
Nano Sonic
NANOTECHNOLOGY
COLORING BOOK

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NANOTECHNOLOGY

COLORING BOOK

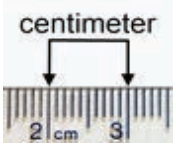
Nanotechnology deals with a tiny world that can't be seen with our eyes. Nanotechnology is the understanding and control of matter at the nanoscale. Nanoscale uses dimensions between 1 and 100 nanometers (nm). A nanometer is so small that the thickness of a sheet of paper measures about 100,000 nanometers. There are 25,400,000 nanometers in one inch. One meter, or yardstick, contains one billion nanometers.

At the nanoscale, materials are engineered with atoms and molecules – the basic, miniscule building blocks of normal matter in the universe. Atoms are even smaller than a nanometer and often are approximately measured in an even tinier unit called a picometer. There are 1000 picometers in one nanometer. An oxygen atom measures approximately 100 picometers across – or one-tenth of a nanometer. The diameter of a water molecule, consisting of one oxygen atom and two hydrogen atoms, measures about 140 picometers across. And there are 30 billion water molecules in a teaspoon of water!

In this small, small world, materials often behave differently because it's easier for atoms and molecules to move around and between one another. For example, copper (a metal) is transparent at the nanoscale. Gold, which is normally unreactive, becomes chemically very active at the nanoscale. Carbon, which is quite soft in its graphite form (the black stuff in pencils), becomes very hard when tightly packed into tiny structures called nanotubes. So, materials can have different physical properties on the nanoscale even though they're still the same materials!

On the nanoscale, gravity is much less important. The smell of baking cookies is a good example. The molecules that are released from a cookie when it bakes are less than a nanometer in size. They are carried through the air to our noses because they are so small that gravity does not have much effect on them. They float through the air and when they are less than a nanometer away, our noses smell them.

This book contains pictures and text related to nanotechnology on about a US fifth grade science level. Most of the images appear as abstract art. When you color them, you can let your imagination run wild because most images of the nano world are taken with an electron microscope in black-and-white. Researchers then apply their own colors to make them interesting and show special features.
The sky's the limit!



One meter equals 100 centimeters.
One centimeter equals 1,000 millimeters.
One meter also equals 3.28 feet or ~39 inches.

EXERCISE: Measure something in your classroom or at home that is one meter long.

What did you measure?_____

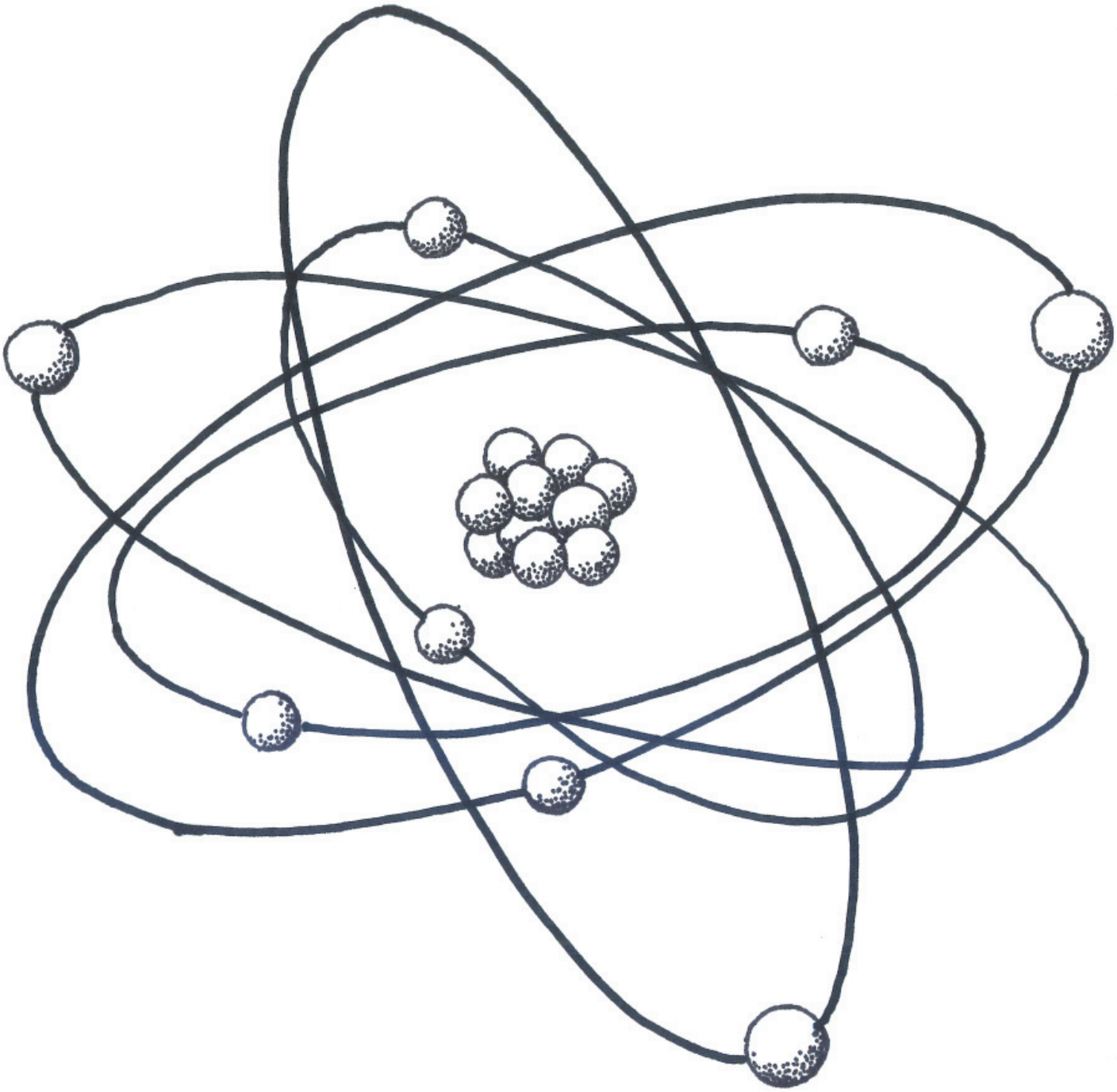


Image based on illustration by Science Spot

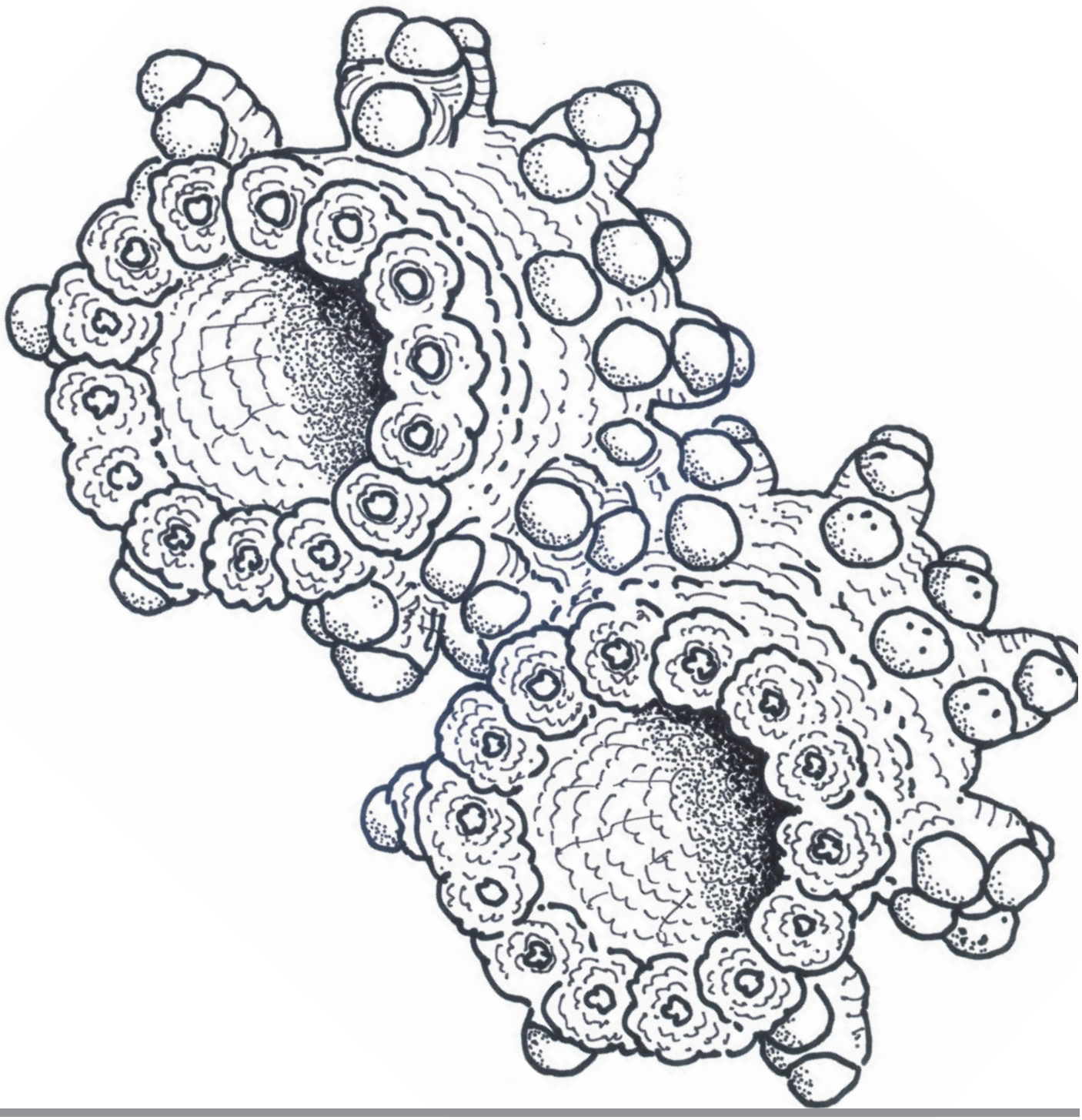
Atom

The atom is a basic unit of matter that consists of a dense central nucleus surrounded by a cloud of negatively charged electrons. The name 'atom' comes from a Greek word that means uncuttable, or indivisible, something that cannot be divided further.

