hearing. Scientific studies also indicate that an ongoing roar can magnify fatigue, elevate stress, even prolong jet lag. The decibel scale is logarithmic: 50 decibels is 10 times more powerful than 40 decibels and typically sounds twice as loud. Some average levels: conversation, 50 to 60; inside a four-cylinder car on the highway, 70 to 75; passenger airliner, coach class, 75 to 80; lawn mower, 95; table saw, 105; full-tilt rock concert, 110 to 120.

QUIET COCKPIT: Engineers have attempted to cancel noise in entire cockpits of military aircraft by installing microphones and speakers every few feet all around the interior. Success requires many, often large, speakers, which occupy space and sap power, along with overcoming reverberation and standing waves. Practical systems have achieved quiet zones rather than uniform silence.



HEADPHONE ear cup and ear seal attenuate high-frequency sound. Low-frequency noise penetrates, creating pressure waves inside the front cavity. A microphone senses the waves, and electronics direct a speaker to create inverse waves, negating the pressure change before it reaches the eardrum.



PORTS increase speaker efficiency by venting air trapped behind it. To cancel a 90-decibel noise, the speaker must be powerful enough to create comparable, opposing sound pressure—an energy-intensive task, making efficiency key.

AUDIO from a CD, MP3 player or airplane seat arm is sensed by electronics, which instruct the speaker not to negate noise frequencies that match the desired audio frequencies.

ORIGINALLY PUBLISHED IN DECEMBER 2004

WORKINGKNOWLEDGE

AIR TRAFFIC CONTROL

Crowded Skies

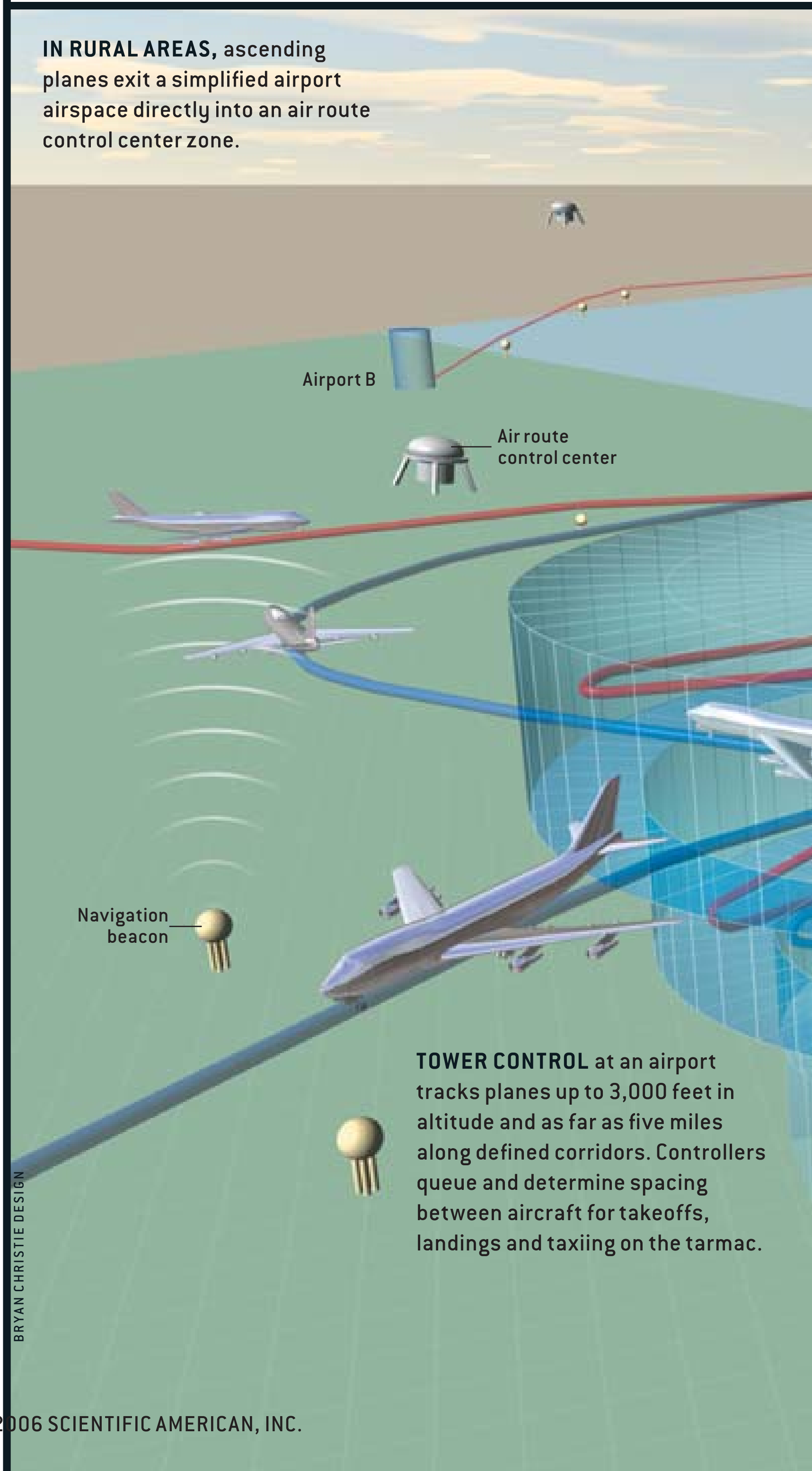
More than 44 million airplane flights through 19,500 U.S. airports will take place this year. At peak times, 5,000 planes are aloft in American airspace. Yet accidents are few, largely because of the air traffic control system and its alert controllers.

Those controllers confer by radio with pilots about which predefined paths to follow for departure, ascent, descent and landing. While cruising, pilots proceed along each leg of a prefiled navigation plan, advancing along established air routes. Controllers ensure that aircraft are safely spaced. Minimum separations near airports are three miles ahead and 1,000 feet vertically; during high-altitude cruising, the minimums are five miles and 2,000 feet. (This may change to 1,000 feet in 2005.) Controllers hand off supervision of a plane as it advances from one control region to the next and may permit pilots to temporarily go "off route" to avoid bad weather.

The entire system may be overhauled, however, to relieve congested skies. "Free flight" is one of the proposed solutions. Today pilots must zigzag along fixed air routes so they cross over the ground-based navigation beacons that are the backbone of the 30-year-old air traffic control scheme. Instead they could choose a straighter path one day or a longer path another day that is faster because of strong tailwinds. "This route flexibility would allow a pilot to fly where he wants when he wants," says Russ Chew, chief operating officer of the Federal Aviation Administration, who oversees its air traffic control operations. For example, high-altitude headwinds can be 100 miles per hour; ducking them would save fuel and speed up transit time.

Free flight would require satellite navigation using Global Positioning System (GPS) transponders and displays in planes and throughout the air traffic control system. And airports would have to add gates to lessen backups that could negate in-transit gains. The FAA has released a "national airspace system" architecture to gradually phase in free flight. Once GPS is widespread, Chew says that "controllers can flex the airways to optimize traffic patterns. The system will gain significant capacity."

—Mark Fischetti

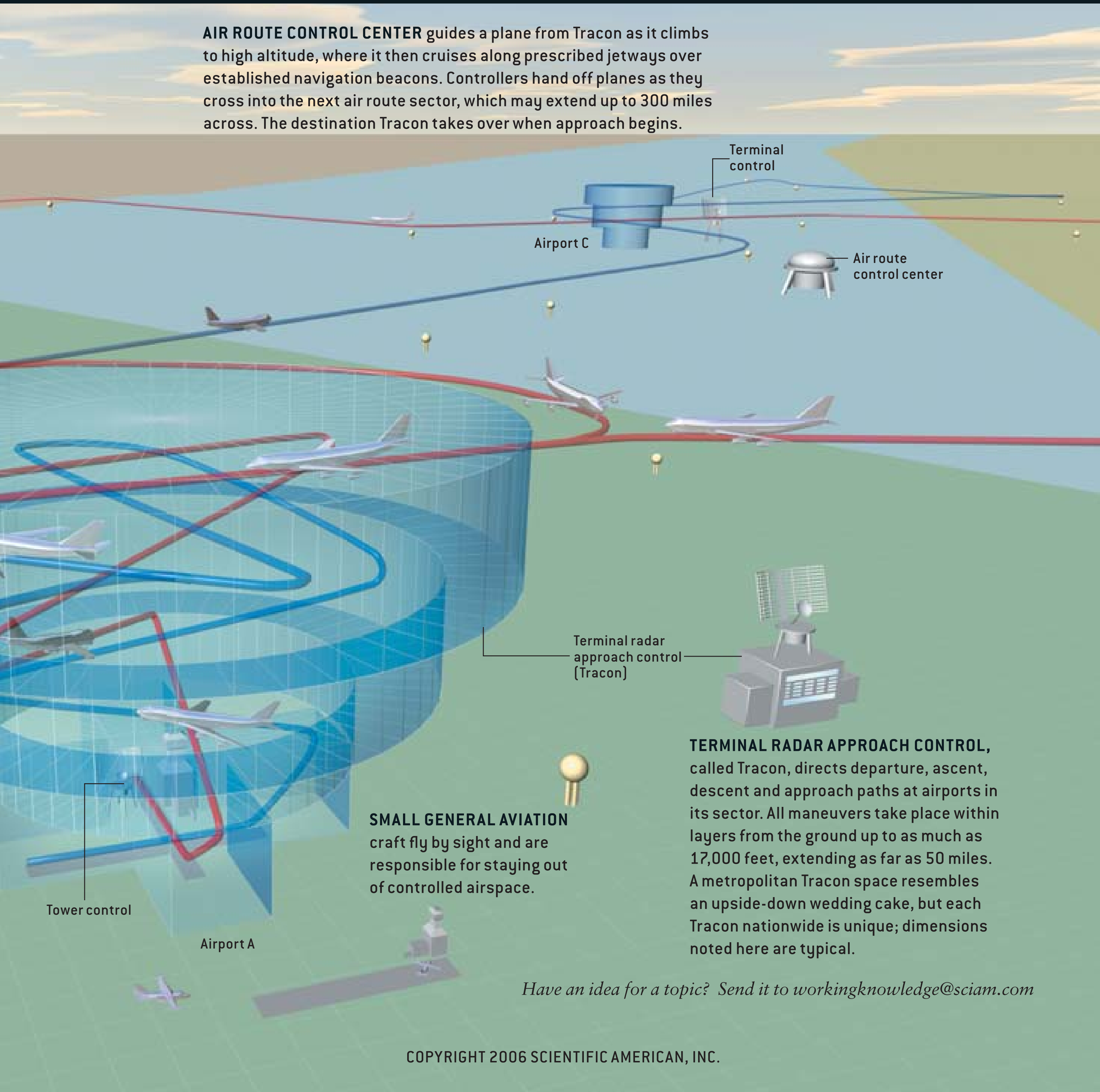


DID YOU KNOW . . .

OCEANS AWAY: Three air route centers—in New York City, Oakland, Calif., and Anchorage, Alaska—monitor traffic over the Atlantic and Pacific oceans. Radar does not cover the vast airspace, so pilots must radio in at predetermined points along strict flight paths, allowing controllers to calculate separation between planes, which must be at least 100 miles. The Oakland center will soon test GPS tracking to see if it could safely reduce that buffer.

HELP WANTED: The nation's 26,000 controllers work a 40-hour week, although overtime is not uncommon. In its job descriptions, the U.S. Bureau of Labor Statistics says, "During busy times, controllers must work rapidly and efficiently. Total concentration is required. The mental stress of being responsible for the safety of several aircraft and their passengers can be exhausting for some persons." Because many of today's controllers will retire within a decade, "substantial" replacements will be needed, the bureau notes. Median annual earnings are about $92,000.

NO CONTROL: Tens of thousands of small, private "general aviation" craft that fly from little airports are not tracked by air traffic control, chiefly because they do not have the needed radar or radio equipment. Pilots fly under "visual flight rules"—they file a flight plan with a local flight service station, navigate by altimeter and visual cues, and stay out of controlled airspace.



AIR ROUTE CONTROL CENTER guides a plane from Tracon as it climbs to high altitude, where it then cruises along prescribed jetways over established navigation beacons. Controllers hand off planes as they cross into the next air route sector, which may extend up to 300 miles across. The destination Tracon takes over when approach begins.

SMALL GENERAL AVIATION craft fly by sight and are responsible for staying out of controlled airspace.

TERMINAL RADAR APPROACH CONTROL, called Tracon, directs departure, ascent, descent and approach paths at airports in its sector. All maneuvers take place within layers from the ground up to as much as 17,000 feet, extending as far as 50 miles. A metropolitan Tracon space resembles an upside-down wedding cake, but each Tracon nationwide is unique; dimensions noted here are typical.

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WORKINGKNOWLEDGE

PACEMAKERS

Keep the Beat

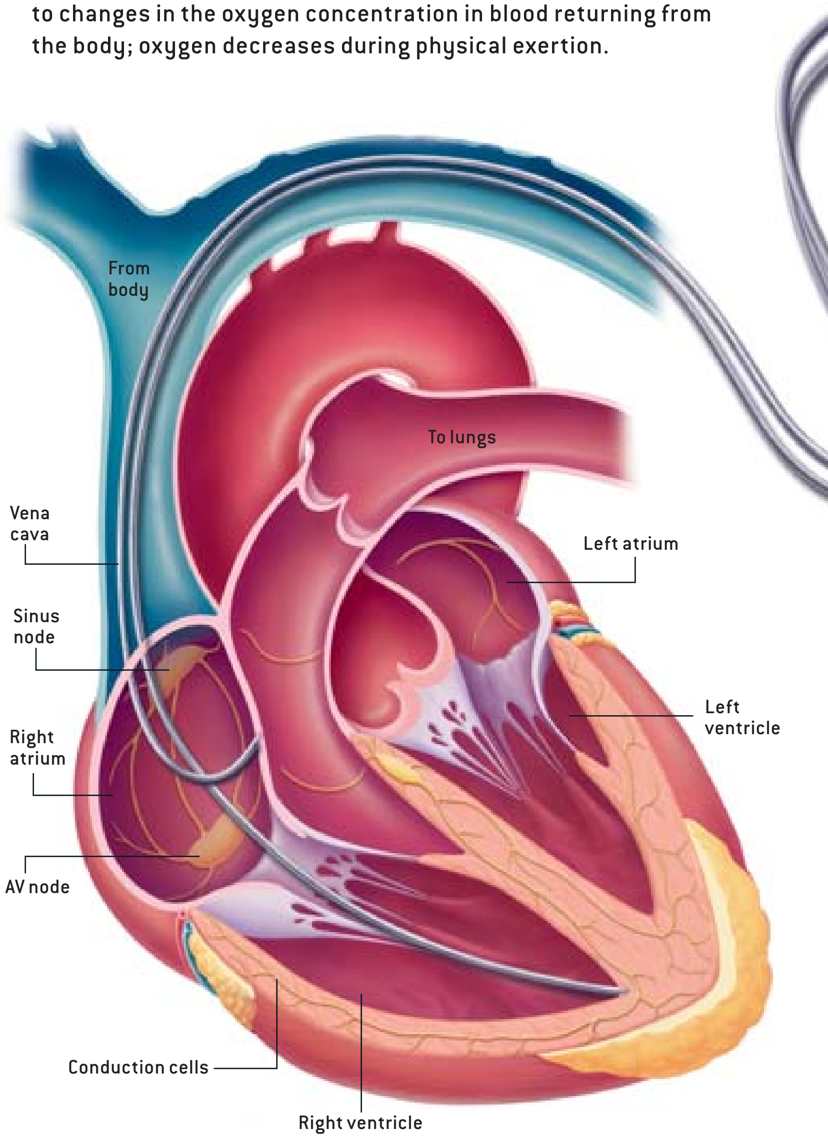
Almost four million people worldwide have pacemakers, which were first deployed experimentally 50 years ago to speed hearts that beat too slowly.

In a healthy heart, electrically conductive muscle cells fire for each contraction of the atria and ventricles [*see illustration*]. In cases of distress, a pacemaker sends an electrical impulse to select points in the heart to speed up or coordinate the firing. Historically pacemakers could deliver one pulse rate, but most modern instruments are rate-responsive—they track conduction activity as well as body motion and adjust heart rate accordingly. Doctors can now also implant special pacemakers that stimulate each ventricle directly, resynchronizing ventricles that contract out of phase. This condition often occurs in people whose cardiac muscle has been weakened by a heart attack.

Pacemakers have shrunk to the size of a matchbox, thanks to better electronics and software but also to a reservoir of steroid at the tip of the wire that sparks the heart. By reducing inflammation after implantation, the drug keeps the electrode close to viable heart muscle, thus lowering the voltage the pacemaker must generate and allowing for smaller components. "The steroid has been key," says Toby Markowitz, a Medtronic distinguished scientist who oversees pacemaker research at the Minneapolis company. When batteries fade, usually after six to 10 years, the entire unit (but not the leads) is replaced, because the battery is fused with the case and because pacemaker technology generally improves markedly over that interval.

Since the 1980s a technical spin-off has also gained prominence: the implantable cardioverter defibrillator (ICD). The size of a small pager, it can shock atria or ventricles that are quivering (fibrillating) or racing out of control so the patient's heart can reset itself to normal, preventing the sudden cardiac arrest that kills 450,000 Americans every year. About 80,000 ICDs were implanted in 2003. ICDs can provide pacing, too, and Markowitz says they could one day replace pacemakers if they come down in size and cost—and if insurers, particularly Medicare, approve the switch. —*Mark Fischetti*

ELECTRICAL CONDUCTION triggers each heartbeat. Muscle cells at the sinus node depolarize as the atria fill with blood, setting off a chain of depolarization—an electrical impulse wave—toward the atrioventricular (AV) node. The AV node slows the impulse until the atria fill the ventricles. It then forwards the impulse around the ventricles, prompting them to contract simultaneously. The sinus node adjusts heart rate in response to changes in the oxygen concentration in blood returning from the body; oxygen decreases during physical exertion.



