Stuff: The Materials the World is Made Of
by Ivan Amato
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INTRODUCTION

STUFF, *stuff,* *Everywhere* STUFF

Stop reading this book. Instead, hold it in your hand. Feel its weight. Run your finger over a page and feel its smooth texture, its dryness. Sense the page's compliance to the pressure of your finger. See how its whiteness is punctuated with black symbols printed in ink in a few dozen rows. If you sniff the page, you even may smell some aromatic chemicals still fleeing from the ink. Rub the page between your thumb and forefinger and hear that familiar papery noise. Twist a corner and see how the paper crinkles. Rip the page and see how the ragged edges hint of the tiny wood fibers that became entangled at a mill to become the paper.

Now examine the book's fabric spine to which the pages are attached with an adhesive. The stack of pages, in turn, attaches to the back and front covers of the hardcover edition by way of sheets of heavier-gauge paper that flank the book's first and last pages. At the bindery a machine pasted these flanking sheets to the rectangular pieces of stiff, heavy paperboard that the front and back covers are made of. These heavy covers, themselves enveloped with a sheet of paper or polymer-impregnated cloth, are attached to each other by a flexible paper or fabric bridge that ends up directly over the spine so that readers can open the book. The softcover edition is a simpler affair of paper, ink, and glue.

Soft or hard, this book is made through and through of stuff.

And so is every thing else. Human beings extract about 15 billion tons of raw material—that's 30 trillion pounds—from the earth each year, and from that they make every kind of stuff that you can find in every kind of thing. Mined ore becomes metal becomes wire becomes part of a motor becomes a cooling fan in a computer. Harvested wood becomes lumber becomes a home. Drilled petroleum becomes chemical feedstock becomes synthetic rubber becomes automobile tires. Natural gas becomes polyethylene becomes milk jugs and oversize, multicolored yard toys. Mined silica sand become silicon crystal becomes the base of microelectronic chips. Each kind of stuff is a link to enormous industrial trains whose workers process the world's raw materials into usable forms that constitute the items of our constructed landscape.

Each kind of stuff also is a palimpsest of innovations in the use of materials, some going back to prehistoric times. The wood-pulp paper from which books are made today comes from a pedigree of cotton and linen rags, animal-skin parchment, Nile-reed papyrus, and Sumerian clay tablets. The ink, a black pigment made from the ground ash of some carbon-bearing fuel and then suspended in a rapidly evaporating solvent, has its roots in crushed ore and charcoal mixed with spit or animal grease for use on cave walls and faces. The materials in every book tell a tale that rivals the one conveyed in its words.

It is the same for every other material thing that you encounter. Train your attention on the stuff of things rather than on their function. What you see is a rich medley of materials: the liquid crystal display of your laptop computer; the gritty concrete sidewalk on which you are strolling; the nylon of your raincoat's zipper; the carbon-fiber-reinforced epoxy polymer of your tennis racket; the Kevlar polymer in your police force's bullet-proof vests; the oak of your dresser; the diamond in your engagement ring; the nickel-based superalloy in the turbine blades in the engine of an airliner you are flying in; the warm, supple skin of your newborn; the cool, transparent glass of your office window; the combination of slick, high-density polyethylene and stainless steel that make up the artificial hip which a surgeon may have implanted into you; the cotton of the shirt you are wearing; the aluminum of the can you just drank from.

In a single day the thousands of man-made materials that you encounter, engage, manipulate, and use display a diversity every bit as wondrous as that found in living organisms, which are composed of the most miraculous of all the world's materials—skin, bone, tendon, muscle, nail, hair, and scads of other biological tissues—all of them honed by evolutionary engineering into a beautiful marriage of form and function.

That books and buildings and the things in the world are supposed to be made of materials suited for their functions is so obvious that it almost goes without saying. But things that go without saying long enough are readily forgotten. That is why the materials that make up the world are most often not on people's minds.

When the stuff of the world does comes to the fore, it is often a consequence of a material failing to serve its intended role. This happened in 1988, when the aluminum-alloy skin of an airliner flying over the Pacific Ocean peeled open and sheared off like the top of a sardine can, sending a flight attendant to her death. Articles about metal fatigue appeared in the *New York Times* and all over the media. Aluminum and material failure enjoyed their fifteen minutes of fame. To the unseen scientists, engineers, and workers who actually transform the raw stuff of the world into materials like aerospace alloys, the way materials can go bad is never far from their minds. They—and their bosses, lawyers and insurance companies—know how lives, economies, and national security depend upon understanding what makes materials the right stuff or the wrong stuff.

But materials are far too central to our lives and too fascinating to remain out of mind until they become sensational headlines. Paying attention to the materials in your life spawns an endless stream of fascinating questions (and even more fascinating answers). Why is a skyscraper's frame made of steel, not copper or polyethylene? What is so special about silicon crystal that it became the foundation of a society-changing electronics revolution? What kind of materials does it take to build a plane that can take off like a jet, accelerate at 20,000 miles per hour, zoom into outer space, and then land two hours later in an airport on the other side of the planet?

Simply noticing the diversity of stuff in the material world can evoke an openmouthed sense of wonder akin to visiting a zoo filled with animals that you had never really seen up close. That sense of wonder might even grow into awe when you consider this: the constructed world brims with metals, ceramics, plastics, fabrics, glass, and thousands of other specific materials that are found nowhere in the wilderness.

And that sense of awe naturally leads to a question like this one, which is at the heart of this book: How in the world did humanity learn to transform the raw stuff of the wilderness into the contemporary zoo of materials? Nylon doesn't grow on trees. It starts out in a barrel of tarry, smelly coal tar or petroleum. Someone—in this case a chronically depressed and brilliant chemist who ultimately committed suicide—figured out how to pull off the transformation. Someone had to figure out how to convert a handful of sand into an optical fiber that can pipe light around for miles and miles the way a copper wire pipes electricity.

Aristotle wrote that you cannot know something fully unless you know it from its beginnings. This applies to the human use of materials. So in this book, I will start from the beginning—about 2.5 million years ago. That is when our hominid progenitors in the Great Rift Valley of Africa likely had the original insight that materials as they are found in the wilderness can be transformed into more useful and empowering forms.

The original noisy act of materials engineering—striking a stone against another to produce a sharp, cutting edge where before there had been a dull surface—is no different in its core from what modern engineers in Silicon Valley do when they implant boron and phosphorous atoms (stepping stones for electrical charges) into pristine wafers of crystalline silicon to create the semiconductor of the microelectronics revolution. The goal of both procedures is the same: to alter materials so that they can perform in new technological ways.

Despite the apparent crudeness of chipping stones to make tools, the kinship between the original stone flakers and the most modern materials engineers goes atomically deep. Silicon atoms, when combined with oxygen atoms to form specific minerals, is the basis of one of the most coveted materials of the first stone toolmakers—flint. Because of the arrangement of internal mineral grains in flint, the stone can cleave conveniently in a shell-like pattern that leaves sharp edges. Moreover, its edges are hard and tough enough to remain sharp even after cutting and scraping into materials like tendon and bone. Silicon has been a celebrity element from the beginning.

From the Great Rift Valley, the story of materials progresses through some 125,000 hominid and human generations (based on a twenty-year generation) to the present day. During that vast stretch of time, the first hominid toolmakers evolved into us, *Homo sapiens*. Punctuating those thousands of millennia were a few major turning points, each leading to entirely new powers of material transformations that have changed the course of individual lives and of global history. (See Figure 1.)

The use of fire to change the stuff of the world was one of them. Fire's heat has the capacity to reach down to the molecular identity of a material and then to jumble, reorient, and rearrange it to yield almost magical transformations. Wood becomes smoke, heat, invisible gases, and ash. Dull, crumbly ore becomes lustrous metal. Wet, malleable clay becomes hard pottery. Sand become glass. It may all have been accidental chemistry in the hands of the first fire users, but the consequences were and are world-changing.

Another major turning point was the development of a more deliberate type of chemistry and its far more extensive ways of reaching into and transforming the anatomy of stuff. For centuries alchemists, chemists, and sundry tinkerers pulverized, mixed, boiled, distilled, roasted, extracted, electrolyzed, and otherwise fiddled with whatever substance they could find in the mineral, animal, and vegetable domains. Out of this obsessive quest came a myriad of previously unseen substances—solid, liquid, and gaseous—some of which harbored uses by themselves or as participants in new chemical reactions.

