IEEE Spark
IEEE
2014, Issue 1

ENGINEERING INSIDE: NANOTECHNOLOGY

The Big Wide World of the Smallest Scale

April, 2014

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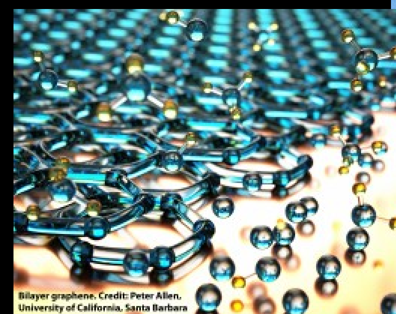
Bilayer graphene. Credit: Peter Allen, University of California, Santa Barbara

Meet Harold Craighead!

April, 2014

Have you ever wondered what it would be like to explore phenomena tinier than the width of a human hair? We have interviewed Harold Craighead, Professor of Applied & Engineering Physics at Cornell University. Craighead has been a pioneer in nanofabrication methods and the application of engineered nanosystems for research and device applications.

The Surface Area Effect

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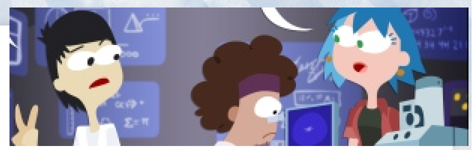
Large-scale particles and nanoparticles can exhibit very different properties. One of the main reasons nanoparticles behave differently is that they have much higher surface area than larger particles. In this activity you can try growing sugar crystals to explore how surface area can change at the nanoscale.



Nano Rescue

IEEE SPARK CHALLENGE

Think you know IEEE Spark? Test your knowledge of engineering, computing and technology with the IEEE Spark Challenge! Answer questions correctly to help your team move to the top of the leaderboard.

About IEEE Spark

IEEE Spark is an online publication intended to inspire students ages 14-18 to learn more about engineering, technology, and computing, and raise excitement about careers in these disciplines. *IEEE Spark* features articles on technological innovation, university preparation tips, professional career profiles, at-home activities, comics, and more! *IEEE Spark* is brought to you by IEEE with generous funding from the IEEE New Initiatives Committee.

About IEEE

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The Big Wide World of the Smallest Scale

April, 2014
by Robin Hegg

What if you could watch atoms transfer electrons and form new molecules? Or observe a red blood cell as it travels through your vein? With the recent development of advanced tools like Scanning Tunneling Microscopes and Atomic Force Microscopes, these up-close, small-scale observations are becoming possible. Nanotechnology, or nanoscience, are the terms given to this new, exciting ability to observe, measure, and even manipulate materials at the molecular or atomic scale and it promises to change the way we manufacture everyday objects, build computers, store information, create our electronics, produce energy, and even deliver medical therapy.

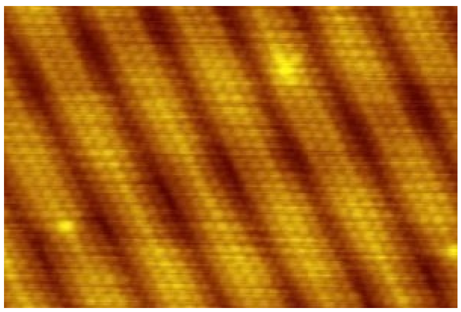
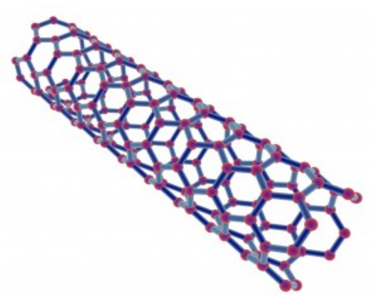


Image of surface reconstruction on a clean Gold (Au(100)) surface, as visualized using scanning tunneling microscopy.

”Nano” is the prefix given to a number of terms, referring to a billionth of that thing. Nanometers (length), nanoseconds (time), nanoliters (volume), and nanograms (mass) are some of the measurements used to discuss materials at this very small scale. It takes about 10 hydrogen atoms in a row to create a line 1nm in length, meaning individual atoms are less than 1 nanometer (nm) in diameter. A typical virus is about 100 nm in diameter and a bacterium is about 1000 nm from head to tail.

