Nanotechnology

Big Things from a Tiny World

Think small. Think really, really small—smaller than anything you ever saw through a conventional microscope at school.

Think atoms and molecules, and now you're there.
You're down at the nanoscale, where scientists are learning about these fundamental components of matter and are putting them to use in beneficial ways.

Working at the nanoscale, scientists are creating new tools, products, and technologies to address some of the world's biggest challenges, including:

- smaller, faster, more portable electronics with larger data storage capacity.
- medical devices and drugs to detect and treat diseases more effectively with fewer side effects.
- low-cost filters to provide clean drinking water.
- stronger, lighter, more durable materials.
- techniques to clean up hazardous chemicals in the environment.
- sensors to detect and identify harmful chemical or biological agents.

What is Nano?

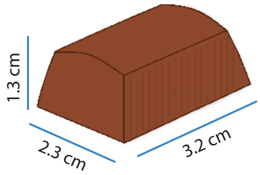
So what is nanotechnology? Nanotechnology is science, engineering, and technology at the nanoscale, which is about 1 to 100 nanometers. Nanotechnology is the study and application of extremely small things and is used across all other science fields, such as chemistry, biology, physics, materials science, and engineering.

What's so special about the nanoscale? The short answer is that **materials can have different properties at the nanoscale**—some are better at conducting electricity or heat, some are stronger, some have different magnetic properties, and some reflect light better or change colors depending on their size.

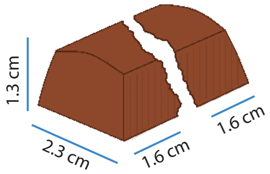
Nanoscale materials also have far larger surface areas than similar volumes of larger-scale materials, **meaning that more surface is available for interactions** with other materials around them, making nanomaterials ideal for many applications that require high surface area, such as batteries.

If you have block of a material, only its surface will interact with its surroundings. If more surface is exposed, then more of the material is available for a reaction. Cutting up that block of material will increase its surface area while keeping the total amount of material the same. For example, you don't just swallow a piece of chocolate: you chew it up so it can interact with more of your taste buds.

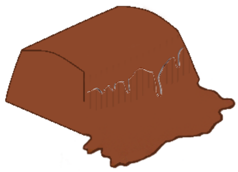
Imagine putting a block of chocolate in your mouth. It has a surface area of about 25.7 cm^2. If you bite it in half, you increase the amount of chocolate you can taste to 30.8 cm^2, about half the area of a Post-it™ note. Bite each of those pieces in half and now you've got 41.5 cm^2 of chocolate to enjoy. If you keep chewing until you have 1 nanometer sized cubes of chocolate, you'd have a surface area equal to almost 10 football fields (but still just the calories from one piece!).



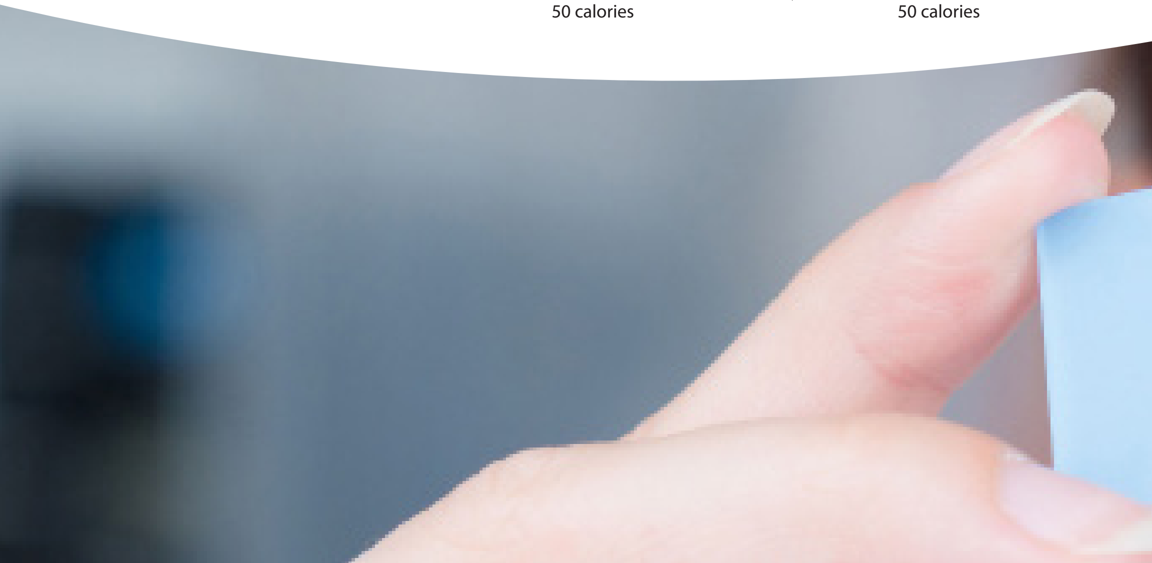
One piece of chocolate:
25.7 cm^2 of surface area
50 calories