Along the way, chemists also learned about the limitations of their business. Despite the two-thousand-year alchemical quest to transform "base" materials into gold, no one ever succeeded in transmuting one element into another. At least on earth, under normal conditions (that is, without enormous

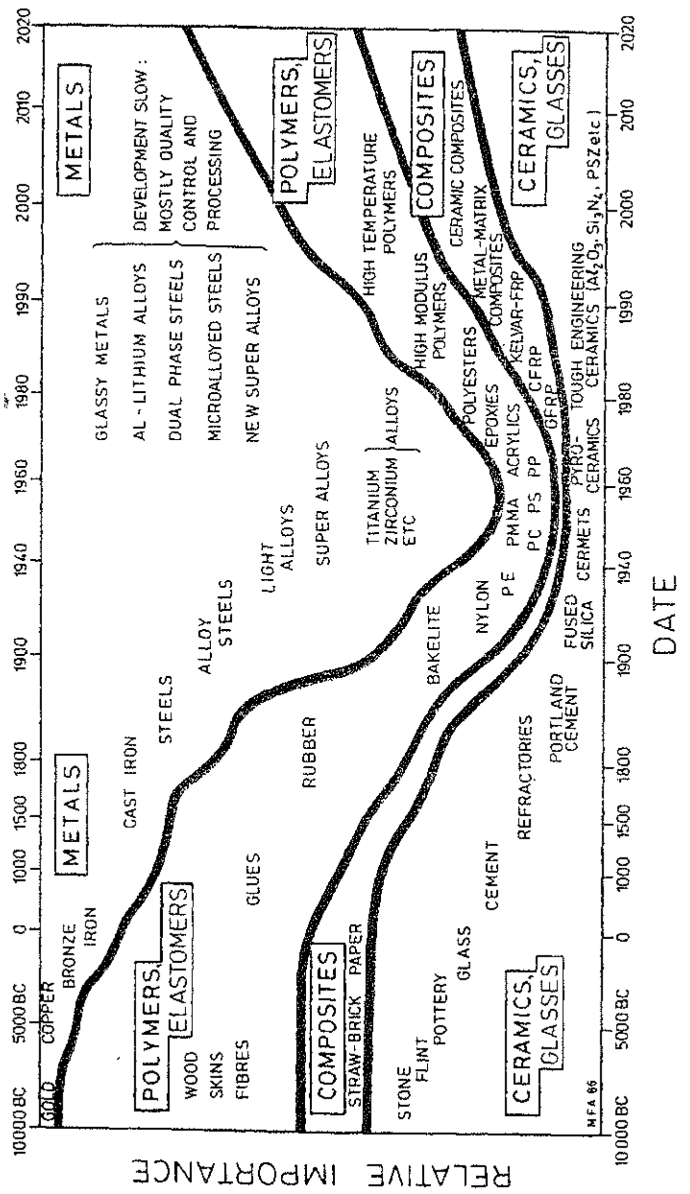

FIGURE 1

The Stuff of History. To follow each of the heavy lines across this diagram is to trace a word-byte history and projection of four major classes of materials—*metals, polymers-elastomers, composites* (whose properties are derived from two or more materials—such as a polymer with glass fibers as reinforcement—bound into a single overall structure), and *ceramics-glasses*. The relative importance to humanity of each material class at each historical period is *suggested* on the diagram by the proportion of the diagram's vertical axis corresponding to each material class. So in 1960, for example, composites were least important while metals were head and shoulders most important. In 2020, however, the four classes of materials are projected to have roughly equal importance.

MICHAEL F ASHBY

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accelerators), scientists realized they would never become alchemists—they would never change lead into gold or oxygen into carbon or any one element into any other element.

This limitation, it turns out, was always more a state of mind than of reality. The hard-won insight that the vast menagerie of materials in the world is a result of a small pantry of elements, that the personality of each material is the result of an inner hierarchy of chemical and physical structures, has became the principle of a new alchemy practiced by people known as materials scientists. Rather than gold from lead, their trophies are numerous, ranging from new lightweight alloys to build a next-generation fleet of superefficient jetliners to harder-than-diamond materials for industrial machine tools to polymeric drug-soaked medical implants that can release their cargo into diseased brain tissue.

Yet another major turning point in the human control over the material world—perhaps the last one possible—is in the offing. In the past half century a field known as materials science and engineering has emerged as a powerful hybrid of many other technical fields. The practitioners of this field are coming to a point where they are gaining the ultimate level of control over the material world.

No longer contented to manipulate "stuff," they have tools for seeing, moving, and understanding individual atoms and the ever larger atomic collections that become the materials we use. The emerging ability to micromanage materials even at the atomic level is giving researchers unprecedented access to the mostly untapped material wonders of the periodic table of the chemical elements. Even compared to today's most sophisticated materials like the semiconductor in a computer chip or the gallium arsenide in a CD player's laser, materials scientists say we still ain't seen nothing compared to the materials that will come.

Materials scientists now recognize that within their new powers lie new solutions to many of the globe's most vexing

problems—among them pollution, energy supply, housing, transportation, communications, and poverty: new superconductors that can dramatically increase the efficiency with which electricity is generated, distributed, and used could demote petroleum as a factor in geopolitical dynamics; raw materials for making these superconductors—say, ores containing unfamiliar elements like yttrium and bismuth—could become strategic materials; new metallic alloys such as titanium-aluminides and new composite materials—perhaps ones made of tough ceramic materials laced with superstrong diamond fibers that overcome the ceramic's endemic vulnerability to catastrophic fracture—will be the stuff of new aircraft that can fly at twenty-five times the speed of sound.

"Smart materials" that can respond to external conditions by changing their color, shape, stiffness, or permeability to air or liquids could become the stuff of future cities whose buildings are more comfortable and better able to field sudden violent challenges from earthquakes or terrorist bombs. Smart materials also could lead to cities whose infrastructure can sense—and even automatically compensate for—the wounds of corrosion, metal fatigue, age, and the other slings and arrows of urban decay.

On the down side is that today's wonder materials could become tomorrow's environmental villains. It has happened before. When chlorofluorocarbons (CFCs) were first invented in the 1930s, their combination of inertness, nonflammability, and thermophysical properties fated them to become materials of choice for technologies such as refrigeration (which previously relied upon extremely noxious materials including ammonia and sulfur dioxide), aerosol propellants, and blowing agents for making lightweight materials such as styrofoam.

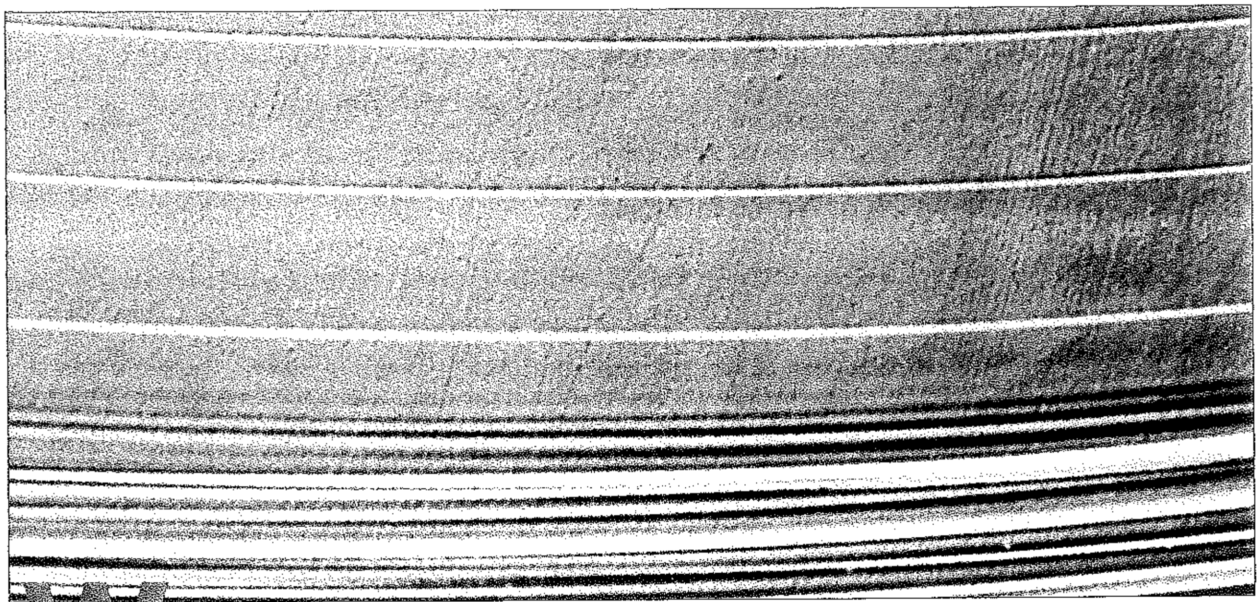
The inventor of CFCs, Thomas Midgely, used to breathe CFCs into his lungs and then extinguish a candle with a CFC-rich exhalation to impress audiences with the material's benign nature. Over the course of decades of ever higher volume use, however, CFC molecules had been meandering into the stratosphere where, it turns out, they trigger reactions that destroy ozone molecules. Ozone molecules absorb much of the sun's life-unfriendly ultraviolet radiation. So what were once new wonder materials have become one of the century's most prominent chemovillains.