Many materials exhibit different properties when observed on the nanoscale because of changes in size and surface area. Nanotechnology involves the creation of useful materials, systems, and devices of any size through the control or manipulation of matter on the nanoscale. Nanomaterials, such as nanotubes (CNT), graphene, quantum dots, dendrimers, nanoparticles, and inorganic nanowires are already being put to use. Research in this area is moving fast and applications have already been found that are advancing how we live, produce energy, and even receive medical care.



Nanotube Structure

Carbon nanotubes are thin sheets of graphite formed into single- or multi-layer tubes with unique electronic and mechanical properties. They can behave as either a metal or a semiconductor, meaning one day electronics could be all carbon-based. They are also incredibly strong and light (one hundred times stronger than steel but one-sixth its weight). This means carbon nanotubes can be used to make objects stronger and lighter at the same time. They can also carry current and heat, making them possible replacements for copper wires. Researchers are working to develop a stronger, lighter bulletproof vest using carbon nanotubes.

Graphene, a one-atom thick, honey-comb shaped crystal lattice made of densely packed carbon atoms, exhibits interesting electrical, optical, mechanical, and thermal properties. It can function as a semimetal or a semiconductor and is highly opaque, blocking all but two percent of white light. Scientists are researching how graphene can be used in electronics, solar cells, energy storage, plasma displays, and chemical and biological sensors.

IN THIS ISSUE:

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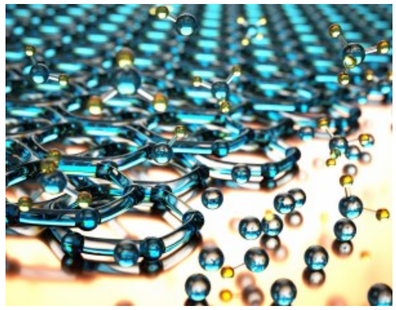
Read this issue!

Dendrimers are large molecules with tree-like branches spreading out from a relatively hollow core. This core can be used to hold “guest molecules,” allowing them to be tailored for different applications. They could be used to deliver drugs, cancer therapy, or antimicrobial and antiviral agents.



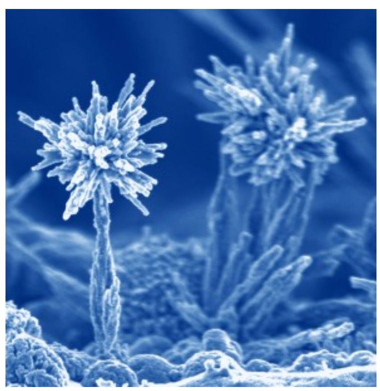
Bilayer graphene. Credit: Peter Allen, University of California, Santa Barbara

Luminescent porous silicon nanoparticles. Credit: Luo Gu, Ji-Ho Park, UCSD

Because of their tiny size, nanoparticles have lots of surface area. Since most activity takes place on the surface level, nanoparticles are more active than their larger counterparts. Because they’re highly soluble, nanoparticles are used in paints, pigments, cosmetics, and medicines and because they’re highly attractive nanoparticles, they can be used in catalytic converters, water purifiers, varnishes, and adhesives. This same attractive property can also cause nanoparticles to lump together, making them less effective. Scientists are looking to find coatings that would help keep nanoparticles separate.

Quantum dots are tiny solid structures. They are so tiny that an electron inside has extremely restricted movement, meaning the electron’s kinetic energy is determined by the quantum dot’s qualities (material, size, and shape). Quantum dots also have extremely large surface-to-volume ratios, making them effective chemical and biological sensors. Quantum dots are also used in multi-colored displays, because different-sized quantum dots emit different colored lights. Quantum dots are being increasingly put to use in commercial and defense related products.

Inorganic nanowires are tiny wires with diameters of 1-50 nanometers. They could be used to link tiny components into small-scale circuits and could be used to make a new generation of computer chips and memory storage devices. They may also be used for ultraviolet (UV) lasers and light emitting diodes (LEDs), and could help replace filament light bulbs.



“Nano Trees,” a 3-D nanostructure grown by controlled nucleation of silicon carbide nanowires on gallium catalyst particles. Credit: ©Ghim Wei Ho and Prof. Mark Welland, Nanostructure Center, University of Cambridge.