Bite it in half:
30.8 cm^2 of surface area,
about half a Post-it™
50 calories



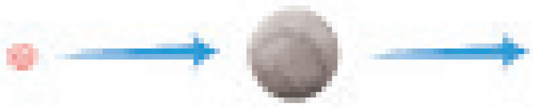
Break it down to 1 nm cubes:
510,000,000 cm^2 of surface area,
about 10 football fields
50 calories



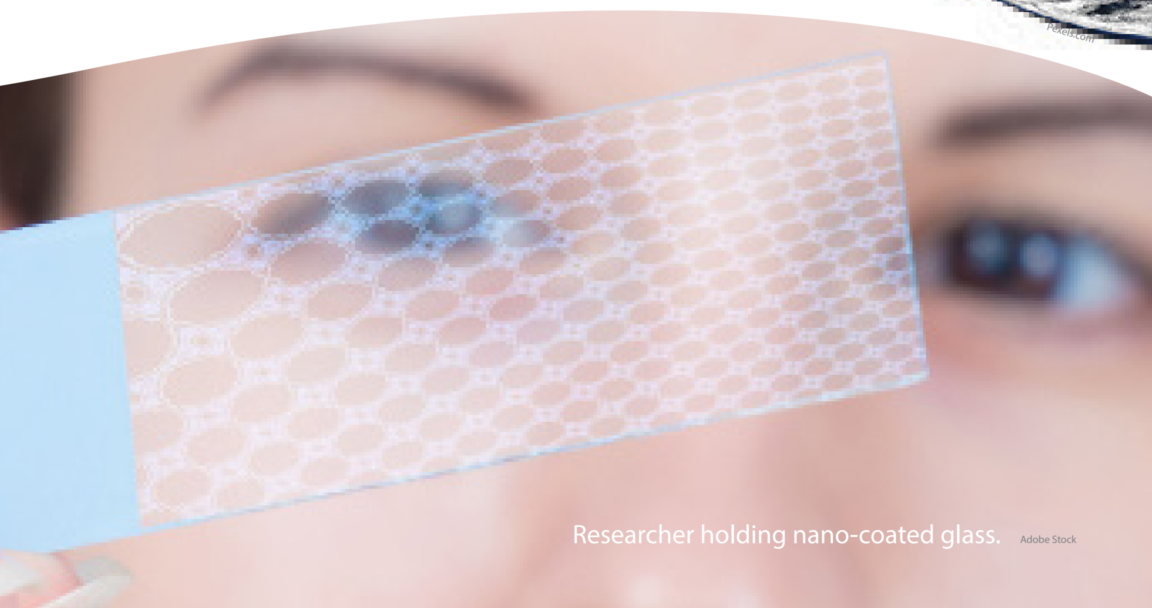
Visualizing the Nanoscale

Just how small is "nano?" In the International System of Units, the prefix "nano" means one-billionth, or 10^{-9}; so one nanometer is one-billionth of a meter. It's difficult to imagine just how small that is, so here are some examples:

- A sheet of paper is about 100,000 nanometers thick.
- A strand of hair is 80,000 – 100,000 nanometers in diameter.
- There are 25,400,000 nanometers per inch.
- Your fingernails grow about one nanometer per second!



If a buckyball were as big as a softball, a softball would be as big as the Earth. (A buckyball is a buckminsterfullerene molecule with 60 carbon atoms arranged in a sphere, with a diameter of 1.1 nanometers.)



