NISE network
NANOSCALE INFORMAL SCIENCE EDUCATION

Engaging the Public in Nano:

Key Concepts in Nanoscale Science, Engineering, and Technology

What is nano?

Nanoscale science, engineering, and technology (or "nano," for short) is a relatively new, interdisciplinary field of research. Just within the past couple of decades, scientists have developed methods and tools that allow them to explore some of the most fundamental aspects of our natural world, and to develop new materials and technologies. Some experts think that nanotechnology may transform our lives, similar to the way that the automobile and personal computer changed how we live and work.

The great potential of nano comes from its tiny size. Nano research and development happens at the scale of atoms and molecules. Some things have different properties at the nanoscale, which allows scientists and engineers to create new materials and devices.

Nanotechnology isn't just in the lab—we can already find examples in our homes, stores, and hospitals. In the next 10 years or so, nanotechnology will become even more present in our lives. We'll find it in everyday products like computers, food, cosmetics, and clothing. Nanotechnology might also be part of solutions to big problems, helping address needs such as clean energy, pure water, and cancer treatments.

It's important for everyone to be informed about nanotechnology, because it will be a significant part of our future. Like all technologies, any given nanotechnology has costs, risks, and benefits. Since nanotechnologies are still developing, we can influence what they are and how they're used. We all have a role in determining how these new technologies will play out in our future.

Nano is a large and exciting field of study and there's a lot to know. Learning more about nano will help us understand our natural world, the process of science and engineering, and the ways that society and technology are interconnected.

To begin to understand nano, we can explore four main concepts.

1.
Nano is small and different

Nanoscale things are very small, and often behave differently than larger things do.

2.
Nano is studying and making tiny things

Scientists and engineers have formed the interdisciplinary field of nanotechnology by investigating properties and manipulating matter at the nanoscale.

3.
Nano is new technologies

Nanoscale science, engineering, and technology lead to new knowledge and innovations that weren't possible before.

4.
Nano is part of our society and our future

Nanotechnologies have costs, risks, and benefits that affect our lives in ways we cannot always predict.

1.

Nano is small and different

Nanoscale things are very small, and often behave differently than larger things do.

The nanoscale is very, very small.

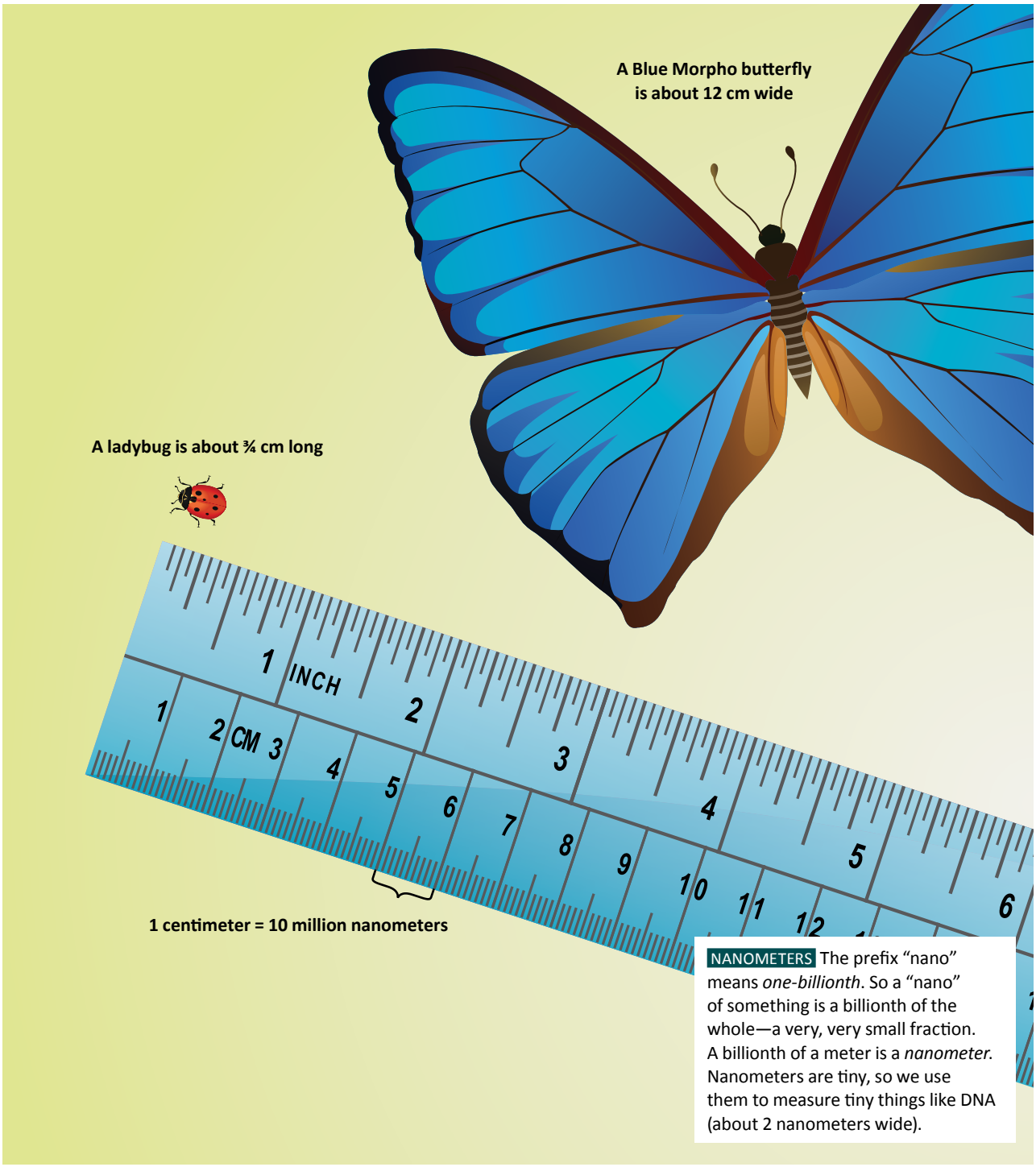
The world is full of things of all different sizes. In everyday life, we come across things in at least three different size scales: the *macroscale*, the *microscale*, and the *nanoscale*. Macroscale objects are big, and we can see them with our eyes. Microscale objects are smaller, and we need tools like microscopes to see them clearly. Nanoscale objects are even smaller. We need special tools to study and work on the nanoscale.

MACRO:
A child is about 1 meter tall
1 meter = 1,000,000,000 nm (1 billion nanometers)

MICRO:
A red blood cell is about 10 micrometers wide
10 micrometers = 10,000 nm (10 thousand nanometers)

NANO:
DNA is about 2 nanometers wide

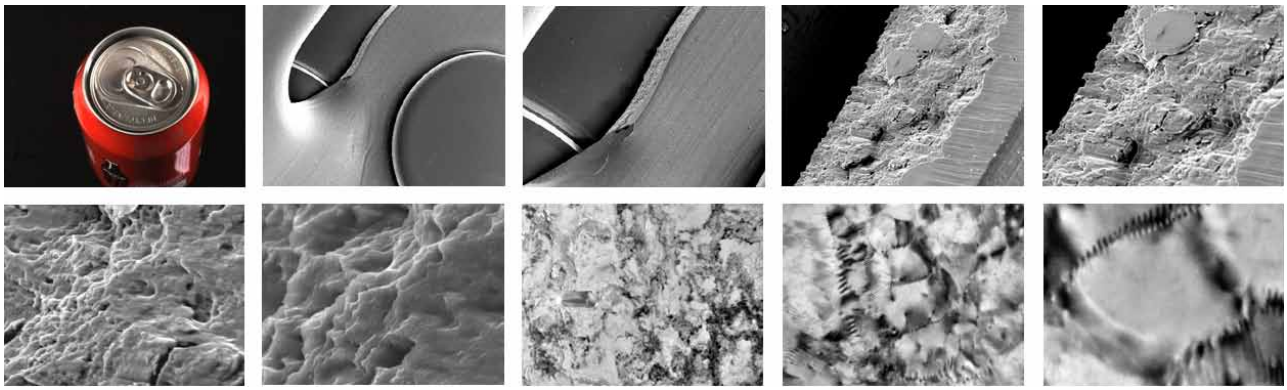
Nanoscale science focuses on things that are measured in *nanometers*, including atoms and molecules, the basic building blocks of our world. A nanometer is a billionth of a meter.