Nanotechnology is already being put to use in our everyday lives with new applications being quickly developed. Nanoparticles have been integrated with clothing material to make stain resistant cloth, car bumpers have been enhanced with nanocrystals to make them stronger, and carbon nanotubes have been used to make products like tennis rackets and bicycle frames lighter and stronger.

Nanotechnology also holds incredible possibilities in its biomedical applications. Biosensors could be used within the body for early detection of several life threatening illnesses. Nanotechnology could also help in the development of improved drugs and dendrimers, with their hollow core, could be used to deliver drugs to targeted areas, treating sick cells and leaving healthy cells alone. Nanotechnology allows the possibility of individualized medicine based on a patient’s own genetic makeup, rather than data collected from the general population. Nanomaterials could help in the creation of stronger, more reliable prosthetics and rejection-proof donor organs. IBM recently announced that they have discovered that new types of nanoparticles can detect antibiotic-resistant bacteria like Methicillin-resistant Staphylococcus aureus (MRSA), seek it out, and destroy it by breaking down its cell wall and membrane.

Nanotechnology has the potential to make our lives better and more efficient, and the number of possible applications seems practically endless. However, there is still a lot we don’t know about nanomaterials and their possible consequences and safety issues. Some nanoparticles used in clothing have been found to wash into the water supply, damaging important bacteria in water systems. There is also concern that tiny nanofibers could pose a health problem if they were to get loose and be inhaled, or that nanoparticles might be able to be absorbed into skin. There is research that shows that under some conditions carbon nanotubes can cross membrane barriers. These are reasons that research into nanotechnology—both its possible applications and its potential dangers—is such an important and exciting field right now.

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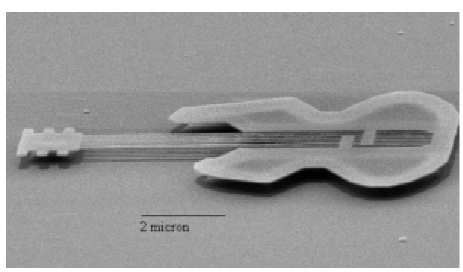
Q: When did you first find that your career path focused on nanotechnology?
Craighead: It was during my Ph.D. thesis, around 1975 — in the previously century. I did my thesis on optical properties of small metal particles imbedded in insulators. Back then, we just called them small metal particles, but they were tens of nanometer diameter particles that had altered optical properties because of their size, and we used those for a variety of applications, including solar energy collectors. That was well before there was the national nanotechnology initiative, or even before the word "nanotechnology" was commonly used, but my initial experience in research was actually in what we today call nanotechnology and plasmonics.

Q: What current nanotechnology applications are you working on?
Craighead: Actually, my entire career, following my thesis research I have been working on various forms on nanotechnology, initially grown particles and etched rods, but then I worked on lithographic approaches, that made some of the smallest electronic devices. After working at Bell Labs and Bellcore, I moved to Cornell, where I began using the capabilities that came from electronic device fabrication, for biotechnology and bioanalytical devices. When we began this work we termed it nanobiotechnology. So my research has moved towards bio-inspired and bio-analytical devices, using concepts that came from our IEEE community.

Q: What's the most rewarding thing about working with nanotechnology?
Craighead: I think the nano area — and research in general — is always pushing into the unknown. So in this field you're always learning new things and figuring out how to use this new information to do something useful. I think, it just happened that my directions were in nanotechnology, but I think the answer is probably the same for most people who are inspired by exploring new research areas. I've used nanostructure engineering as a vehicle to approach new areas of science and device applications.



"Nanoguitar" Dustin Carr & Harold Craighead, Cornell University

Q: Is there an example you can provide that shows how something you've worked on has positively impacted the world?
Craighead: I guess some of the things I've done have provided new fabrication and manufacturing capabilities. I have worked on lithographic approaches that have helped improve our ability to design and manufacture small objects — so that may have been a small contribution to the overall technologies that are being employed in modern electronics. I think part of my motivation for using these related technologies to these biological systems is using these for medical diagnostic devices. So, one of the things I am currently working on is to use these for

USEFUL LINKS:

Cornell University
Craighead Research Group

EDUCATIONAL BACKGROUND:

Ph.D., Physics, Cornell University

B.S. Physics, University of Maryland

ADVICE TO STUDENTS:

I'd just say, study math and science. Those are the core disciplines to focus on. From there one can go in many directions. By the time today's young students are my age, the world will have changed dramatically and nanotechnology may be passé.

more compact and cheap medical diagnostics. We have had some success in DNA sequencing methods that are now in commercial products and I am now working on methods of reading epigenetic information from single chromosomes for the study of cancer and engineering nucleic acids molecules for use in medical devices and treatment.