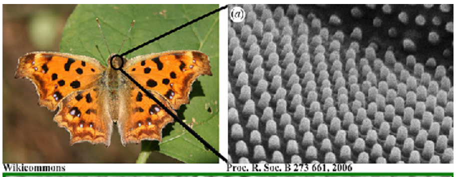
Researcher holding nano-coated glass. Adobe Stock

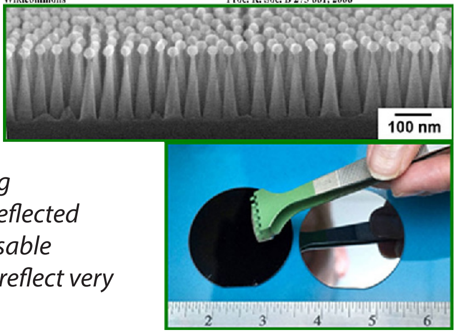
Biomimicry

Biomimicry is the design and production of materials and structures that are inspired by naturally occurring materials and processes. Nanoscale materials are common in nature. From the molecular machines that translate DNA into proteins to the structures that keep leaves clean and bacteria off insect wings, nature operates at the nanoscale. Our bodies use natural nanoscale materials, such as proteins and other molecules, to function.

In fact, **many important functions of living organisms take place at the nanoscale**; the diameter of double-stranded DNA is just 2.5 nanometers. Researchers have copied the nanostructure of lotus leaves to create water-repellent surfaces. Today, these coatings are used to make stain-proof clothing and anti-icing coatings for airplane wings and wind turbines. Scientists are also creating antimicrobial surfaces that mimic the nanoscale structures on cicada wings.

The gecko's ability to climb has inspired researchers to develop gloves with nanoscale features like the ones on a gecko's foot. These gloves enable a person to climb a wall of glass. Nanoscale structures can control how light is reflected and create the vibrant blue of butterfly wings and peacock feathers. This structural color may be the key to creating camouflage or even an invisibility cloak that bends light, hiding whatever is behind it.





Center for Functional Nanomaterials, Brookhaven National Laboratory.

Scientists are improving solar cells by adding nanoscale texture that traps light so less is reflected away, allowing more to be converted into usable energy. This was inspired by moth eyes that reflect very little light, allowing them to see in the dark.

What distinguishes nanotechnology from nature's use of the nanoscale? Thanks to the development of high-powered microscopes and precision instruments, scientists and engineers can manipulate and control nanoscale materials in a purposeful way.

Iowa State University

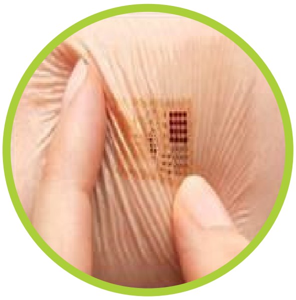
Engineers have made wearable sensors for plants, enabling measurements of water use in crops.

Adobe Stock

Nanotechnology Appl

Nanomedicine
Nanomedicine, the application of nanotechnology in medicine, enables precise solutions for disease prevention, diagnosis, and treatment. This includes new imaging tools like improved MRIs; lab-on-a-chip technologies for rapid testing in a doctor's office; novel gene sequencing technologies; nanoparticles that can help deliver medication directly to cancer cells, minimizing damage to healthy tissue; and graphene nanoribbons to help repair spinal cord injuries.

U.S. Department of Veterans Affairs



J. Rogers, University of Illinois

Wearable Sensors
Scientists are developing smaller and more affordable sensors that can be worn on the body to detect disease or to monitor physiological functions such as temperature or heartbeat. For example, nanomaterials are being used to make flexible, stretchable substrates that conform to the body, allowing doctors to remotely monitor your health and vital signs. Coaches and trainers could use these sensors to monitor athletes to help them reach their peak performance.

Environmental Monitoring and Cleanup
Nanotechnology-enabled sensors and solutions are now able to detect and identify chemical or biological agents in the air, water, and soil with much higher sensitivity than ever before. A smartphone extension has been developed to help firefighters monitor air quality around fires. Researchers have also tested a reusable carbon nanotube sponge for cleaning up oil that can absorb up to 100 times its weight.

freeimage.com

Bio/Nano Tech Group, Univ. of Arkansas

Clean Drinking Water
Nanotechnology is providing solutions to help meet the need for clean, affordable drinking water. Nanotechnology-enabled filters provide rapid, low-cost removal of impurities in water. Engineers have developed a thin-film membrane with nanopores for energy-efficient desalination, turning salt water into drinkable water. Nanocoatings that can be used to prevent organisms from growing on membranes and other surfaces are also being used.