Some materials behave differently at a small scale than they do at a large scale.

Many materials have surprising properties at the nanoscale. For example, chemical reactions often take place much more quickly. That's because reactions occur on the surface of objects, and nanoscale objects have a lot of surface area per unit of volume.

Zooming in on an aluminum can



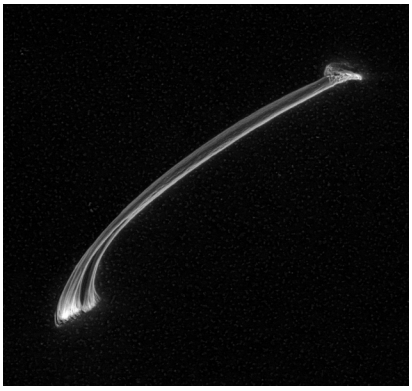
Courtesy MRS and Ontario Science Centre

SURFACE AREA AND ALUMINUM

Aluminum behaves differently on the nanoscale. Large aluminum objects—like soda cans—are usually stable. In contrast, nanoparticles of aluminum can spontaneously combust and explode! Nanoscale objects have a much greater *surface area to volume ratio* than larger objects do, so they react very quickly.

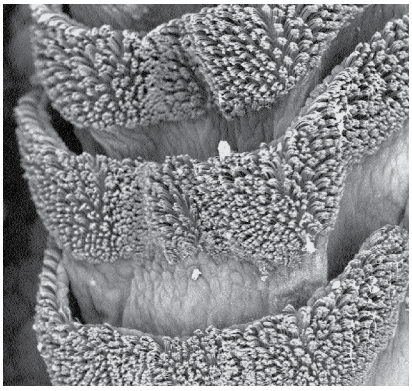
Different physical forces dominate at the nanoscale, making things behave in unexpected ways. For example, at the nanoscale gravity is a relatively weak force, while intermolecular forces (attraction between molecules) are relatively strong.

A single "hair" from a gecko toe

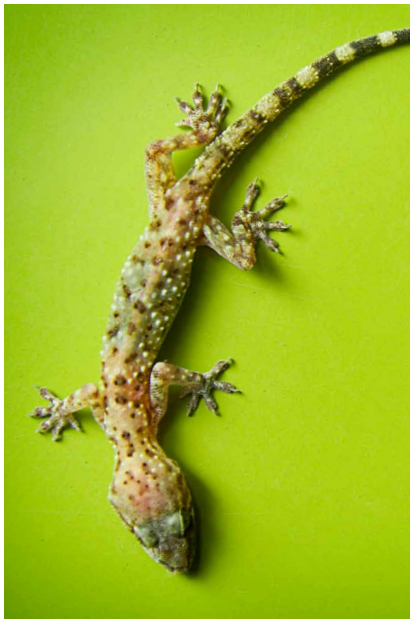


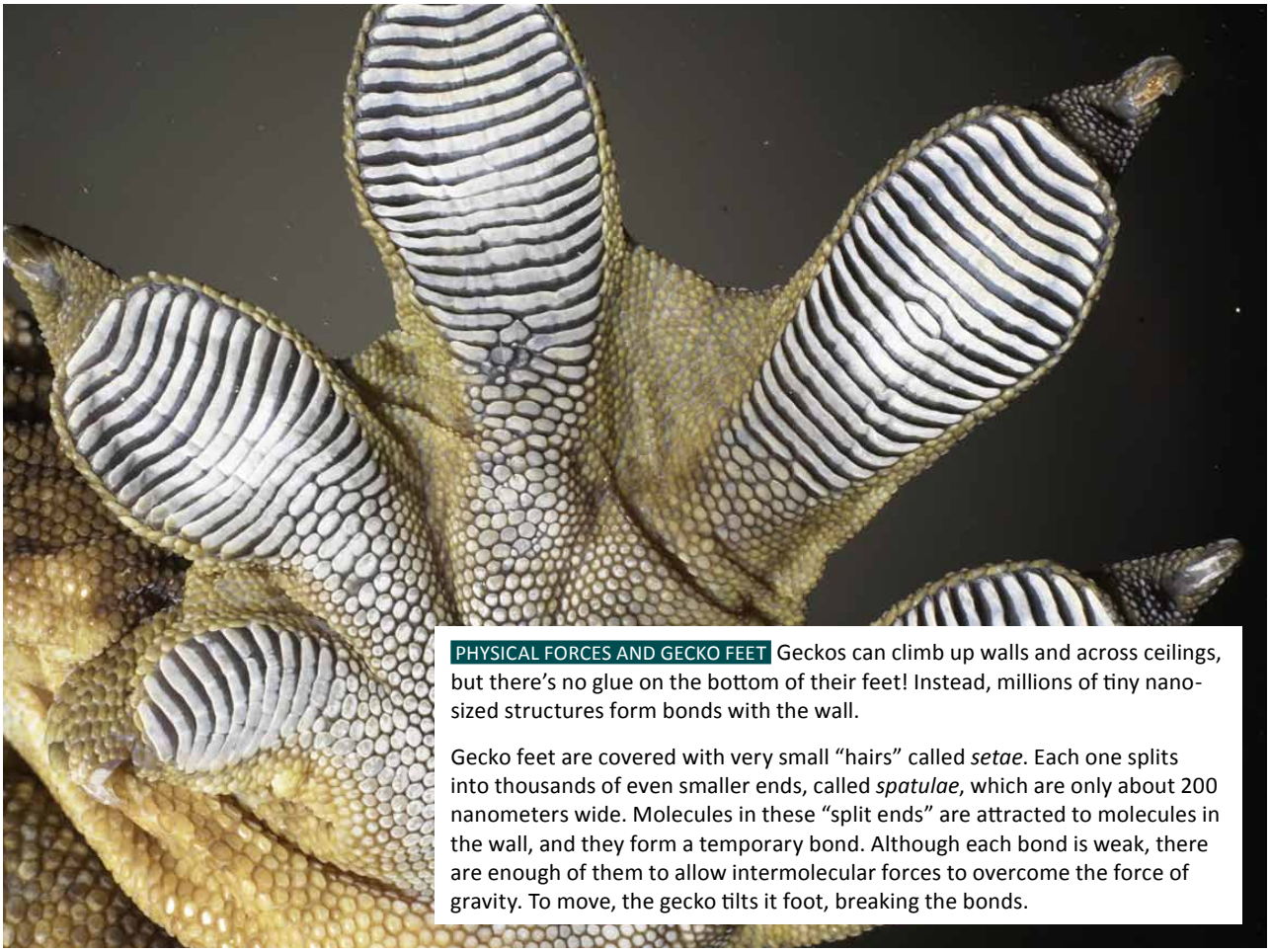
A.Kellar, Lewis & Clark College

Tiny "hairs" on a gecko toe



C. Mathisen, FEI Company





A.Dhinojwala, University of Akron

PHYSICAL FORCES AND GECKO FEET Geckos can climb up walls and across ceilings, but there's no glue on the bottom of their feet! Instead, millions of tiny nano-sized structures form bonds with the wall.