Q: What do you think is the single greatest impact nanotechnology has had on the world thus far?
Craighead: I think the greatest impact has been in electronics. That may be not what everyone thinks nanotechnology is, but I think that's the real technology that's been impacted the greatest by working at the nanoscale. It has enabled enormous changes in our electronics, much of what I see sitting on the table here, our computers, and recorders, and cell phones, and cameras, so I think that's undoubtedly had an impact on people's lives. It's been an evolutionary advance as we follow Moore's law, but I think that's been the most dramatic real technology application that I've seen.

Q: Please give an example of what you envision nanotechnology applications leading to in the future.
Craighead: I think that in the future we will probably make even greater use of nanotechnology; perhaps involving new approaches to data storage and displays. I also expect to see broader impact in other aspects of our lives from physical, chemical and biological sensors. I expect biomedical applications will grow dramatically, but I think that nanotechnology continue to be a driver of advances in consumer electronics.

Q: Do you find yourself working more in a team situation, or more alone?
Craighead: Oh, certainly in teams. There's no question about that. In fact I work almost always with interdisciplinary teams, these days.

Q: If you work more as a team, what are some of the other areas of expertise of your team members?
Craighead: Team members come from many disciplines — chemistry, biology (those are both very broad fields, it includes cell biology, molecular biology, surface chemistry, immunology), in addition to mechanical engineering and electrical engineering. We work in very broad, very intellectually diverse groups these days.

Q: Did your university training help you in your nanotechnology work?
Craighead: Yes, in my case it has directly applied. My undergraduate training was in physics, which I think is at the core of electrical engineering, and so that's provided a solid base on which I've always built. This background also provides a problem-solving approach that one can use in other areas, so the university education and training has been absolutely critical.

Q: Do you have a mentor? Did you in your college years?
Craighead: Not just a single one. There have been faculty members and co-workers at various stages of my career that I found influential or helpful, and I think the university and industrial research environments that I've been in have been very supportive and intellectually stimulating.

Q: If you had to do it all over again, would you still focus on nanotechnology applications?
Craighead: Yes, there are many possible paths to interesting careers, but I think the one that I found has been rewarding, so I probably wouldn't change it. That's not to say there wouldn't have been some other equally rewarding other path, but I don't know what it would be, and I'm satisfied with the one that I took.

Q: If a high school or college student was interested in nanotechnology, what advice would you give them to help prepare take on those roles?
Craighead: I'd just say, study math and science. Those are the core disciplines to focus on. From there one can go in many directions. By the time today's young students are my age, the world will have changed dramatically and nanotechnology may be passé. So, studying the basics such as math and science is important, that's really what everything else is based on. It's hard to predict where we'll be in twenty years. So if we had a course in nanotechnology today, it's undoubtedly going to be out of date twenty years from now. I don't think it's particularly critical that we have a high-school level, age-specific nanotechnology course. By the way, I do teach a freshman course in nanotechnology, but I guess I'm not so concerned that we don't have lower level degrees specifically in nanotechnology. My advice to the current students would be, use nanotechnology as an inspiration and consider an engineering career, but to begin with, study the basics of math and science. Become well-grounded in those basics, and then that will be a platform on which your research, understanding, applications, and jobs will be based. I would say, the most important thing is follow your interests and where you think your skills are. Don't worry too much about what's going to happen in twenty or thirty years, because that's hard to predict. I'd say study math, and whatever subjects that you find interesting: physics, chemistry, biology, or computers — whatever it is. Just do what's of interest, but consider the basics, because the applications will change.

Q: Were you interested in science or engineering as a child? What was your experience then?

Craighead: As near as I can tell I was born interested in science and technology. I suppose it was biology first because this was most available and as collected insects, salamanders, snakes, and all sorts of small critters. When a little older I started soldering together vacuum-tube electronics and building model airplanes and rockets. I started building things and tinkering with devices at an early age and I haven't stopped yet. Maybe now I've come full circle and now making more devices to study biology, living cells and molecules.