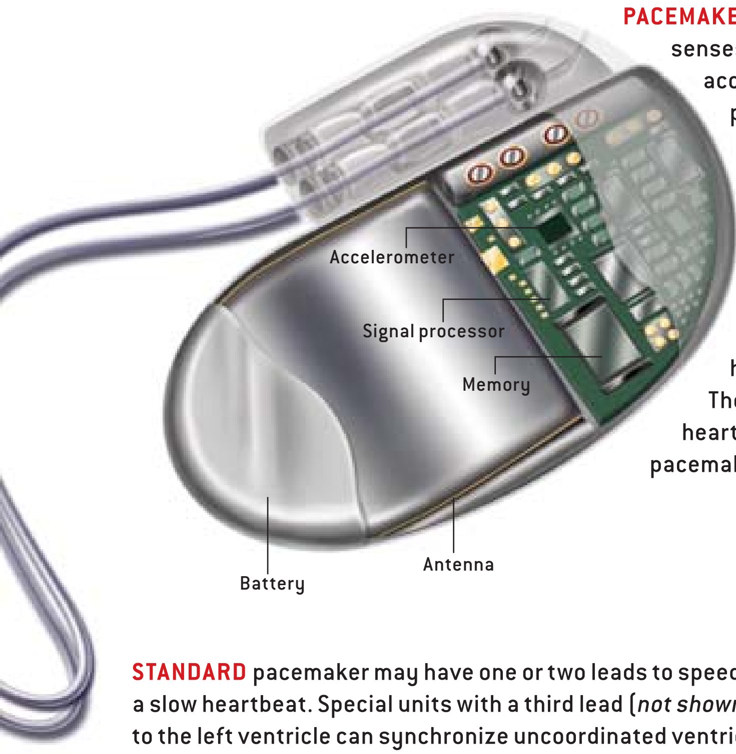
ALICE CHEN

DID YOU KNOW...

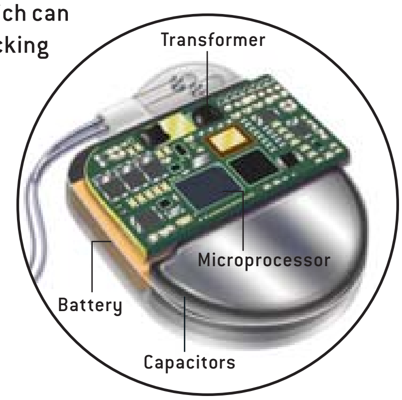
BACKUP: All cardiac cells can beat on their own. Cells in the sinus node beat most quickly, though, and therefore start the contraction impulses that sweep across the heart, establishing a resting pulse of 60 to 100 beats per minute (bpm). If the sinus is damaged, atrium cells will take over the conductor duties but can only set a pace of 40 to 80 bpm. If they fail, AV node cells can muster 30 to 40 bpm—just enough to keep a human alive.

YOU MAKE THE CALL: Patients can check their pacemakers remotely. The patient places wristbands on each arm and holds a magnetic wand against his chest, over the pacemaker. He then places his telephone handset on a transmitter pad connected to the wristbands and wand and calls the doctor, who tests the pacemaker's functions and battery life. New units can send data to a doctor's computer.

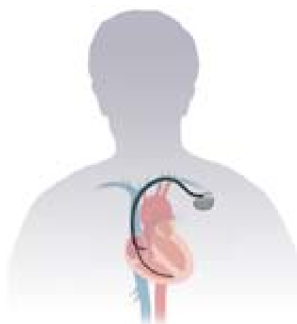
DON'T GO THERE: According to Medtronic, pacemaker wearers need not worry about electromagnetic interference from microwave ovens, electric blankets or airport metal detectors. Antitheft arches by store doorways are fine if patients don't linger next to them. Trouble can arise by getting too close to items that produce strong magnetic fields, such as large stereo speakers and gasoline engines. Cell phones should not be kept in a breast pocket. Magnetic resonance imagers are off limits. Moving away from a source ends the complication; pacemaker damage rarely occurs.



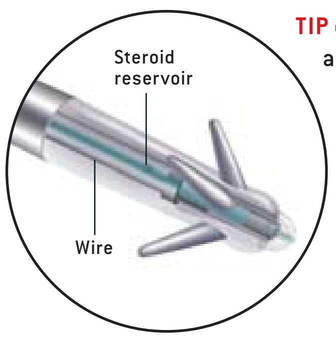
PACEMAKER circuitry emits a 1- to 5-volt impulse if the signal processor senses that the heart's pulse is too slow, stopped or uncoordinated. An accelerometer tells the unit to quicken the heartbeat if it senses physical activity. A technician can retrieve information from the memory using a magnetic wand that communicates through the skin via radio-frequency signals to an antenna. Implantable cardioverter defibrillators (*inset*) correct quivering (fibrillation) by the atria or ventricles, which can cause cardiac arrest, by shocking the heart with 30 joules or more of energy, resetting the heart's conduction system. The unit can also stop a racing heartbeat (tachycardia) and provide pacemaker functions.



STANDARD pacemaker may have one or two leads to speed up a slow heartbeat. Special units with a third lead (*not shown*) to the left ventricle can synchronize uncoordinated ventricle contractions, which plague some people who have weak or damaged hearts.



MAIN CASE of a pacemaker or ICD is implanted in the chest, and leads are threaded through veins to the heart.



TIP of a wire lead is fixed into heart tissue and delivers a small electrical impulse that causes conduction cells to fire. The wire also senses heartbeat, tracked by the pacemaker. A reservoir of steroid is slowly released for several months after implantation, minimizing inflammation and the chance of rejection.

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ORIGINALLY PUBLISHED IN OCTOBER 2004

WORKINGKNOWLEDGE

EARTHQUAKE PROTECTION

Shock Absorbed

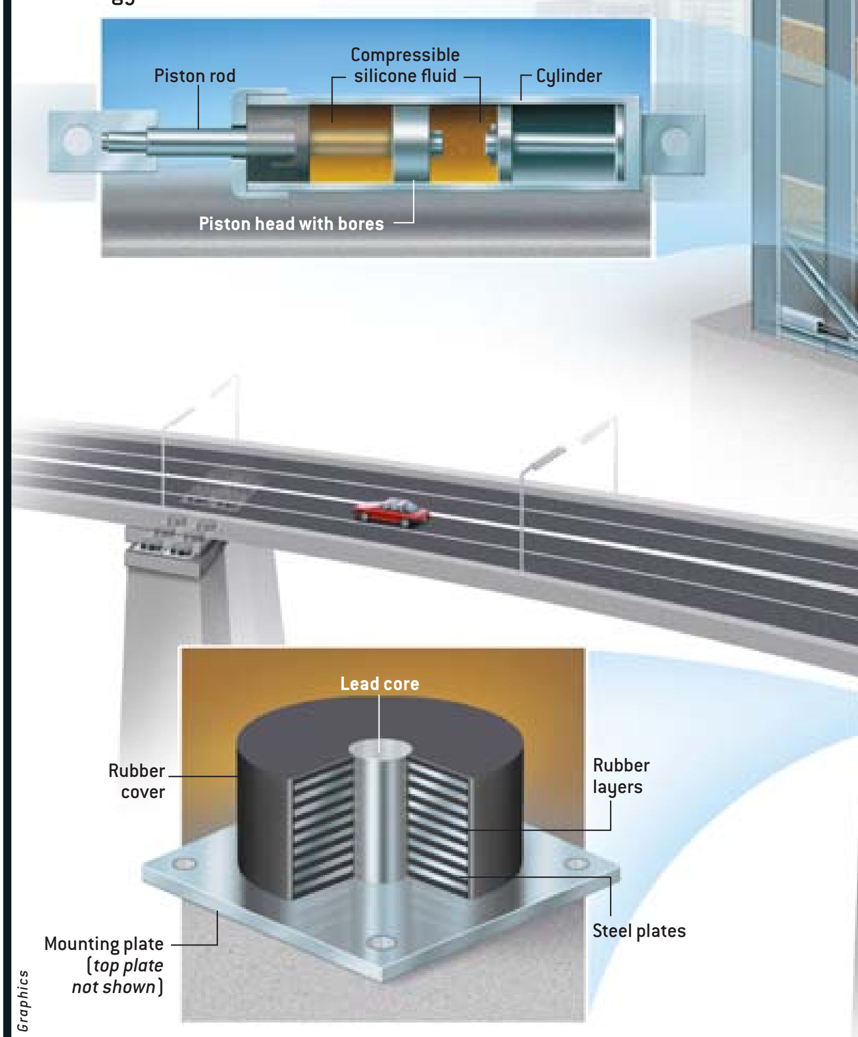
Earthquakes kill thousands of people and cause billions of dollars in damage every year. Reinforced concrete and special trusses have toughened large buildings, but mechanisms that actually reduce the shake from a quake are still relatively new.

Building codes require structures to provide "life safety"—that is, they should not collapse, so people can evacuate. But the real challenge is economic. "We could design a building with conventional techniques that would survive the largest earthquake without damage, but it would be so expensive no one would build it," says André Filiatrault, deputy director of the Multidisciplinary Center for Earthquake Engineering Research at the State University of New York at Buffalo. More and more, building owners are considering the incremental cost to minimize damage to the structure, to its mechanical systems, to the contents inside and, ultimately, to allow for immediate reoccupancy. "In a hospital, for example," Filiatrault says, "the structure accounts for only 10 percent of the total cost. The other 90 percent is equipment, and designing for life safety won't spare it."

The leading techniques "try to absorb a lot of the ground motion energy so the building doesn't have to," says James Malley, senior principal at Degenkolb Engineers in San Francisco. That often means inserting heavy-duty fixtures between the building and its foundation, such as base isolators that act as rubber mats, viscous fluid dampers that operate like shock absorbers, or slide bearings that allow the building to sway instead of snap. Much of the hardware is adapted from military gear for hardening missile silos, ship decks and submarines against bombs and missiles, and it is being rolled out by contractors looking for civilian work, notes Douglas P. Taylor, CEO of Taylor Devices in North Tonawanda, N.Y.

A few researchers are examining novel technologies, such as actuators that would pull on tendonlike beams to counteract ground motion or electrorheological fluids in a foundation that would turn from liquid to gel to filter out shock waves. In the meantime, installations at new sites and retrofits to old ones are booming. Even in California, most buildings are not yet outfitted. —*Mark Fischetti*

VISCOUS FLUID DAMPERS act like a car's shock absorbers, neutralizing ground movement and minimizing displacement between floors so they do not tear apart. A piston head with bores pushes through a silicone oil, dissipating the quake's mechanical energy as heat.



KENT SNODGRASS *Precision Graphics*

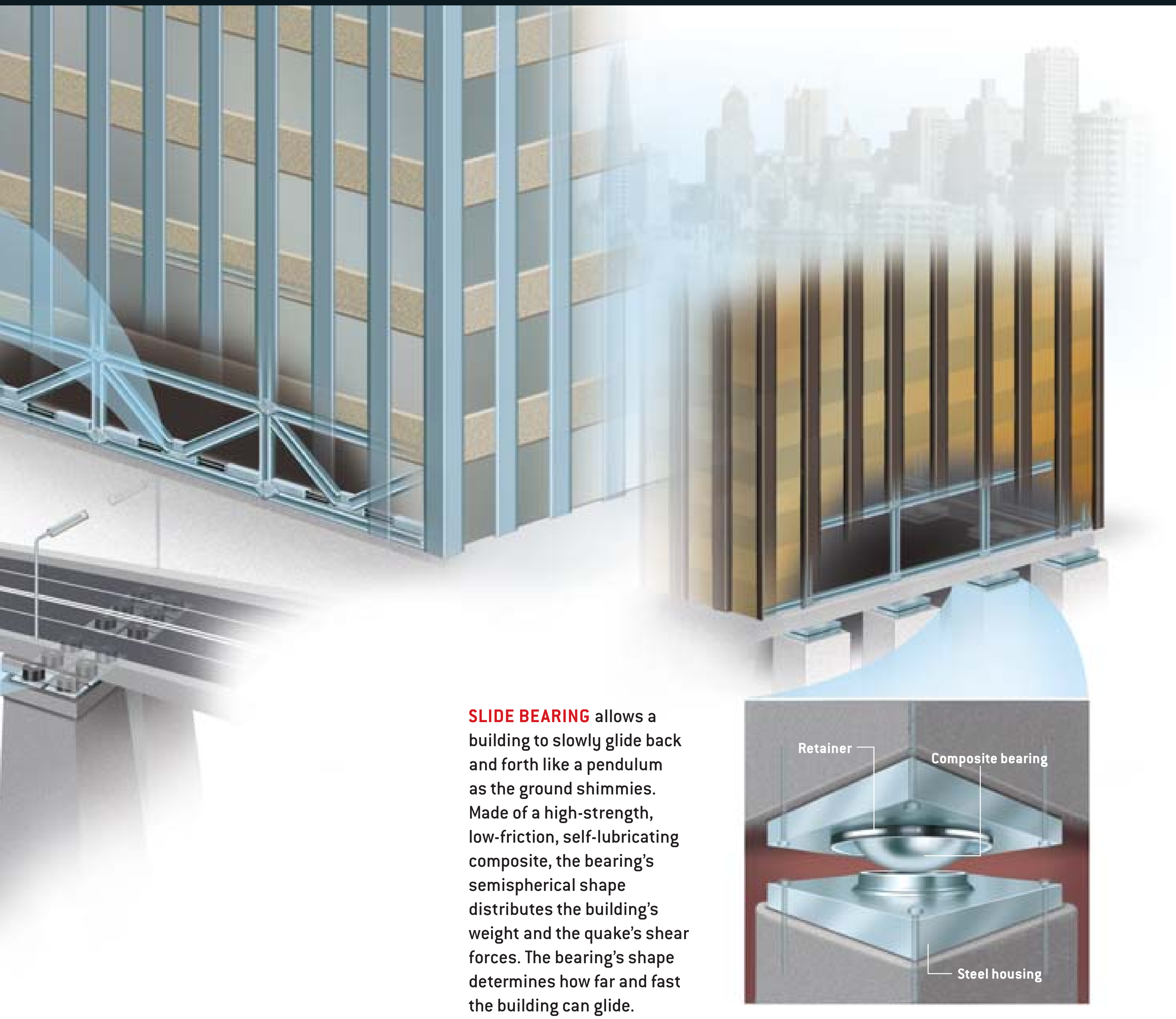
BASE ISOLATORS underneath a bridge pillar, roadway or building column lessen earthquake shear and therefore damage. Rubber layers displace sideways to absorb lateral motion and spring back to return the structure to its original position. Steel layers bonded to the rubber create stiffness that prevents vertical motion. The lead core stops the structure from shifting in the wind.

DID YOU KNOW...

SHARE A SHAKE: In 1999 the National Science Foundation launched the Network for Earthquake Engineering Simulation to research how best to protect structures against earthquakes. The NSF will spend more than $100 million over 15 years at almost 20 university research centers. The centers, which are building gigantic shake tables and wave tanks, will run experiments at one another's facilities over high-speed networks that should be fully operational this fall.

IT TAKES A DISASTER: Work on structural isolation techniques has accelerated sharply because of two disasters. The January 1994 Northridge earthquake near Los Angeles took 60 lives and caused $20 billion in damage. The January 1995 quake in Kobe, Japan, killed more than 5,000 people and crippled more than 50,000 buildings. History repeats: the 1971 San Fernando Valley quake in California prompted codes requiring steel-reinforced concrete in buildings.

ILL WIND: Even light skyscrapers can withstand strong winds. Still, they may sway at a frequency that can make occupants feel seasick. Builders can cancel the movement by installing huge roof tanks with water that swishes to counter the motion (and is available to quench fires). Alternatively, slide bearings [*see illustration*] can support the roof, allowing it to rock back and forth. This technique can also isolate the heavy mass during a quake, lessening stress on vertical columns.



SLIDE BEARING allows a building to slowly glide back and forth like a pendulum as the ground shimmies. Made of a high-strength, low-friction, self-lubricating composite, the bearing's semispherical shape distributes the building's weight and the quake's shear forces. The bearing's shape determines how far and fast the building can glide.

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WORKINGKNOWLEDGE

LASER EYE SURGERY

Clear Favorite

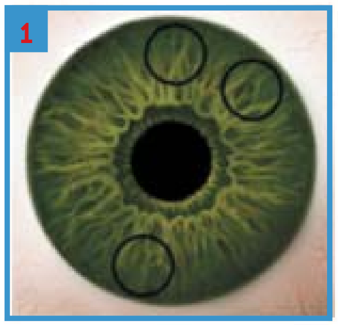
Since excimer laser eye surgery was approved by the U.S. Food and Drug Administration in 1995, it has soared in popularity. Last year more than 1.5 million nearsighted, farsighted or astigmatic people underwent the procedure to eliminate the need to wear eyeglasses or contact lenses.