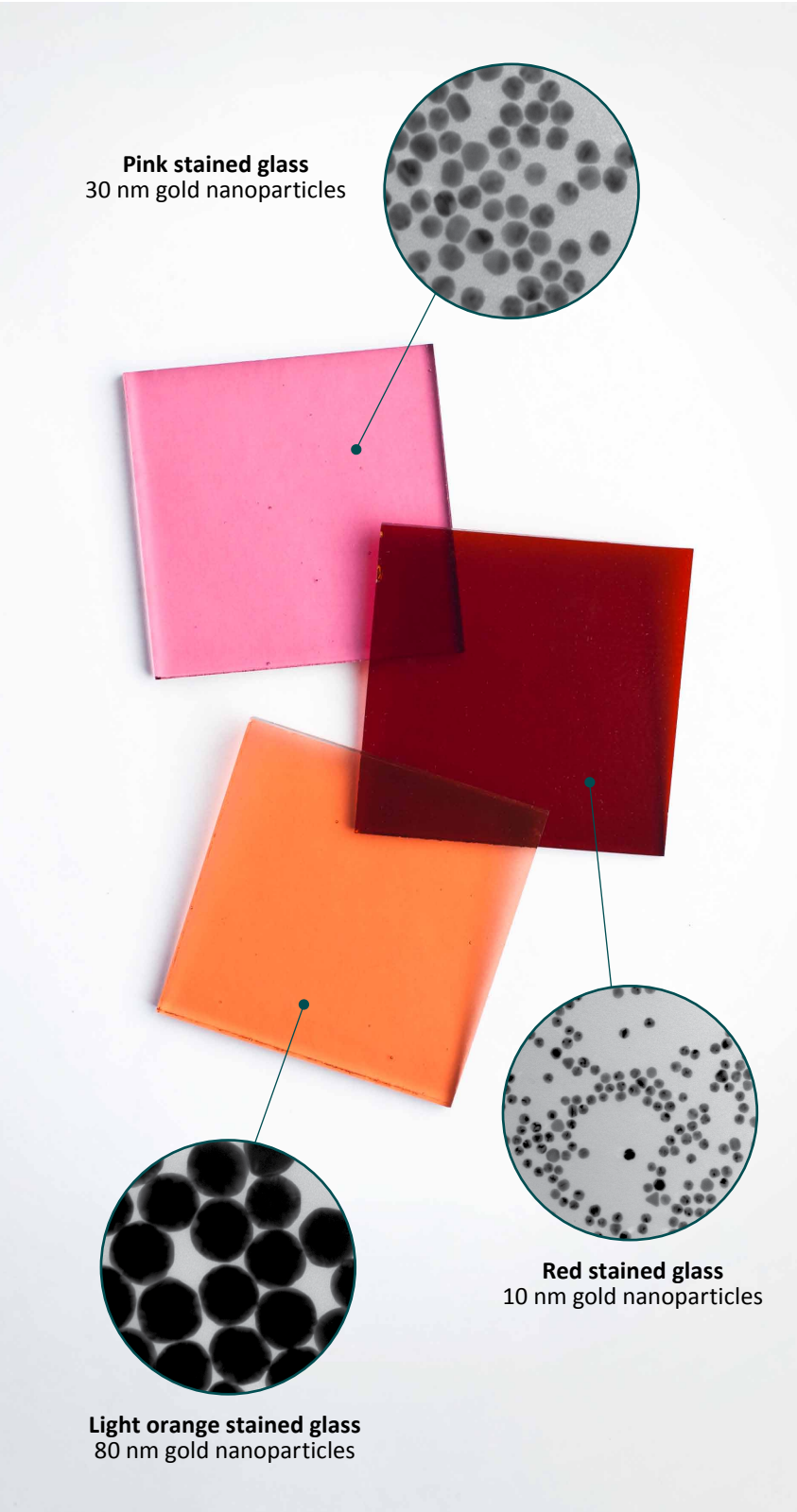
Gecko feet are covered with very small "hairs" called *setae*. Each one splits into thousands of even smaller ends, called *spatulae*, which are only about 200 nanometers wide. Molecules in these "split ends" are attracted to molecules in the wall, and they form a temporary bond. Although each bond is weak, there are enough of them to allow intermolecular forces to overcome the force of gravity. To move, the gecko tilts it foot, breaking the bonds.

Nanoscale properties can lead to new uses for common materials.

Nanomaterials and nanotechnologies take advantage of novel properties at the nanoscale. For example, some materials appear as a different color on the nanoscale, because light interacts differently with very small particles. Scientists are learning how to take advantage of special nanoscale properties to create new materials and technologies.

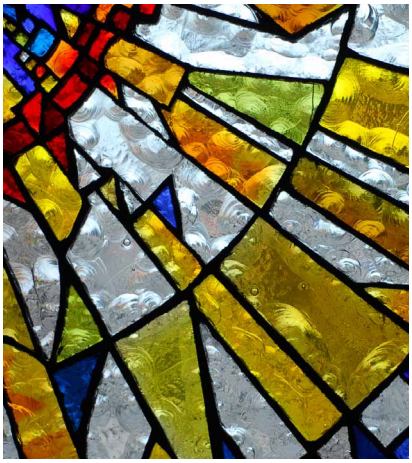
MINERAL SUNBLOCKS Lifeguards used to put white ointment on their noses made of microscale mineral particles that blocked UV rays (titanium dioxide or zinc oxide). Today, many sunblocks are transparent because they're made with nanoscale mineral particles.

Nanoscale particles offer the same UV protection, but they're so small that they don't reflect visible light. Sunblocks are one of the most common applications of nanotechnology.



NANOSCALE GOLD Gold is a familiar metal, but on the nanoscale, it has some unfamiliar properties. Large pieces of gold are shiny and golden, but nanoparticle gold can be red, purple, or blue. The color depends on the size of the particles and the distance between them.

Nanoscale gold has been the secret ingredient in red stained glass since the Middle Ages! Today, the color-changing properties of gold nanoparticles have many different medical and biological applications.



2.

Nano is studying and making tiny things

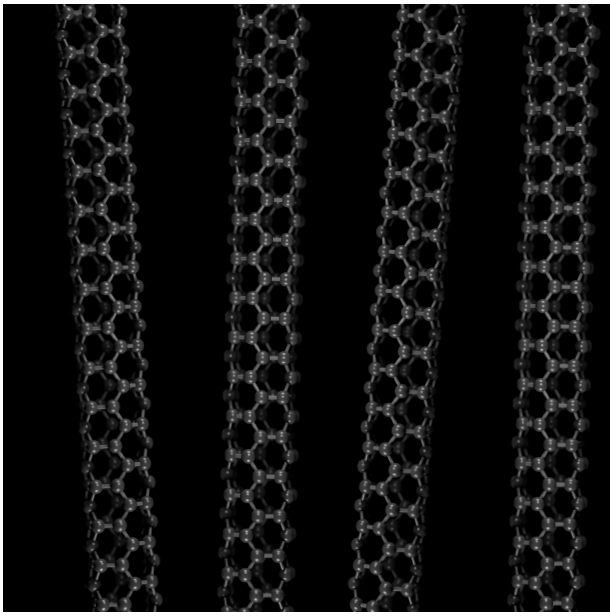
Scientists and engineers have formed the interdisciplinary field of nanotechnology by investigating properties and manipulating matter at the nanoscale.

Everything is made of atoms.

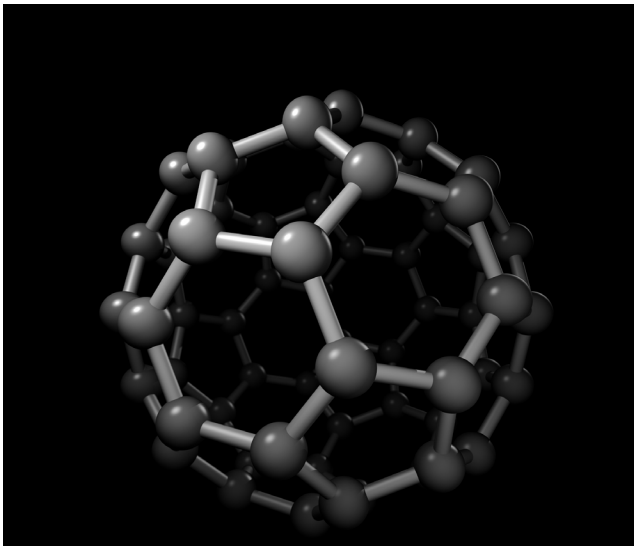
Everything on Earth is made of *atoms*, which are tiny particles smaller than a nanometer. Carbon, oxygen, and hydrogen are examples of atoms. Atoms join together in different ways to form *molecules*. The way these tiny building blocks are arranged helps determine the properties, or behavior, of a material.

DIAMOND AND GRAPHITE Carbon atoms can form diamonds, the hardest natural material known on Earth. But they can also form one of the softest materials, graphite (pencil lead). Both diamonds and graphite are made entirely from carbon. They have different properties because the carbon atoms are arranged differently. Diamonds are hard and shiny because they have a sturdy molecular structure. Graphite is soft and slippery because its carbon atoms are stacked in sheets.

