**Reading: Welcome to the World of Nanotechnology**

Tiny technology promises big rewards. Some may already be in your closet.

**By Jennifer Kahn**

*National Geographic*

“I sit before you today with very little hair on my head. It fell out a few weeks ago as a result of the chemotherapy I’ve been undergoing. Twenty years ago, without even this crude chemotherapy, I would already be dead. But 20 years from now, nanoscale missiles will target cancer cells in the human body and leave everything else blissfully alone. I may not live to see it. But I am conﬁdent it will happen.” Richard Smalley spoke these words on June 22, 1999. He died of non-Hodgkin’s lymphoma on October 28, 2005. The 62-year-old Nobel Prize-winning chemist was a nanotech pioneer.

A tsunami is unnoticeable in the open ocean—a long, low wave whose power becomes clear only when it reaches shore and breaks. Technological revolutions travel with the same stealth. Spotting the wave while its still crossing the ocean is tricky, which explains why so few of us are aware of the one that's approaching. Nanotechnology has been around for two decades, but the first wave of applications is only now beginning to break. As it does, it will make the computer revolution look like small change. It will affect everything from the batteries we use to the pants we wear to the way we treat cancer.

The main thing to know about nanotechnology is that it’s small. Really small. Nano, a preﬁx that means “dwarf” in Greek, is shorthand for nanometer, one-billionth of a meter: a distance so minute that comparing it to anything in the regular world is a bit of a joke. This comma, for instance, spans about half a million nanometers. To put it another way, a nanometer is the amount a man’s beard grows in the time it takes him to lift a razor to his face.

Nanotechnology matters because familiar materials begin to develop odd properties when they’re nanosize. Tear a piece of aluminum foil into tiny strips, and it will still behave like aluminum—even after the strips have become so small that you need a microscope to see them. But keep chopping them smaller, and at some point—20 to 30 nanometers, in this case—the pieces can explode. Not all nanosize materials change properties so usefully (there’s talk of adding Nano aluminum to rocket fuel), but the fact that some do is a boon. With them, scientists can engineer a cornucopia of exotic new materials, such as plastic that conducts electricity and coatings that prevent iron from rusting. It’s like you shrink a cat and keep shrinking it, and then at some point, all at once, it turns into a dog.

Substances behave magically at the nanoscale because that’s where the essential properties of matter are determined. Arrange calcium carbonate molecules in a sawtooth pattern, for instance, and you get fragile, crumbly chalk. Stack the same molecules like bricks, and they help form the layers of the tough, iridescent shell of an abalone.

It’s a tantalizing idea: creating a material with ideal properties by customizing its atomic structure. Scientists have already developed rareﬁed tools, such as the scanning tunneling microscope, capable of viewing and moving individual atoms via an exquisitely honed tip just one atom wide.

“Nano’s going to be like the invention of plastic,” says Paul Alivisatos, associate director of physical sciences at Lawrence Berkeley National Laboratory’s new nanofabrication center. “It’ll be everywhere: in the scalpels doctors use for surgery and in the fabrics we wear.” Alivisatos already owns a pair of stain-resistant nanopants from the Gap, made from fibers treated with fluorinated nanopolymer. “I spilled coffee on them this morning, and it rolled right off.”

On a table in a lab at Rice University, André Gobin, a graduate student, is working with two slices of raw chicken. He nudges the slices together so they touch and dribbles greenish liquid along the seam. The liquid is a solution of nanoshells: minuscule silica beads covered, in this case, with gold. Switching on an infrared laser, Gobin deftly traces the beam down the length of the green line. Tweezing the chicken up, he dangles what is now a single piece of meat.

Someday soon surgeons may be able to use a nanoshell treatment like this to reconnect veins that have been cut during surgery. “One of the hardest things a doctor has to do during a kidney or heart transplant is reattach cut arteries,” says Gobin. “They have to sew the ends together with tiny stitches. Leaks are a big problem.” With Gobin’s nanoshell solution a surgeon could simply meld the two ends and get a perfect seal. It would make grafting veins as easy as soldering wire.

Although much of nanotechnology’s promise remains unrealized, investment in the ﬁeld is booming. The U.S. government allocated more than a billion dollars to nanotechnology research in 2005—more than twice what it spent on sequencing the human genome when that project was at its height. Japan and the European Union have spent similar amounts, and even smaller countries are hurrying to get a foot in the door. A Korean company has used nanosilver-based antibacterials in refrigerator interiors. The same material can be incorporated in bandages. The hope is the same on all fronts: to get the jump on a growing global market that the National Science Foundation estimates will be worth a trillion dollars by 2015.

One reason for the rapid global spread of nanotechnology is that the entry cost is comparatively low. Countries that missed out on the computer revolution because they lacked the capital to build vast, high-tech factories that make silicon chips are less likely to miss the nanotech wave.

“It’s science you can do in a beaker,” says Stephen Empedocles, vice president of Nanosys, a company that’s developing cheap solar nanostructures. Traditionally, the manufacture of solar-energy cells has required a multimillion-dollar fabrication facility that cooks sheets of glass at extremely high temperatures until the atoms order themselves into a receptive latticework. Solar nanostructures, on the other hand, grow like rock candy. You can “mix them up in a beaker with a hundred dollars’ worth of starter chemicals,” Empedocles says, and then paint them on window glass to turn an entire building into a solar-energy generator. Or, they might be embedded in the plastic body of a cell phone or laptop computer.