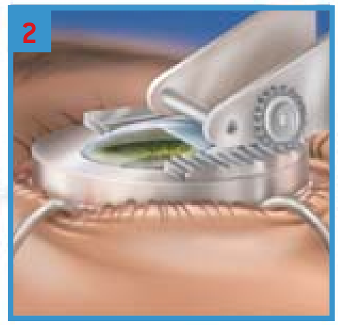
Several laser-correction schemes exist, but laser-assisted in situ keratomileusis (Lasik) is by far the frontrunner. The procedure reshapes the cornea by vaporizing cells so that light focuses onto the retina properly. Up to 8 percent of patients develop minor complications, among them poorer night vision and visual distractions such as glare or halos, which may disappear after a few months or can be improved with a second treatment. Less than 1 percent develop severe conditions such as infection or scarring.

Fully corrected vision may not last forever, though. Ophthalmologists have only 10 years of data. Most of the early patients "appear to retain their full correction, but a few began to regress after eight or five or even three years," says Douglas D. Koch, an ophthalmology professor at the Baylor College of Medicine. Regression is usually mild and caused by natural changes in the eye. In most cases, a laser fix can be repeated, but each surgery thins the cornea, which should not be trimmed to less than 250 microns. Any thinner, Koch says, and the cornea may develop an irregular curvature because it cannot support itself.

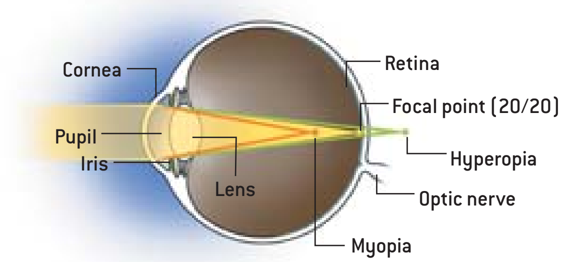
Competition has pushed prices down to $1,000 per eye. Cheaper discount providers have sprung up, but ophthalmology associations worry that patients might be misled or receive poor care. (The FDA offers advice at www.fda.gov/cdrh/lasik) Other procedures include photorefractive keratectomy (PRK) and laser epithelial keratomileusis (Lasek), which avoid certain Lasik side effects such as dry eyes but may involve more initial discomfort and recuperation time.

The latest advance is wavefront-guided Lasik. It allows a surgeon to ablate specific points on each person's eye instead of implementing a generalized fix, as is done with standard Lasik. Wavefront technology has been shown to provide better vision than regular Lasik, but it can increase the cost by $400 or more for each eye treated. *—Mark Fischetti*





LASIK SURGERY begins with anesthetic drops that numb the eye. A surgeon then places registration marks on the cornea (*1*). A suction ring immobilizes and pressurizes the eye so it can be cut cleanly by a motorized blade (*2*) that slices into the cornea, creating a flap about eight millimeters in diameter and 0.15 millimeter thick. (In a new procedure, a laser makes the cut.) The flap is pulled back, exposing the stroma. A laser vaporizes cells to a certain depth (*3*), reshaping the cornea in 60 seconds or less. The laser emits pulses of 193-nanometer ultraviolet light to ablate cells to an accuracy of 0.25 micron. The surgeon repositions the flap (*4*), which rebonds naturally.



CLEAR VISION occurs when the cornea focuses light rays exactly on the retina. In myopia (nearsightedness), the cornea is too steep or the eyeball is too long; although diverging rays coming from close objects converge at the retina, parallel rays from distant objects convene too early. Vaporizing the center of the cornea to flatten it fixes the problem. In hyperopia (farsightedness), the cornea is too flat or the eyeball is too short; parallel rays from distant objects focus behind the retina, and diverging rays from near objects are even farther behind. Vaporizing a ring of cells gives the cornea the needed, steeper slope.

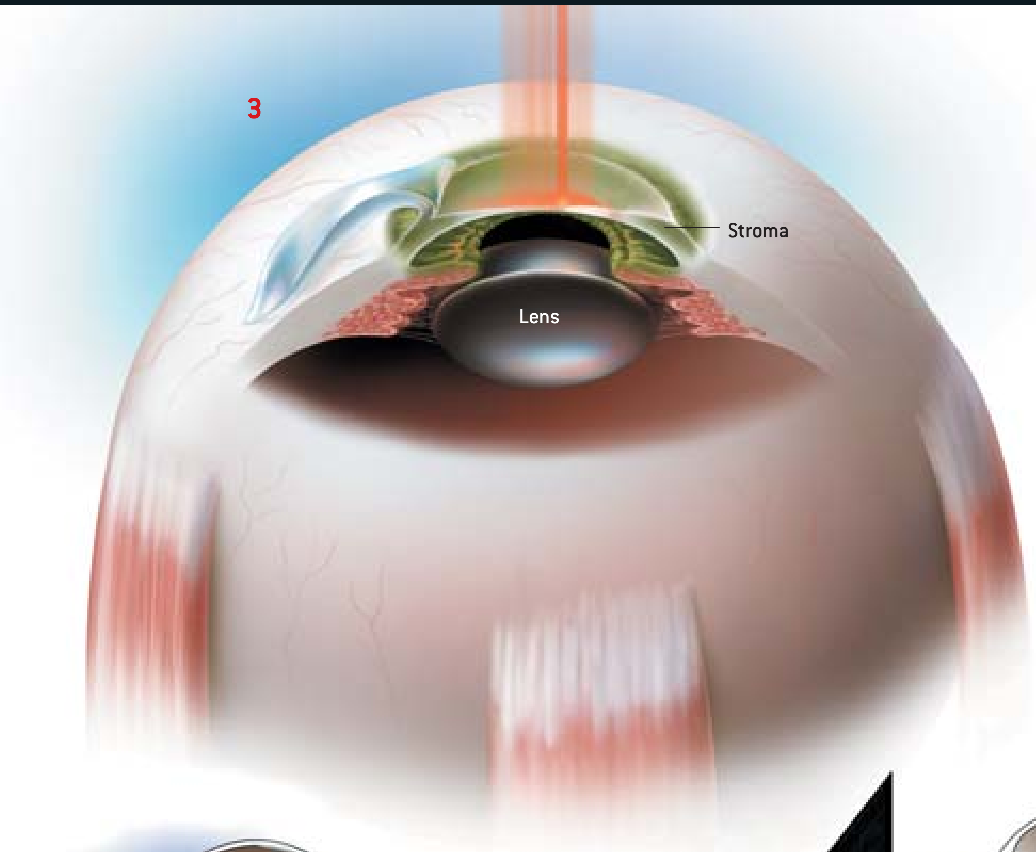
CONNIE FUNKHOUSER BALEK *Precision Graphics*

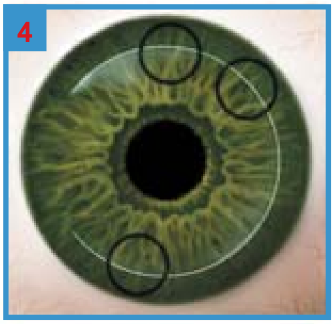
DID YOU KNOW...

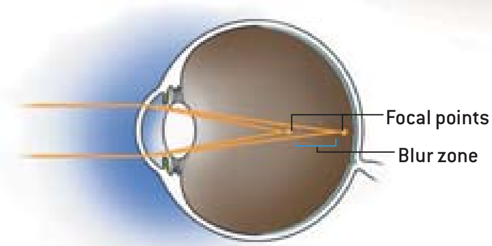
BETTER ONE: Eye doctors determine prescriptions with the subjective, decades-old process of sliding different glass lenses in front of a patient's eyes and asking if a chart of letters looks "better with lens one or better with lens two." Laser wavefront sensors approved to guide Lasik surgery are being adapted for more objective measurement. They sample numerous points on the eye, leading to diagnoses that are 50 times as accurate.

SUPER-VISION: Good vision is labeled 20/20—a person sees objects 20 feet away as they should appear (at 20/40, the person must stand at 20 feet to see what normal eyes see at 40 feet). But the density of light-sensing cones in the retina would allow 20/8 vision (more than twice as sharp) if every cornea aberration could be eliminated. Advanced wavefront-guided lasers recently approved could approach that goal. "They are finding distortions we didn't know existed," says Daniel Durrie, director of refractive surgery at Durrie Vision in Overland Park, Kan., "and they can tell surgical lasers how to correct them." Super-vision might be possible—unless the procedure creates unforeseen distractions such as distorted color perception.

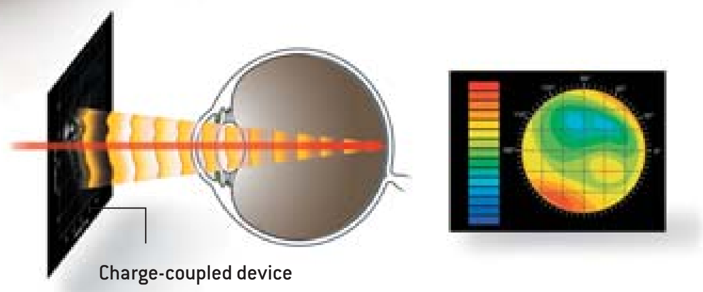
HELLO, READING GLASSES: Tiny muscles push and pull the eye's crystalline lens to bring objects into focus. As people age, the lens loses elasticity, making it difficult to zoom in on small objects close at hand. By age 45 virtually everyone has this degradation, which stabilizes in another 10 to 20 years when the lens simply loses all flex. The condition is called presbyopia—"old eye." It cannot be prevented.







ASTIGMATISM (blurry vision) results when the cornea has uneven regions of curvature, which focus rays at multiple points. Smoothing the surface helps to bend rays uniformly.



WAVEFRONT-GUIDED Lasik surgery bounces a laser beam off the retina and senses the reflections on a charge-coupled device. Software maps the distorted rays caused by ocular aberrations (*such as blue region, right*) as small as 0.05 micron and directs the laser to vaporize specific points on the stroma to compensate for each error. In regular Lasik, the surgeon measures the cornea with traditional instruments and the laser ablates a standard, symmetric region to provide a good but generalized correction.

Have an idea for a topic?
Send it to workingknowledge@sciam.com

ORIGINALLY PUBLISHED IN NOVEMBER 2003

WORKINGKNOWLEDGE

NAILS AND STAPLES

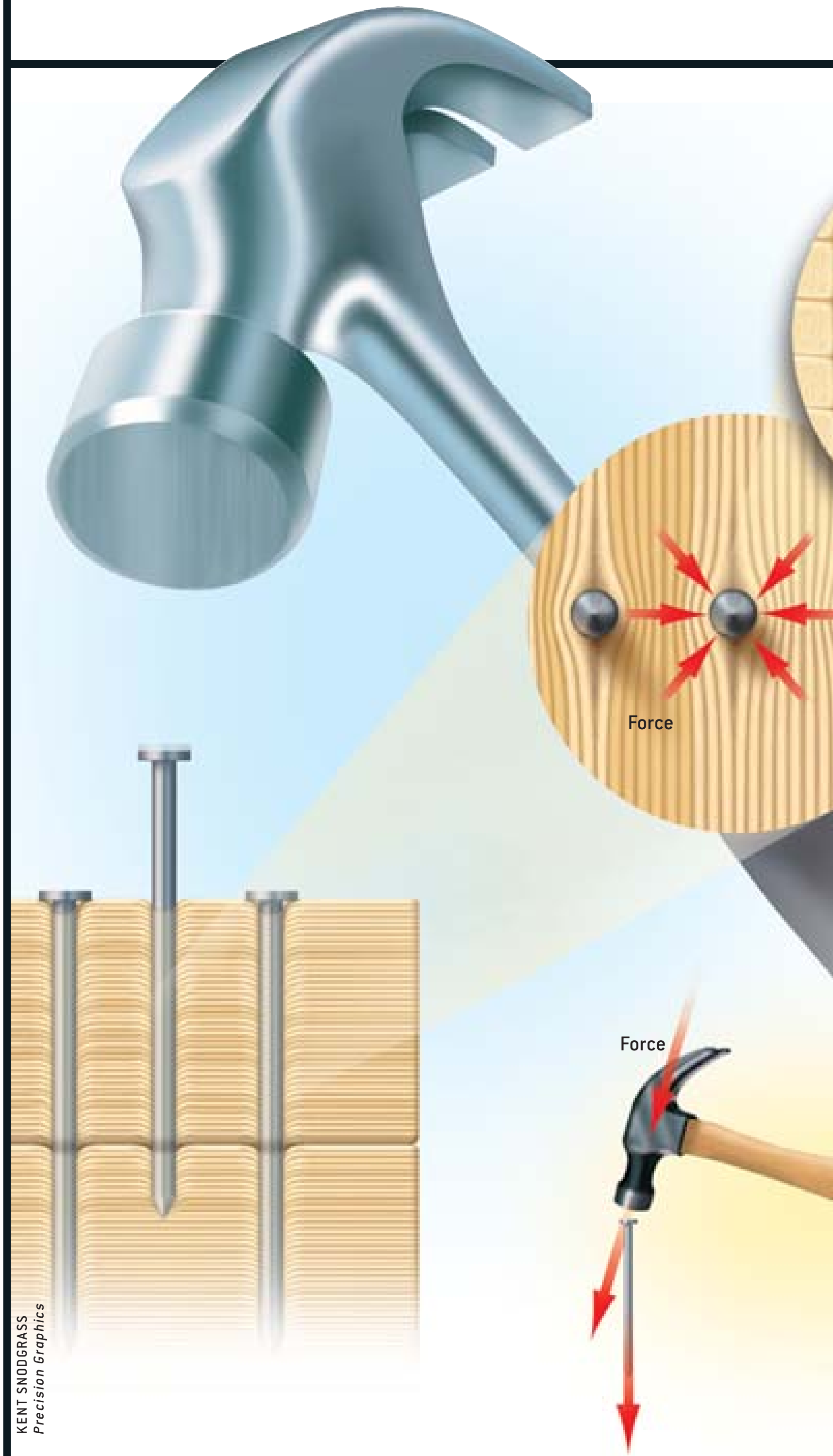
Staying Power

People have pondered the power of nails since the Roman days. But only in the past 100 years have nails come into widespread use in homes and furniture. For centuries, blacksmiths made nails one at a time, at considerable expense, by drawing a short rod of red-hot iron, hammering one end to a point and pounding the other end to a head. By the late 1700s nailsmiths had devised hand-operated machines that could cut nails from flat iron sheets. By the 1880s steam-powered machines sped up the process and "cut nails" became less expensive; however, their strength was still variable.

That changed in the early 1900s, when steel became both flexible and very strong. Machines cut nails and formed the tip and head in one step from a long spool of steel wire. That process allows manufacturers to craft many types of nail points and shanks that improve performance.

Simple friction against a nail shank [*see illustrations at right*] holds two pieces of wood together and prevents the nail from loosening as vibrations and changes in temperature and humidity expand and contract the wood's fibers. The same manufacturing techniques and holding traits apply to staples, which are essentially two nails joined by a crossbar. To help a nail stay put, manufacturers may etch micropits into what appears to be a smooth shank or add rings or barbs, all to better grip the fibers. Certain coatings, such as resin, may increase friction, too, although others may not. "Different manufacturers make different claims, but little scientific research has been done on coatings," says Ron Wolfe, a research engineer at the U.S. Forest Products Laboratory in Madison, Wis., which tests the properties of nails.

Most people take nails for granted, but their simple yet powerful physics make them vital tools. English poet George Herbert reminded his contemporaries of their worth in his early 1600s work *Jacula Prudentum* (first three lines that follow), extended by other, unknown enthusiasts (final two lines): "For want of a nail the shoe is lost/For want of a shoe the horse is lost/For want of a horse the rider is lost/For want of a rider the battle is lost/For want of a battle the kingdom is lost." —*Mark Fischetti*



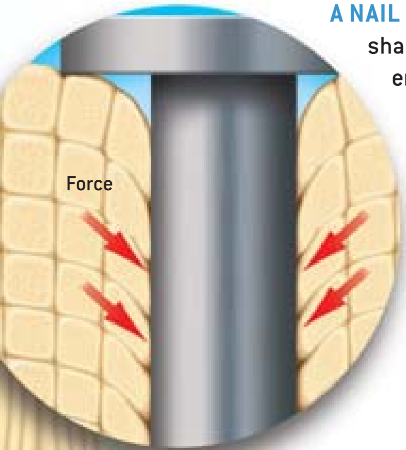
KENT SNODGRASS *Precision Graphics*

DID YOU KNOW...

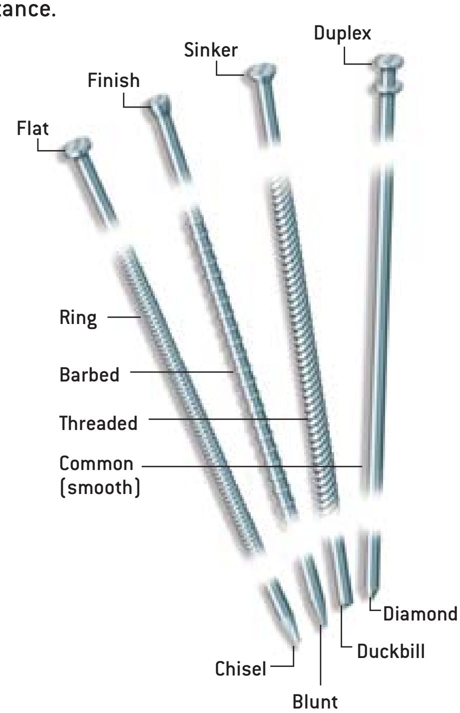
4D, 8D, 12D: Centuries ago nails were expensive, handmade by blacksmiths. Carpenters could buy 100 one-inch nails for two pennies, or pence, abbreviated as "d." One hundred three-inch nails cost 10d. In time, the cost per 100 came to represent a common nail's size, from 2d to 60d (six inches). The standard persists in nonmetric countries today. Nails shorter than 2d are called brads, longer than 60d are spikes, and both extremes are measured only in inches.