Today's materials researchers are far more aware of the Promethean catch that new materials can harbor, having learned from experience with CFCs, lead-based paint pigments, asbestos insulation, and many other materials. The challenge for today's researchers is to use their ever more sophisticated knowledge base to more accurately predict the balance of potential benefits and costs new materials will bring with them.

In the words of Cyril Stanley Smith, the late materials historian and Manhattan project metallurgist: "Materials themselves have interacted with mainstream history, for they are the stuff on which virtually all human activities are based."[1] As materials researchers discover and create ever more capable materials, human aspiration and achievement will soar into new places.

MICROGRAVITY RESEARCH DIVISION

Materials Science



On the cover: Longitudinal section of a gallium-doped germanium crystal grown in a sounding rocket experiment. In the bottom portion of the crystal, which solidified under acceleration during launch, variations in gallium concentration in the crystal (caused by turbulent convection in the melt) are seen as random striations. The top portion of the crystal was grown under microgravity conditions, in which buoyancy-driven convection is absent; hence, the lack of striations. The evenly spaced lines in the upper part of the crystal are intentionally introduced time markers that indicate that the crystal was growing at a constant rate.

What Is Materials Science?

Materials science is an extremely broad field that encompasses the study of all materials. Materials scientists seek to understand the formation, structure, and properties of materials on various scales, ranging from the atomic to the microscopic to the macroscopic (large enough to be visible). Establishing quantitative and predictive relationships between the way a material is produced (processing), its structure (how the atoms are arranged), and its properties is fundamental to the study of materials.

Materials exist in two forms: solids and fluids. A fluid is any material that flows in response to an applied force. Gases such as air and helium are fluids, as are liquids like water, oil, and molten aluminum.

Solids can also be subdivided into two categories — crystalline and noncrystalline (amorphous) — based on the internal arrangement of their atoms or molecules. Metals (such as copper, steel, and lead), ceramics (such as aluminum oxide and magnesium oxide), and semiconductors (such as silicon and gallium arsenide) are all normally crystalline solids because their atoms form an ordered internal structure. Most polymers (such as plastics) and glasses are amorphous solids, which means that they do not have a long-range, specifically ordered atomic or molecular arrangement.

Marshall Space Flight Center in Huntsville, Alabama, is NASA's Microgravity Center of Excellence for materials science.

Why Conduct Materials Science Research in Microgravity?

One principal objective of microgravity materials science research is to gain a better understanding of how gravity-driven phenomena affect the solidification and crystal growth of materials. Primarily, materials processing is affected by buoyancy-induced convection (fluid flow resulting from temperature-driven density differences within the fluid), sedimentation (settling of different materials into distinct layers), and hydrostatic pressure (due to the weight of material above the point of measurement). These gravity-induced effects can create irregularities, or defects, in the internal structure of materials, which in turn alter the materials' properties. In microgravity, these gravity-driven phenomena are significantly suppressed, allowing researchers to study underlying events that would otherwise be obscured and therefore difficult or impossible to study quantitatively on Earth. For example, in microgravity, where buoyancy-driven convection is greatly reduced, scientists can carefully and quantitatively study segregation, a phenomenon that influences the distribution of a solid's components as it forms from a liquid or gas. (See back page for more information about microgravity, or µg.)

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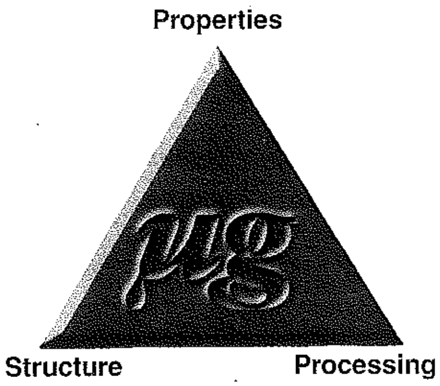


Many materials scientists use a triangle such as this to describe the relationship between structure, processing, and properties. Microgravity (μg) can play an important role in establishing these relationships in a quantitative and predictive manner.

Microgravity also supports an alternative approach to studying materials called containerless processing. Containerless processing has an advantage over normal processing in that containers, on the ground and in space, can contaminate the materials being processed inside them. In addition, there are some cases in which there are no containers that will withstand the very high temperatures and/or corrosive environment needed to work with certain materials. Containerless processing, in which acoustic, electromagnetic, or electrostatic forces are used to position (levitate) and manipulate a sample, thereby eliminating the need for a container, is an attractive solution to these problems.

Although containerless processing can be accomplished on Earth, the forces required to levitate samples are so strong that they can interfere with and influence the behavior of the material (for example, turbulent fluid flows can be induced in the sample). Microgravity requires much smaller forces to control the position of containerless samples, so the materials being studied are not disturbed as much as they would be if they were levitated on the ground.

Researchers in materials science are particularly interested in increasing their fundamental knowledge of the physics and chemistry of phase changes (when a material changes from liquid to solid, gas to solid, etc.). This knowledge could be applied to designing better process-control strategies in laboratories and production facilities on Earth. In addition, microgravity experimentation may eventually enable the production of limited quantities of high-quality materials and of materials that exhibit unique properties for use as benchmarks.

Microgravity researchers are interested in studying various methods of crystallization, including solidification (like freezing water to make ice cubes), crystallization from solution (the way rock candy is made from a solution of sugar and water), and crystal growth from the vapor (like frost forming in a freezer). These processes all involve fluids, which are the materials that are most influenced by gravitational effects. Examining these methods of transforming liquids or gases into solids in microgravity gives researchers insight into other influential phenomena at work in the crystallization process.

Materials Science Research Areas

Electronic Materials

Electronic materials play an important role in the operation of computers, medical instruments, power systems, and communications systems. Semiconductors are well-known examples of electronic materials and are a primary target of microgravity materials science research. Applications include creating crystals for use in lasers; computer chips; solar cells; and X-ray, gamma-ray, and infrared detectors. Each of these devices depends on the ability to manipulate the crystalline and chemical structure of the material, which can be strongly influenced by gravity as crystals are formed.

The properties of electronic materials are directly related to the chemical and crystalline perfection of the material. However, perfect crystals are not normally the ultimate goal. The presence of just a few intentional impurities in some electronic materials can drastically affect their ability to conduct electricity. By carefully controlling crystalline defects and the introduction of desirable impurities into the crystals, scientists and engineers can design better electronic devices with a wider range of applications.

Glasses and Ceramics

A glass is any material that is formed without a long-range ordered arrangement of atoms. Materials that naturally form glasses have liquid and chemical bonding properties that prevent atoms from aligning into crystalline structures as the liquid cools. One important aspect of glass formation is the limited mobility of the atoms in the liquid form of the material. This sluggishness of atomic movement is one of the things that prevents the formation of a crystalline solid. Some materials that usually take crystalline forms, like metals, can also be forced to form glasses by rapidly cooling the molten materials to temperatures far below their normal solidification point. When the materials finally solidify, they freeze so quickly that the normally mobile atoms or molecules do not have time to arrange themselves systematically.