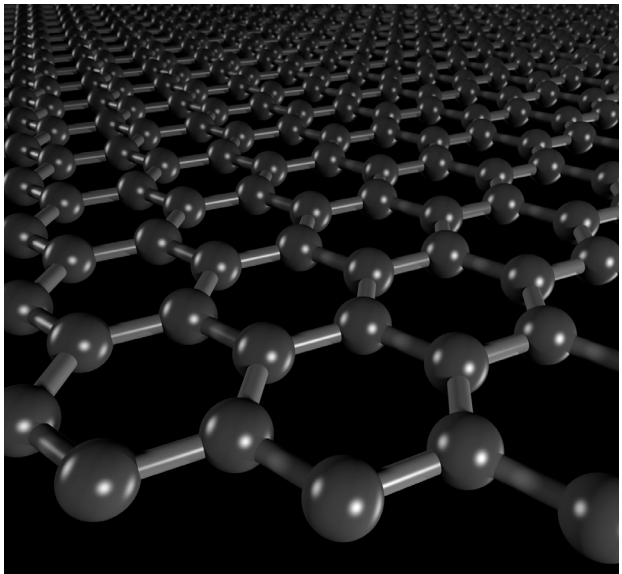
CARBON NANOTUBES AND BUCKYBALLS Carbon can form nanoscale structures, including carbon nanotubes, buckyballs, and graphene. Like larger forms of carbon, these tiny objects have special properties due to the way their carbon atoms are arranged. Researchers are now able to study these nanoscale forms of carbon and use them to build nanotechnologies.



CARBON NANOTUBES are very strong and light, and can act as semiconductors or conductors. Researchers are studying ways to use carbon nanotubes in electronics, fuel cells, and other technologies.



BUCKYBALLS are good lubricants because of their spherical shape. Their hollow structure could make them useful for delivering medicine in the future.

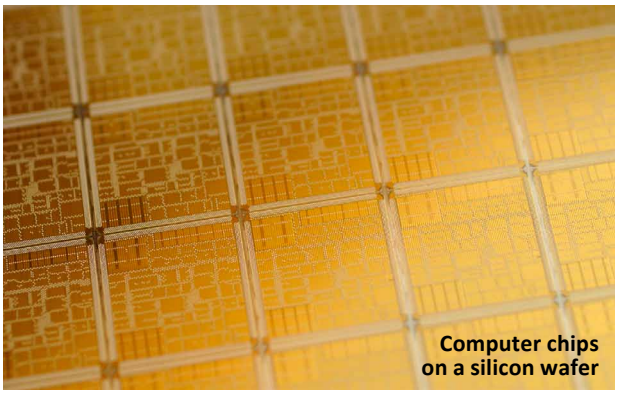


GRAPHENE is strong and flexible, and it conducts electricity and heat. Potential uses for graphene include integrated circuits in computers and sensors to detect gases.

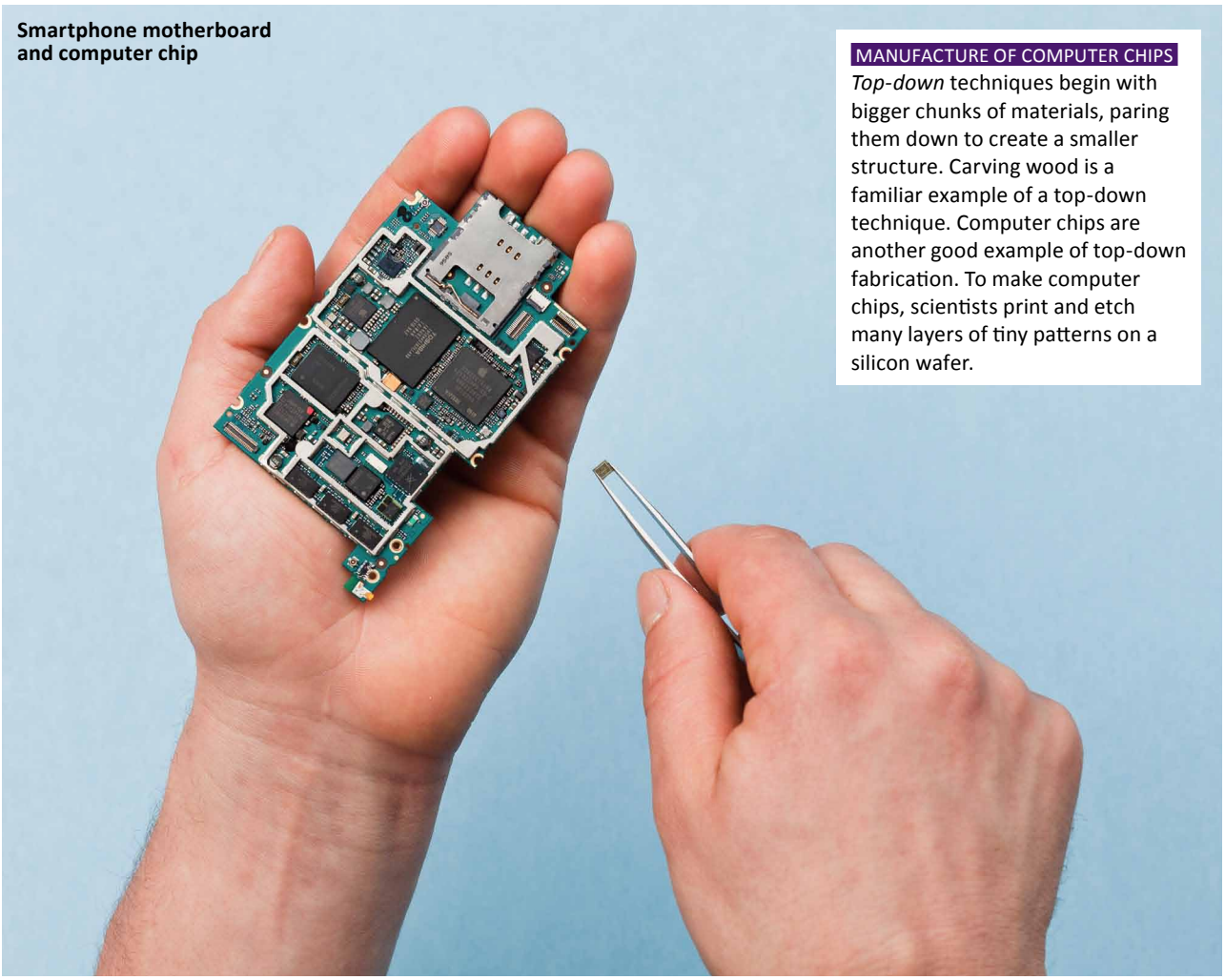
Scientists have developed new ways to study and build tiny nanoscale things.

Nanoscientists and engineers study and make things that are less than 100 nanometers in size. Sometimes nanotechnologies and materials can be built from individual atoms!

To work at such a small scale, nano researchers have developed new ways to investigate and build tiny things. The two main ways to make nanoscale objects and devices are known as *top-down* and *bottom-up* techniques.