Q: What prompted you to join IEEE?
Craighead: I have worked in electronics-based industry and heavily utilized techniques developed for microelectronics in my research. The IEEE is a society that fosters technology development and new application of engineered devices. It seems like a natural community for me.

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NANOTECHNOLOGY

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The Surface Area Effect

April, 2014
by Robin Hegg

As you've probably already learned by now, large-scale particles and nanoparticles can exhibit very different properties. And changes made on the nanoscale can create materials that exhibit different properties as well. The development of nanomaterials have led to the development of stain resistant cloth, bicycle frames that are both stronger and lighter, and the possibility of being able to deliver medicines just to the cells that need them.

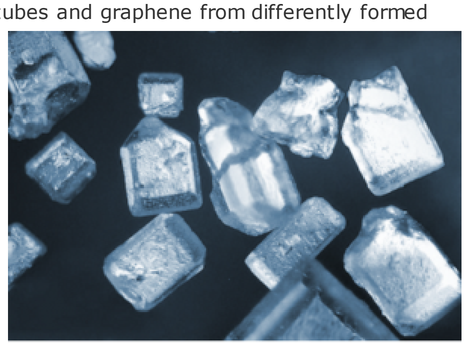
One of the main reasons nanoparticles behave differently is that they have much higher surface area than larger particles. Surface area is the measure of how much exposed area an object has. Since chemical reactions take place at the surface level, a larger surface area allows more available space for reactions. This can change a material's mechanical, electrical, thermal, and chemical properties.

Surface area is expressed in square units and for objects with flat faces, it can be calculated by adding together the areas of its faces. All objects (even those with round surfaces) have surface area. As particles are broken down, more surface area becomes exposed, so one large object has less surface area than many smaller objects.

Sugar Sweet Nano

Bakers use two common types of sugar when cooking: granulated sugar (regular table sugar) and confectioner's sugar (powdered or icing sugar). The difference between these two types of sugar is surface area. Powdered sugar (also called icing sugar) is made up of smaller particles, and as such, the same volume of powdered sugar has more surface area than granulated sugar. Granulated sugar normally has grains about .5mm across and powdered sugar normally has grains about .06mm across.

In the same way that scientists grow carbon nanotubes and graphene from differently formed carbon molecules, sugar crystals can be grown from sugar solutions made from different-sized sugar particles.



In this activity, you will grow crystals from sugar solutions made from sugar with two different surface areas. How do you think the difference in surface area will affect the behavior of the sugar particles and the resulting crystals?

To grow and compare your sugar crystals, you'll need:

- Two clean glass cups or measuring cups
- 2 pieces of thin cotton string (with length at least 1.5 times the cup's height)
- 2 pencils or sticks
- A washer or screw to weigh down the string
- 3 cups of granulated sugar
- 3 cups of powdered confectioners' sugar (icing sugar)

DID YOU KNOW?

1. Researchers at the Institute of Bioengineering and Nanotechnology (IBN) in Singapore have discovered a new process that could make it possible to create clothing from sugar.
2. A reliable blood sugar detection sensor was developed using carbon nanotubes and iron oxide nanoparticles by researchers at the University of Tehran.
3. Sugar cane was used by researchers the University of Florida's Institute of Food and Agricultural Sciences to create nanotubes that could someday improve chemotherapy treatments.

FIND OUT MORE:

You can also visit **TryEngineering.org** to explore other engineering activities and resources. Additional activities and lessons can be found **here**.

- 2 cups very hot water (poured by an adult)

Step One: Label each cup with the type of sugar it will hold. Have an adult pour one cup of very hot water into each of the two cups.

Step Two: Add 3 cups of each type of sugar into their respective cups and stir to dissolve (the water will look perfectly clear when the sugar is dissolved).

Step Three: Soak a piece of string in each cup of sugar water, then place it on a plate to dry for at least ten minutes. This allows starter crystals to form.

Step Four: Tie one end of the string to a pencil. Add a weight (a washer or screw) to the other end of the string.

Step Five: Place the appropriate string into the water with the weighted end down, allowing the pencil to sit across the top of the cup, holding the string in place.

Step Six: Observe the cups each day for 4-7 days. If possible, examine a sample of each of the resulting crystals under a microscope.