Ceramics are inorganic nonmetallic materials that can be extraordinarily strong at very high temperatures, performing far better than metallic systems under certain circumstances. They will have many more applications when important fundamental problems can be solved. If a ceramic turbine blade, for example, could operate at high temperatures while maintaining its strength, it would provide overall thermodynamic and fuel efficiencies that would revolutionize transportation. The problem with ceramics is that when they fail, they fail catastrophically, breaking in an irreparable manner.

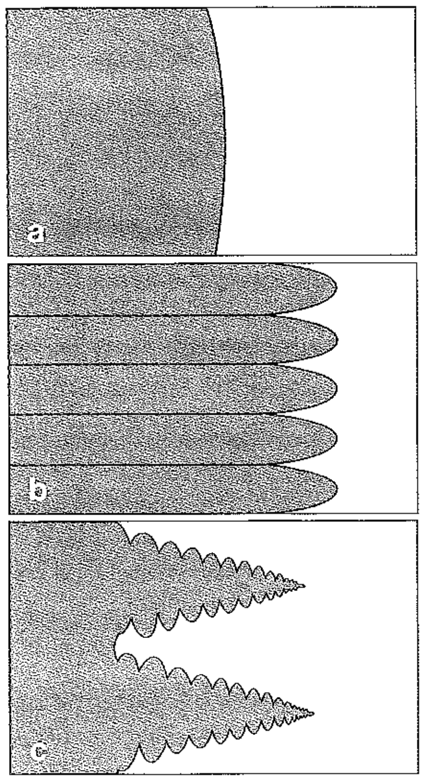
Glasses and ceramics are generally unable to absorb the impacts that metals can; instead, they crack under great force or stress (whereas metals generally bend before they break). An important part of ceramics and glass research in microgravity involves controlling the minute flaws that govern how these materials fail. From information obtained through microgravity research, scientists hope to be able to control the processing of glasses and ceramics well enough that they can, during processing, prevent the formation of imperfections that lead to catastrophic failure.

Applications for knowledge obtained through research in these areas include improving glass fibers used in telecommunications and creating high-strength, abrasion-resistant crystalline ceramics used for gas turbines, fuel-efficient internal combustion engines, and bioceramic artificial bones, joints, and teeth.

Metals and Alloys

Metals and alloys (combinations of two or more metals) constitute an important category of engineered materials, which include electrical conductors, many types of composites, and structural and magnetic materials. Research in this area is primarily concerned with advancing the understanding of metals and alloys processing so that structure and, ultimately, properties can be controlled as the materials are originally formed. By removing the influence of gravity, scientists can more closely observe important processes in structure formation during solidification. The properties of metals and alloys are linked to their crystalline and chemical structure; for example, the mechanical strength and corrosion resistance of an alloy are determined by its internal arrangement of atoms, or its microstructure, which develops as the metal or alloy solidifies from its molten state.

One aspect of the solidification of metals and alloys that influences their microstructure is the shape of the boundary, or interface, that exists between a liquid and a solid in a solidifying material. As the rate of solidification increases under the same thermal conditions, the shape of the solidifying interface goes through a series of transitions.



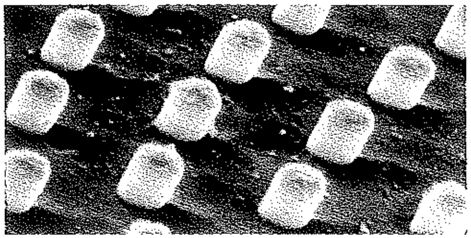
Representations of the different shapes of the liquid/solid interface in a solidifying material: planar (**a**)*, cellular* (**b**)*, and dendritic* (**c**).

At low growth rates, the interface is planar (flat or smoothly curved on a macroscopic scale). As the growth rate increases, the interface develops a corrugated texture until three-dimensional cells form in the solid. A further increase in growth rate causes the formation of dendrites (tree-shaped structures) in the solid. The development of these different interface shapes and the transition from one shape to another is controlled by the morphological stability of the interface, which is influenced by many factors, including buoyancy-driven convection. Data obtained about the conditions under which certain types of solidification boundaries appear can help to explain the evolution of the final microstructure of a material.

Another area of interest in metals and alloys research in microgravity is multiphase solidification. Certain materials known as eutectics and monotectics transform from a single-phase liquid to substances of more than one phase when they are solidified. When these materials are processed on Earth, the resulting solid structures show the influence of gravity-induced effects (buoyancy-driven convection and/or sedimentation). But when these materials are processed in microgravity, theory predicts that the end product should consist of an evenly dispersed, multiphase structure. Eutectic and monotectic alloys with this type of internal structure may be useful for specialized applications such as superconductors, high-performance magnets, bearing materials for engines, catalysts, and electrical contacts.

A eutectic solidifies from one liquid of uniform composition to form two distinct solid phases. An example of such a material is the alloy manganese-bismuth (Mn-Bi). Solidifying liquid Mn-Bi results in two different solids, each of which has a chemical composition that differs from the liquid. In eutectic solidification in microgravity, one solid (the minor phase) is distributed as rods, particles, or layers throughout the other solid (a continuous matrix, or the major phase).

Monotectics are similar to eutectics, except that a monotectic liquid solidifies to form a solid and a liquid (both of which are different in composition from the original liquid). Aluminum-indium (Al-In) is a monotectic that starts out as indium dissolved completely in aluminum, but when the alloy is solidified under the appropriate conditions, it forms a solid aluminum matrix with long thin "rods" of liquid indium inside it. As the system cools, the rods of liquid indium freeze into solid rods. These indium rods are dispersed within the structure of the solidified material.



An etched sample of the aluminum-indium alloy (magnified). When the monotectic mixture is cooled, aluminum transitions to a solid first, trapping the indium in cylindrical "rods" within the solid.

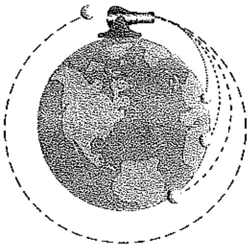
Polymers

Polymers are organic macromolecules (very large molecules) made up of numerous small repeating molecular units called monomers. They appear naturally in wool, silk, and rubber and are manufactured in the form of acrylic, nylon, polyester, and plastic. Important optoelectronic and photonic applications are emerging for polymers, and many of the properties needed for these applications are affected by the polymers' crystallinity. This crystallinity, which is the extent to which chains of molecules line up with each other when the polymer is formed, may be more easily manipulated when removed from the influence of gravity.

Polymers are typically composed of long chains of monomers. These chains appear to have a spine of particular elements such as carbon or nitrogen. The bonding between individual polymer molecules affects the material's physical properties such as surface tension, miscibility, and solubility. Manipulation of these bonds under microgravity conditions may lead to the development of processes to produce polymers with more uniform and controlled specific properties.

Growing polymer crystals can be more difficult than growing inorganic crystals (such as semiconductors) because the individual polymer molecules weigh more and are more structurally complex, which hinders their ability to attach to a growing crystal in the correct position. Yet in microgravity, the process of polymer crystal growth can be studied in a fundamental and systematic way, with special attention to the effects of such variables as temperature, compositional gradients, and the size of individual polymer units on crystal growth. In addition, just as microgravity enables the growth of larger protein crystals, it may allow researchers to grow single large polymer crystals for use in studying the properties of polymers and determining the effects of crystal defects on those properties.

Gravity and Microgravity



In his "thought experiment," Isaac Newton hypothesized that by placing a cannon at the top of a very tall mountain and firing a cannonball at a high enough velocity, the cannonball could be made to orbit the Earth.