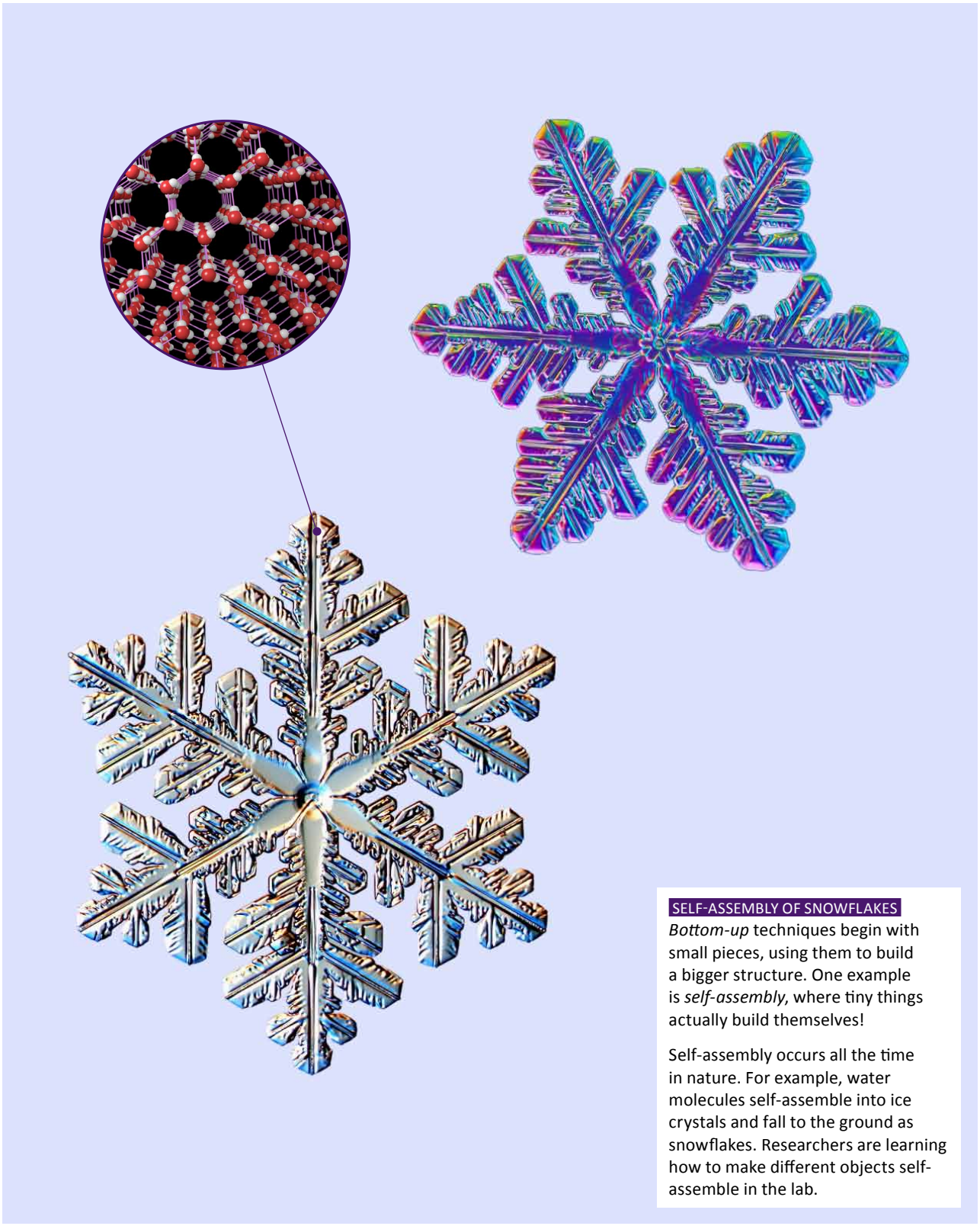
Computer chips on a silicon wafer



Smartphone motherboard and computer chip

MANUFACTURE OF COMPUTER CHIPS

Top-down techniques begin with bigger chunks of materials, paring them down to create a smaller structure. Carving wood is a familiar example of a top-down technique. Computer chips are another good example of top-down fabrication. To make computer chips, scientists print and etch many layers of tiny patterns on a silicon wafer.



Snowflakes: Kenneth Libbrecht, Caltech, www.snowcrystals.com, Crystal structure: Martin McCarthy

SELF-ASSEMBLY OF SNOWFLAKES

Bottom-up techniques begin with small pieces, using them to build a bigger structure. One example is *self-assembly*, where tiny things actually build themselves!

Self-assembly occurs all the time in nature. For example, water molecules self-assemble into ice crystals and fall to the ground as snowflakes. Researchers are learning how to make different objects self-assemble in the lab.

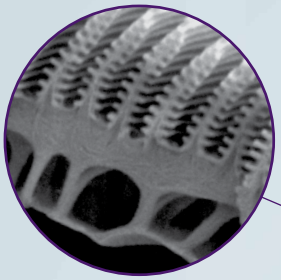
Nano is all around us—in nature and in technology.

Some of the beautiful and surprising things we observe in nature are due to special nanoscale properties. The iridescent color of insect wings, the self-cleaning property of lotus leaves, and the "sticky" feet of geckos are examples of natural phenomena caused by tiny nanostructures. Researchers can be inspired by nature to create new materials and technologies.

Qualcomm Technologies, Inc.

Low-energy display

Tiny nanostructures: S Yoshioka, Osaka University

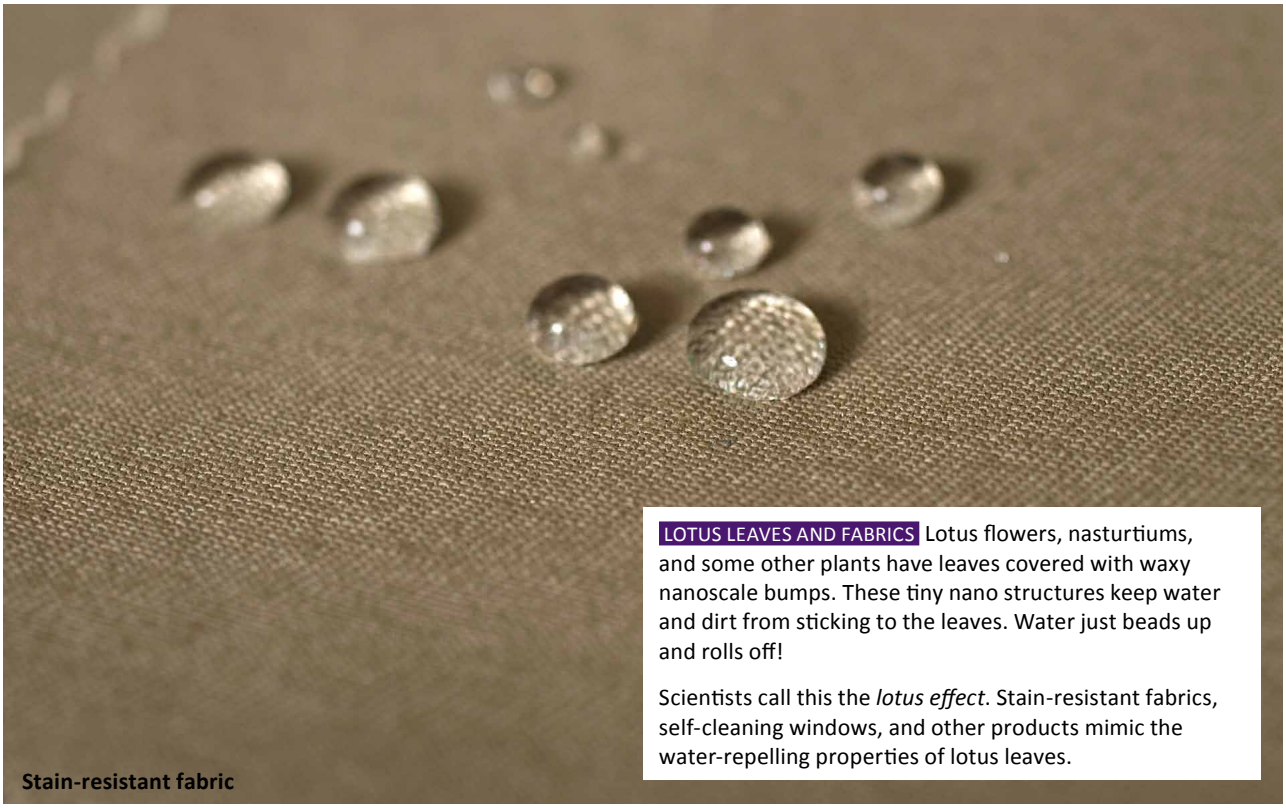


Tiny nanostructures on the scales of a Blue Morpho butterfly

BUTTERFLY WINGS AND DISPLAYS Blue Morpho butterfly wings are a bright, shimmering blue. Surprisingly, their iridescent color is actually created by tiny, colorless scales with nano-sized ridges! Light waves bounce off the scales and interfere with each other, reflecting blue light to your eyes.

Researchers are working on new nanotechnologies that mimic the Blue Morpho's wings. They've already invented low-energy displays that adjust the spacing between materials to create colors.