NOT CREATED EQUAL: Could Brand X's 10d nail be better than Brand Y's? Yes. The steel in nails is highly variable, and the industry has shown little interest in standards related to stiffness of the steel. Michael O'Connor, president of Pacific Steel & Supply in San Leandro, Calif., explains that wholesalers order nails from mills according to the degree of carbon content in the steel—more carbon means greater tensile strength but higher cost. Virtually no hand-driven nails (as opposed to those for power nailers) are made in the U.S. any longer; most come from Asian mills.

CORROSION: Rainwater will rust steel nail heads, which can stain a house's siding and shingles, so stainless-steel, aluminum or galvanized nails should be used. The so-called pressure-treated wood popular for decks resists rot because it is treated with ammoniacal copper arsenate or chromated copper arsenate. These chemicals corrode steel and zinc; copper, bronze and stainless-steel nails hold up



A NAIL TIP BENDS wood cells in the direction of the incoming shank as it penetrates. Removing the nail requires enough force to break cells against the bend. A longer or thicker nail provides more surface area and therefore withdrawal resistance.



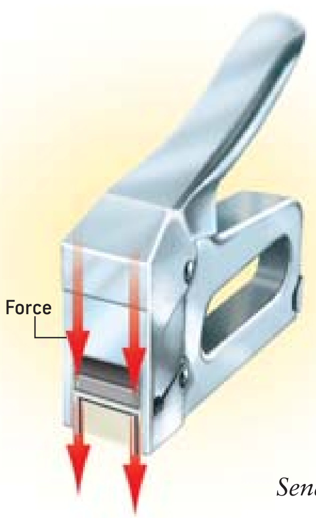
FLAT HEADS add some clamping power and ease hammering. Finish and sinker heads can be recessed and covered to improve aesthetics; scaffolding can be held on duplex heads.

RINGED, BARBED OR THREADED SHANKS are less likely than common (smooth) shanks to gradually back out, because the deformations mechanically hook into wood fibers.

A NAIL SPREADS wood's dense fibers, causing them to compress and therefore push back, holding the nail in place with considerable friction. A longer or thicker nail creates more compression and thus holding power.

SHARP POINTS SPREAD wood fibers cleanly, so all can push back to maximize holding power, but they are more likely to split wood. Blunt tips crush fibers, which reduces splitting but lessens the number of fibers that push back. A diamond point offers a compromise.

NAILS WOULD RARELY BEND if humans could hammer a nail in parallel with its shank every time, but even a few degrees off line creates sideways force that can buckle the steel. Nail guns have guide rails that align the plunger and shank to prevent buckling.



A STAPLE BENDS with the gentle pushing of a finger. But when struck hard with the plunger of a stapler it will not, because rails keep the force in line with the legs, and channels prevent the legs from buckling.

Nicholas William suggested this month's topic. Send your ideas to workingknowledge@sciam.com

WORKINGKNOWLEDGE

BILL VALIDATORS

On the Money

If you have ever stepped up to a vending machine, arcade game or slot machine and inserted a $1, $5, $10 or $20 bill, your money has been scrutinized by a "bill validator." Relatively unchanged since they were first tested in the late 1960s for $1 bills, in the past few years these chunky sensors have gone high tech.

For decades, bill validators simply had a magnetic head—similar to a tape recorder's—that brushed up against the lengthwise center of a bill, drawn by rollers. Magnetic ink in one of the note's seals, and in the middle of the portrait, created characteristic signatures that circuitry compared against a table of reference values to determine the bill's denomination and authenticity. But the magnetic head got grimy as ink flaked off, requiring frequent servicing, and counterfeiters could sometimes fool the machinery with "bills" duplicated on copy machines that used magnetic toner.

Today's validators use optical, inductive and dielectric sensors that assess all kinds of traits. Much harder to fool, they are cropping up at self-checkout counters in stores and in automatic teller machines (ATMs) that accept cash as deposits.

Whenever the U.S. Treasury changed a bill design, however, makers of validators had to scramble to install new integrated circuit chips in hundreds of thousands of machines. In 1998 the treasury made things easier when it decided to introduce a new generation of $5 and $10 notes. "The government for the first time gave the validator industry samples six months in advance so we could reprogram our machines," says Marlon Silver, technical service manager at CashCode in Concord, Ontario, one of the largest of the world's 15 or so suppliers. The newest validators have a port for a flash-memory stick that a technician can insert to update the circuitry, instead of installing a new chip.

This autumn the treasury plans to introduce a new $20 that has a subtle background color. "We have the bills," Silver notes, "but we still don't have a release date." There are now more than 2.5 million vending machines in North America and millions more slot machines. "If we're given short notice to update the validators," Silver says "it'll be a war out there."

BILL VALIDATOR spins its rollers when a note's leading edge interrupts an activator beam. As the bill heads through the validator, optical sensors go to work. They each contain light-emitting diodes that shine different wavelengths of infrared and visible light and one phototransistor (receiver); they sense the reflectivity, transmittance and fluorescence of various spots on the bill to read its denomination and the position and colors of the seals, portrait and security threads.

CURRENCY has features unique to each denomination that a bill validator can verify, among them a seal printed with colored ink, a black seal and portrait printed in part with magnetic ink, security threads that absorb specific wavelengths of light, coatings that filter light (*not shown*), and a watermark that alters the paper density .

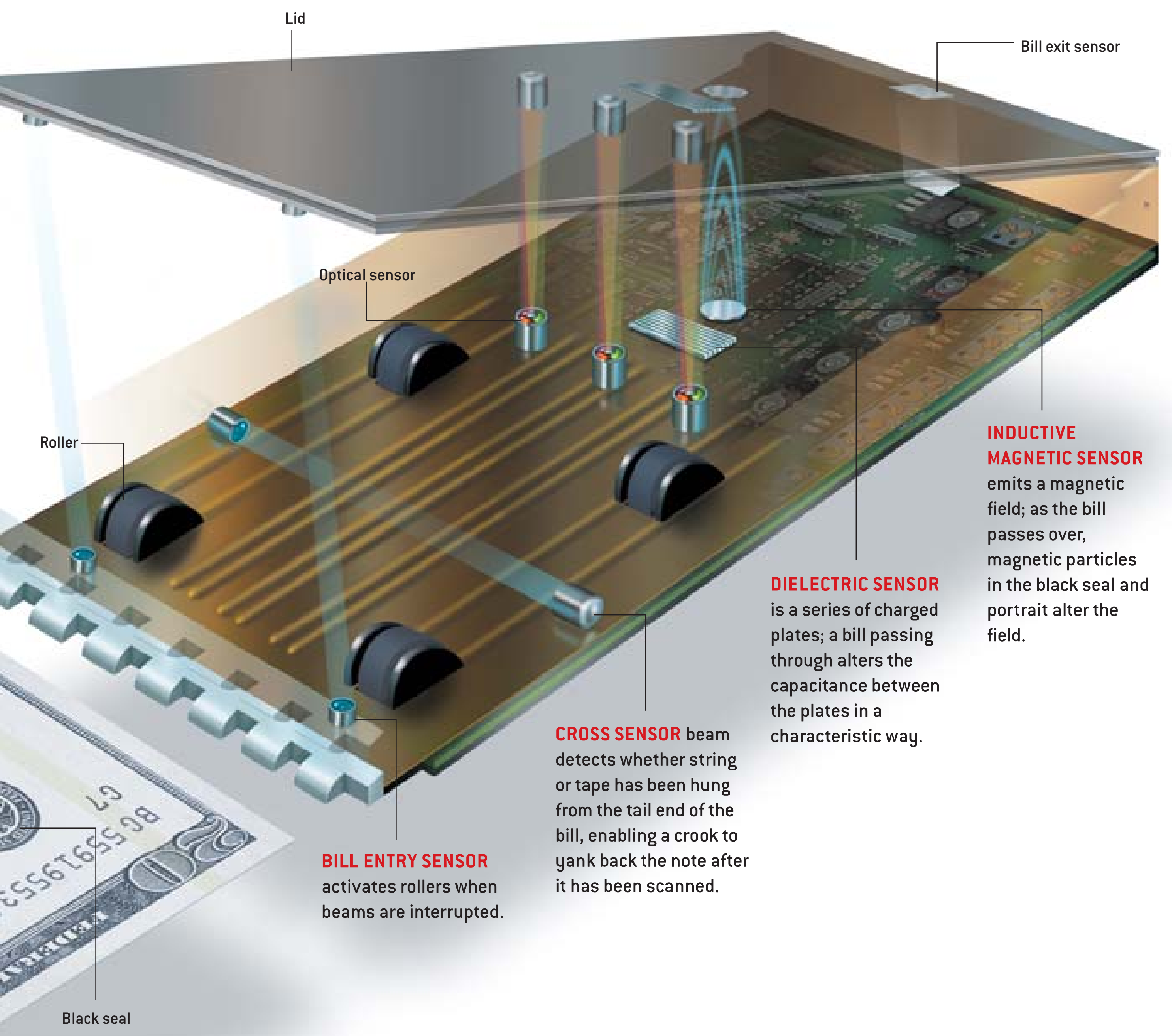
KENT SNODGRASS *Precision Graphics*

DID YOU KNOW...

▯ REJECTED: You feed a nice dollar into a vending machine, but the blasted machine spits it back at you. Why? Three leading reasons: Repeated folding across the portrait can break up the magnetic ink, presenting an invalid magnetic signature to sensors. Holding the money too long as you insert it can disrupt the smooth intake speed the validator needs to move the bill accurately over sensors. And if the bill's corners are bent, they can jam the rollers, so the validator gives it back.

▯ LAUNDERING: When programming chips or flash-memory sticks that will update validators for new bill designs, employees at manufacturers artificially age sample greenbacks by manually passing them around, wrinkling them and running them through a washing machine. "Still," says Marlon Silver at CashCode, "they're just not the same as street money." Once bills are in circulation, technicians may need to further update machines to improve the acceptance rate of worn currency.

▯ WIDE WORLD OF MONEY: Many countries issue notes of various widths for different denominations. To handle these variations, some machines have an elliptical wheel just inside the mouth of validators that props the bill above the rollers for a moment. As the bill floats back down, side rails quickly veer in to center it over sensors, then retract out of the way.



INDUCTIVE MAGNETIC SENSOR emits a magnetic field; as the bill passes over, magnetic particles in the black seal and portrait alter the field.

DIELECTRIC SENSOR is a series of charged plates; a bill passing through alters the capacitance between the plates in a characteristic way.

CROSS SENSOR beam detects whether string or tape has been hung from the tail end of the bill, enabling a crook to yank back the note after it has been scanned.

BILL ENTRY SENSOR activates rollers when beams are interrupted.

This month's topic was suggested by reader Tim Silverstein. Send your ideas to workingknowledge@sciam.com

ORIGINALLY PUBLISHED IN JUNE 2003

COCHLEAR IMPLANTS

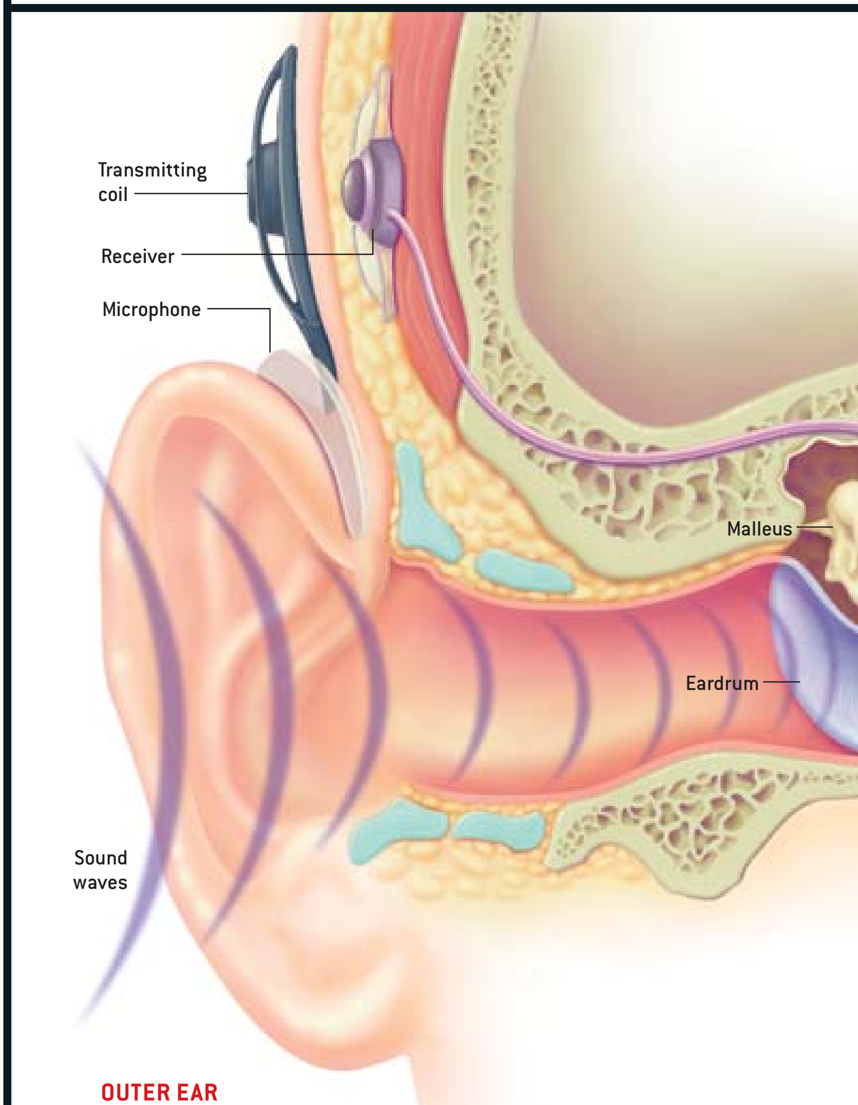
To Hear Again

We hear when the cochlea, in the inner ear, stimulates the auditory nerve. Deafness occurs most commonly when tiny hair cells inside the cochlea are damaged as a result of a genetic defect, infection, loud noise or aging. Cochlear implants bypass the damage by receiving and converting sound into signals sent along electrodes to cells adjacent to the auditory nerve.

Worldwide, more than 40,000 children and adults depend on cochlear implants. Certain hair cells lining the cochlear ducts alongside auditory neurons are tuned to respond to specific frequencies. Therefore, implants such as the Nucleus or the Clarion have from eight to 22 electrodes that surgeons place at different positions to maximize the range of frequency stimuli forwarded to the brain. Recent research indicates that more electrodes won't improve performance as much as optimizing their placement; most implant wearers perceive loudness properly but can still have trouble sensing pitch correctly, making speech comprehension difficult. "Something is preventing the brain from extracting or assimilating all the coding information," says Philip Loizou, a professor of electrical engineering at the University of Texas at Dallas. "We don't know what yet."

The sooner a person receives an implant after becoming deaf, the more likely he will adapt to the new sound input; people who have been deaf for years do not respond as well because of degeneration in the cochlea or auditory nerve. Typically, success means the wearer can hear moderate and perhaps soft sounds, can communicate without lip reading or signing, and may be able to converse over the telephone. Completely normal hearing is still uncommon.

To help, engineers are trying, among other things, to tailor signal-processing algorithms for particular situations. People with implants often have trouble perceiving speech clearly in noisy environments and appreciating music, which has complex waveforms. Today's implant processors come with a general algorithm, but perhaps they could store specialized ones as well. "That way," Loizou says, "an individual could select an algorithm depending on whether he was talking at home, eating in a noisy restaurant or sitting at a concert." *—Mark Fischetti*



OUTER EAR collects the pressure waves of a sound, which the eardrum converts into mechanical vibrations in tiny bones in the middle ear. The oscillating stapes sets off pressure waves within the fluid in the cochlea, which in turn stimulate nerve cells on the auditory nerve that leads to the brain.

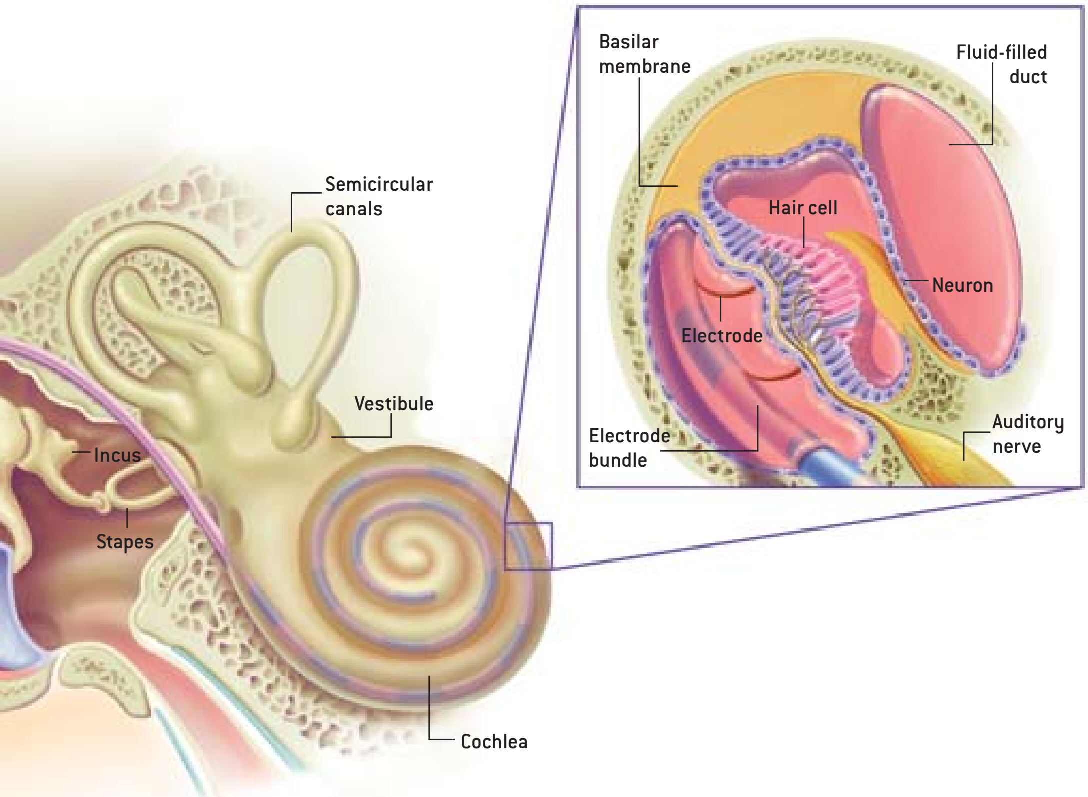
ALICE Y. CHEN

DID YOU KNOW...