Gravity is such an accepted part of our lives that we rarely think about it, even though it affects everything we do. Any time we drop or throw something and watch it fall to the ground, we see gravity in action. Although gravity is a universal force, there are times when it is not desirable to conduct scientific research under its full influence. In these cases, scientists perform their experiments in microgravity — a condition in which the effects of gravity are greatly reduced, sometimes described as "weightlessness." This description brings to mind images of astronauts and objects floating around inside an orbiting spacecraft, seemingly free of Earth's gravitational field, but these images are misleading. The pull of Earth's gravity actually extends far into space. To reach a point where Earth's gravity is reduced to one-millionth of that on Earth's surface, one would have to be 6.37 million kilometers away from Earth (almost 17 times farther away than the Moon). Since spacecraft usually orbit only 200–450 kilometers above Earth's surface, there must be another explanation for the microgravity environment found aboard these vehicles.

Any object in freefall experiences microgravity conditions, which occur when the object falls toward the Earth with an acceleration equal to that due to gravity alone (approximately 9.8 meters per second squared [m/s^2], or 1 g at Earth's surface). Brief periods of microgravity can be achieved on Earth by dropping objects from tall structures. Longer periods are created through the use of airplanes, rockets, and spacecraft. The microgravity environment associated with the space shuttle is a result of the spacecraft being in orbit, which is a state of continuous freefall around the Earth. A circular orbit results when the centripetal acceleration of uniform circular motion ($\mathbf{v}^2/\mathbf{r}$; $\mathbf{v}$ = velocity of the object, $\mathbf{r}$ = distance from the center of the object to the center of the Earth) is the same as that due to gravity alone.

Microgravity Research Facilities

A microgravity environment provides a unique laboratory in which scientists can investigate the three fundamental states of matter: solid, liquid, and gas. Microgravity conditions allow scientists to observe and explore phenomena and processes that are normally masked by the effects of Earth's gravity.

NASA's Microgravity Research Division (MRD) supports both ground-based and flight experiments requiring microgravity conditions of varying duration and quality. These experiments are conducted in the following facilities:

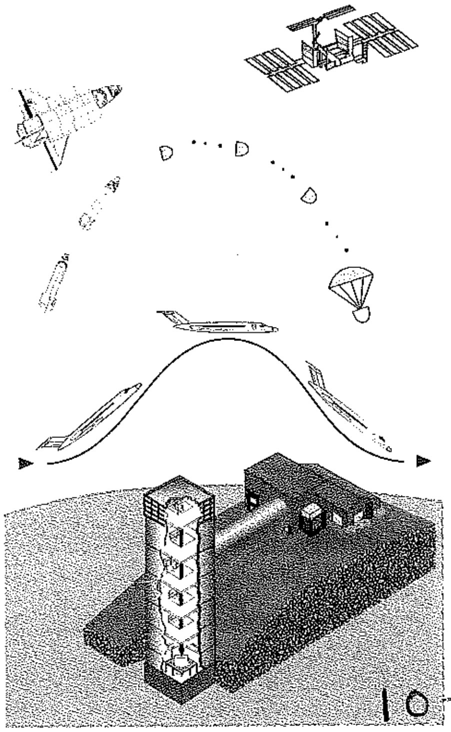
A **drop tower** is a long vertical shaft used for dropping experiment packages, enabling them to achieve microgravity through freefall. Various methods are used to minimize or compensate for air drag on the experiment packages as they fall. Lewis Research Center in Cleveland, Ohio, has two drop facilities (one 24 meters tall and one 132 meters deep) that can accommodate experiments which need only a limited amount of time (2.2 or 5.2 seconds) in microgravity or which are test runs of experiments that will later be performed for longer periods in an aircraft, rocket, or spacecraft.

Reduced-gravity aircraft are flown in parabolic arcs to achieve longer periods of microgravity. The airplane climbs rapidly until its nose is at an approximate 45-degree angle to the horizon. Then the engines are briefly cut back, the airplane slows, and the nose is pitched down to complete the parabola. As the plane traces the parabola, microgravity conditions are created for 20–25 seconds. As many as 40 parabolic trajectories may be performed on a typical flight.

Sounding rockets produce higher-quality microgravity conditions for longer periods of time than airplanes. An experiment is placed in a rocket and launched along a parabolic trajectory. Microgravity conditions are achieved during the several minutes when the experiment is in freefall prior to re-entering Earth's atmosphere.

A **space shuttle** is a reusable launch vehicle that can maintain a consistent orbit and provide up to 17 days of high-quality microgravity conditions. The shuttle, which can accommodate a wide range of experiment apparatus, provides a laboratory environment in which scientists can conduct long-term investigations.

A **space station** is a permanent facility that maintains a low Earth orbit for up to several decades. The facility enables scientists to conduct their experiments in microgravity over a period of several months without having to return the entire laboratory to Earth each time an experiment is completed.



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Microgravity Research Division

Biomaterials Facilitate Medical Breakthroughs

FEATURE

by Jennifer Ouellette

Biocompatibility is the goal with polymers, metals, and ceramics

Biomaterials has an exotic ring, but the design of materials suitable for use as replacements for damaged or diseased human organs or tissues has a long history of R&D. Polymeric sutures (absorbable and nonabsorbable), implant devices, polymer-based prosthetics, and metallic and ceramic implants are common applications today. And in recent years, new materials with unique properties have emerged with the potential for marked advances in areas such as artificial heart valves, controlled drug delivery, and tissue engineering.

Most biomaterials for medical applications are based on common polymers, such as polypropylene, polycarbonates, polyurethanes, polysulphones, poly(ethylene terephthalate) and poly(ethylene ether ketone), as well as metals such as stainless steel and titanium. All these materials offer desirable properties for medical uses, including high tensile strength and stability; and polymers can be engineered for controlled biodegradation. However, such materials are not necessarily compatible with the human body. Medical catheters, guide wires, and stents are often made with materials that can cause potential complications, including bacterial infection, blood clots, and tissue trauma.

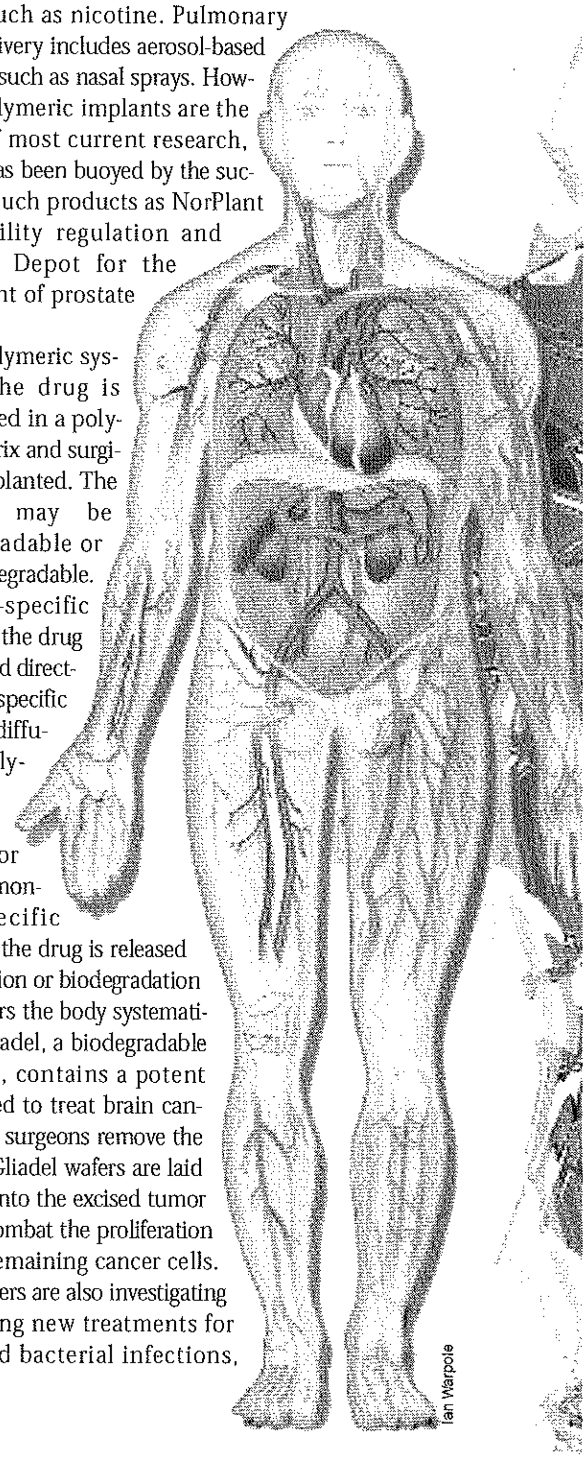
Thus, it is critical to modify material properties, through either the application of coatings or surface modification by the covalent attachment of bioactive molecules. Coatings can effectively address biocompatibility and its complications without changing the device's bulk material, says Susan Conroy, business manager of Advanced Surface Technology Products (ASTP) in Billerica, Massachusetts.