SIZE: Approximately one-tenth of one nanometer

What is the smallest item you can see in your classroom or at home? _____

Image based on illustration from Great Images in NASA



Benzene Nanogears

Benzene molecules, composed of carbon and hydrogen atoms, can be bound with carbon nanotubes to form nanogears. Nanogears are teeny, tiny machines with gear "teeth" made of benzene for stability and flexibility. Benzene is chemical compound used in plastics, paints, rubber, resins, detergents, lubricants and synthetic fabrics.

SIZE: Each gear approximately 1 nm wide

Name an ordinary machine that uses gears. _____

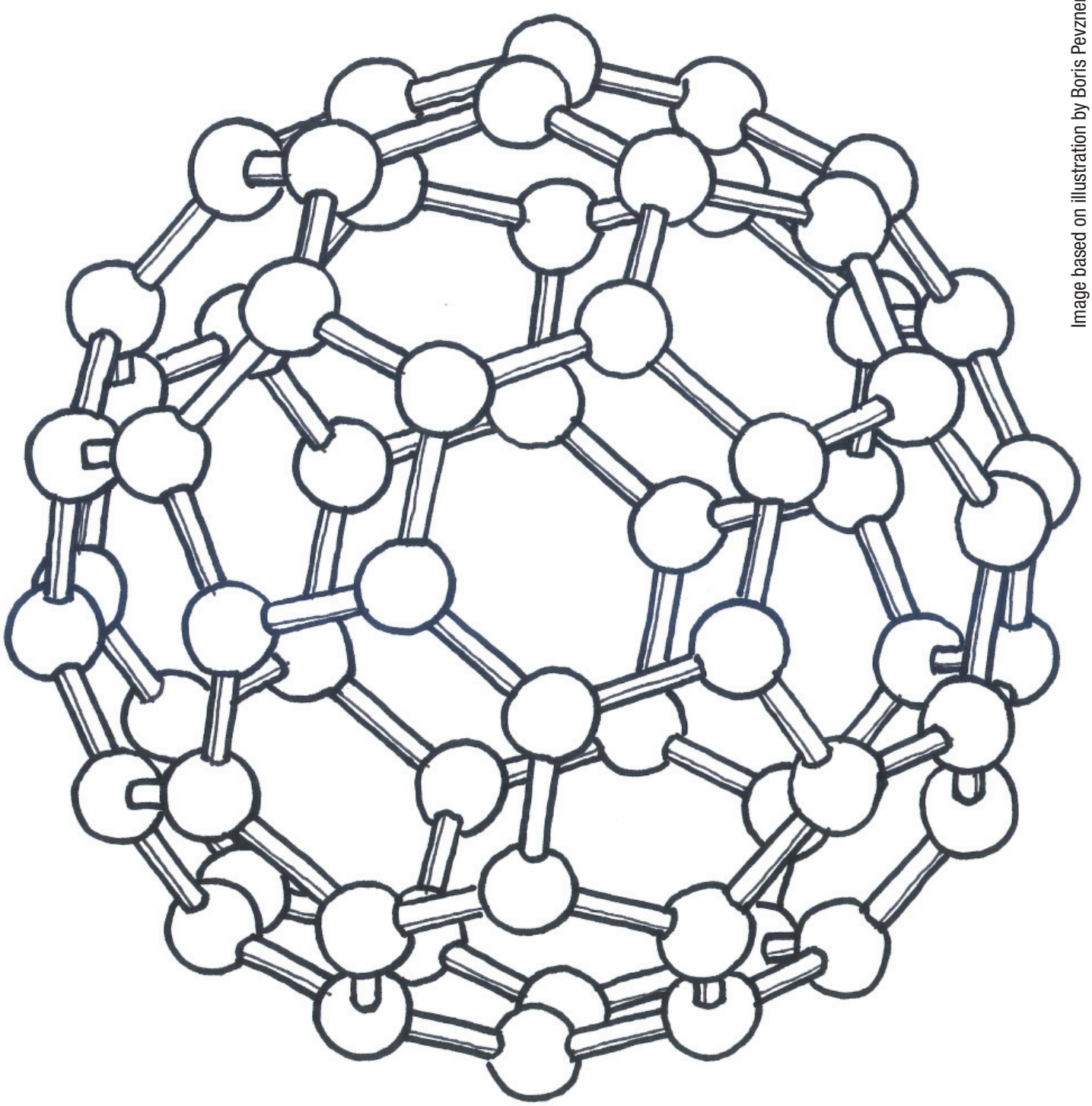


Image based on illustration by Boris Pevzner

Bucky Ball

Spherical fullerenes are called buckyballs partly because they resemble soccer balls and partly because they look like geodesic domes designed by inventor Buckminster Fuller. The round "cage" is usually made from a network of carbon. In 1996, a Nobel Chemistry Prize was awarded for the discovery of fullerenes.

SIZE: Approximately 1 nm

Name something shaped like a Bucky Ball. _____

Image based on illustration by Science Photo Library / Barcroft Media

Calcium Phosphate Crystal

Calcium phosphate is the main form of calcium found in cow's milk. Seventy percent of bone and ninety percent of tooth enamel are made up of a calcium phosphate mineral. It is also used in baking and in cheese products.

SIZE: Approximately 2,500,000 nm (400x if printed 10 cm wide)