Questions:

1. Which type of sugar dissolved more quickly? What effect do you think the difference in surface area had on the results?

2. How are the crystals grown from the granulated sugar and those grown from the powdered sugar different? How did your results differ from your hypothesis?

3. What does the difference in the two types of crystals show you about nanotechnology and nanostructures?

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ENGINEERING INSIDE: NANOTECHNOLOGY

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Explore Nanotechnology with Games and Simulators!

April, 2014
by Robin Hegg

Working at the nanoscale isn't something everyone will get a chance to do, but luckily there are games and tools online that can simulate the real thing and help put your new knowledge into perspective.

NanoMission is a series of four downloadable nanotechnology games. After registering on the site, the game modules can be downloaded and played on your computer. The games include

-"NanoScaling" lets players explore and visualize the huge scale of different objects from gigameters (used to measure the diameter of the sun and the distance between planets) to picometers (one trillionth of a meter, used to measure atoms and molecular bonds).
-"NanoImaging" asks players to save the world's lakes and rivers from by using scanning electron microscope (SEM) technology to image, identify and destroy the dangerous organisms putting them at risk.
-"NanoMedicine V1" has players working to deliver an anti-cancer compound to a tumor. First players must select a suitable vehicle to deliver the drug, then navigate it through the patient's bloodstream to the tumor, while avoiding the body's defenses.
-"NanoMedicine V2" helps players get a better understanding of how nanomedicines are created. In it, players build nanoscopic particles and, through observation and experimentation, try to cure cancer in a patient by measuring the particles' effects on the patient at the cellular level.

Duckboy in Nanoland is a nanotechnology theme park adventure from the Museum of Science, London that can show you how different things can be on the nanoscale. Each ride you take Duckboy on begins on the normal scale, then zooms in to the nanoscale where properties and behaviors change in interesting ways.

Virtual Microscope is a NASA-funded microscope simulator. It includes a Scanning Electron Microscope (SEM), Light Microscope, Atomic Force Microscope, and an Energy Dispersive Spectrometer for the SEM. The simulator allows you to examine real specimens using hundreds of images taken at different positions and magnifications.

nanoHUB is an online resource for nanoscience and nanotechnology created by the Network for Computational Nanotechnology. In addition to great overall information on the basics of nanoscience, it includes simulations for over 300 scientific tools.

If you're looking for more information about nanotechnology, check out IEEE's **trynano.org** and the National Nanotechnology Initiative at **nano.gov**.

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IEEE Nanotechnology Council

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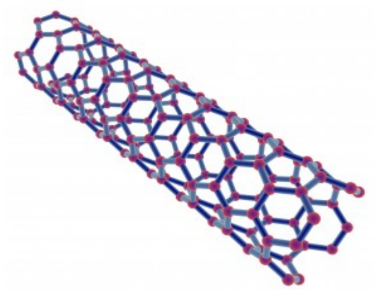

The IEEE has been working to advance collaboration and research in nanotechnology since the very beginnings of the nanotechnology industry. The IEEE Nanotechnology Council (NTC) has been around for more than a decade, working to support nanotechnology theory, design, and development in its industrial, scientific, and engineering applications. The IEEE Nanotechnology Council is made up of representatives from 21 IEEE societies, including those dealing with aerospace, manufacturing technology, and engineering in medicine and biology. There are currently 14 council chapters spread throughout the world as well as three student chapters.

The council sponsors four annual nanotechnology conferences: the **IEEE International Conference on Nanotechnology (IEEE NANO)**, which covers nano manufacturing, biomedicine, energy, plasmonics, electronics, and sensors, as well as the modeling of nano structures and devices; the **IEEE Nanotechnology Materials and Devices Conference**, which looks at ongoing work and the future directions of nanomaterials and their construction, nanoelectronics, nanophotonics, and devices; the **IEEE International Conference on Nano/Molecular Medicine and Engineering**, which deals with nano and molecular technologies in medical therapy, diagnosis, imaging, drug delivery, biochips, cell mechanics, biological interfaces, and new frontiers in nanobiotechnology; and the **IEEE International Conference on Nano/Micro Engineered and Molecular Systems**, which brings together leading researchers to discuss microelectromechanical systems and nanotechnology.