Most coating technologies use ultraviolet curing or solvents in the application process, which can, however, modify the material's structure and alter its properties. To address this materials problem, ASTP makes water-based, solvent-free coatings that can be customized to include drugs such as antimicrobials and blood thinners in controlled-release systems. They are also used to coat the outside of neurological catheters to improve maneuverability and reduce blood-vessel damage in the brain, and to coat intraocular lenses implanted in cataract surgery.

Drug delivery

Biomaterials for controlled drug delivery emerged in the 1970s, and there are now four basic modes. Oral delivery, the most common form, is used for many pharmaceuticals, including long-acting cold remedies. Transdermal systems deliver drugs through the skin by diffusion, although this technique is limited to small-molecule drugs such as nicotine. Pulmonary drug delivery includes aerosol-based systems such as nasal sprays. However, polymeric implants are the focus of most current research, which has been buoyed by the success of such products as NorPlant for fertility regulation and Lupron Depot for the treatment of prostate cancer.

In polymeric systems, the drug is embedded in a polymer matrix and surgically implanted. The matrix may be biodegradable or nonbiodegradable. For site-specific delivery, the drug is released directly into a specific area by diffusion, polymer degradation, or both. In non-site-specific delivery, the drug is released by diffusion or biodegradation and enters the body systematically. Gliadel, a biodegradable implant, contains a potent drug used to treat brain cancer. After surgeons remove the cancer, Gliadel wafers are laid directly into the excised tumor bed to combat the proliferation of any remaining cancer cells. Researchers are also investigating promising new treatments for viral and bacterial infections,



Ian Warpole

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AIDS, birth control, and the delivery of dopamine into the brains of Parkinson's patients.

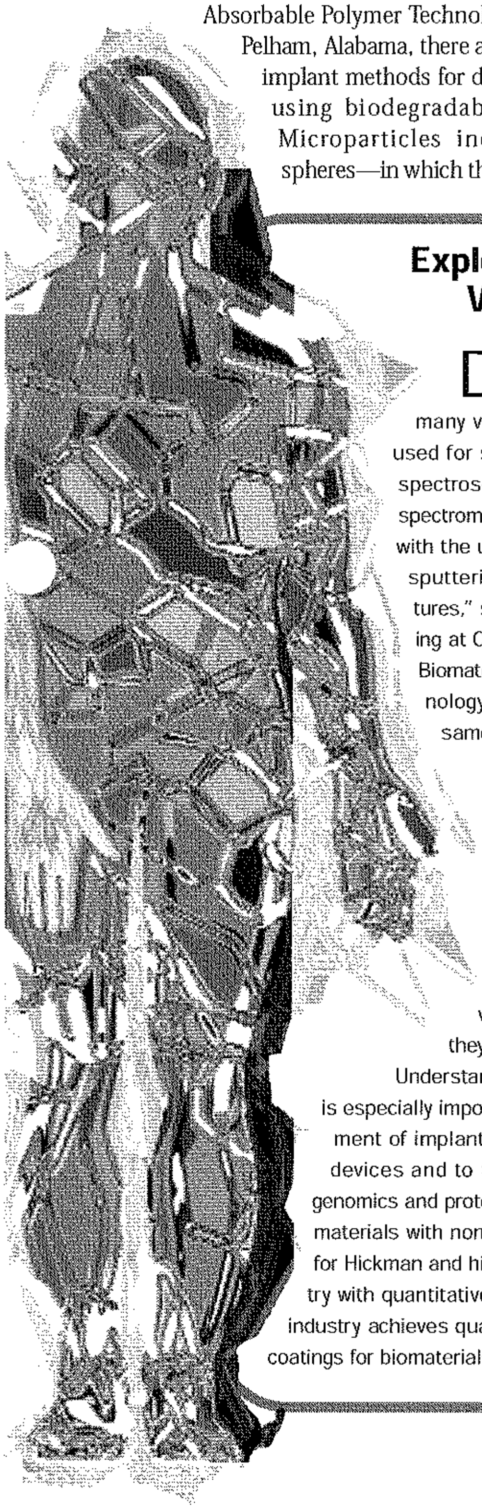
According to James English, president of Absorbable Polymer Technologies (APT) in Pelham, Alabama, there are two primary implant methods for delivering drugs using biodegradable polymers. Microparticles include microspheres—in which the drug is incorporated into a polymer matrix and released by diffusion and polymer degradation—and microcapsules, which have a controlling membrane as an outer sheath through which the drug diffuses. There are also solid implants such as Gliadel.

"By controlling the delivery of the drug, you get a release profile that is continuously controlled over a prolonged period of time that is neither toxic nor ineffective," says English. "Plus, it is a lot easier to have a single injection that lasts longer instead of multiple injections."

APT is currently assisting Guilford Pharmaceuticals (Baltimore, MD), which produces Gliadel, in developing a new class of biodegradable materials known as polyphosphoesters, initially targeted for drug-delivery applications. "No single material is a panacea," says English, and the continual development of new materials opens up new realms of potential properties to meet medical needs.

Medical devices

Biodegradable polymers are now used in more than 40 medical devices, English says, including surgical adhesives, screws, and clips, as well as fixation pins and rods. Potential future applications include bone plates, ear-vent tubes, and wound dressings. Global spending for implantable medical devices is about $120 billion a year. "Metals have been the mainstay for years, and there are still going to be application areas where you can't replace them with a



Exploring Interfaces with Vacuum Technology

Drawing on lessons learned by the electronics industry, biomaterials researchers are adapting many vacuum-based technologies, particularly those used for surface analysis, including X-ray photoelectron spectroscopy, scanning electron microscopy, and mass spectrometry. "The electronics industry was very involved with the use of vacuum technologies for analysis and for sputtering processes to create very fine heterostructures," says James Hickman, a professor of bioengineering at Clemson University and a founding member of the Biomaterials Interface Group of the AVS Science & Technology Society. "We are trying to apply a lot of those same techniques to biomaterials."

As its name implies, the group's primary objective is to understand the interfaces of biomaterials through surface analysis as a way to better address issues including biocompatibility. "The human body is exquisitely sensitive to surfaces," says Hickman. "So you have to characterize the surfaces of implants before they are implanted,and then observe them interact with various fluids and tissues in the body to see how they respond."

Understanding the surface characteristics of biomaterials is especially important as the industry looks ahead to the development of implantable microelectromechanical systems (MEMS) devices and to the next generation of bioinstrumentation for genomics and proteomics,which require the interaction of biological materials with nonbiological devices. However, the immediate goal for Hickman and his colleagues is supplying the biomaterials industry with quantitative descriptions of materials interfaces. Once the industry achieves quantification, it will be easier to develop improved coatings for biomaterials-based medical devices.

biodegradable polymer because of property requirements," says English. "But polymers are moving into more and more applications each year."

One common absorbable biomaterial is polylactide, which degrades to lactic acid, a natural metabolite that is ultimately converted into carbon dioxide and water. It and other biodegradable polymers are used in screws for reattaching ligaments in the knee and for biodegradable staples to replace traditional sutures. Polylactide has helped to eliminate adverse tissue reactions that sometimes occur with metal implants, and it ends the need for a second surgery to remove a metal implant, because the polymer gradually biodegrades once it has performed its function.

Absorbable sutures, the first commercial application of biodegradable polymers, entered the market in the 1960s, and innovations continue to be made in them. In England, researchers have adapted software for automatically embroidering decorations on garments to the repair of abdominal aortic aneurysms. The software uses data gleaned from computerized tomography scans to design and make a polyester patch for the damaged artery. The ultimate goal is to use the embroidery technology to create a framework for artificial organs using the patient's own cultured tissue, thus avoiding the rejection problems associated with transplant surgery. And last year, Tissuemed Ltd. (Leeds, England) launched a new surgical adhesive—composed primarily of porcine albumin, methylene blue, glycerol, and water—designed to reduce bleeding during surgery.