Name an animal without bones. _____

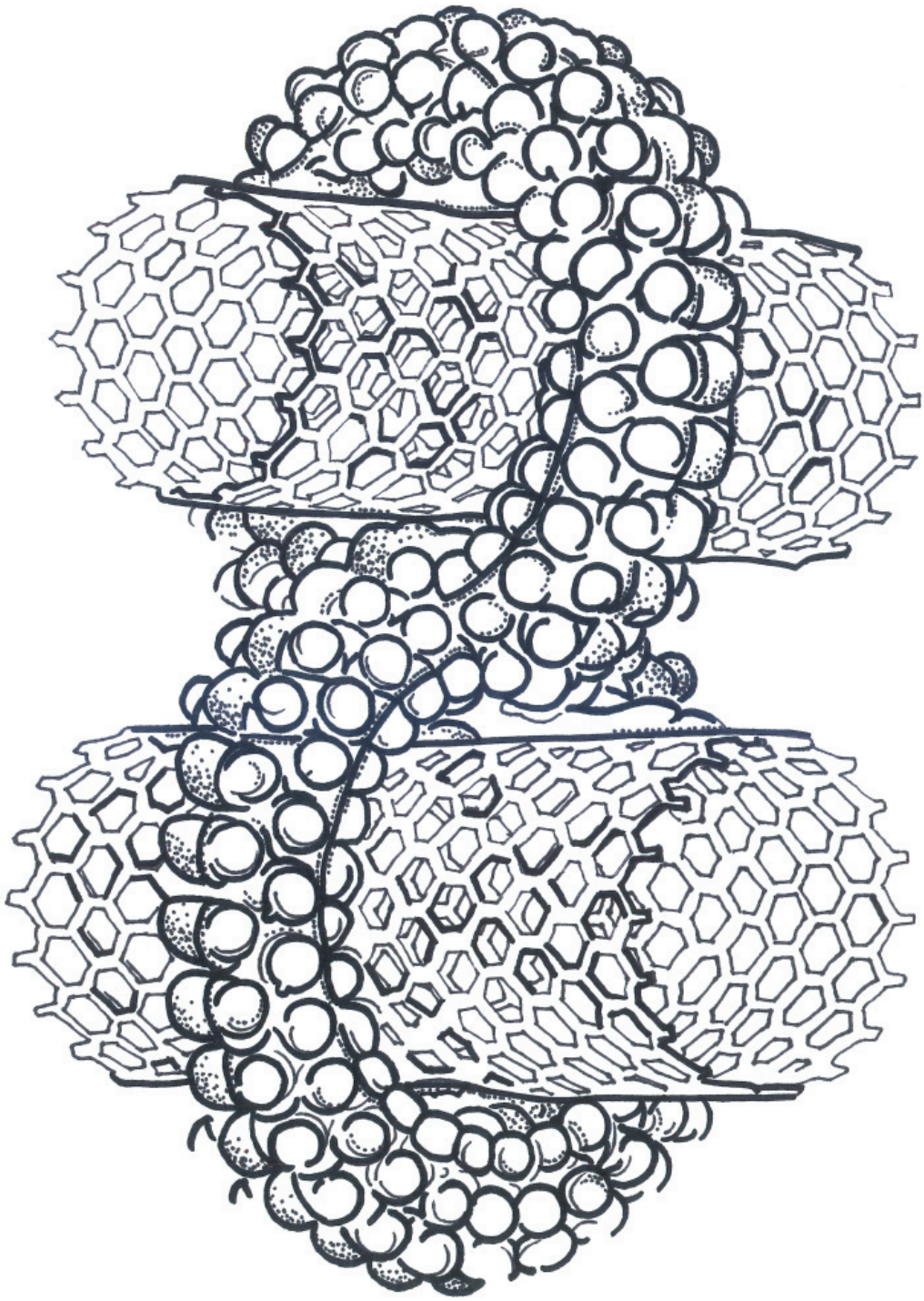


Image based on illustration by Damian G. Allis, Syracuse University

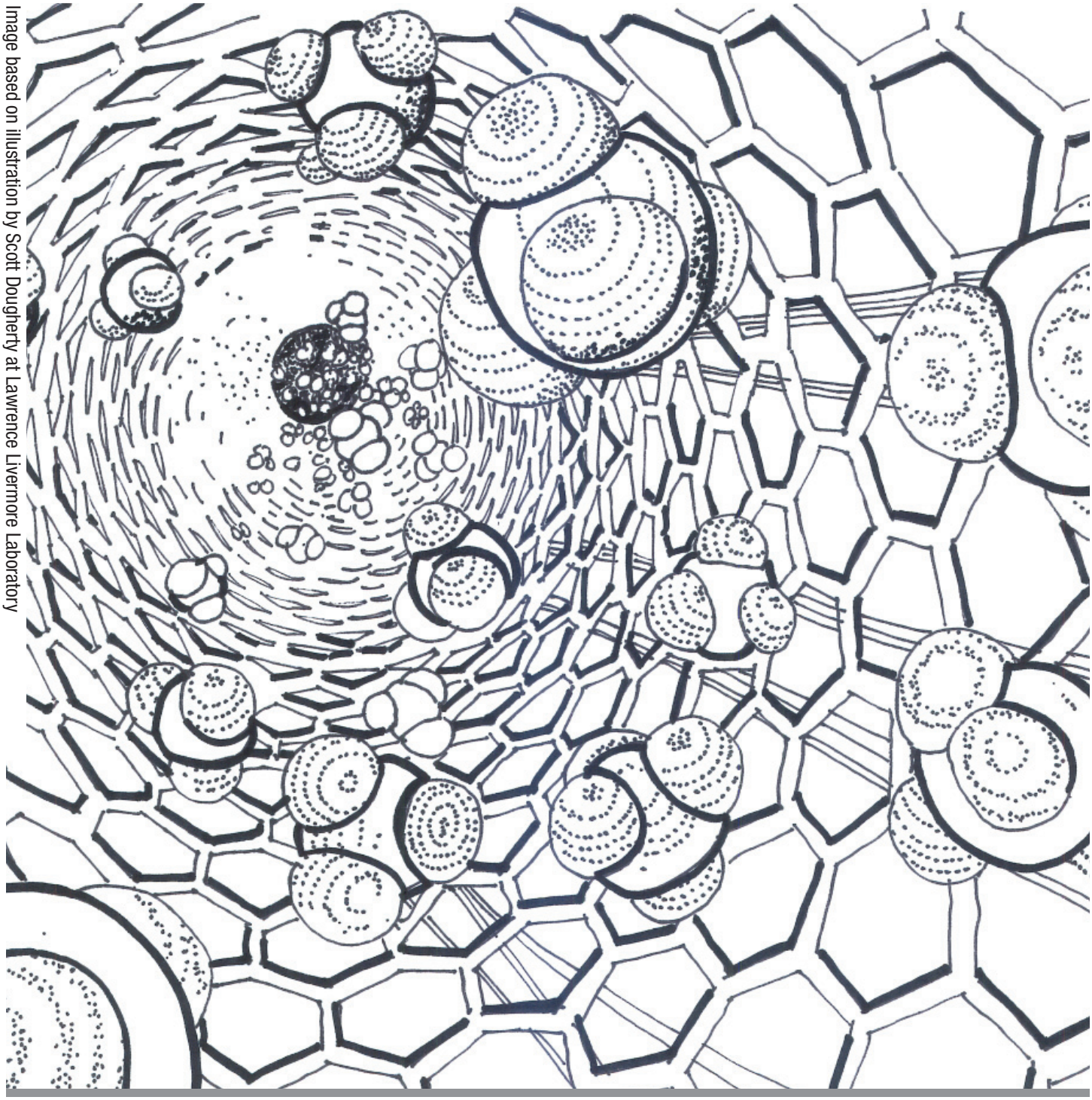
Carbon Nanotube with Methane

Carbon nanotubes have high stretching strength which makes them suitable for future nanoscale manufacturing applications. By locking two nanotubes in opposite directions with “rings”, a tiny support structure could be created to help with biomedical repairs in the human body.

SIZE: Approximately. 1 nm in width

What is shaped like a nanotube and stretches? _____

Image based on illustration by Scott Dougherty at Lawrence Livermore Laboratory



Carbon Nanotube with Methane

This image shows an artist's vision of methane molecules travelling through a carbon nanotube. Such carbon nanotubes could transport molecular and nano fluids – sort of like a tiny garden hose. This invention could someday be used to power automobiles with methane. Methane is the most abundant compound on Earth and is flammable. Methane is one of the gases in, ahem, farts.

SIZE: Approximately 3 nm in diameter, with lengths millions of times longer than that

How many vehicle fuels can you name? _____

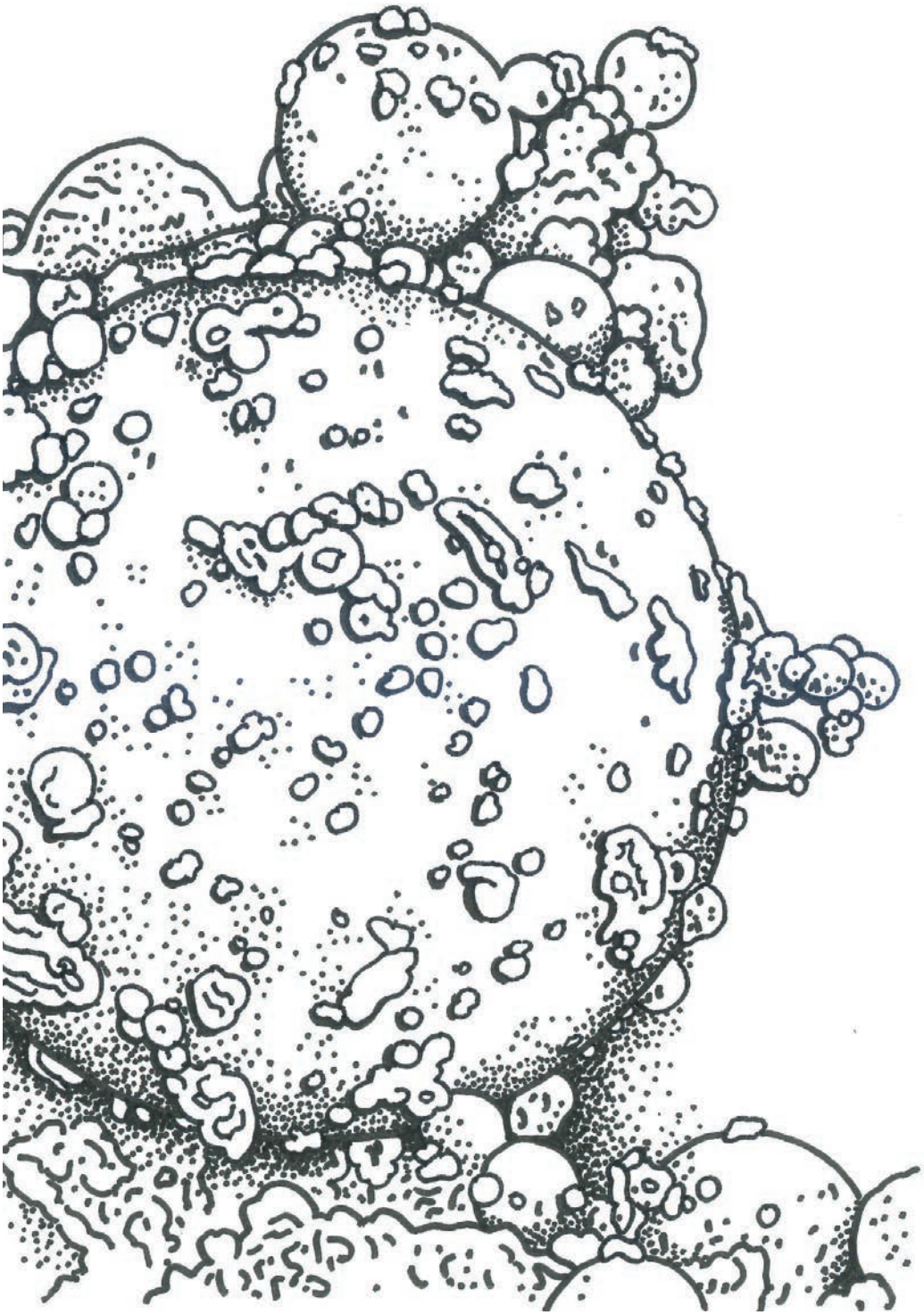


Image is based on SEM photograph by Lee Williams of NanoSonic

Ceramic Microspheres

Microspheres, or microparticles, can be manufactured from natural and synthetic materials including glass and other ceramics and polymers. They can be solid or hollow. The ceramic microspheres pictured here can be used to increase hardness and abrasion-resistance of coatings.

SIZE: Microspheres can be approximately 1,000 to 16,000 nm in diameter

What is a sphere? _____

Image based on an Atomic Force Microscope photograph by Michal Jerzy Wozniak at National Institute for Materials Science in Japan

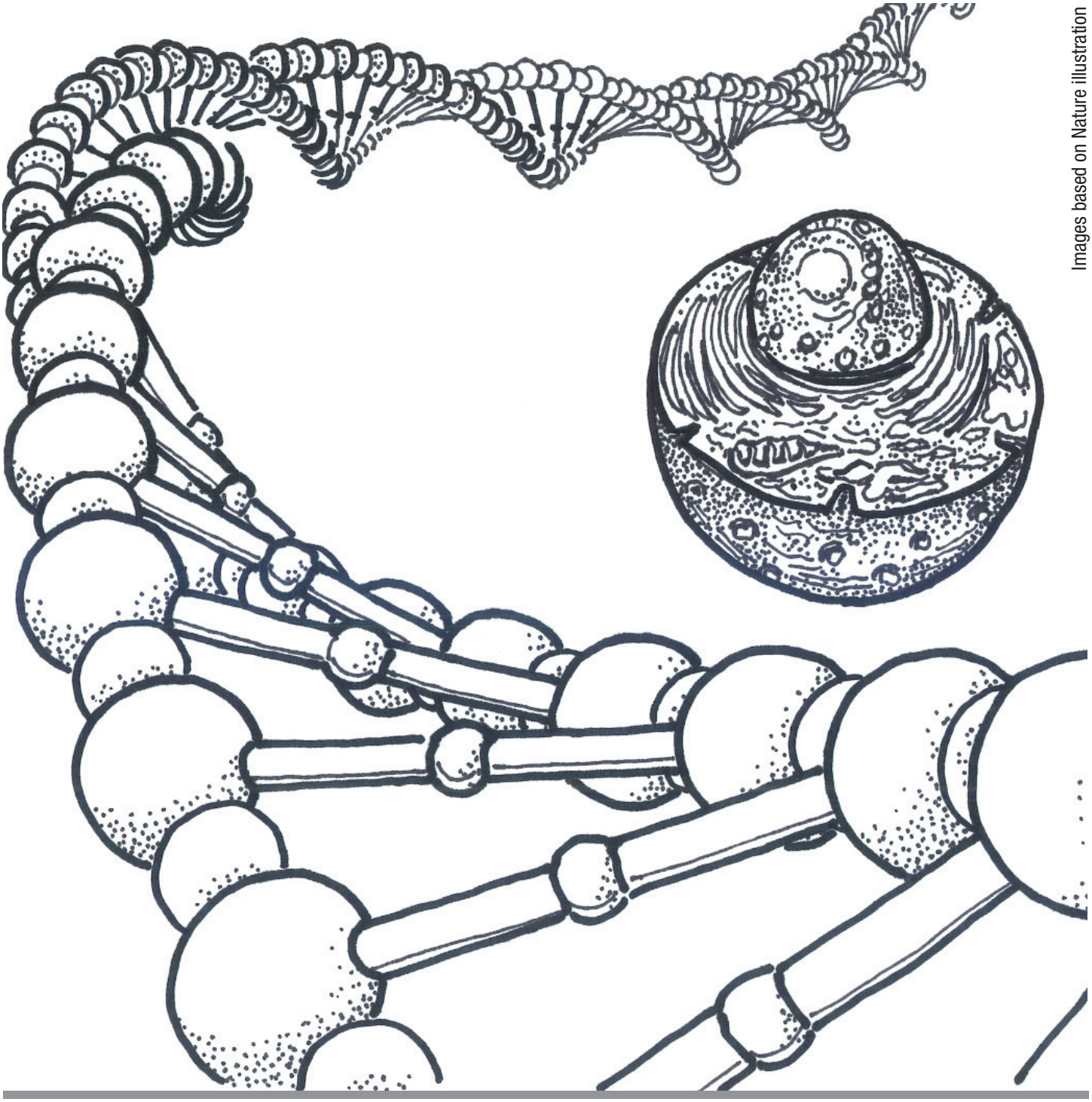
Collagen Fibers

Collagen is a group of naturally occurring proteins found in animals, especially in the flesh and connective tissues of mammals, including humans. It comprises about ¼ of the whole-body protein content. It is found in skin, the cornea of the eye, bones, blood vessels and the guts.