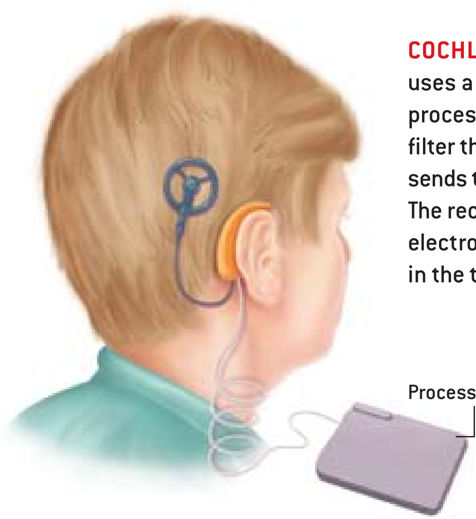
LOUD! Audiologists measure how loud a test signal must become before a person can hear it. The normal threshold is anything up to 15 decibels. People who have "moderate" hearing loss require a signal of 41 to 55 dB; "severe" loss, 71 to 90 dB; and "profound" loss, 91 dB or greater. Typical conversation rings in at 40 to 50 dB; freeway traffic at 50 feet, 70 dB; and a blender, 90 dB. Only people with severe or profound loss in both ears qualify for cochlear implants.

HAIRPIN TURN: Tipping the head forward, back or to the side tilts a gelatinous substance inside the vestibule, beside the cochlea. The shifting gel bends hair cells that tell attached nerve fibers which way the head is headed, so the brain can keep the body upright. Similarly, hair cells inside three fluid-filled semicircular canals, at right angles to one another just above the cochlea, respond to sudden changes in the head's velocity, to maintain balance.

HARD ON HEARING: In its "Position Statement on Cochlear Implants," the U.S. National Association of the Deaf notes that the technology doesn't always work. It also discourages the use of implants in children who are born deaf or become deaf before learning language, because even with the technology, it is very hard for them to develop the cognition for spoken language. Meanwhile the children are often not taught visual, or sign, languages, which "can result in developmental delays that can be extremely difficult to reverse."



COCHLEA
transmits pressure waves through its duct fluid, displacing the basilar membrane, which bends hair cells to various degrees. The cells release neurotransmitters that cause attached neurons to fire, telling the brain where along the duct the bending has occurred (which corresponds to the frequency of the original sound) as well as the amplitude of the bending (which indicates the loudness).



COCHLEAR IMPLANT
uses a microphone worn behind the ear to pick up sound and send it to a processor, where integrated circuits and algorithms amplify, digitize and filter the sound into a coded signal sent to the transmitter coil. The coil sends the signal via radio waves through the skin to an implanted receiver. The receiver converts the waves into electrical impulses that travel along electrodes that end at cells at certain points along the cochlea. A magnet in the transmitter holds it against the implanted receiver.

This month's column was suggested by reader Thomas Boehm.
-Have a topic for a future column? Send it to workingknowledge@sciam.com

WORKINGKNOWLEDGE

TRANSDERMAL DRUG DELIVERY

Potent Patches

Swallowing a pill is simple. Yet people still forget to take their medication, and drug levels in the bloodstream surge and sink with each dose. Medicated patches that stick to the skin prevent such problems.

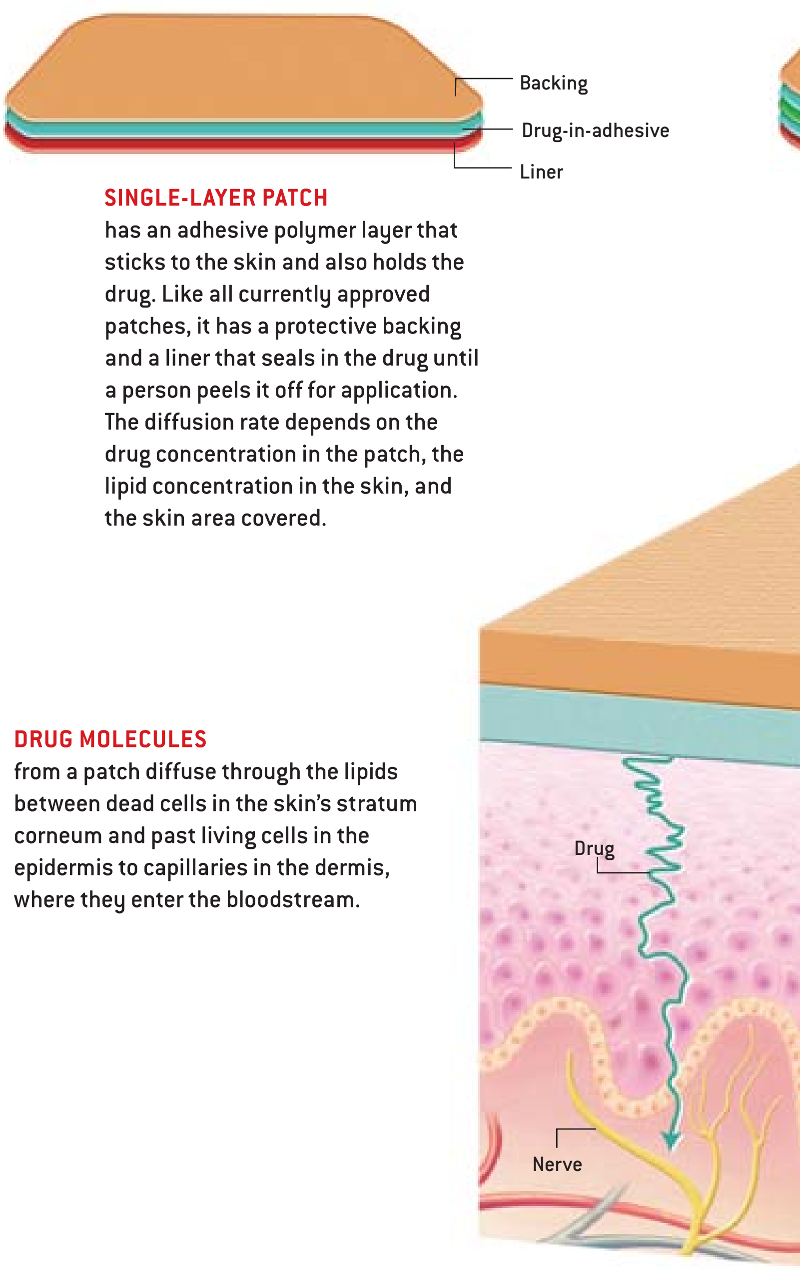
"The patch" became popular around 1990, as smokers used it to kick the habit. A series of patches worn over several weeks' time supplied decreasing amounts of nicotine, gradually weaning people from their addiction. Today transdermal patches deliver estrogen for hormone replacement therapy, nitroglycerin for angina, scopolamine for motion sickness and seasickness, fentanyl for pain control, clonidine for hypertension and, recently, ethinylestradiol plus norelgestromin for contraception.

In most cases the patch is saturated with the drug, which steadily diffuses through microscopic gaps between skin cells and through the skin's pores. The trick is designing the appropriate polymer adhesive that will retain a given drug molecule yet also allow it to diffuse, a delicate balancing act, notes Sharon Grosh of 3M Drug Delivery Systems.

The skin's outer layer of dead cells—the stratum corneum—is a good barrier, so it controls the diffusion rate. Drug molecules must be small enough to sneak between the cells and must dissolve in the oily lipids there, so they can reach capillaries deeper in the skin. Furthermore, the stratum corneum varies in thickness and porosity from person to person, so it is advantageous if a drug has a big therapeutic window—not too toxic at a high concentration yet still potent at a low one, says Mark R. Prausnitz of the Georgia Institute of Technology. Because of these vagaries, only a handful of drugs are effective in patch form.

Researchers are trying to modify the passive patch with active drivers that force molecules that are larger or water-soluble, or both—such as insulin and vaccines—through the skin. Electric current from a tiny battery within the patch could widen cell gaps and push ionized drug molecules through them. Or an array of hollow microneedles on the patch could provide microscopic funnels through the skin. The active designs are costlier and bulkier than passive patches, but several are already in advanced clinical trials.

—Mark Fischetti



SINGLE-LAYER PATCH has an adhesive polymer layer that sticks to the skin and also holds the drug. Like all currently approved patches, it has a protective backing and a liner that seals in the drug until a person peels it off for application. The diffusion rate depends on the drug concentration in the patch, the lipid concentration in the skin, and the skin area covered.

DRUG MOLECULES from a patch diffuse through the lipids between dead cells in the skin's stratum corneum and past living cells in the epidermis to capillaries in the dermis, where they enter the bloodstream.

ALICE Y. CHEN

DID YOU KNOW...

- THROW IT AWAY: A patch lasts only so many hours or days before its drug delivery falls below an effective threshold. The patch must then be removed, but it still contains medication. Users must therefore be certain that children or pets don't accidently ingest the patch, which could be toxic or even fatal.

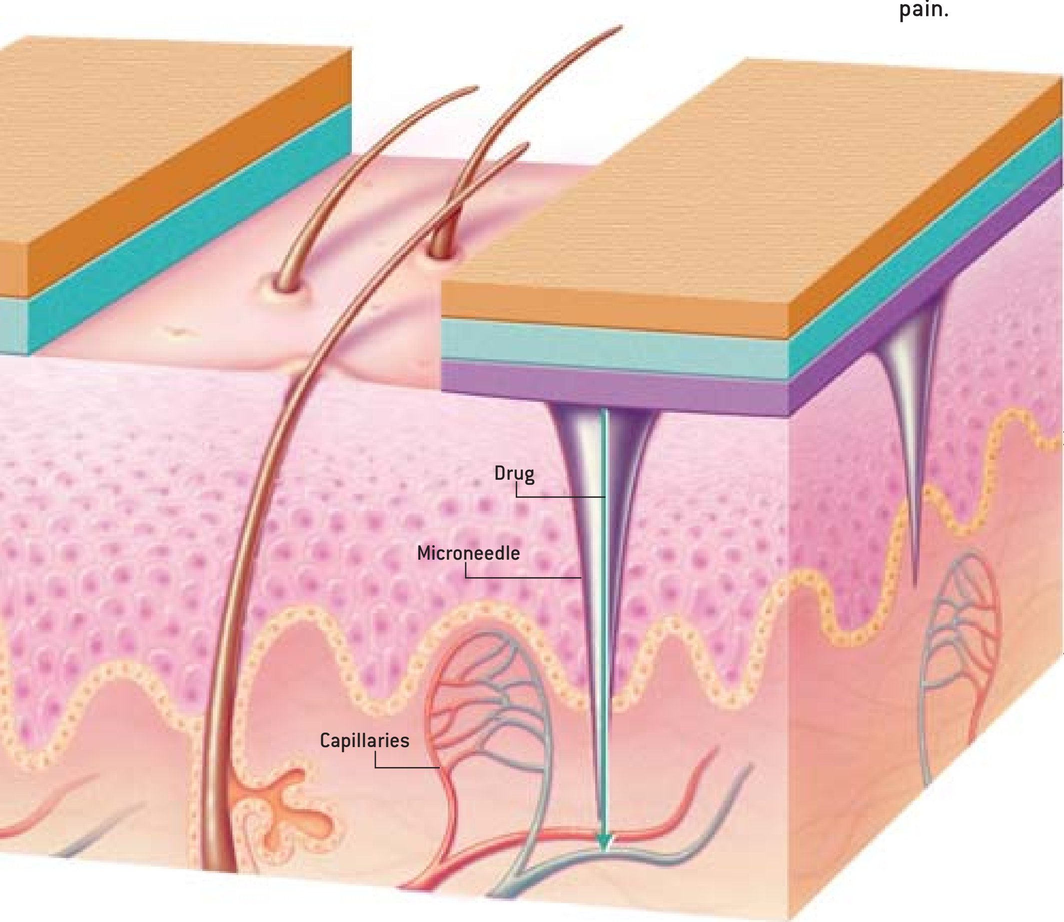
- MAX VACCINE: Certain vaccines—including those for HIV and influenza—may elicit a strong immune response in Langerhans immune cells in the epidermis. But hypodermic needles and pills miss this target, sending vaccine to the bloodstream. If patches can be developed to handle vaccine molecules, which are large, they could bathe Langerhans cells, maximizing the vaccines' effectiveness.

- THICK-SKINNED: The stratum corneum is thickest on the palms and soles; it is thinnest behind the ear, in the armpit and on the scalp. The region behind the ear is also rich with blood vessels, so it is an excellent place for a patch, although only small designs will fit there. The armpit and scalp are generally unsuitable because hair interferes. Most patches end up on the arm, inner thigh, lower back or chest, where they can remain hidden and are unlikely to be rubbed off.

- NO PAIN? The microneedles on experimental patches don't hurt, yet developers are worried that the name will scare away customers. Their synonyms—microprojections, microblades—sound no better. A euphemism is sure to be found once trials are completed.

MULTILAYER PATCH has a membrane that controls the delivery rate of drugs, especially those that would otherwise diffuse too quickly into the skin.

MICRONEEDLE PATCH retains drugs in a liquid or polymer reservoir. Hollow, micromachined needles penetrate the top edge of the dermis—deep enough to bring drugs to capillaries but not so deep that they touch nerve endings, causing pain.



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ORIGINALLY PUBLISHED IN NOVEMBER 2001

WORKINGKNOWLEDGE

GROUND FAULT CIRCUIT INTERRUPTERS

Current Safety

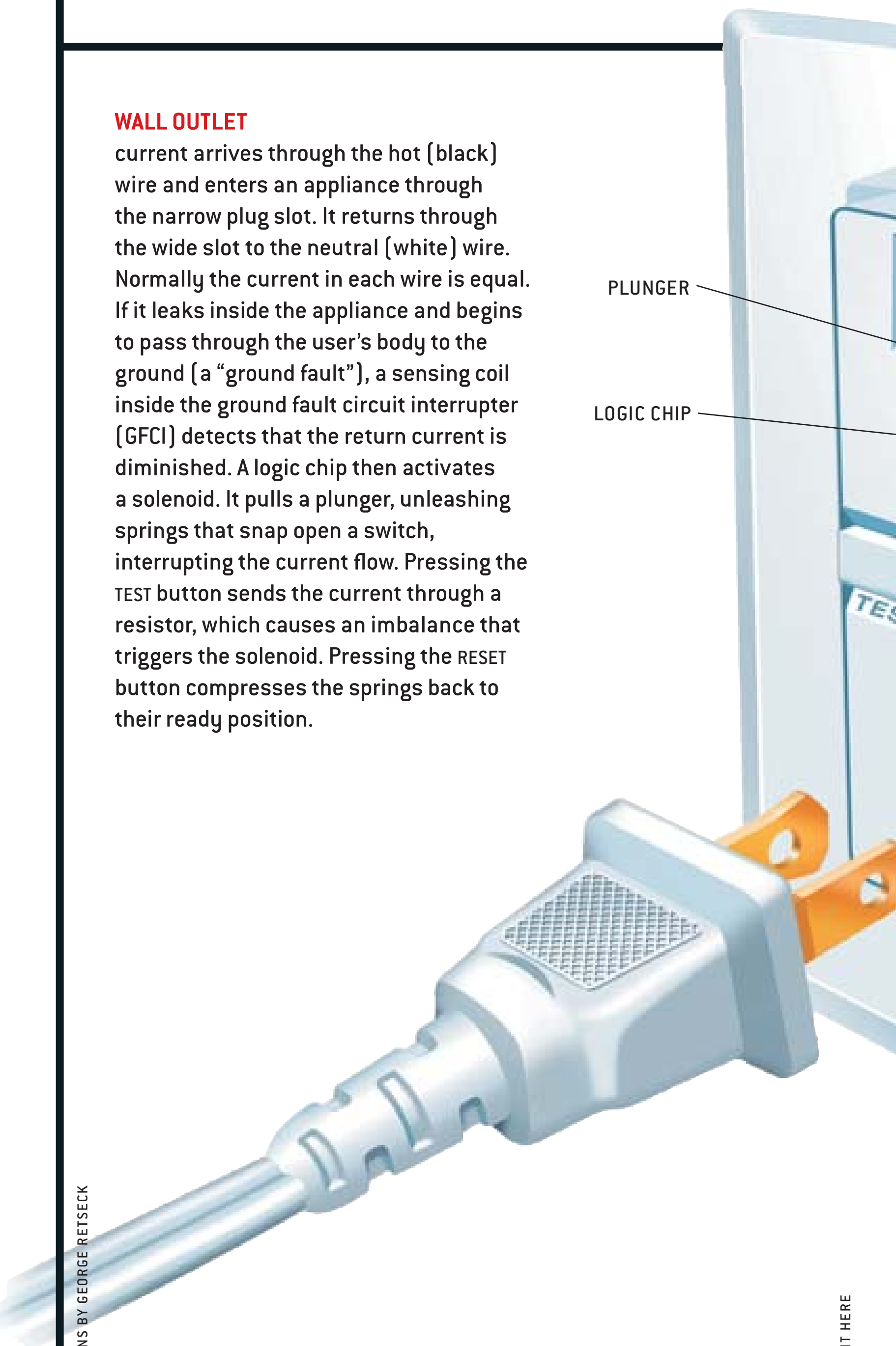
That strange electrical outlet with the TEST and RESET buttons is rapidly becoming widespread. Now required by the U.S. National Electrical Code in new bathroom, kitchen, garage and outdoor receptacles, the ground fault circuit interrupter (GFCI) can protect you from nasty electric shocks and electrocution.