Water drops on a lotus leaf



Stain-resistant fabric

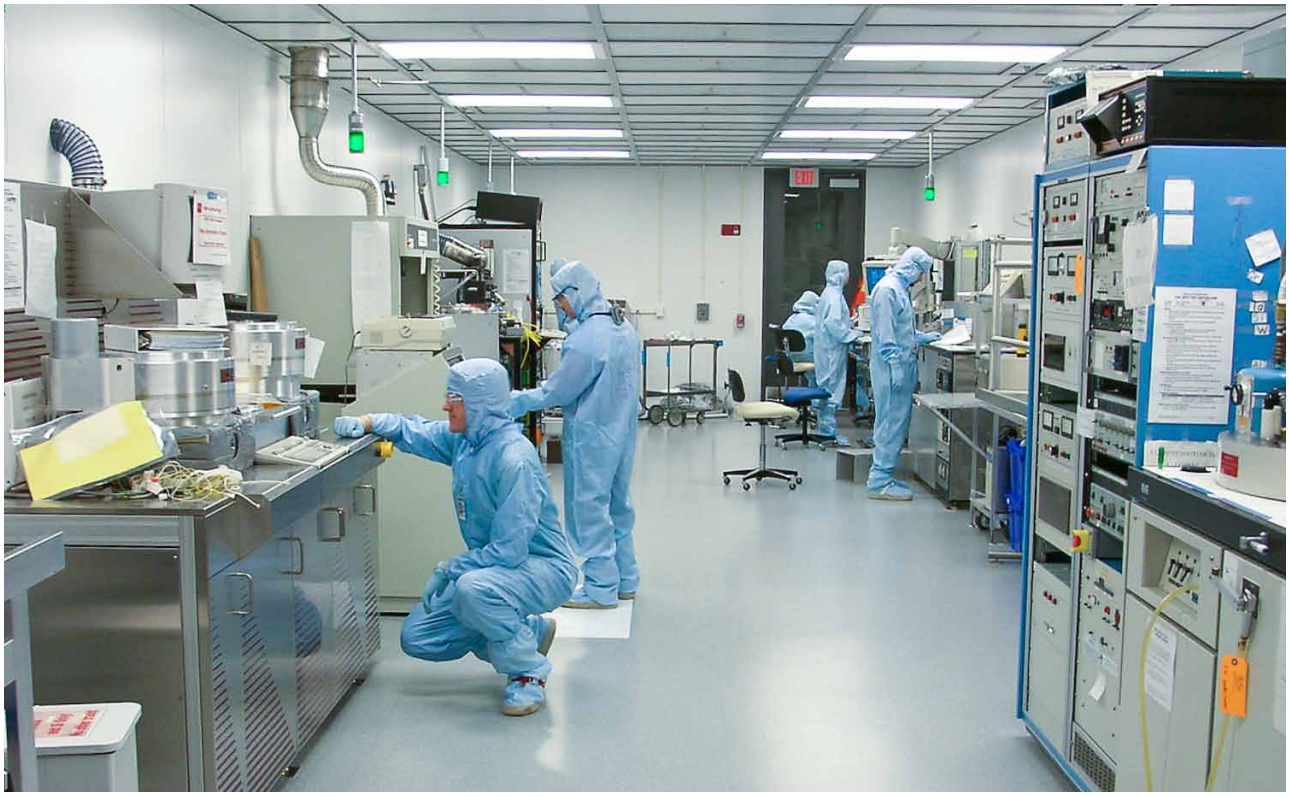
LOTUS LEAVES AND FABRICS Lotus flowers, nasturtiums, and some other plants have leaves covered with waxy nanoscale bumps. These tiny nano structures keep water and dirt from sticking to the leaves. Water just beads up and rolls off!

Scientists call this the *lotus effect*. Stain-resistant fabrics, self-cleaning windows, and other products mimic the water-repelling properties of lotus leaves.

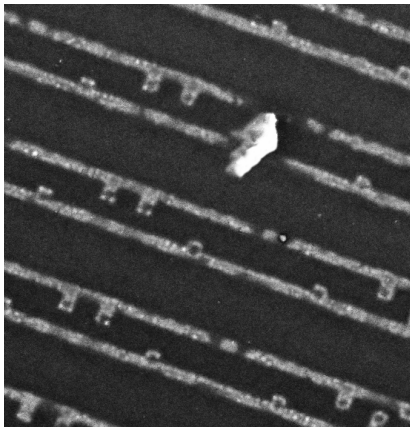
Nanoscale science, engineering, and technology are possible because of new tools and techniques.

Nanoscale science and engineering is a large, interdisciplinary field. Nanoscientists and engineers work in many areas of science, including physics, chemistry, materials science, and biology.

Nano research often combines two or more fields, allowing new ideas, knowledge, and innovations to emerge. By working together, researchers with different expertise can tackle problems in new ways.



Cornell NanoScale Science & Technology Facility / Charles Harrington Photography

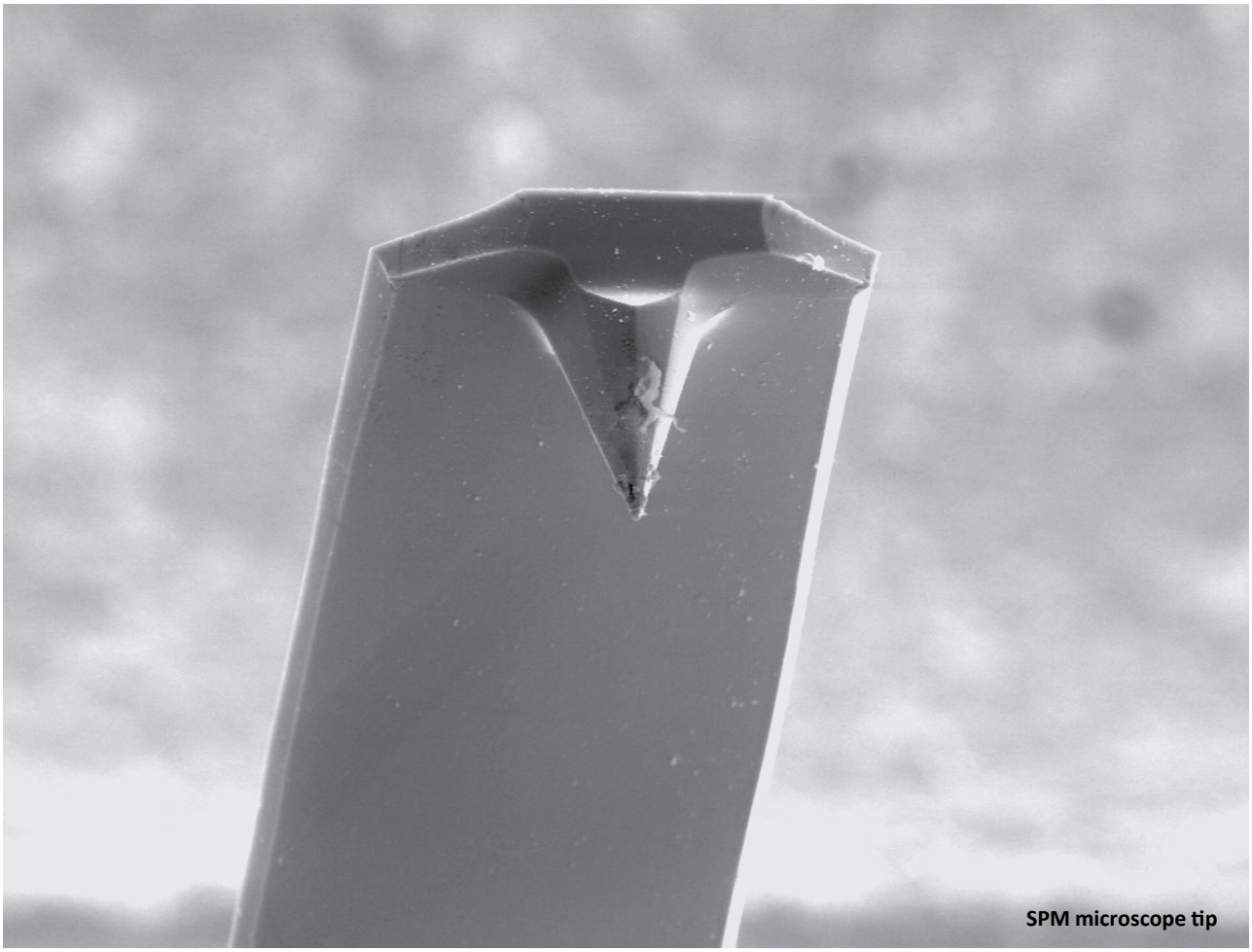


Dust on a computer chip

NANO LABS Computer chips and some other nanotechnologies are made in labs known as *cleanrooms*. Dust and other tiny particles in the environment are huge in size compared to nanoscale objects. Just one speck of dust can destroy an entire device!