SIZE: The large “sun burst” is approximately. 2,000 nm

If one-quarter of the human body is protein, what type of material is the rest made of?

Name one _____



Images based on Nature illustration

DNA Strand

All living organisms on Earth are divided into tiny pieces called cells. In the nucleus, or center, of every cell, DNA carries the genetic, or hereditary, information of the organism. DNA is shaped like a spiral ladder - or double helix - formed by two strands with connecting “rungs”. It provides a blueprint for life.

SIZE: Average human cells approximately 50,000 nm; DNA approximately. 2 nm

What is one hereditary characteristic that can be passed genetically from one generation to another in humans? _____

Image based on Scanning Electron Microscope photograph by James Brittin

Feather

A bird feather is magnified 1500 times in this image that was originally taken with a Scanning Electron Microscope.

SIZE: Field of view approximately. 400,000 nm

What function do feathers perform on a bird?

Name one. _____

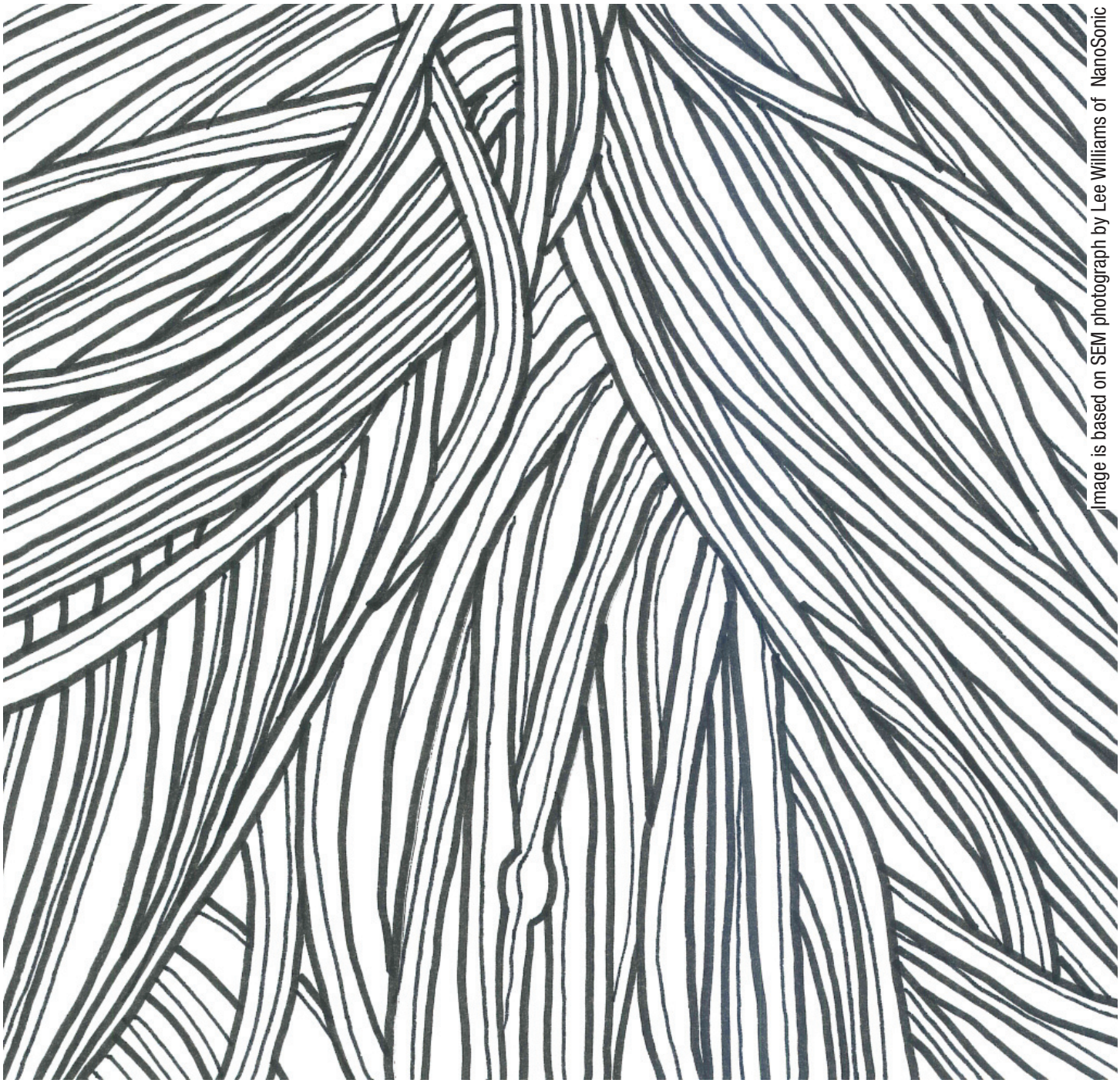


Image is based on SEM photograph by Lee Williams of NanoSonic

Fibers Coated with Nanocomposites

Fibers coated with nanocomposites can result in enhanced strength, stiffness, and resistance to wear and damage. Nanocomposites have exceptionally high surface-to-volume ratio which means that a little goes a long way. Fibers such as those pictured can be used to potentially make protective firefighter gear stronger, for example.

SIZE: Each strand is approximately 15,000 nm in width

Describe why nanocomposites have a high surface-to-volume ratio

_____

Image is based on SEM photograph by Lee Williams of NanoSonic

Fibers Coated with Nanocomposites

Different formulations of nanocomposites can be used to coat fibers. The nanocomposites can make the fibers stronger and better able to shed dirt, or make them more heat resistant or fireproof, among many other properties. The coatings can provide enhanced protection with a very thin layer - usually less than 100 nanometers thick.

SIZE: Thin strands are approximately 30,000 nanometers across

Name one fiber product that uses nanotechnology to improve performance _____.

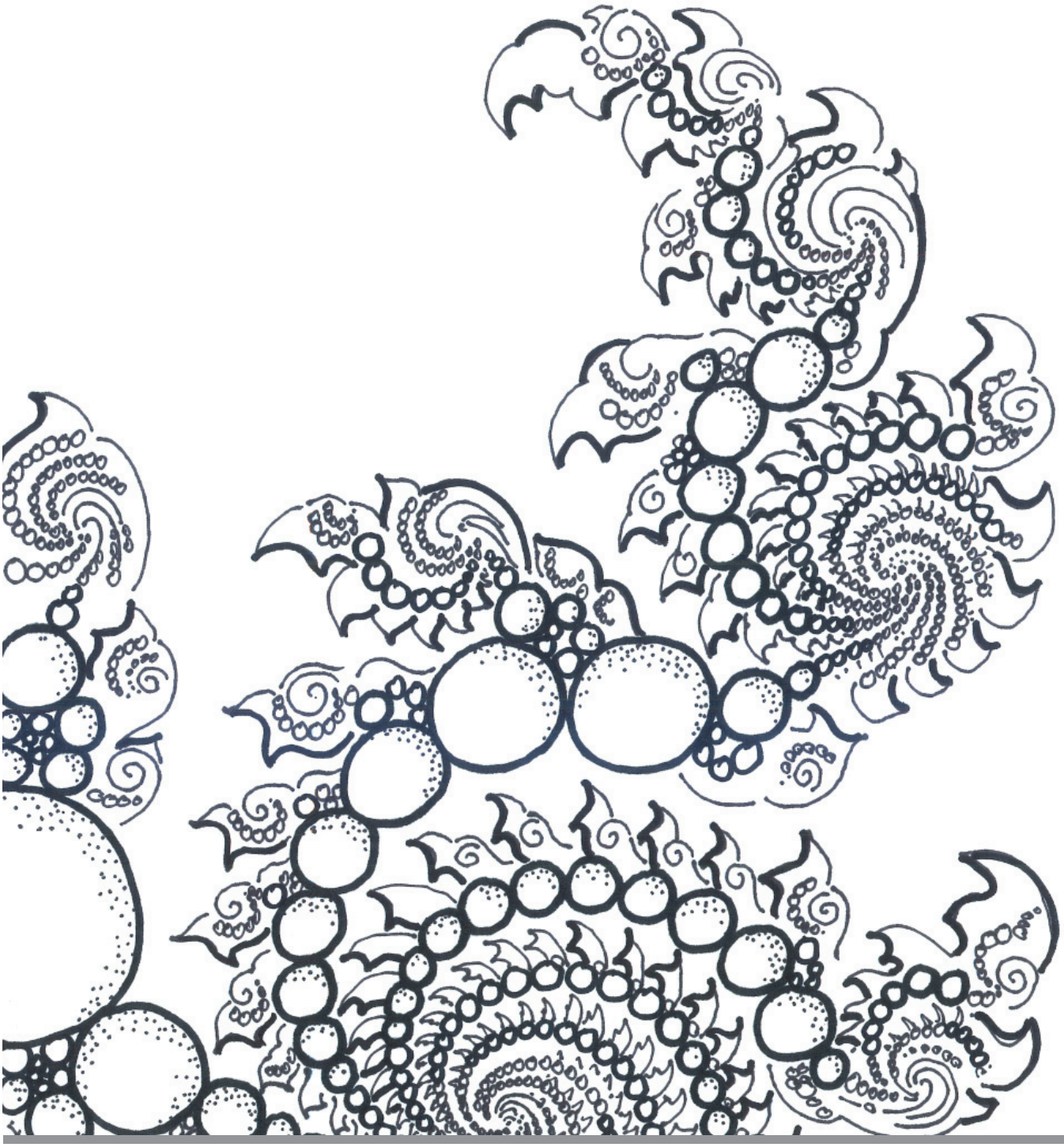


Image based on Mandelbrot fractal

Fractals

Fractals are geometric patterns that repeat themselves at smaller and smaller scales to produce exactly self-similar irregular shapes – no matter what size they are viewed. Computer technology has the capability to do intensive math calculations, and therefore allows fractals to be visualized. Objects in nature with similar properties include snowflakes, crystals, clouds, lightning, river networks, systems of blood vessels and mountain ranges as seen here in Tibet.