For highly demanding applications, such as insulation for pacemaker leads and long-term catheter implants, the choice of materials has been limited, says Mike Skalsky, managing director of Aortech Biomaterials (formerly Elastomedic) in Sydney, Australia. Such applications require polymers with excellent biostability, good mechanical strength, and high resistance to fatigue, abrasion, and tearing. Silicone rubber has been the material of choice, with polyurethane emerging in recent years as the principal alternative. For 10 years, Aortech researchers worked to devise a material that combines the best properties of silicone and polyurethane, a difficult task because the two are not normally compatible. They succeeded, and Aortech announced Elast-Eon polymers last year.

The initial target market for Elast-Eon is synthetic heart valves, approximately 150,000 of which are implanted annually worldwide. Existing synthetic heart valves are either mechanical, with a metal housing and carbon disks, or made from pig tissue. Although the mechanical valves are durable, patients require anticoagulants to prevent blood clots from forming around them. Tissue implants do not have this clotting problem, but they are not as durable.

"So for a long time, there has been a concerted effort to find new materials to make valves that would be both durable and not require anticoagulants," Skalsky says. The first clinical trials for a heart valve made with Elast-Eon are under way. The material is also in human testing for possible use in products such as coronary arterial grafts and orthopedic implants.

Biomaterials have already had an impact in ophthalmology, particularly in the implanting of intraocular lenses during cataract surgery. Researchers at Optobionics (Wheaton, IL) have developed implantable silicon chips for artificial retinas, which convert incident light into electrochemical signals to trigger any remaining retinal cells into processing images. Unlike other sight-saving implants, which are positioned on the retina's surface, the Optobionics chips sit behind the retina. The pin-sized chips contain about 3,500 microphotodiodes. They have been implanted into the eyes of three patients blinded by retinal disease, and plans call for three more patients to receive implants.

Looking to the future

For now, most commercial biomaterials research is focused on combining implant devices with targeted drug delivery. It would be, for example, more beneficial for patients if an adhesive or staple could both hold damaged tissue together and deliver an agent that promotes new tissue growth, or if an implanted medical device could also deliver an anti-inflammatory drug.

Coatings are a promising method for such applications. Biocompatibles, Ltd. (Surrey, England), has developed two drug-delivery/stent systems using coatings to deliver therapeutic agents to implantation sites. The technology is now in clinical trials to determine its effectiveness in fighting postimplant inflammation and other complications. NjeX Medical Systems, Inc. (Industry, CA), has achieved a technology breakthrough that may make delivering implanted devices easier. Its technique is simpler, more precise, and faster than those now used for implanting, and it requires less surgical skill. The implant is placed into a protective sealed cartridge, which is positioned at the implant site with a catheter. The cartridge then opens, releases the device, and is withdrawn, leaving the implant precisely positioned at the desired site. NjeX president James Elliott foresees the implant device as useful for emerging products such as gene-therapy implants, nanomechanical and electronic chip implants, and a variety of vascular and intraorgan stents.

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Liquid-crystal elastomers are another promising class of materials for controlled drug delivery. Such materials are similar to those that form the basis of spider silk, and they combine the molecular mobility of a liquid with the solidity of a crystal. They can self-assemble into complex hierarchical structures and are also highly tunable. Their controlled degradation and good biocompatibility make them excellent candidates for the production of fine sutures, wound dressings, and woven or embroidered materials for prosthetics. According to David Knight, a zoologist at Oxford University in England, future applications of liquid-crystal elastomers include controlled drug-delivery implants, implantable biosenors, and artificial muscles. The materials can also be modified to have conducting or magnetic properties. Thus, they might one day be used as components in implantable microelectronic devices that would interface with living cells to repair the effects of nerve damage.

Tissue-engineered medical products (TEMPs) are among the most rapidly developing areas of research aimed at repairing, replacing, or restoring function to damaged or diseased soft or hard human tissue. Several such products are on the market, primarily for skin replacement. A range of TEMPs is under development, including cartilage and ligaments, heart valves, liver tissue, and insulin-producing pancreatic cells, all engineered from human tissue.

Nevertheless, the field is in its infancy, and Skalsky points out that researchers are still working to develop a deeper understanding of the cellular responses to engineered human tissue. In addition to the difficult technological and manufacturing hurdles, TEMPs face stringent regulatory barriers. Concerns over mad cow disease and tissue rejection have influenced public acceptance of animal tissue for this application. And the use of human tissue, including stem cells from embryos, is a source of considerable ethical controversy.

Larry Perry, who heads Pluris Research (Nashville, TN) sees the strongest market opportunities for biomaterials in the consumer applications, particularly in light of the high cost, long time to market, and inherent risk associated with cutting-edge R&D. "Tissue engineering, for example, is very complex, and those developments will take a very long time," says Perry. "People are now trying to take advantage of what we already know to target new consumer applications right now." ■

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MATERIALS FOR SPORTING

Golf clubs, bicycles, scooters, shuttlecocks, and other sporting goods perform better and last longer thanks to developments in aluminum, steel, polymers, and composites.

◆Zirconium-aluminum alloy, carbon composites make stronger bicycles

A zirconium-aluminum alloy called ZR9000 is the first alloy developed exclusively for the bicycle industry, reports Trek Bicycle Corp., Waterloo, Wis. To make superior bicycle tubes, such as those on the mountain bike shown, an alloy must be able to withstand the stresses and strains unique to cycling. After twelve years of development, Trek engineers determined the perfect amount of zirconium to add to aluminum to create a strong aluminum alloy for bicycle frames. ZR9000 is said to be 15% stronger and 15% lighter than standard aluminum, and as strong as steel. The new alloy is also dense, weldable, formable, and capable of heat treatment.

Trek made a special carbon composite racing bicycle frame for Lance Armstrong to ride during the last stage of the 2004 Tour de France. Called the Madone SSL, the frame is made of OCLV 55 carbon composite, and includes just 55 grams of carbon fiber per square meter. Trek is said to have optimized its carbon-fiber layup technology so that the composite weighs 50% less than its previous low-density composite OCLV 110, which contains 110 grams of carbon per square meter. The OCLV 55 frame weighs 950 grams over its entire 58 cm length, the lightest frame Trek has ever built.

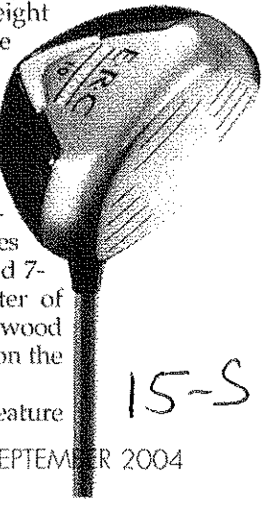
OCLV is short for Optimized Compaction, Low Void. The technology involves compressing carbon fiber and epoxy into a composite having a ratio that is higher than the aerospace standard 60/40 compaction ratio. The OCLV carbon is a directional material, meaning that its strength and stiffness are based on the direction of the carbon fibers. By correctly orienting these fibers along different parts of the frame, specific areas can be optimized for greater strength. Finally, the OCLV frames are bonded with an aerospace structural adhesive strong enough to withstand 16 tons of stress.

For more information: Trek Bicycle Corp., 801 West Madison Street, Waterloo, WI 53594; tel: 920/478-2191; Web site: www.trekbikes.com.

◆Titanium alloy and carbon composites combined in golf club

The best attributes of titanium and carbon composite material are combined in the ERC Fusion Driver golf club from the Callaway Golf Co., Carlsbad, Calif. The Fusion driver shown here has a forged titanium face and a carbon composite body that is 75% lighter than titanium. The low weight allows mass to be repositioned in ways thought impossible a year ago. Variable face thickness technology is said to provide a larger "sweet spot."

ERC Fusion Fairway Woods also feature a two-part clubhead: The body, face, and sole are cast from heat-treated stainless steel, while the crown is composed of lightweight carbon composite material. The ultra-light carbon composite body allowed design of fairway woods with an exceptionally low center of gravity and a very high moment of inertia. The high MOI of the ERC Fusion Fairway Woods keeps the clubhead stable at impact, while the low center of gravity helps get the ball up in the air from nearly any lie.