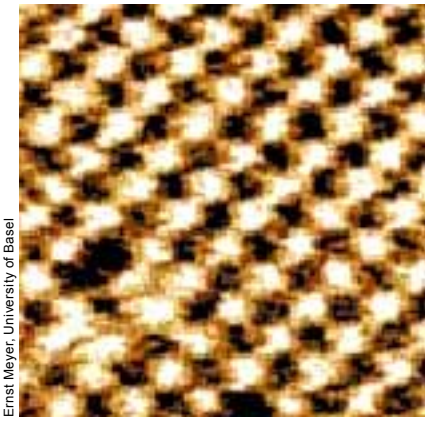
Cleanrooms let researchers study and build nanoscale things. Researchers who work in cleanrooms use special clothes, tools, and equipment.

Researchers have developed new tools and techniques to work on the nanoscale. Nanoscale objects are too small to see with regular microscopes, because they're smaller than the wavelength of visible light. Tools such as scanning probe microscopes (SPMs) allow researchers to image and move nanoscale objects, making the field of nanotechnology possible.



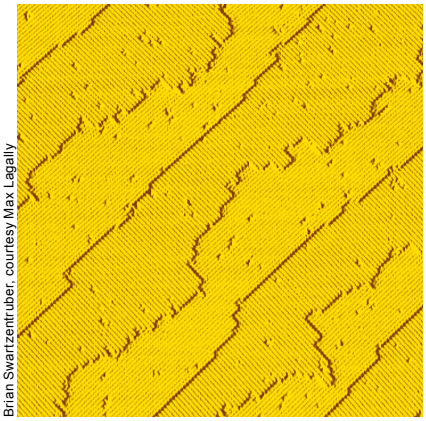
SecretDisc

SPM microscope tip



Ernst Meyer, University of Basel

SPM image of salt



Brian Swartzentruber, courtesy Max Lagally

SPM image of silicon

SCANNING PROBE MICROSCOPE Scanning probe microscopes can detect and make images of things as small as a single atom!

SPMs have a sharp tip that moves back and forth across a sample. As it moves, the tip "feels" and measures changes in the surface. A computer combines the information gathered by the tip and makes an image.

Some kinds of SPMs can also be used to move atoms around. This allows researchers to build tiny things one atom at a time!

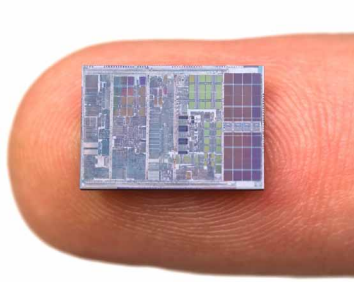
3.

Nano is new technologies

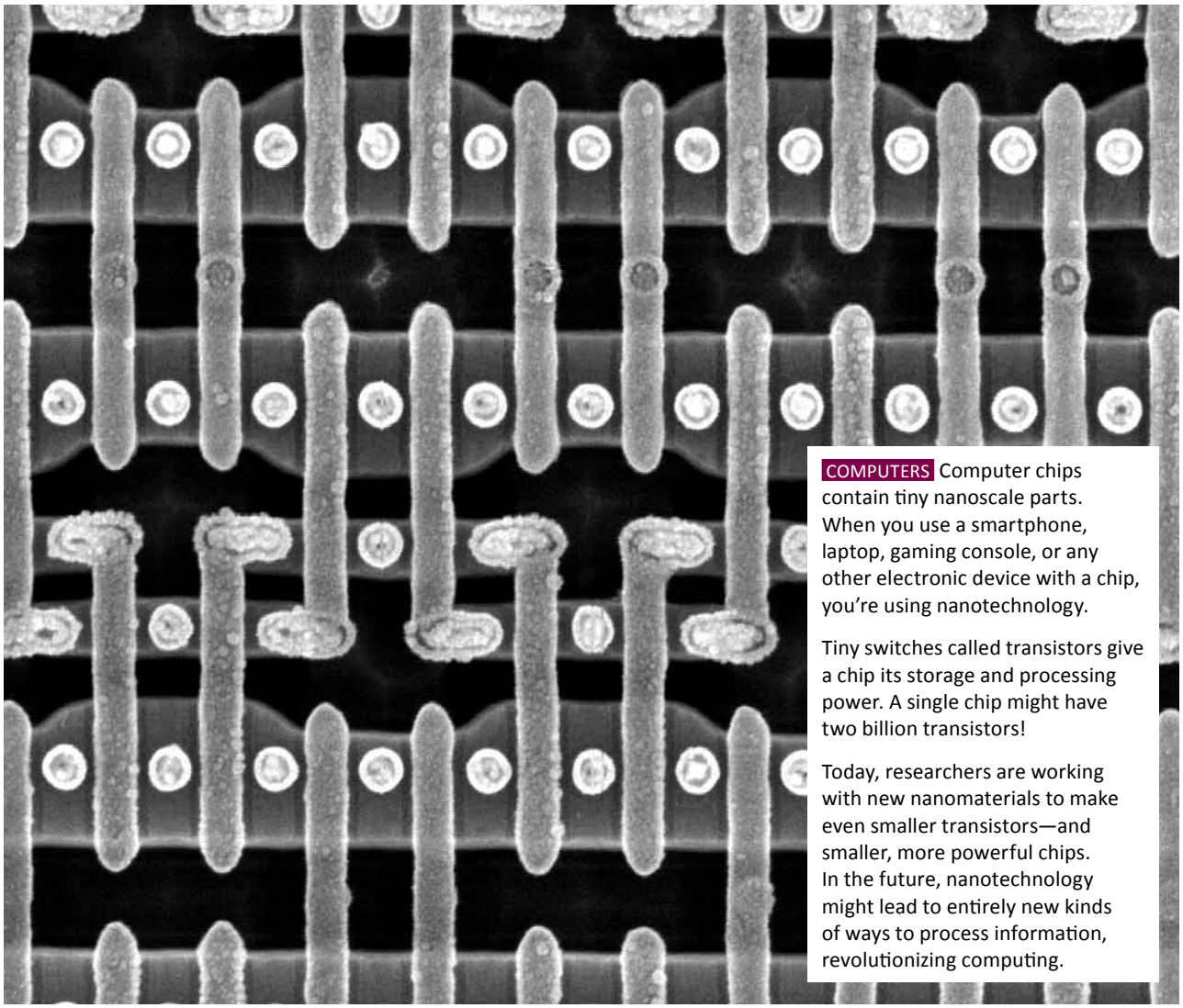
Nanoscale science, engineering, and technology lead to new knowledge and innovations that weren't possible before.

Researchers and engineers use nanoscale properties to improve and create materials, devices, and applications.

Nanotechnology is not all one thing—there are many different nanoscale technologies. Nanotechnology includes a wide range of research and applications in areas such as computing, food science, and medicine. It allows us to improve existing products by reengineering them at the nanoscale. For example, nanotechnology makes sunblock transparent and computer chips faster.



Nanoscale transistors inside a cell phone microprocessor chip



COMPUTERS Computer chips contain tiny nanoscale parts. When you use a smartphone, laptop, gaming console, or any other electronic device with a chip, you're using nanotechnology.

Tiny switches called transistors give a chip its storage and processing power. A single chip might have two billion transistors!

Today, researchers are working with new nanomaterials to make even smaller transistors—and smaller, more powerful chips. In the future, nanotechnology might lead to entirely new kinds of ways to process information, revolutionizing computing.