Flexible Electronics
Flexible, bendable, foldable, rollable, and stretchable electronics are being integrated into a variety of applications in medicine, athletics, aerospace, and the Internet of Things. Future potential uses include tablet computers that can roll up to fit in your pocket or clothing and appliances with built-in, flexible displays.

Nanosys

freeimage.com

Energy Operations
Oil companies have developed novel methods for using nanomaterials to refine crude oil into high-value products. Nanomaterials are also reducing cost and improving production levels. Scientists have developed sensors that can quickly detect pipeline leaks for faster repairs and less waste.

IBM

Consumer Electronics

Transistors, the basic switches that enable computing, have gotten smaller and smaller with nanotechnology. Smaller, faster, and better transistors brought about smartphones, wearables, and many other devices we use every day. Novel nanoscale electronic devices may soon help achieve quantum computers, or an entirely new type of supercomputer that can learn and solve problems like a human brain.

Infrastructure

Embedded nanoscale sensors and devices may provide cost-effective continuous monitoring of the structural integrity and performance of bridges, tunnels, railways, parking structures, and pavement over time. Corrosion-resistant, self-healing nano-enabled paints can help bridges and concrete last longer. Nanocoatings could be used to increase the life span of water and sewer pipes.

freeimage.com

freeimage.com

Transportation

Cars have nano-enabled stronger body parts, stain-resistant surfaces, rechargeable batteries, materials for temperature control, better tires, high-efficiency sensors and electronics, and components for cleaner exhaust and extended range.

Nanofilms and Coatings

Clear nanoscale films on displays, windows, and other surfaces can make them water-repellent, antireflective, self-cleaning, resistant to ultraviolet or infrared light, anti-fogging, antimicrobial, scratch-resistant, or electrically conductive. Antibacterial coatings are being developed for use in hospitals. Superhydrophobic coatings make smartphones waterproof. Paints use nanoscale materials to resist marks and scuffs.

Adobe Stock

U.S. Army

Nano-Enabled Clothing

Stain-resistant pants, shirts, ties, and more are now widely available for purchase. There are also nano-enabled uniforms that are not only stain- and dirt-resistant, but protect against chemicals and germs.

Food Safety

Nanosensors in food packaging can measure pathogens and other contaminants in food, indicating if it is safe to eat. Similarly, a sensor has been developed to tell you when a pear is ripe. Nano-enabled packaging protects food from moisture and better traps in carbonation. Scientists have also developed sensors to measure pesticide levels in the field, allowing farmers to use less while still protecting their plants.

freeimage.com

Into the Future

Today, many of our nation's most creative scientists and engineers are finding new ways to use nanotechnology to improve the world in which we live. These researchers envision a world in which new materials, designed at the atomic and molecular level, provide **cost-effective methods** for harnessing energy sources through movement. They forsee nano-enabled diagnostics that will allow doctors to detect disease at its earliest stages—and the treatment of illnesses such as cancer, heart disease, and diabetes with **safer and more effective medicines**. We may soon develop methods of growing artificial muscle to give improved mobility to amputees and wounded veterans. Vaccine scaffolds could enable faster and more effective inoculations for the flu and many other contagious diseases. Although there are many research challenges ahead, **nanotechnology is already producing a wide range of beneficial materials, and shows promise for more breakthroughs in many fields**. Scientific inquiry at the level of molecules has opened up a world of new opportunities.

Adobe Stock

A nanoparticle-based universal flu vaccine may one day provide immunity to all strains, not just the strains predicted to be present during a given flu season.

Advanced textiles with piezoelectric nanowires woven into clothing may allow us to harvest energy through movement. You could charge your phone in your pocket as you walk around.

Adobe Stock

Artificial, self-healing muscle could allow amputees to better control their prosthetics.

Z. Bao, Stanford University

A t-shirt that actively heats and cools will allow the wearer to stay comfortable in any climate.

J. Wang, University of California, San Diego

Nano-enabled microscopic devices you can swallow may one day let doctors diagnose and treat disease without invasive surgery.