People often assume that a building's circuit breakers or fuses will protect them. But these switches trip primarily when wiring short-circuits or an outlet overloads, which could heat the building's wiring and start a fire. Typical home breakers don't trip until the current surpasses 15 or 20 amps, yet a current of only 0.1 amp through a person's body can cause a heart attack, according to Matt Marone, who teaches experimental and applied physics at Mercer University.

Most residential shocks are caused by a "ground fault" in a tool or appliance. A loose or worn internal wire, splashed water or even high humidity electrifies the outside of the appliance. The current can then pass through someone's body to the ground, especially if he or she is wet, standing in water, or touching metal sinks or plumbing. That's when the GFCI cuts the power.

Considering that the average GFCI costs a mere $10, its inner workings are an elegant exploitation of the fundamental laws of electricity and magnetism [*see diagrams at right*]. It springs into action when the current returning to the outlet from an appliance is less than the current feeding the appliance, which indicates a "leak" resulting from a ground fault. A GFCI can detect leaks as small as 0.005 amp and interrupt the current as fast as 1⁄40 of a second.

Nevertheless, GFCIs will not save do-it-yourselfers who decide to tinker with an outlet without shutting off its circuit breaker. "If you touch the black and the white wires with different hands and you are insulated from the floor by, say, rubber sneakers or boots, the current out of the outlet and back to it will be balanced; there will be no ground fault," Marone says. "But you could die because the 120-volt potential across your arms will create a current in your body that could stop your heart." Not even physics can overcome foolish behavior. —*Mark Fischetti*



WALL OUTLET
current arrives through the hot (black) wire and enters an appliance through the narrow plug slot. It returns through the wide slot to the neutral (white) wire. Normally the current in each wire is equal. If it leaks inside the appliance and begins to pass through the user's body to the ground (a "ground fault"), a sensing coil inside the ground fault circuit interrupter (GFCI) detects that the return current is diminished. A logic chip then activates a solenoid. It pulls a plunger, unleashing springs that snap open a switch, interrupting the current flow. Pressing the TEST button sends the current through a resistor, which causes an imbalance that triggers the solenoid. Pressing the RESET button compresses the springs back to their ready position.

ILLUSTRATIONS BY GEORGE RETSECK

Ideas for the text and illustrations were supplied by Matt Marone, assistant professor of physics at Mercer University in Macon, Ga.

PHOTO CREDIT HERE

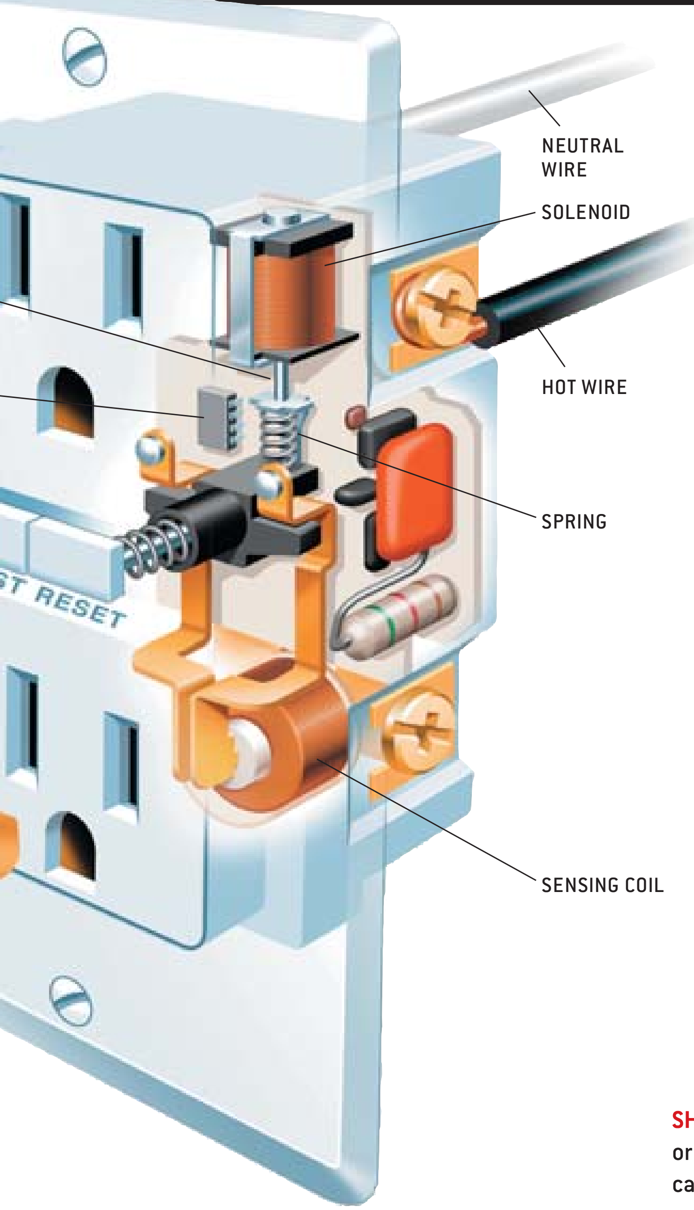
DID YOU KNOW...

▯ CAN'T LET GO: A shock can progress to electrocution when a person who has, say, touched a knife to a toaster coil can't let go of the implement. "A flow of only 0.01 amp will contract your muscles" and hold them there, says Matt Marone of Mercer University. If you witness this, turn off the outlet's wall switch or breaker, pull the plug or, as a last resort, knock the person away. But don't grab and hold on, because you will become electrified yourself.

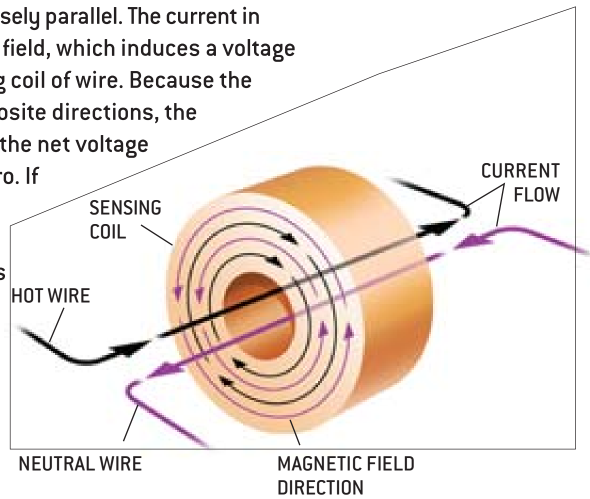
▯ DOWN THE LINE: One GFCI can protect several receptacles farther down the same line, if properly wired. You can check by pressing the TEST button, then plugging a lamp or radio into the GFCI outlet and others nearby to make sure the power is off.

▯ PORTABLE PROTECTION: If you're not handy or can't alter old outlets, you can buy a stand-alone GFCI that plugs into an existing three-prong outlet. GFCI extension cords are also available.

▯ ELECTROCUTIONS: Nearly 200 Americans were electrocuted in 1997 in nonindustrial settings (latest data), according to the National Center for Health Statistics; this is down 39 percent from a decade earlier. Tens of thousands were injured. The leading causes were bad building wiring and faulty consumer products. Other causes: hedge trimmers cutting their own power cord, electric hair curlers or dryers falling into a wet sink, and drilling into a wall and hitting an electrical cable.



HOT AND NEUTRAL WIRES inside a GFCI outlet lie closely parallel. The current in each creates a magnetic field, which induces a voltage in a surrounding sensing coil of wire. Because the two currents flow in opposite directions, the fields nearly cancel and the net voltage in the coil is virtually zero. If the returning (neutral) current drops, however, a stronger voltage arises in the coil. A voltage comparator signals a logic chip to fire the GFCI into action.



SHOCK or electrocution can occur when a person touches a live conductor or holds a tool or appliance that has been inadvertently electrified by worn internal wiring, water or even high humidity.

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Have a topic for a future column? Send it to workingknowledge@sciam.com

ORIGINALLY PUBLISHED IN SEPTEMBER 2001

FLEA TREATMENTS

Killer Drops

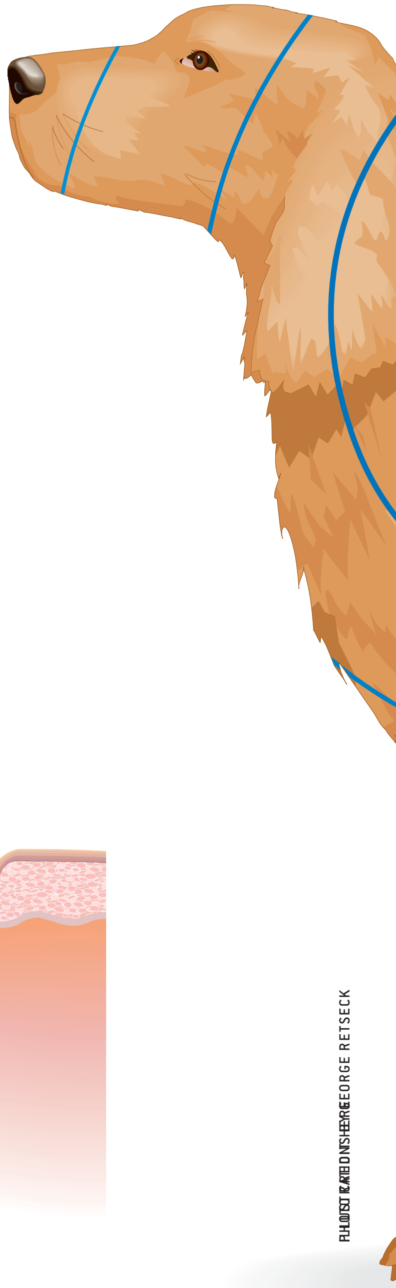
Shampoos, powders, sprays and collars all aim to control fleas on pets, but the most popular treatments today are the "spot" medications. Squeeze a few drops on the skin along a dog's or cat's back, and the insecticide will control fleas for a month. The products are available only from veterinarians, in doses adjusted for an animal's weight.

The formulations spread by mixing with a pet's skin oils, which migrate as a result of body movement and gravity. Some products flow into the sebaceous glands of hair follicles, where they are stored and secreted over time; others remain on the skin's surface. Advantage (imidacloprid) from Bayer and Frontline (fipronil) from Merial—the two market leaders—will fan out across the body in less than 12 hours and kill more than 90 percent of fleas by then. Tests by Bayer show that after 28 days, concentrations across a dog's body decrease to as little as one part per million, but less than one tenth of that amount is needed to kill fleas, according to Bob Arther, Bayer's manager of parasitology. And because they reside in or on skin, spot compounds do not readily wash off like treatments that stick to an animal's hair.

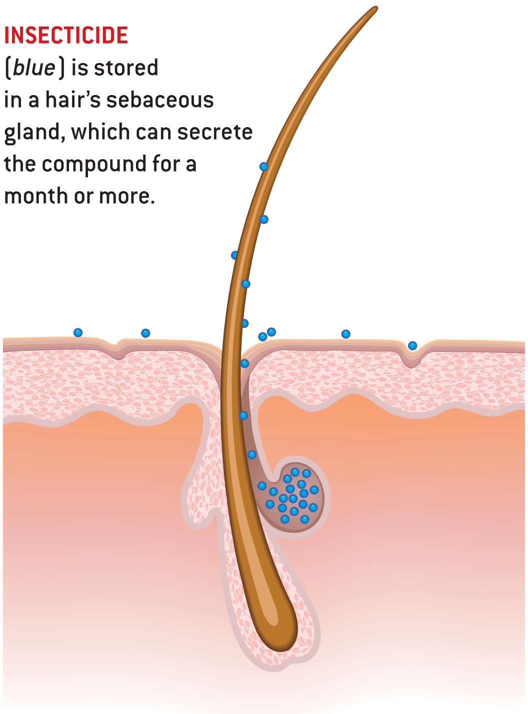
Pets can be given anti-flea pills, sending medication into their bloodstream. But a flea must bite the pet to be exposed to the insecticide. Some pills do not kill adult fleas but make their eggs unviable. The spot treatments kill virtually all fleas within 18 hours and prevent eggs from being laid. Buyers should be wary of over-the-counter knockoffs; many contain permethrin, which is less effective on dogs and is toxic to cats.

Some critics claim that pets can be harmed by ingesting small amounts of spot treatments as they groom themselves (although the same could be said of a spray, collar or pill). But tests required by the Environmental Protection Agency show that "animals that had received even gross overdosages had no change in their kidney or liver values," says Bruce Klink, manager of veterinary services at Merial. Manufacturers say the active ingredients do not affect people.

No insecticide is 100 percent safe. But be skeptical about "natural" or "chemical-free" alternatives such as vitamin B or garlic. There is little scientific proof that the potions send fleas fleeing. —*Mark Fischetti*



"SPOT" FLEA TREATMENTS mix with a pet's skin oils. A few drops disperse readily. Tests by maker Merial on midsize dogs given the recommended dose of the treatment fipronil show that concentrations quickly spread across the body. And although concentrations are low after 56 days, they are still high enough to kill fleas (95 percent of fleas die when exposed to 0.7 microgram per gram of fur).



INSECTICIDE (*blue*) is stored in a hair's sebaceous gland, which can secrete the compound for a month or more.

GEORGE RETSECK

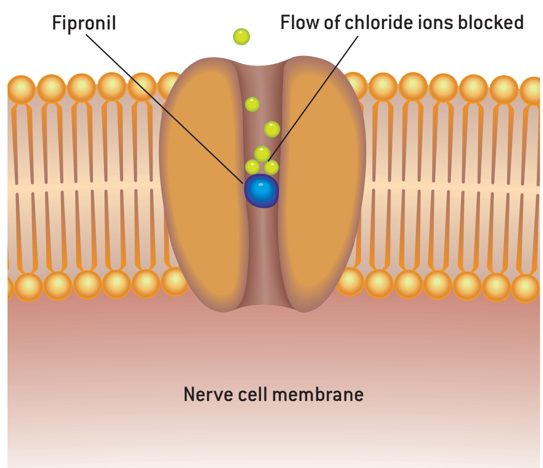
DID YOU KNOW...

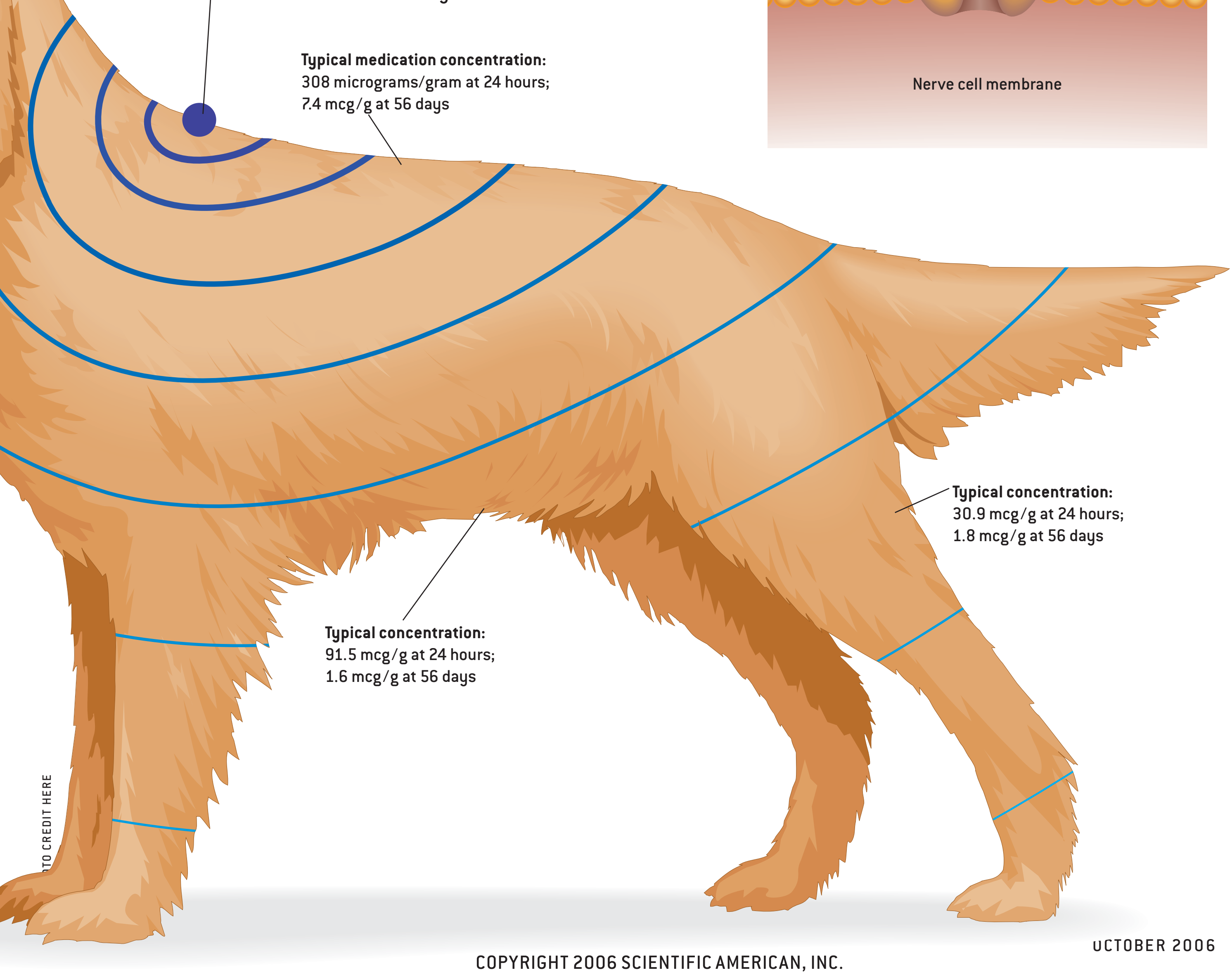
- FADING FAD: When a flea bites, it deposits saliva in the skin. Pets can have an allergic reaction that causes redness and severe itching. As they scratch, they develop flea-allergy dermatitis. For years, FAD was the leading skin problem in dogs and cats, but veterinarians report that "spot" treatments, because of their quick kills, have dramatically reduced the incidence of the disorder.