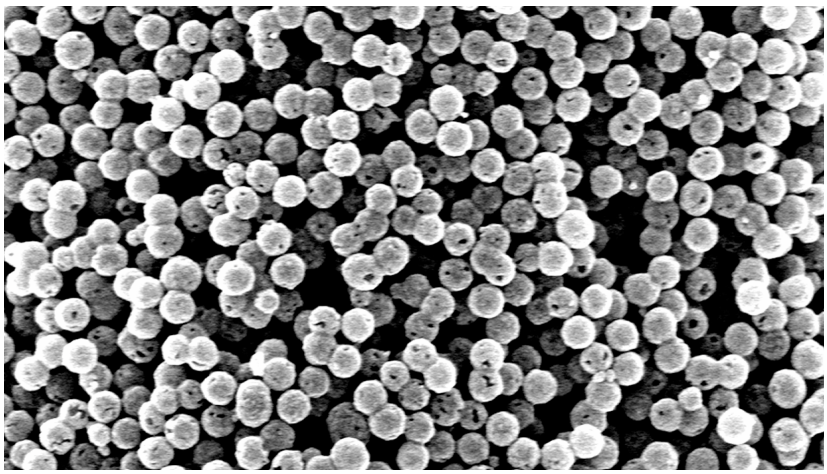
Chipworks, www.chipworks.com

FOOD Nanotechnology is already on the shelves of your supermarket. Tiny nanostructures make some brands of ice cream look and taste better, while nanoparticles in bottles can keep beer fresh. Supplements contain nanoscale nutrients that are readily absorbed by your body.

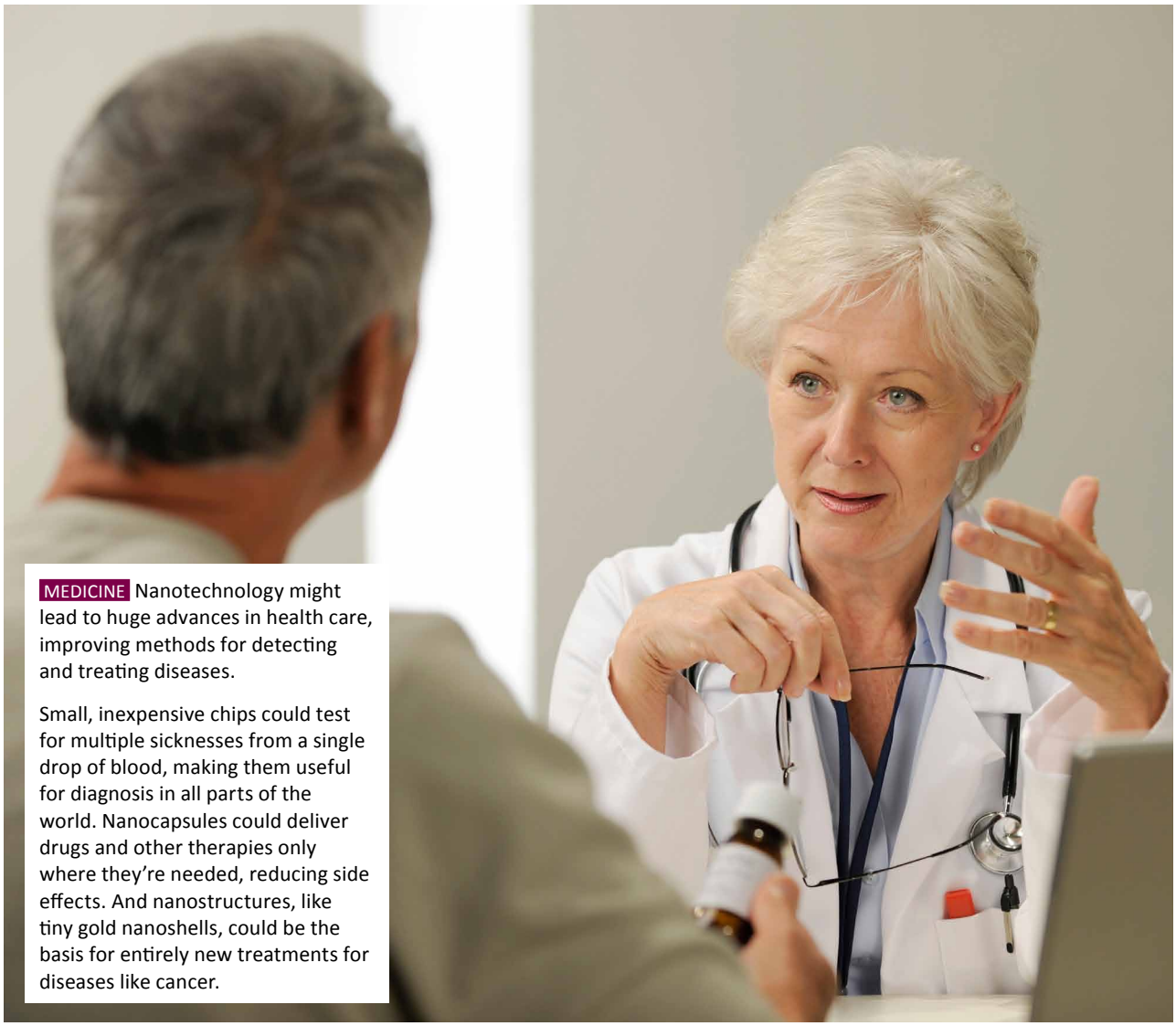
In the future, nanotechnology could be used in all stages of food production, from cultivation to processing to distribution. Nanosensors might be deployed in farm fields, monitoring plant health and dispensing water and nutrients as needed. Other sensors might detect microbes such as salmonella, keeping harmful foods from entering stores.

Nanotechnology also allows us to create entirely new materials and technologies. Right now, most of the nanotechnology you come across is incorporated into certain consumer products. But future applications of nanotechnology will address issues of global importance such as food, water, medicine, and energy.

Gold nanoshells



G.Koeing, University of Wisconsin-Madison



MEDICINE Nanotechnology might lead to huge advances in health care, improving methods for detecting and treating diseases.

Small, inexpensive chips could test for multiple sicknesses from a single drop of blood, making them useful for diagnosis in all parts of the world. Nanocapsules could deliver drugs and other therapies only where they're needed, reducing side effects. And nanostructures, like tiny gold nanoshells, could be the basis for entirely new treatments for diseases like cancer.

ENERGY Nanotechnology could transform the ways we create, transmit, store, and use energy. Some scientists think nanotechnology will allow us to build ultra-efficient transmission lines for electricity, produce more effective and inexpensive solar cells, make cheap, efficient biofuels, and improve the safety of nuclear reactors.

But more research and investment is needed before nanotechnology energy solutions are developed or widely distributed.

4.

Nano is part of our society and our future

Nanotechnologies have costs, risks, and benefits that affect our lives in ways we cannot always predict.

Nanotechnology will affect our economy, environment, and personal lives.

Some scientists think that nanotechnology could transform our lives just as much as cars or computers! As individuals and communities, we'll need to balance the costs, risks, and benefits of different nanotechnologies. Citizens, scientists, government agencies, and companies can work together to maximize the benefits of nanotechnology and minimize the risks.

HEALTH AND BEAUTY PRODUCTS

Certain shampoos, cosmetics, toothpaste, and other personal care products contain nanotechnology.

For example, many sunblocks contain nanoparticles of zinc oxide and titanium dioxide. Cosmetic products aren't regulated by the Food and Drug Administration (FDA), and their labels don't have to indicate if they contain nanoparticles. This concerns some advocates for consumers and the environment.

Materials can act differently when they're nanoscale, so an ingredient that's safe on the microscale isn't necessarily safe on the nanoscale.

Everyone has a role in shaping nanotechnology. Companies and governments decide which technologies to invest in and how to regulate them. Individuals can help shape nano research and development by deciding whether to use products containing nanotechnology. As we develop and use new nanomaterials and technologies, we need to consider how to do so in a way that's equitable and responsible.

NANOSILVER Nanosilver is one of the most common nanomaterials found in consumer products today. Silver is naturally antimicrobial, and nanoscale particles of silver are especially effective at killing germs. Bandages, washing machines, cutting boards, doorknobs, and even socks can contain nanosilver.

There are tradeoffs to using nanosilver products, and many people feel differently depending on the product. Nanosilver equipment in hospitals can help prevent dangerous infections, but overuse of nanosilver could lead to highly bacteria-resistant "superbugs." Nanosilver socks can keep feet from smelling, but their washwater could contaminate water supplies, harming fish and other wildlife.

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www.nisenet.org

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