SIZE: Estimated and relative

Name two other fractals in nature. _____

Fractal Exercise

In the space below draw an equilateral triangle with sides that are four inches long. Now divide the triangle into four smaller, equal triangles (hint: divide the sides in half). Now divide those triangles each into four smaller, equal triangles. Then divide those triangles into smaller triangles… this shows you the idea of how a fractal works. All of the triangles are exactly the same shape; only their size has changed. This could theoretically be calculated infinitely.

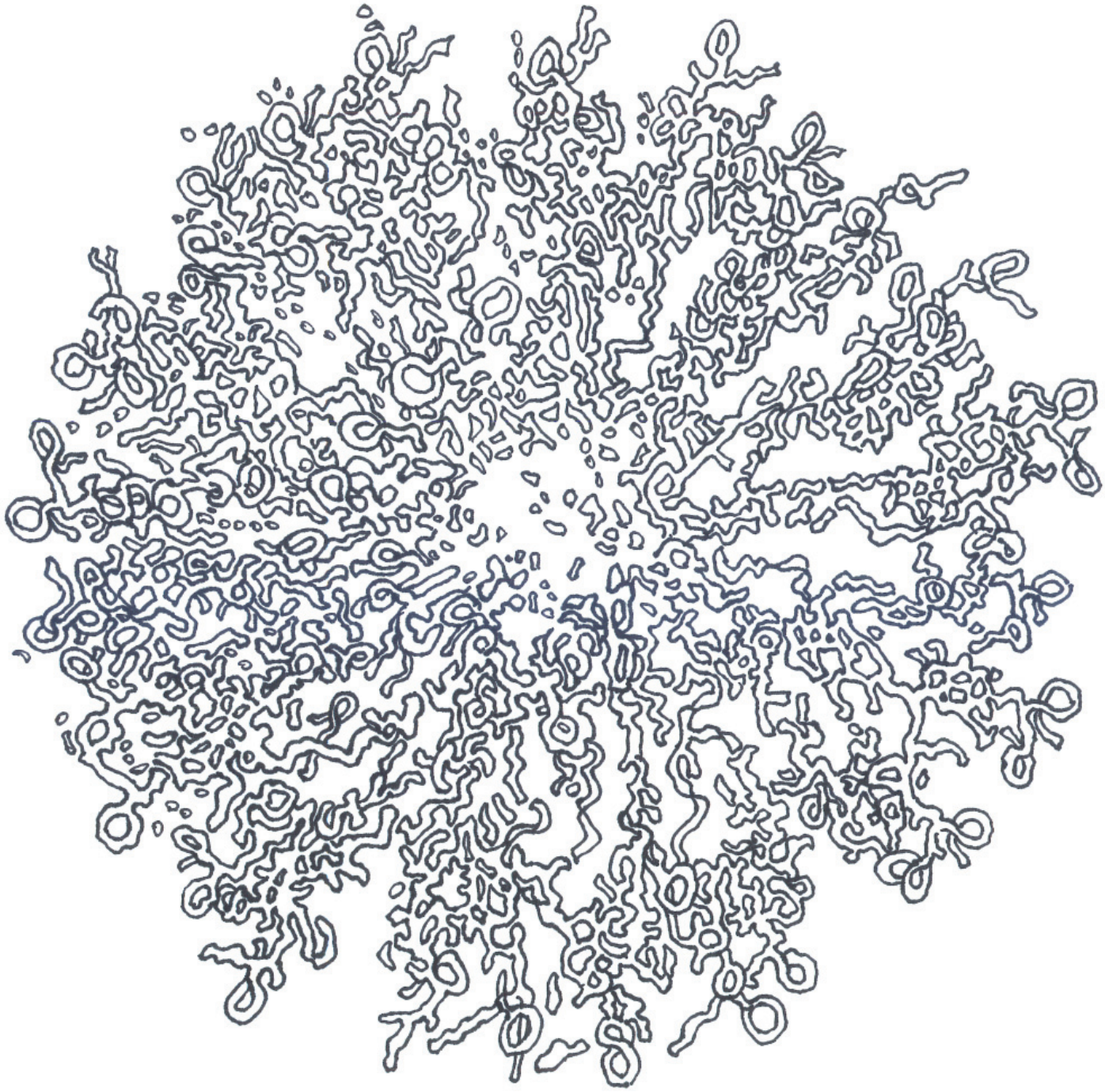


Illustration based on an image from Eugen Zubarev of Rice University

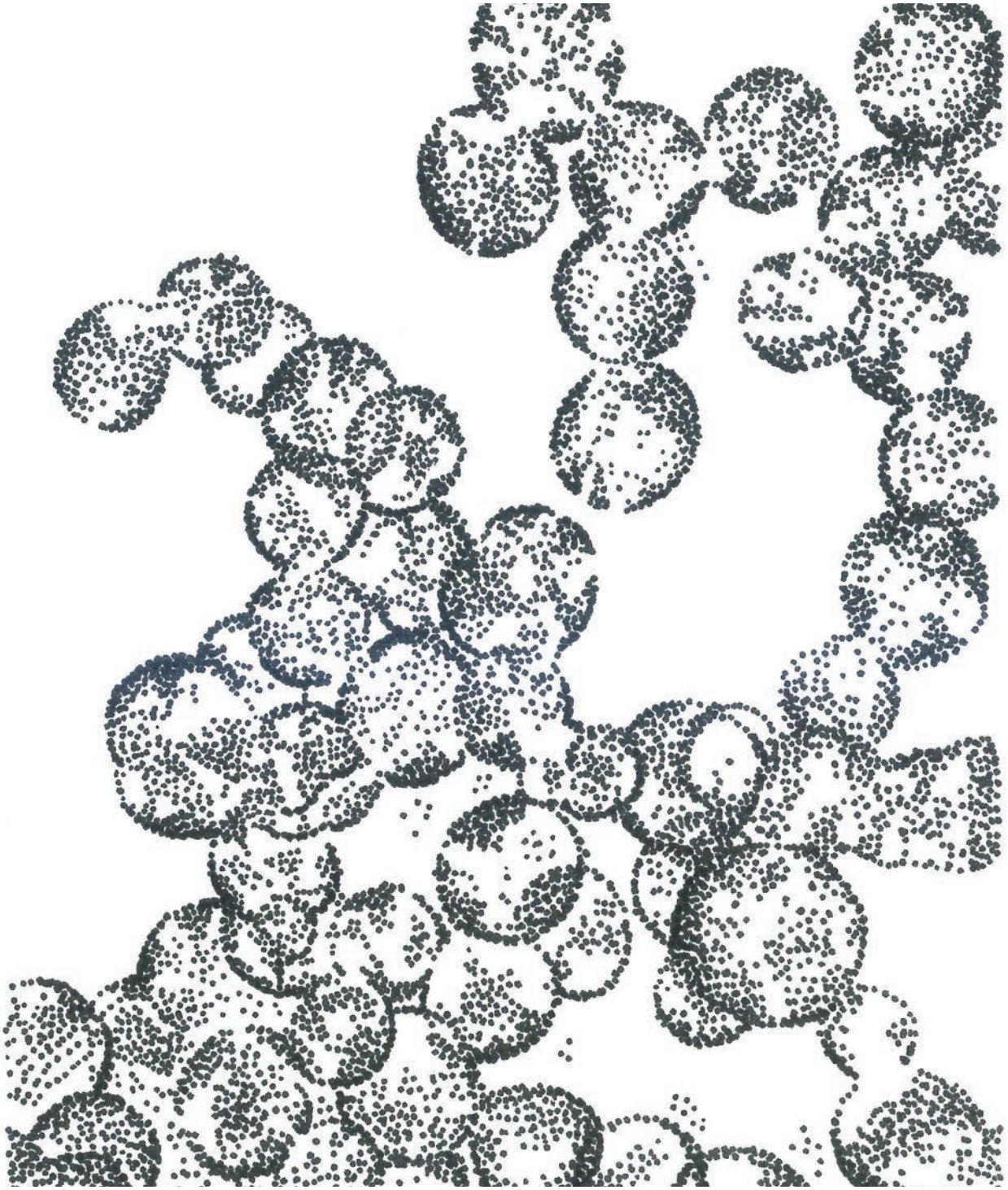
Gold at Nanoscale

Gold is typically a non-reactive metal. That means it doesn't tarnish (also known as oxidation). But at the nanoscale, gold has different properties, including colors that range from red to purple. The particles are so small that they cannot move freely, and therefore they react differently with light to reveal different colors.

SIZE: Approximately. 4 nm at the nucleus

Name something that is made with gold. _____

Image is based on TEM photograph by Liz Gladwin of NanoSonic



Gold Particles

These tiny gold particles become visible using a Transmission Electron Microscope (TEM). The TEM works rather like a slide projector, except instead of passing light through a glass slide, it shines beams of electrons through a specimen. Because electrons have a much lower wavelength, the image resolution is a thousand times clearer than with a light microscope.