- BLACK DEATH: Rat fleas carry bacteria that can cause plague, such as the bubonic plague that wiped out one third of Europe's population in the 14th century. In 1999 microbiologists identified plague in flea-infested squirrels, chipmunks and other wild rodents in 22 counties surrounding Sacramento, Calif.; in 2000 state health officials began issuing regular warnings about plague-prone areas there.

- MAN BEFORE BEAST: The French established the world's first veterinary school, in Lyon in 1762. Veterinary science was originally developed not so much to help animals but to improve the understanding of zoonotic diseases in order to prevent their transfer to humans.

FLEA'S NERVE CELL is the target of the spot medication's active ingredient, which binds to a specific receptor there. The treatment fipronil (*shown at right*) blocks the flow of chloride ions that otherwise interrupts nerve signals. This hyperexcites a flea's central nervous system, sending it into a deadly seizure.





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WORKINGKNOWLEDGE

SUNSCREEN

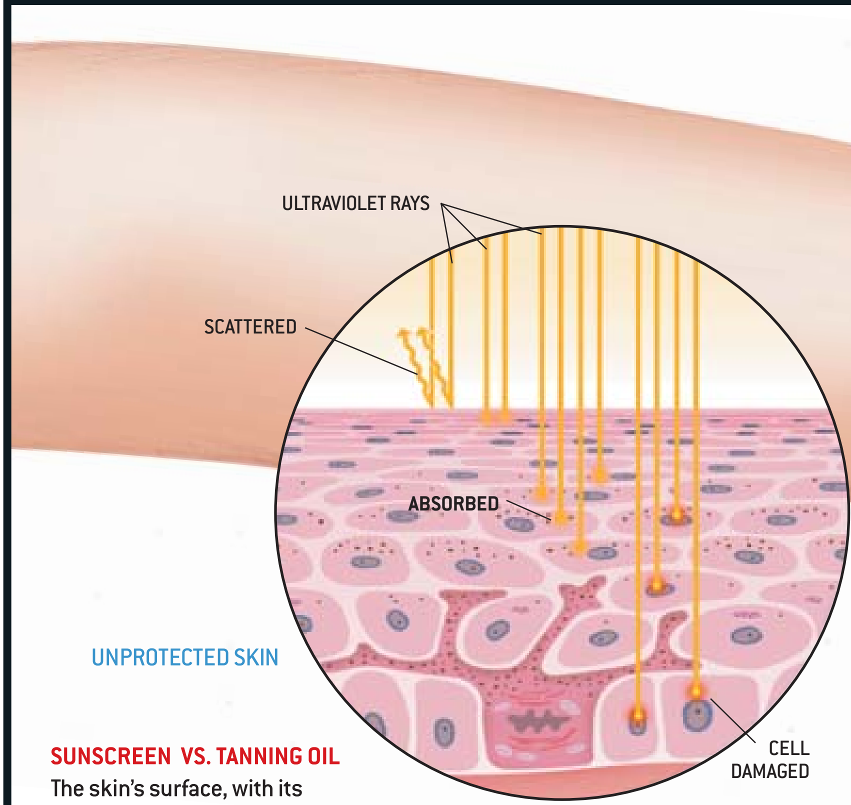
Tan or Burn

While protecting your body, skin must protect itself from the sun's ultraviolet radiation, which can cause premature aging and cancers. Sunscreens can help. Sunburn occurs when strong UV rays harm cells in the skin's outermost layer, the epidermis. Blood vessels in deeper layers dilate, turning the skin red: a sunburn. Regular exposure causes the epidermis to produce more melanin pigment in an attempt to absorb UV rays. If enough melanin accumulates, the skin darkens: a tan. Dark-skinned people have more melanin than light-skinned people and so don't burn as readily.

Active chemicals in sunscreen also filter UV rays, slowing injury and thus the sunburn and tanning reactions. Sunscreens are labeled with an SPF, or sun protection factor—a relative rating standardized by the FDA. Say that skin begins to burn after 10 minutes of exposure. When it is protected by an SPF 15 sunscreen, a comparable burn will take 15 times as long. An SPF 30 sunscreen will slow the burn for 30 times as long. But don't get cocky. Labs rate sunscreens on human subjects at a density of two milligrams per square centimeter, according to J. Frank Nash, a principal scientist at Procter & Gamble. Yet a typical beachgoer lathers up at perhaps half that concentration, halving protection. And Nash says no compound can fully stop UV penetration; there's no such thing as sunblock.

You can also discount claims about antioxidant vitamins E and C. Oxidation accounts for only a few percent of the UV damage, notes dermatologist Barbara A. Gilchrest of the Boston University School of Medicine, and "there's no good evidence" that vitamins in topical products can even enter the skin in active form. More worry comes from the fact that sunscreens primarily filter the shorter, or UVB, ultraviolet wavelengths, yet recent studies show that the longer (UVA) rays may contribute more to skin aging than previously thought.

So what's the best sunscreen? A thick shirt. And because cell damage is cumulative, experts recommend daily use of sunscreen, or of moisturizers with sunscreen, on areas such as the hands and face. A one-hour exposure every day for five days could be as threatening as one long day at the beach. —*Mark Fischetti*



SUNSCREEN VS. TANNING OIL
The skin's surface, with its many micropeaks and valleys, scatters a small number of the sun's ultraviolet rays. Most of the rays penetrate the epidermis. Melanin absorbs many of these photons, but some of the remainder injure DNA in the living cells. This damage signals capillaries in the dermis to dilate, increasing blood content and producing redness, or sunburn. Sunscreen acts as a filter that absorbs additional UV rays, dissipating their energy. Tanning oil smooths the surface, so fewer rays scatter and more penetrate, speeding sunburn or tanning.

ILLUSTRATIONS BY GEORGE RETSECK

PHOTO CREDIT HERE

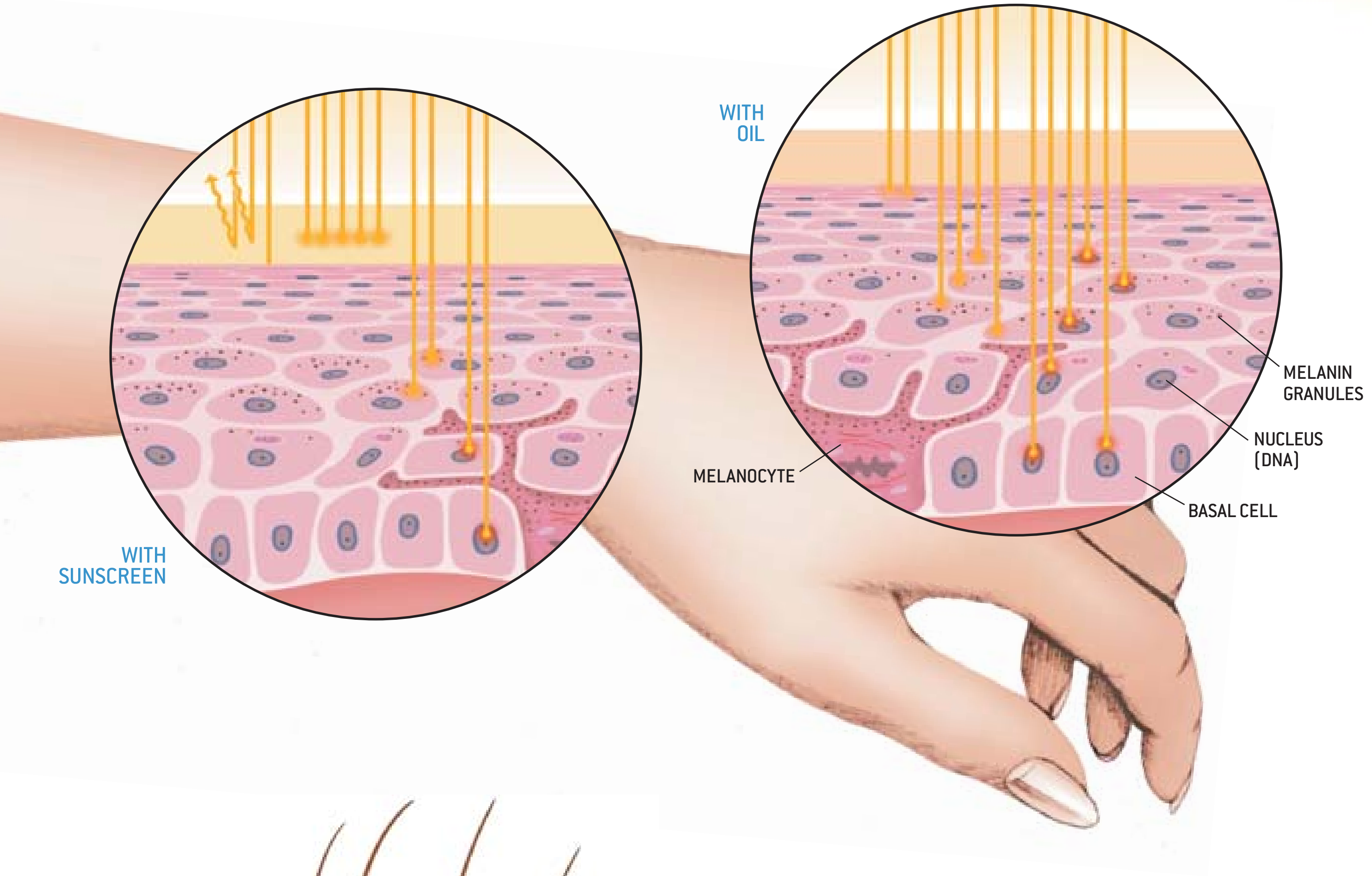
DID YOU KNOW...

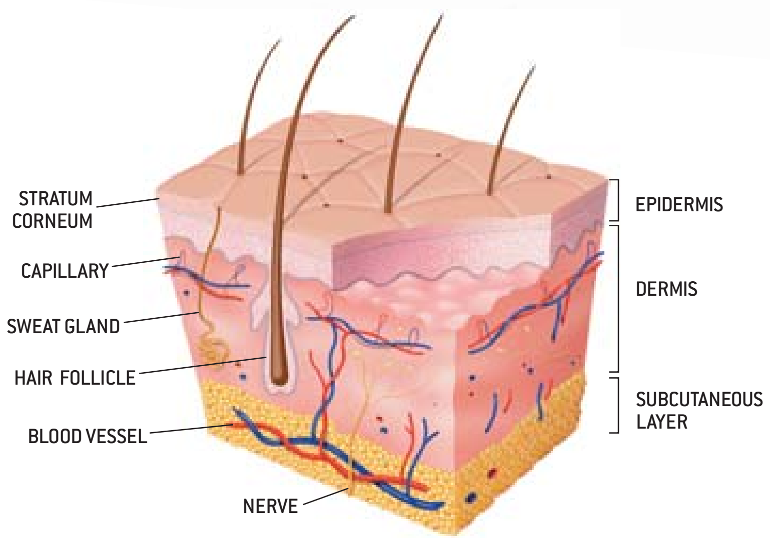
-PABA-FREE For decades sunscreen makers used para-aminobenzoic acid (PABA) as an active ingredient. But it stains clothes and causes an allergic reaction in 5 percent of the population, and controversial evidence suggests it might be carcinogenic. Today many brands shout out "PABA-free."

-YOUR EPIDERMIS IS SHOWING Melanin, the epidermis pigment that absorbs ultraviolet rays, also absorbs visible light. The more eumelanin (brown pigment) you have, the darker your skin color, from white to black. Redheads produce relatively more phaeomelanin (red and yellow), a poorer UV absorber, so they are more likely to sunburn and less likely to tan. Albinos have no melanin and are at great risk in the sun.

-TRUCKER'S ELBOW Glass absorbs UV rays very effectively, so you can grip your car's steering wheel for hours in baking heat and not sunburn your hands or arms. But roll down the window and rest your elbow on the ledge, and you might arrive with a telltale burn truckers know well.

-TAN IN A BOTTLE "Sunless" tanning sprays and lotions contain dihydroxyacetone (DHA), which binds to amino acids in the outermost (dead) layer of skin to produce a tan—some more realistic than others. They provide no UV protection, however, so sunscreen is still needed outdoors.





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BENEATH THE SURFACE

Two main layers make up the skin. The dermis contains blood vessels and nerves. The epidermis contains melanin, an inert protein that gives skin its color. Melanocytes (*above*) insert melanin granules inside cells as newly formed cells push older ones to the surface. As the cells migrate, they produce keratin, another inert protein, and then die, leaving the keratin to form the tough stratum corneum we see every day. The same keratin also constitutes our hair and nails, as well as the feathers, scales, hooves and claws that adorn eagles, trout, horses and alligators.

WORKINGKNOWLEDGE

TOUCH SCREENS

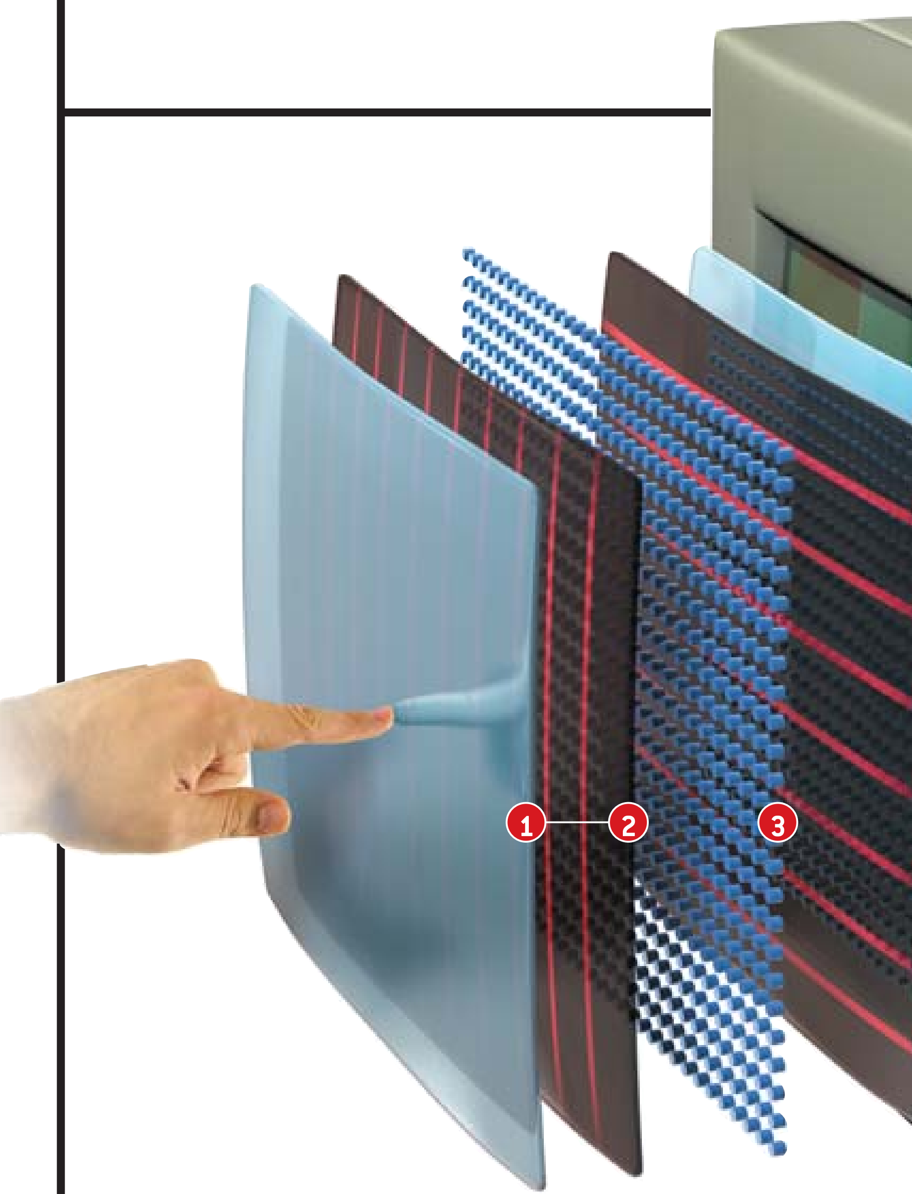
At Your Fingertips

We use touch screens everywhere: tourist kiosks, automatic teller machines, point-of-sale terminals, industrial controls. Half a dozen vendors, plus in-house departments at major manufacturers, produced $800 million worth in 2000. The market is growing because the interfaces are easy-to-use, durable and inexpensive.