For a hundred dollars, in fact, anyone can buy nanoparticles—speciﬁcally a gram of carbon nanotubes—online. Place the order, and you’ll receive a small ziplock bag of what looks like soot tucked inside a cardboard FedEx envelope along with some safety instructions. (They recommend gloves to keep the carbon slivers off the skin and a respirator to keep the tiny black specks from entering the lungs.)

There’s not much you can do at home with a thimbleful of carbon nanotubes. But some of their mysteries are revealed in another Rice University lab, where Matteo Pasquali holds up a test tube containing a few dark threads so stiff that they seem to have been starched and ironed. These are fibers spun from carbon nanotubes—several billion of them—which, in theory, should be stronger than Kevlar, the material in bulletproof vests.

Richard Smalley was interested in fighting cancer with nanoparticles. Smalley’s non-Hodgkin’s lymphoma was a relatively slow-moving cancer, but even when he was in remission, between a hundred million and a billion cancer cells circulated in his body (a number that doctors consider relatively low).

Nanoparticles could enable early detection and therefore early treatment of cancer. One of the advantages of treating cancer in an early stage is that the cells are less likely to have mutated and become resistant. Drug resistance is one of the trickiest things about cancer, which adapts so rapidly that medications can rarely keep up. “You don’t want a killing mechanism to be fancy,” Smalley said. It needs to be fast and thorough.

But targeting a brute-force treatment is difficult, says Jennifer West, a bioengineer who is treating tumors in mice using gold nanoshells. Difficult because things that kill cancer cells typically kill healthy cells as well. “That’s what we’d like to avoid,” West says. Her approach relies on the fact that tumors grow blood vessels so quickly to keep up with the rapidly multiplying tumor cells that they don’t have time to knit tightly and instead leak like rusted pipes. West’s gold nanoshells are about 120 nanometers in diameter—a cancer cell is 170 times bigger. So the nanoshells are minute enough to seep through the cracks in the tumor capillaries and become lodged in the tumor.

To kill the tumor, West activates the shells with infrared rays that pass harmlessly through the skin but heat the gold, killing the adjacent tumor cells. Because the cancer cells die, they don’t develop the resistance that can plague drug-based cures.

Moreover, because the nanoshells lodge only in the tumor and are nontoxic unless activated by infrared light, West expects her treatment to be nearly side-effect free—particularly compared with treatments like chemotherapy and radiation. As part of the FDA approval process, West has injected mice with increasingly large doses of nanoshells. Not a single mouse has died. “We haven’t even been able to induce any adverse effects,” she says with a shrug. “If we had injected these mice with the same amount of table salt, they would have keeled over long ago.”

Unfortunately, the very thing that makes nanoshells such a promising therapy—their ability to move easily through the body and to interact with different cells— is a downside when it comes to the problem of nanoparticle pollution.

In 2004 Eva Oberdorster, a toxicologist at Southern Methodist University in Dallas, reported that largemouth bass exposed to water containing buckyballs, a carbon-based nanostructure, at a concentration of 500 parts per billion suffered brain damage. And people are similarly vulnerable. After exposing lab-grown human skin and liver cells to an even weaker solution—a mere 20 parts per billion—Rice University chemist Vicki Colvin found that fully half the exposed cells died.

Results like these are troubling, in part because of the rapidly growing number of products already on the market that contain nanoparticles. “With nanomaterials, it’s not enough to look at the properties of the bulk material,” Colvin warns. “Whether you’re working with gold or lead, the toxicity will be hard to predict.” There is some evidence, for example, that the nanoscale particles of titanium dioxide used in sunscreen, depending on the way they are Nano sized, can produce high amounts of free radicals when exposed to sunlight. Free radicals can damage cells, making some more likely to turn cancerous.

Because nanotech applications are so potentially useful, Colvin doesn’t think research should be stopped, or even slowed. But she does think that a larger proportion of government money should be directed toward safety and related questions—like whether nanoparticles could accumulate undetected in the water and food chains.

Such safety issues are key, given the speed with which the nanotech tsunami is moving. Corporations will invest more than four billion dollars in nanotech this year alone, and a recent nanotech conference in Japan drew a crowd of 30,000.

Meanwhile, commercial applications continue to spread. Homeowners now have the option of installing windows manufactured by PPG Industries, a company that uses nanoscale particles of titanium dioxide to make glass that doesn’t streak and never needs washing. Food companies have begun experimenting with nanopackaging that changes color when food spoils or contains bacteria like E. coli. The prefix has even trickled over into popular culture, where it’s the advertising hit du jour, with GM hawking a “nano” Hummer, and Apple its iPod Nano digital music player.

“What’s amazing is how quickly this is evolving,” Colvin says. “Even ten years ago, a lot of these applications would have seemed pretty unrealistic.”

The boom left Richard Smalley downright nostalgic. “Nano is a baby that’s all growed up,” he mused shortly before his death. Perhaps, but we’ve still got some interesting years ahead.