SIZE: Particles are approximately 10 to 15 nanometers in diameter

What is an electron? _____

Image based on Field Emission Gun Transmission Electron Microscope photograph by Anke Husmann

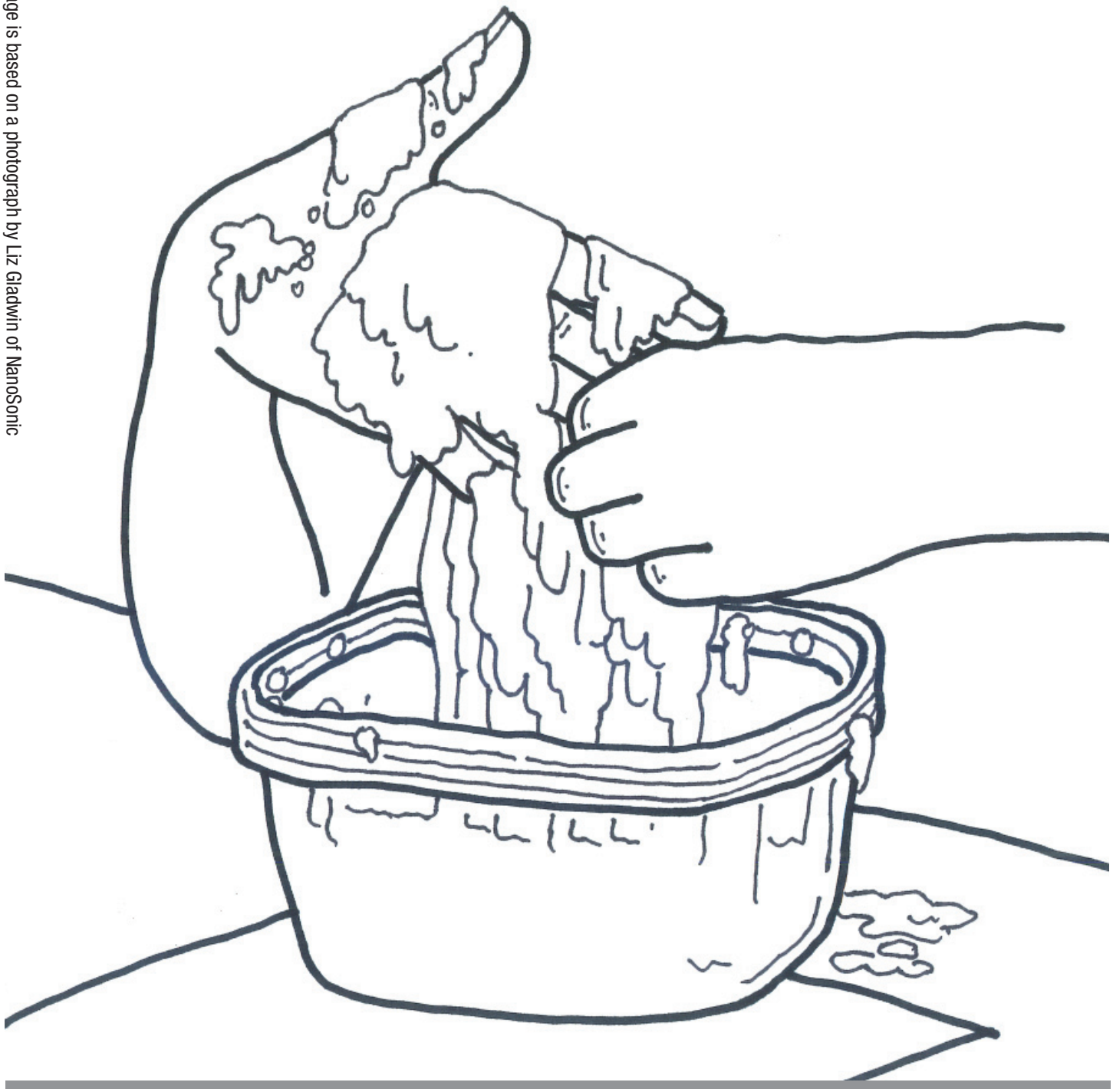
Magnetic Polycrystalline Cobalt

This polycrystalline cobalt structure shows different directions of its magnetic field in the various "strands." Magnetic materials are used in technologies such as permanent magnets – similar to magnets holding up notes on a refrigerator door. Cobalt has been used since ancient times to create blue pigments.

SIZE: Field-of-view 200,000 nm

Describe a magnet and how it works. _____

Image is based on a photograph by Liz Gladwin of NanoSonic



Mixing Goo

Oobleck is a simple polymer goo that can be mixed by hand using one part water and two parts cornstarch. When the surface of Oobleck is squeezed or punched, the molecules act as a barrier, feeling like a solid material. When Oobleck is pressed very slowly on the surface, it feels like a liquid. Polymers are large molecules that make up natural materials such as rubber or manufactured materials such as plastics.

Can you name the children's book author who created the name "Oobleck" for a gooey, green substance in one of his stories?

_____

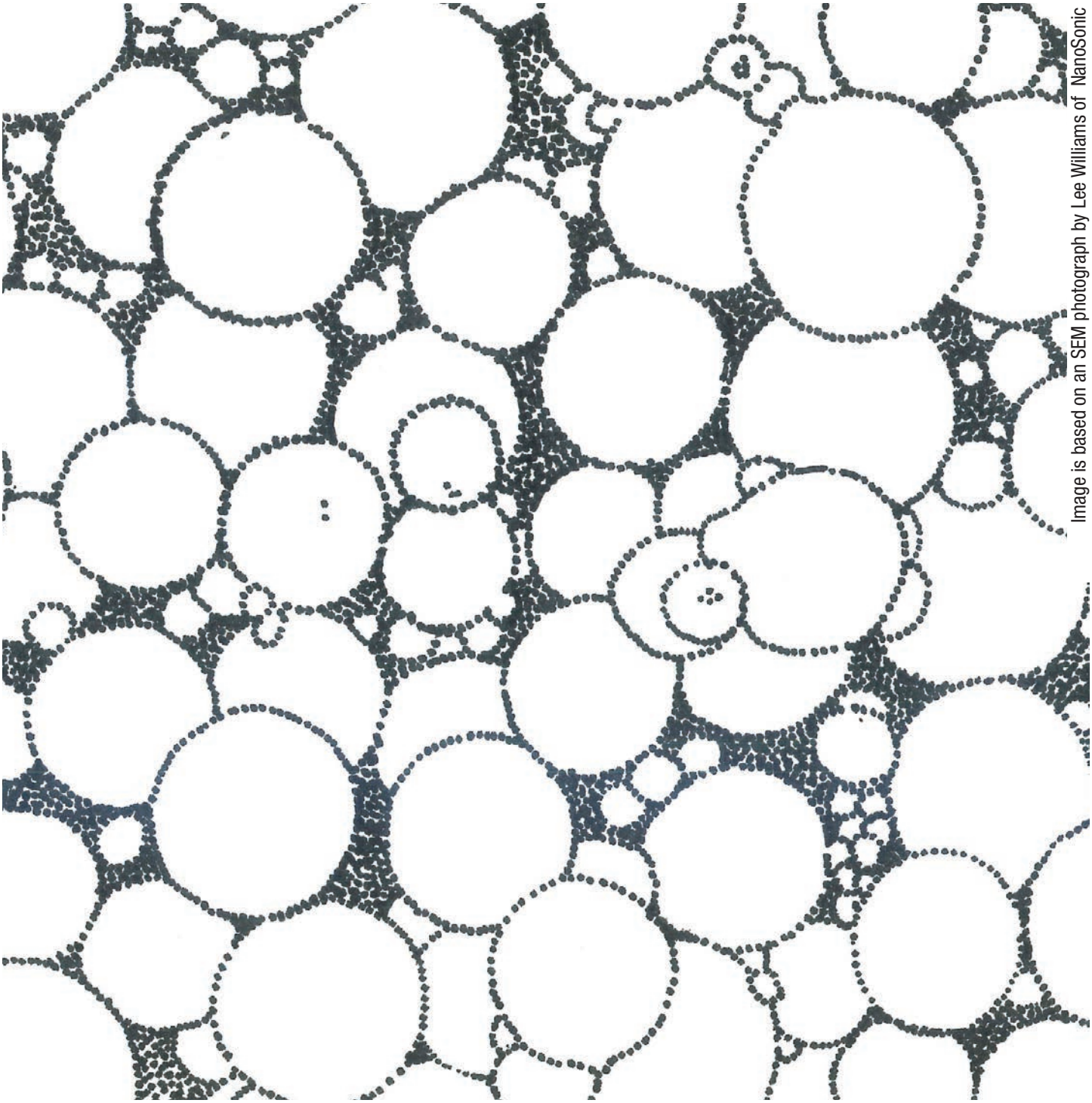


Image is based on an SEM photograph by Lee Williams of NanoSonic

Nano Coatings

Innovative protective coatings can be engineered at the nanoscale to provide improved durability for applications on aerospace, marine and land vehicle surfaces. Other desirable properties that can be achieved in nano coatings include scratch resistance, fire proofing, light transmission, heat resistance and the ability to shed dirt.

SIZE: The "bubbles" can be from approximately 5,000 nm to 100,000 nm in diameter

What are some protective coatings? _____

Image is based on a Scanning Electron Microscope photograph from the book "Microcosmos" by Brandon Brill

Nylon Stocking Fibers

Nylon was the first synthetic – or manufactured – fiber ever produced. Nylon fibers are stronger and more elastic than silk and are not sensitive to moisture. The weave of nylon is used in ladies' stockings, carpets and medical "stitches" or sutures.