Touch screens employ one of three physics principles for detecting the point of touch. Pressing a "resistive" design with a finger or other stylus raises a voltage. In "capacitive" models, a finger draws a minute current (this method is often used for cursor pads on notebook computers). In other designs, a finger or stylus interrupts a standing pattern of acoustic waves or infrared lights that blanket the surface.

Resistive screens are the oldest, most widely used and least expensive, and they work with any stylus (finger, pen). Capacitive screens must be touched by a finger or an electrically grounded stylus to conduct current. Wave screens are the newest and most expensive. Surface acoustic wave screens must be touched by a finger or a soft stylus such as a pencil eraser to absorb energy; infrared screens work with any stylus. The different technologies may be used in the same applications, although pros and cons lead to prevalent combinations: resistive screens for industrial controls and Palm Pilots; capacitive screens for slot machines; wave screens for ATMs and indoor kiosks.

Most people are unaware of the type of screen they are using. But tricks can help you tell, according to Frank Shen of Elo TouchSystems in Fremont, Calif., the largest U.S. maker. Push the screen lightly with your fingernail (not your skin). If it responds, it could be resistive or infrared. In this case, place two separated fingers against the screen at the same time. If the cursor moves beneath one finger, the unit is infrared (software registers the first touch); if the cursor moves between the fingers, it is resistive (the points are averaged). If the unit does not respond to your fingernail, again place two separated fingers against it. If the cursor moves beneath one finger, the unit is acoustic wave; if the cursor moves between the fingers, it is capacitive. —*Mark Fischetti*



RESISTIVE
A glass panel that lies against a cathode-ray tube (CRT) or liquid-crystal display (LCD) is coated with a conductive material. Tiny polyester spacer dots separate it from a polyester cover sheet, which has a conductive metal coating on its inside surface. A controller applies a small voltage gradient across the x-axis of the panel and the y-axis of the cover sheet. When a stylus presses the conductive layers together, the control electronics detect its x- and y-coordinates.

PHOTO CREDIT HERE

DID YOU KNOW...

BUTTERFLIES AND CHADS The U.S. presidential recount fiasco might have been avoided if Florida had used common touch-screen voting machines instead of confusing paper butterfly ballots and unreliable poke-through chads. Several manufacturers aim to modernize the state. Global Election Systems released a report in December 2000 that said wryly, "The election has created numerous new opportunities for voting-system sales." The company already supplies 850 jurisdictions nationwide. The name of its product? AccuVote.

DOLPHINS Biologist Ken Marten of Sea Life Park Hawaii is using the first underwater, infrared touch screen (made by Carroll Touch) and a Macintosh G4 computer to create a cross-species language. The computer generates dolphinlike whistles and clicks. The park's dolphins touch images with their rostrums (noses). When a dolphin mimics the computer sound for "up" and then swims upward, a bit of language is born. The dolphins get no food rewards, only recorded sounds and video they find intellectually stimulating.

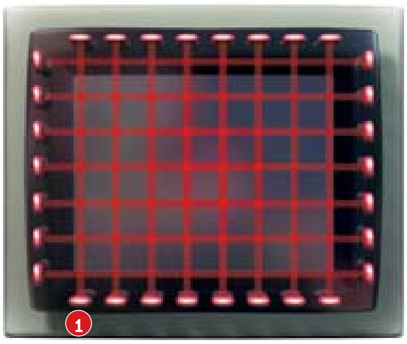
TOUCH TV Bill Colwell, an engineer at Elo TouchSystems, developed the first touch screen in 1977. The key to commercializing the resistive design was a subsequent Elo patent for polyester "dots" that separated the screen's layers [*see diagram on opposite page*]. The company unveiled the technology on 33 televisions at the 1982 World's Fair in Knoxville, Tenn.

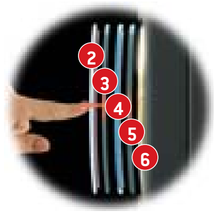
1. Polyester cover sheet, with scratch-resistant coating
2. Conductive coating
3. Spacer dots
4. Conductive coating
5. Glass panel
6. CRT/LCD

PHOTOILLUSTRATIONS BY JOE ZEFF

CAPACITIVE

A glass sheet is coated on both sides with a conductive material. The outer surface is covered with a scratch-resistant coating. Electrodes around the panel's edge distribute a low-voltage field uniformly across the outer conductive layer. (The inner layer provides shielding and noise reduction.) When a finger touches the screen, it causes a capacitive coupling with the voltage and draws a minute current. The electrodes measure the current flow from the corners, and a controller determines the finger's coordinates.



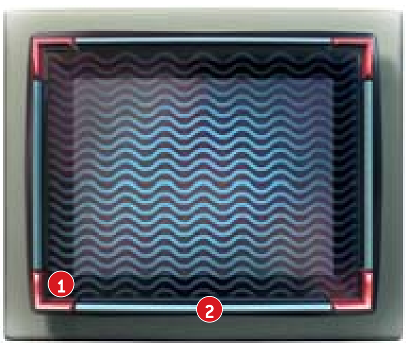


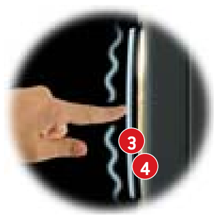
1. Electrodes
2. Scratch-resistant coating
3. Conductive coating
4. Glass panel
5. Conductive coating
6. CRT/LCD

SURFACE ACOUSTIC WAVE (AND INFRARED)

The screen is an uncoated glass panel. Transducers in the corners convert a signal from a controller into ultrasonic waves on the glass surface. Reflectors on the edges create a standing wave pattern. When a soft stylus touches the screen, it absorbs part of the wave. The transducers sense the attenuation, and the controller determines the stylus's coordinates.

On infrared screens, tiny light-emitting diodes and phototransistors on the edges set up a standing grid of invisible infrared light; a stylus obstructs the beam.





1. Transducers
2. Reflectors
3. Glass panel
4. CRT/LCD

RADAR_GUNS

Gotcha!

You're zipping along the highway. Suddenly you see the patrol car up ahead. You slam on the brakes. Too late—the radar gun already has a bead on you. You're busted.

Radar has snared speeding drivers since the early 1950s. Handheld radar guns have evolved ever since to increase range, improve targeting and outwit radar detectors. Radar's microwaves, which reflect off objects to indicate speed, have climbed in frequency from the original X band (10.525 gigahertz) to K band (24.150 GHz) in the 1970s to Ka band (33.4 to 36.0 GHz) in the late 1980s. The microwave power output is a relatively harmless 15 to 50 milliwatts.

In 1991 manufacturers unveiled laser radar, or lidar. It nails motorists with 904-nanometer infrared light. Lidar's chief advantage is its narrow beam, only three feet wide at 1,000 feet downfield, enabling an officer to pick out a speeding car or motorcycle among three vehicles abreast, says Steve Hocker, product manager at Kustom Signals, a radar and lidar manufacturer in Lenexa, Kan. The microwave cone emitted by a radar gun is about 12 degrees, or 210 feet wide at 1,000 feet. Fog, rain and snow, however, reduce lidar's accuracy; they do not affect radar's accuracy, although they might reduce its range. The average lidar unit costs $3,500, whereas the average handheld radar gun costs $1,300.

Four U.S. manufacturers produce almost all domestic police radar guns. They also make devices to measure the velocity of baseballs and speedboats, to regulate speed in the automatic coupling of railroad boxcars and to determine scientific data such as the flow rate of rising rivers, used to predict flooding. A typical radar unit has a 0.75-mile range and lasts 15 years, according to Jim Hester, general manager of Decatur Electronics's radar manufacturing division in Fort Collins, Colo. The total radar gun market is about $30 million a year.

Despite rumors to the contrary, radar detectors are legal in all U.S. states except Virginia and Washington, D.C. The units sound an alarm when they sense an incoming signal that matches standard radar frequencies, supposedly giving drivers time to slow down. Radar jammers are illegal nationwide, carrying a charge of obstruction of justice, but motorists are known to use them. They emit a strong microwave frequency, which the driver tunes to represent a legal speed; a down-road radar gun will select that signal because it is more powerful than the gun's signal that the car is reflecting. Lidar detectors and jammers are sold as well, many sporting militaristic names.

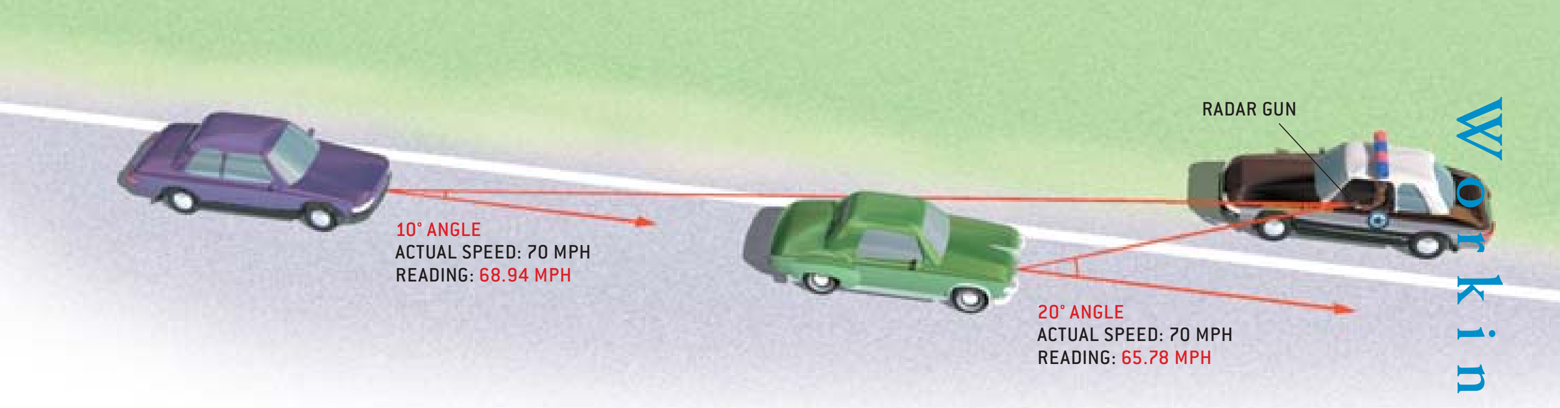
—Mark Fischetti

RADAR GUNS emit a continuous stream of microwaves at a preset frequency. According to the Doppler effect, when the waves reflect off an object moving toward the source, their frequency is shifted higher (objects moving away shift the frequency lower). A stationary gun measures the degree of shift, which determines velocity.

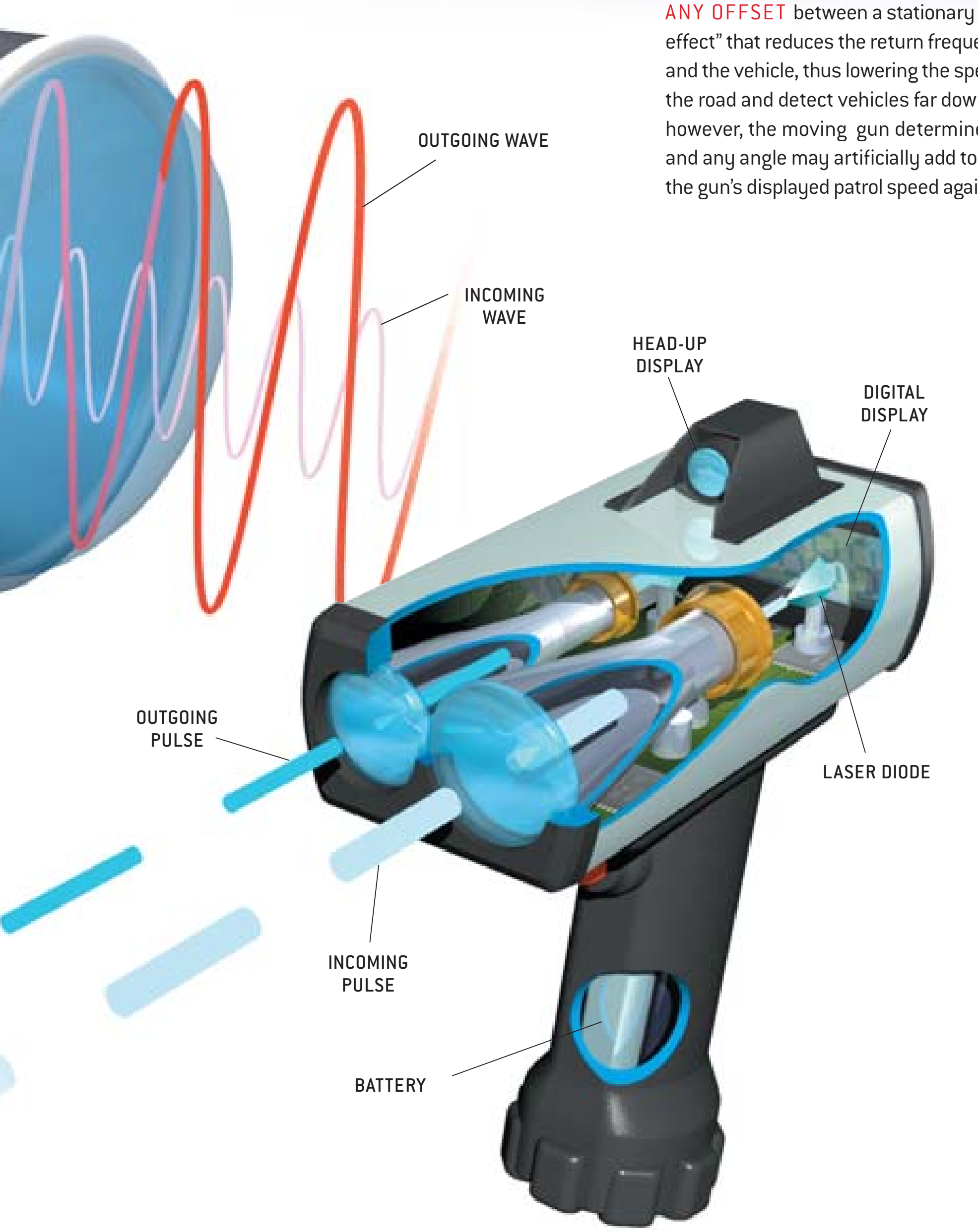
BATTERIES POWER a Gunn diode, part of a microwave oscillator. It emits microwaves that are focused into a beam by a horn and lens (together, the "antenna"). The antenna receives waves reflected by objects in the beam's path. A mixing diode compares the outgoing and incoming signals and sends the difference through an analog-to-digital converter to a digital-signal-processing (DSP) chip. The DSP analyzes the incoming signal frequencies and sends the speed value of the strongest return (typically the closest vehicle) to the gun's display.

ILLUSTRATIONS BY BRYAN CHRISTIE, BASED ON INFORMATION FROM LASERCRAFT AND KUSTOM SIGNALS (*lidar*) AND DECATUR ELECTRONICS (*radar*)

Working Knowledge



ANY OFFSET between a stationary radar gun and a moving target creates a "cosine effect" that reduces the return frequency by the cosine of the angle between the gun and the vehicle, thus lowering the speed reading. Therefore, police try to park close to the road and detect vehicles far downfield. In a patrol car that is cruising with traffic, however, the moving gun determines relative speed between the car and a target, and any angle may artificially add to the speed reading. Officers are trained to check the gun's displayed patrol speed against their own car's speedometer.



IN A LIDAR GUN, electronics ramp up battery power to high voltage that drives a laser diode. The diode emits infrared laser pulses every five milliseconds. Filters receive pulses reflecting off a target object and focus them onto an avalanche diode, which converts them to electronic signals. High-speed timing circuitry tracks the time it takes for a pulse to reflect and return from the target, and algorithms use the data to determine the object's distance. The algorithms calculate distance again for subsequent pulses and then compute velocity by dividing the change in distance by the change in time.

DID YOU KNOW ...

SPEEDING PALM TREE

A 1979 Miami TV report showing a radar gun clocking a palm tree at 86 mph brought radar errors to national attention. Error correction has improved, but units can occasionally be foiled by interference from nearby airport radars, CB radios, cellular phones, mercury vapor lights or other police radars, as well as harmonics from a running patrol car's air conditioner, heater or engine fan. But forget telling a judge the unit was wrong; if calibrated and used properly, they seldom are.

MUSIC TO THEIR EARS

Police radars emit an audio tone that rises in proportion to the target's speed. In the third octave above middle C, the note C-sharp corresponds to 60 mph for Decatur's K-band unit, D-sharp to 70 mph and F-sharp to 80 mph. Some officers become so trained to pitch that they can estimate speed to within 1 mph.

FIRSTS

Hartford, Conn., claims the first auto-speed regulation; its 1901 law limited automobiles to 12 mph in the country and 8 mph in the city. New Amsterdam (now New York City) passed the first American "traffic" law on June 12, 1652; it prohibited the riding or driving of horses at a gallop within city limits.