ETH Zürich

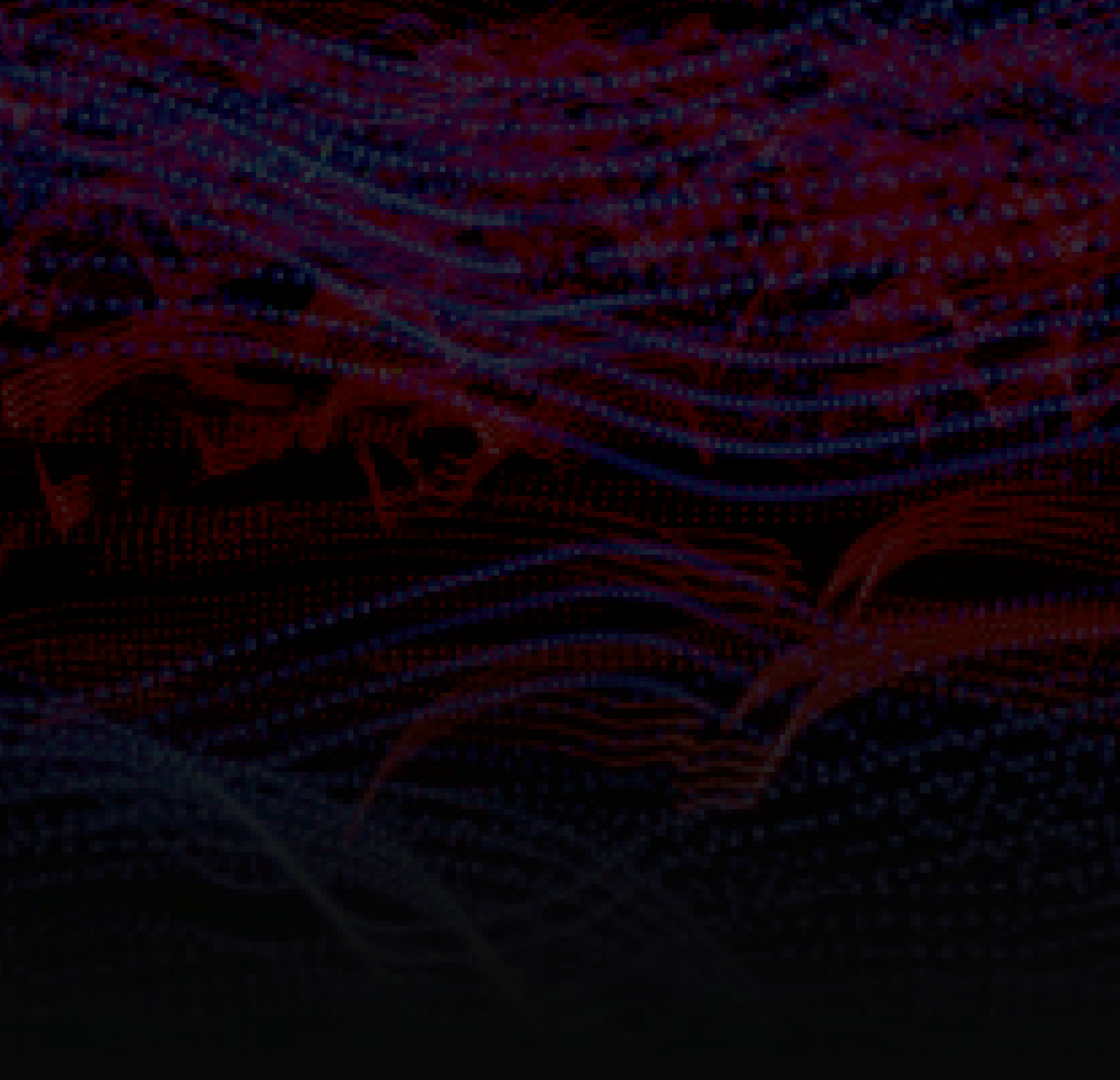
Adobe Stock

About the National Nanotechnology Initiative (NNI)

The United States set the pace for nanotechnology innovation worldwide with the advent of the NNI in 2000. The NNI is a U.S. Government research and development (R&D) initiative involving the nanotechnology-related activities of Federal departments and independent agencies. It brings together the expertise needed to advance this broad and complex field—creating a framework for shared goals, priorities, and strategies that helps each participating agency leverage the resources of all participating agencies. With the support of the NNI, nanotechnology R&D is taking place in academic, government, and industry laboratories across the United States.

The NNI is committed to the responsible development of nanotechnology. Nanotechnology environmental, health, and safety research is one of the important activities of the NNI in support of responsible development. For more information, visit www.nano.gov/you/environmental-health-safety.

For more information on the NNI, see www.nano.gov.



National Nanotechnology Coordination Office

2415 Eisenhower Ave.
Alexandria, VA 22314
202-517-1050

info@nnco.nano.gov
www.nano.gov