SIZE: Approximately. 800,000 nm (magnification x75 at 6x6cm size)

Name another synthetic fiber _____

Name a natural fiber _____

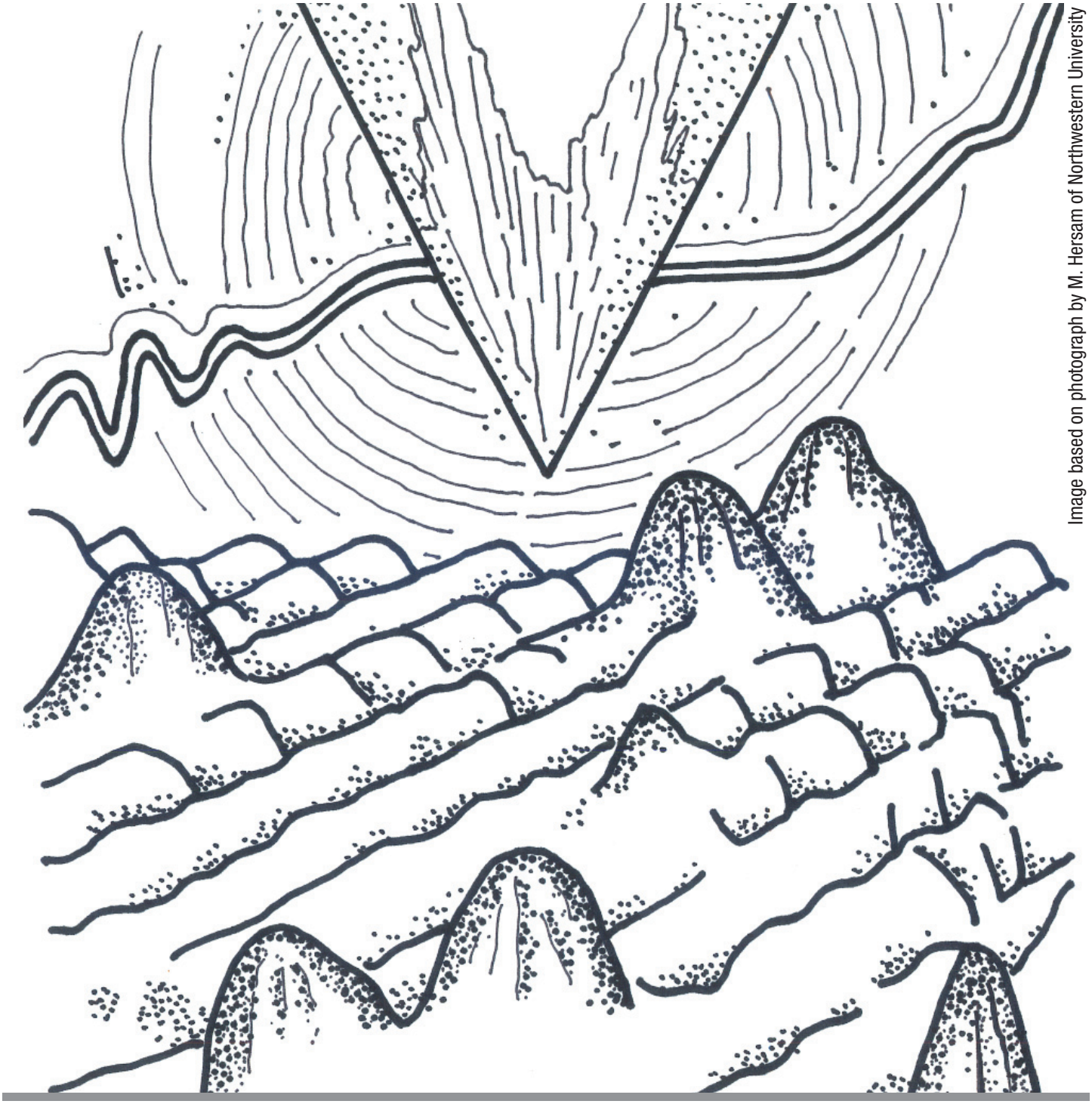


Image based on photograph by M. Hersam of Northwestern University

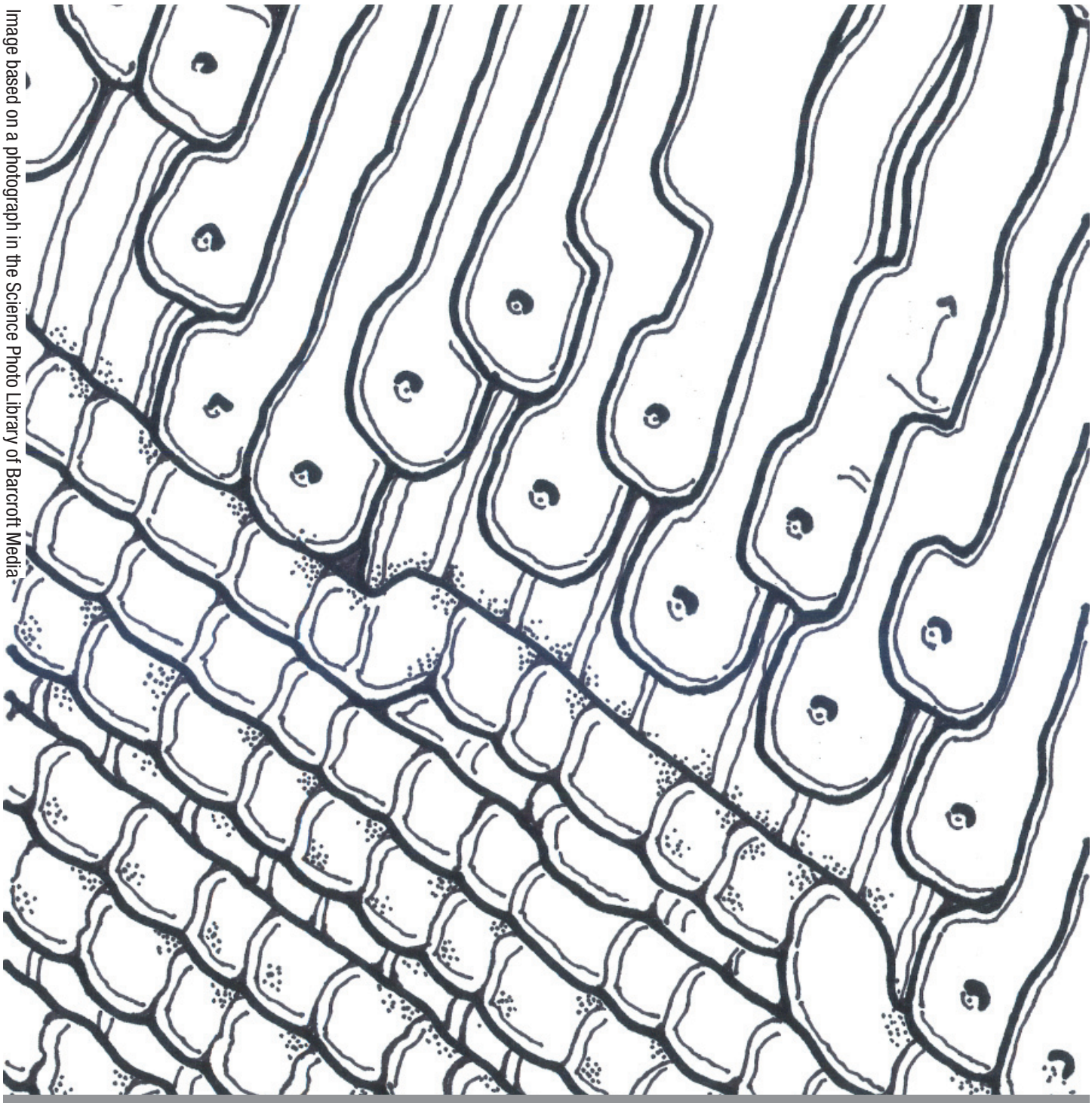
Scanning Probe Microscope Tip

Scientists could not visualize nanoscale objects until the invention of powerful microscopes such as the Scanning Probe Microscope (SPM). The SPM has a very small, very sharp tip that is dragged across a nanoscale object. The movement is monitored with a computer, which creates an image. The method is similar to a blind person "reading" Braille with their fingers.

SIZE: Tip sizes can vary between about 1 nm and 30

Close Your Eyes. Ask someone to hand you an object. Try to identify the object by feeling it. What is it?

Image based on a photograph in the Science Photo Library of Barcroft Media



Silicon Microchip

On the surface of a silicon microchip (chip), the tracks form part of the chip's tiny electronics. The pits in the tracks are connection points to elements on the other side of the chip. Chips are used in virtually all electronic equipment such as computers, mobile phones, and other digital appliances

SIZE: Field of view height approximately 50,000 nm (magnification: x1190 at 6x7cm size)

Silicon is found in abundance on earth in a very common material; can you name the material? _____

Image based on actual US silver dollar photograph

Silver Dollar

One US silver dollar is about 40 millimeters wide with a surface area of about 27.70 square centimeters. If a silver dollar were divided into tiny particles one nanometer (nm) in diameter, the total surface area of those particles would be 122,708 square feet– this surface area of the particles is 4 million times greater than the surface area of the silver dollar!

SIZE: Diameter 26,500,000 nm or slightly more than 1 inch

How many nanometers in diameter is a dime? _____

A nickel? _____ A penny? _____

Image based on electron microscope photograph from the Biological Electron Microscope Facility, University of Hawaii

Spider Spinnerets

Spinnerets are part of a spider's body and they produce silk to make webs. Spider silk is super strong and stretchy, with a toughness greater than bone, synthetic rubber, Kevlar and high-tensile steel. Scientists are using nanotechnology to try to make synthetic spider silk.

SIZE: Field of view approximately. 50,000 nm (magnification approximately. x1500)

What are some shapes of spider webs?