The IEEE Nanotechnology Council also sponsors three annual prizes. The Early Career Award in Nanotechnology is given to individuals who have had a major impact on nanotechnology within seven years of earning their highest academic degree. Those who have been working for at least 10 years since earning their highest degree are eligible for the Pioneer Award in Nanotechnology, which recognizes those who have had a significant impact on nanotechnology by initiating new areas of research, development, or engineering. The Distinguished Service Award is granted to those who have performed outstanding service to benefit and advance the IEEE Nanotechnology Council. The 2013 Pioneer Award winner was Charles M. Lieber, the Mark Hyman Professor of Chemistry at Harvard University, "For pioneering contributions to nanometer diameter wire synthesis and applications and defining leadership in nanotechnology."

The IEEE also works to provide information, education, and opportunities for those interested in finding out more about nanotechnology. IEEE's website **trynano.org** includes information, lessons, and more for those interested in getting involved in the exciting and constantly evolving field of nanotechnology.

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Nano Rescue

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IEEE Spark Challenge: Nanotechnology

Think you know IEEE Spark? Test your knowledge of engineering, computing and technology with the IEEE Spark Challenge!

1) A nanometer is:
    a. One thousandth of a meter
    b. One millionth of a meter
    c. One tenth of a meter
    d. One billionth of a meter

2) Nano comes from the Greek word meaning:
    a. Shrimp
    b. Dwarf
    c. Ball
    d. Wisp

3) Who first coined the term nano-technology?
    a. Norio Taniguchi, 1974
    b. Harry Kroto, 1985
    c. Gerd Binnig, 1986
    d. Richard Feynman, 1959

4) What is a current application of nanotechnology?
    a. Sunscreen
    b. Targeted pharmaceutical delivery
    c. Sports equipment
    d. All of the above

5) Buckyballs are a form of which element?
    a. Nitrogen
    b. Barium
    c. Carbon
    d. Fermium

6) Which of the following is a historical artifact containing nanotechnology?
    a. Lycurgus cup
    b. The Damascus Sword
    c. Chinese ruby color pottery
    d. Medieval church windows
    e. All of the above

7) Materials on the nanoscale exhibit different properties than on the macroscale?
    a. True
    b. False

8) In 2010, the Nobel prize was awarded to Andre Geim and Konstantin Novoselov for their work with which nanomaterial:
    a. Inorganic Nanowires
    b. Graphene
    c. Dendrimers
    d. Quantum dots

9) In nanotechnology, the arrangement of smaller components into more complex assemblies are known as:
    a. Top-down methods
    b. Vertical processes
    c. Bottom-up methods
    d. Scaled processes

10) The hypothetical end-of-the-world scenario involving molecular nanotechnology in which out-of-control self-replicating robots consume all matter on Earth while building more of themselves is also known as:

    a. red smush
    b. grey goo
    c. yellow splat
    d. purple rain

IEEE Spark Challenge: Nanotechnology Answer Key

Think you know IEEE Spark? Test your knowledge of engineering, computing and technology with the IEEE Spark Challenge!

1) A nanometer is:
    a. One thousandth of a meter
    b. One millionth of a meter
    c. One tenth of a meter
    d. One billionth of a meter

2) Nano comes from the Greek word meaning:
    a. Shrimp
    b. Dwarf
    c. Ball
    d. Wisp

3) Who first coined the term nano-technology?
    a. Norio Taniguchi, 1974
    b. Harry Kroto, 1985
    c. Gerd Binnig, 1986
    d. Richard Feynman, 1959

4) What is a current application of nanotechnology?
    a. Sunscreen
    b. Targeted pharmaceutical delivery
    c. Sports equipment
    d. All of the above

5) Buckyballs are a form of which element?
    a. Nitrogen
    b. Barium
    c. Carbon
    d. Fermium

6) Which of the following is a historical artifact containing nanotechnology?
    a. Lycurgus cup
    b. The Damascus Sword
    c. Chinese ruby color pottery
    d. Medieval church windows
    e. All of the above

7) Materials on the nanoscale exhibit different properties than on the macroscale?
    a. True
    b. False

8) In 2010, the Nobel prize was awarded to Andre Geim and Konstantin Novoselov for their work with which nanomaterial:
    a. Inorganic Nanowires
    b. Graphene
    c. Dendrimers
    d. Quantum dots

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