Name two _____

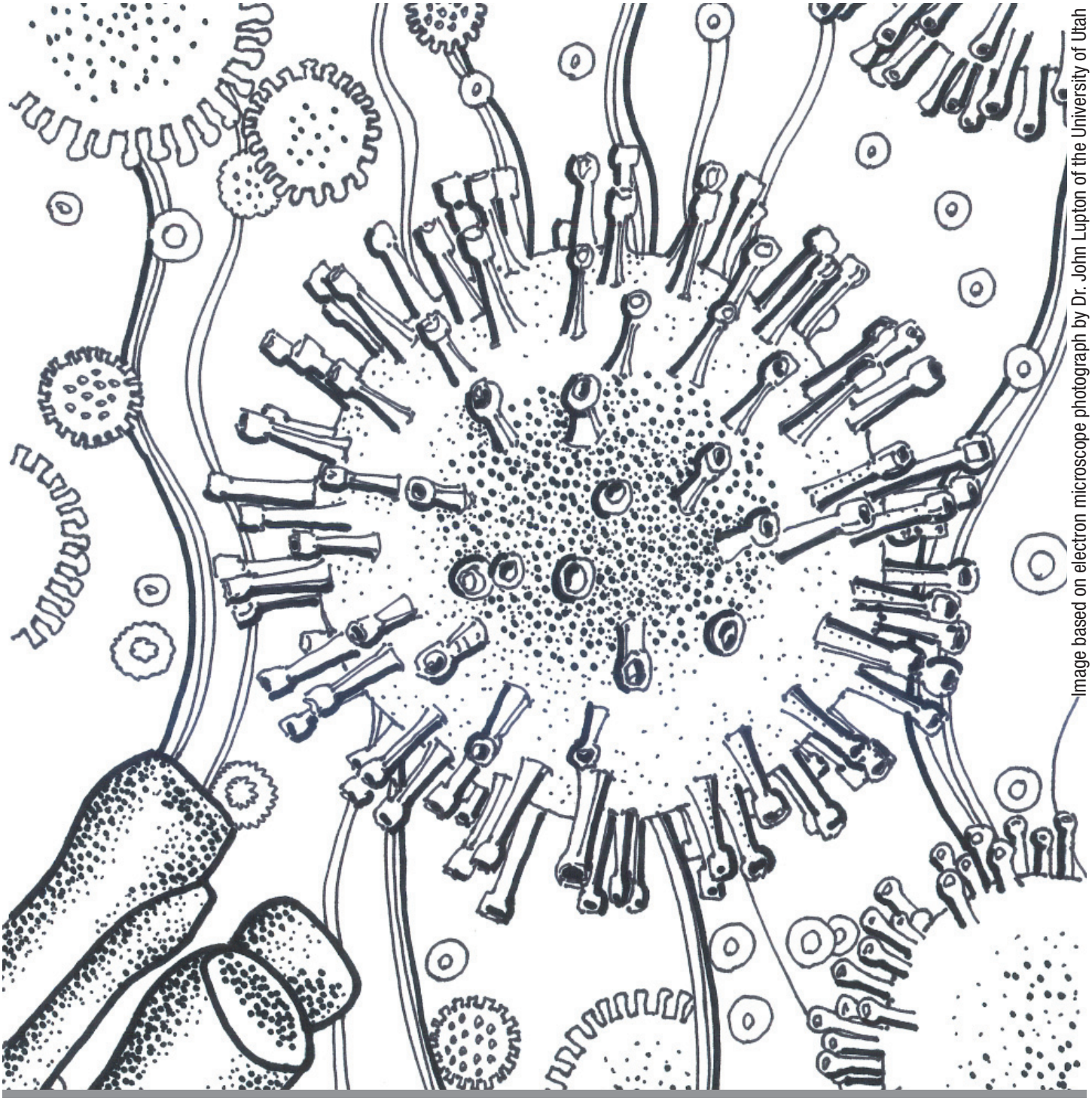


Image based on electron microscope photograph by Dr. John Lupton of the University of Utah

White Light Nanoparticles

Clusters of silver nanoparticles, known as white light nanoparticles, naturally emit white light. They are formed into a sort of nano mirror and then placed under a specimen in a microscope. The white light nanoparticles provide light from both sides and enhance the ability to see the outer and inner structure of a specimen. This technique has been used to look at the iridescent scales of a photonic beetle, malignant tumor cells, and bone.

SIZE: Silver white light nanoparticles can be from 10 to 100 nanometers across

A famous inventor of early microscopes, Anton Van Leeuwenhoek, made his instruments out of what?_____

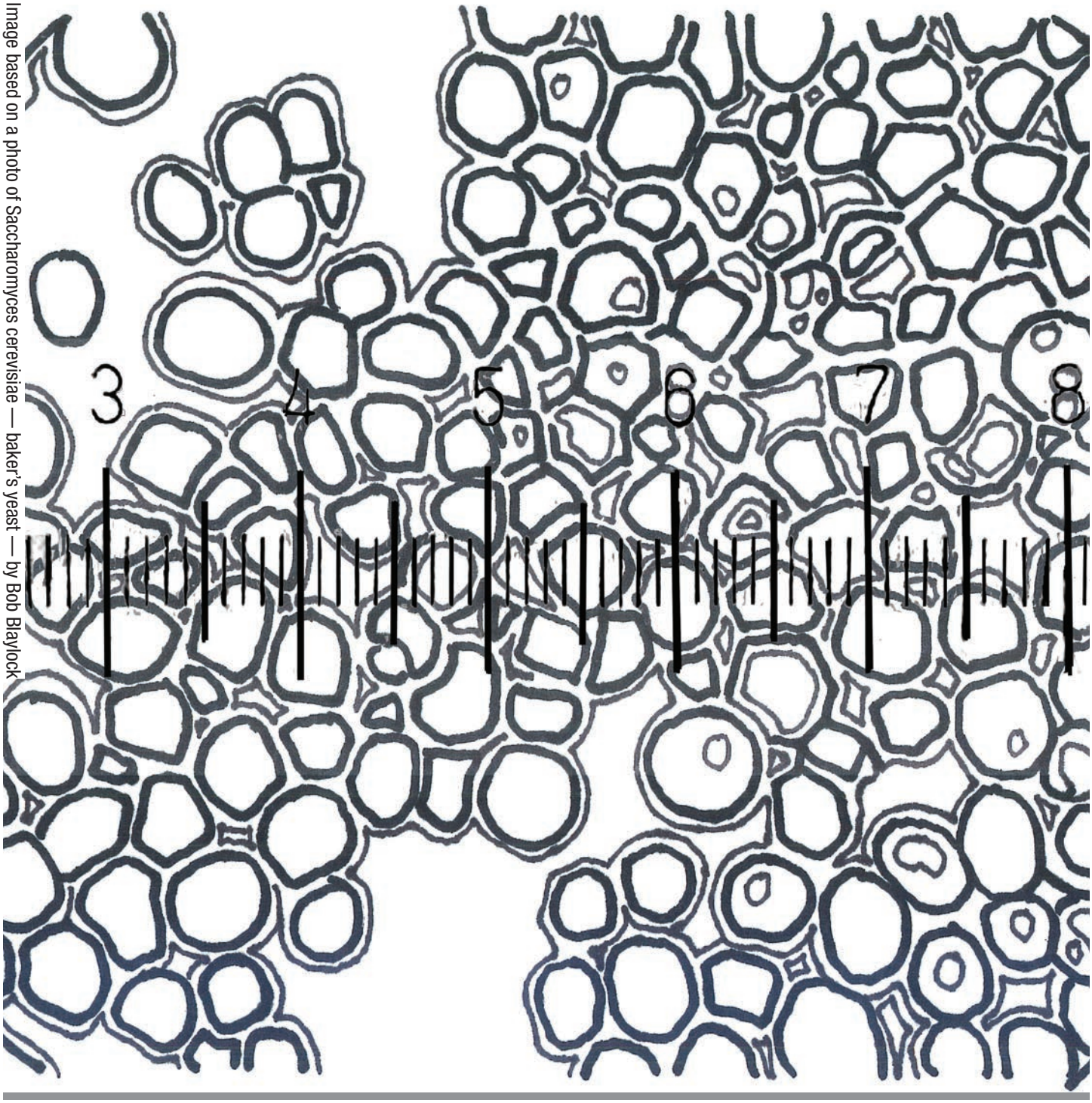


Image based on a photo of Saccharomyces cerevisiae — baker's yeast — by Bob Blaylock

Yeast

Yeast is a fungus (think: mushroom) that produces gas that makes bread rise. It does this by feeding on sugars in flour or added sweeteners, and then expelling carbon dioxide in the process. Yeast is so small that just one gram holds about 25 billion cells.

SIZE: Numbered gradation marks are 1000 nanometers apart.

Yeast Ballon Exercise

You can make a simple yeast-air balloon to get a better idea of what yeast does at the nanoscale so that we can see the result in the normal world.

What You Need

- 1 packet of active dry yeast
- 1 cup very warm water (105° F–115° F)
- 2 tablespoons sugar
- a large rubber balloon
- a small (1-pint to 1-liter) empty water bottle

What You Do

1. Stretch out the balloon by blowing it up repeatedly, and then lay it aside.
2. Add the packet of yeast and the sugar to the cup of warm water and stir.
3. Once the yeast and sugar have dissolved, pour the mixture into the bottle. You'll notice the water bubbling as the yeast produces carbon dioxide.
4. Attach the balloon to the mouth of the bottle, and set both aside.
5. After several minutes, you'll notice the balloon standing upright. If you don't see anything happen, keep waiting. Eventually, the balloon will inflate.

Exercise is from The Science of Cooking: http://www.exploratorium.edu/cooking/bread/activity-yeast.html

Nanometer Scale

A very fine human hair is about 10,000 nanometers wide. This is the smallest dimension we can see with the naked eye. If this image is printed on paper, turn it sideways to see the thickness of the page at 100,000 nanometers. And remember nanoscale is usually considered as less than 100 nanometers.

Ordinary objects have huge dimensions when measured on what scientists call the nanoscale:

- Atom: ~0.1 nanometer
- Atoms in a molecule: ~0.15 nanometer apart
- DNA double-helix: ~2 nanometers in diameter
- Typical protein: ~10 nanometers long
- Computer transistor (switch): ~100-200 nanometers wide
- Typical bacteria: ~200 nanometers long
- Human hair: ~10,000 nanometers in diameter
- One piece of paper: ~100,000 nanometers thick
- Girl 1.2 m (4 feet) tall: ~1200 million nanometers tall
- Man 2m (6.5 feet) tall ~ 2000 million nanometers tall
- Empire State Building: 381m (1250 feet) tall: ~381 billion nanometers tall
- One gold atom is about one-third of a nanometer in diameter
- On a comparative scale, if the diameter of a marble was one nanometer, then the diameter of the Earth would be about one meter
- One nanometer is about as long as your fingernail grows in one second
- Molecules with more than 10 atoms fall into the nanometer range
- Believe it or not, waves of light are too large for viewing nanoscale materials. Visible light has a wavelength between 400 and 750 nanometers. That's much larger than nanoscale objects and larger than most molecules. That's why the specialized microscopes use very tiny probes or electrons instead of light to study nanomaterials.

Nanometer scale information is from Explain That Stuff website

EXERCISE: Measure an item in your room. Now convert its measure into nanometers.
(One inch = 2.54 centimeters; one centimeter = 10,000,000 nanometers)

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COLORING BOOK

This coloring book was funded in part by NASA.
It was designed by Robin Rogers, Andrew Teates and Sally Green of NanoSonic, Inc.
It was reviewed by Virginia public school teachers Brandi Smith of Macy McClaugherty Elementary/Middle School in Giles County and Susan Mauney of Blacksburg Middle School in Montgomery County.

Cover illustration by Sally Green is based on a NanoSonic SEM image by Lee Williams.

NanoSonic is an American company that invents and makes nanomaterials in Giles County, Virginia, USA. NanoSonic created this free coloring book to provide teachers with a resource for helping young students better understand the world of nanotechnology.

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