The lightweight carbon composite crown of the ERC Fusion Fairway Woods allows designers to place weight at specific locations to fine-tune the performance of each individual model. Wall thickness varies among the 3-wood, 5-wood, and 7-wood models, optimizing center of gravity. Each individual fairway wood also has distinct bulge and roll on the face.

ERC Fusion Fairway Woods feature

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GOODS

the same shaft used in the ERC Fusion Driver, the RCH System 55 graphite shaft, which is available in strong, firm, regular, and light flexes. This lightweight shaft helps produce exceptional clubhead speed while still delivering control and balance.

For more information: Callaway Golf Co., 2180 Rutherford Road, Carlsbad, CA 92008-7328; tel: 760/931-1771; Web site: www.callawaygolf.com.

◆Carbon fiber composite bat has low weight, high speed

A carbon fiber composite bat built of aerospace grade carbon fibers and dynamic performance resins comprise the structure of the SCX24B Synergy Fastpitch softball bat from Easton Sports, Van Nuys, Calif. The Synergy Fastpitch features a modified barrel design and lighter weight to better suit fastpitch softball. The bat provides durability and consistency, and its modified barrel design provides evenly balanced weighting for better control and faster swing speeds. The high-strength, lightweight, maximum-elongation aerospace grade carbon fibers represent the highest modulus carbon fibers available. The Synergy Fastpitch is fabricated by high-temperature, high-pressure internal molding technology, which locks and bonds the fibers and resins together for maximum strength, performance, and consistency. The Synergy Fastpitch is expected to retail for $249.99.

For more information: Easton Sports Inc., 7855 Haskell Ave., Suite 200, Van Nuys, CA 91406-1902; tel: 800/632-7866; Web site: www.eastonsports.com.

◆Cross-country skate combines strength and impact resistance

The TrailSkate all-terrain skate has a rugged chassis molded from a new super-strong DuPont Zytel HTN high performance polyamide resin, reports DuPont Plastics, Wilmington, Del. Fitted with pneumatic tires and hand-operated hydraulic brakes, the TrailSkate is made by GateSkate Inc., Richland, Wash. The chassis is 53 cm long (21 in.) and has wall sections ranging in thickness from about 11 to 20 mm (0.04 to 0.79 in.). The combination of air tires, a rugged, flexible chassis, and adjustable boot-binding system provide an extremely smooth low-impact ride.

The skate's polyamide chassis is crucial to performance and durability, and is substantially less costly than a thermoset composite chassis used in early production. The chassis, essentially a ski on wheels, must withstand repeated dynamic loading under the rider's full weight. GateSkate's tests show that parts molded from Zytel nylon meet that requirement.

In addition, long glass fibers in the resin are crucial to performance. Average fiber length in the molded part is several times greater than in standard short-glass reinforced thermoplastics. The long-glass reinforcement provides improved fatigue performance, impact resistance, and surface appearance.

For more information: DuPont Engineering Plastics, Wilmington, DE 19898; tel: 302/999-4592; Web site: www.plastics.dupont.com. GateSkate Inc., Richland, Wash.; tel: 509/371-0726; Web site: www.gateskate.com.

◆Hot-melt adhesive provides strong joint for shuttlecock

A scaled-up version of badminton called Bigminton is in the early development stage by Echelon Sport, Barnsley, England, one of the world's leading shuttlecock manufacturers. The shuttlecocks, as shown here, are bigger and heavier than usual, making Bigminton ideal for the park or beach where windy conditions can be a problem for some games. Echelon wanted to improve its assembly methods, so the company sought free tech-

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nical advice through the *Joining Forces* program at TWI, Cambridge, England.

Echelon Sport asked TWI experts how best to attach the large shuttlecock's nylon flights to the polymer foam nose. After a two-day product and process review, engineers concluded that a hot-melt adhesive would provide a strong yet cost-effective joint. Simple dispensing equipment can be used to place adhesive in a recess in the nose, and the flights are inserted before the adhesive solidifies. The process is fast, equipment is inexpensive to buy and run, and operator training is minimal. Carried out by a team of materials joining specialists, the impartial review allowed Echelon Sport to examine ways of assembling a challenging new product without cost or risk to the company.

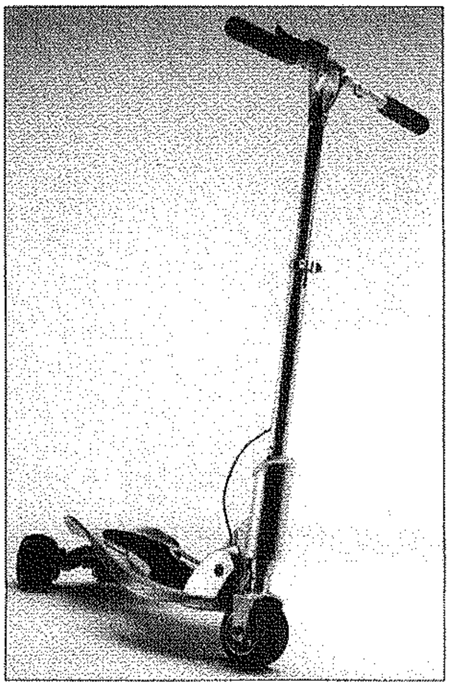
For more information Richard Smith, TWI Yorkshire Technology Centre, England; tel: 0114 269 9046; e-mail: richard.smith@twi.co.uk; Web site: www.twi.uk.

Three-wheel aluminum alloy scooter enables tight corners

The aluminum SlideCarver scooter has fine-tunable hydraulic twin-disk brakes, polyurethane tires, and a deck made of a high-strength sandwich of fiberglass-reinforced polyamide and aluminum. Made by automaker BMW, Germany, it stands 100 cm (39.5 in.) high by 50 cm (20 in.) wide, has a 67 cm (26.5-in.) wheelbase, and weighs approximately 12 kg (26.5 lb). It is recommended for riders age 12 and up.

The wide polyurethane tires can be changed separately and are equipped with wear indicators. High-quality, maintenance-free wheel bearings are standard. All aluminum parts are forged for maximum strength.

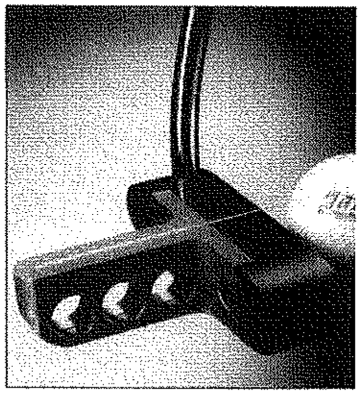
Unlike ordinary scooters, the SlideCarver is steered both in the front and back, so it can turn and pivot on a point. The progressive steering action allows riders to shift weight and change direction while maintaining full control, and the Magura twin-disk brakes ensure a safe ride with smooth stops.



Exceptional handling is achieved by a double-joint support component taken from the running gear of the E39 BMW 5-Series automobile. This ensures that when steering, the board of the SlideCarver pivots in the direction of the turn, improving the rider's center of balance. Handlebar mounted brake levers are linked to a finely adjustable hydraulic twin-disk brake system on its rear wheels. The brake cables are located within the tube of the handlebars, giving a more streamlined appearance and protection from weather and scuffing. The BMW SlideCarver retails for $695 and is available at BMW dealerships, at www.bmw-online.com, or by calling 888/269-6654.

Light-emitting compounds on putter guide the stroke

A golf putter that incorporates a light-emitting guidance system that draws the eye to align the putter, steadying the head and allowing the golfer's hands and eyes to act in unison, is made by Ram Inc., Cisco, Texas. The putter head is composed of a precolored polycarbonate compound from RTP Company, Winona, Minn. The material has low water absorption and exceptional dimensional stability through a range of environments.



RTP 300 Series precolored polycarbonate compound is based on an edge glow color effect that provides a steady, defined line of light. Edge glow compounds include dyes that absorb ultraviolet light and reemit that energy in longer wavelengths, effectively changing nonvisible light to a visible wavelength. Internal reflection within the compound refocuses the light, emitting it more intensely along edges, thereby creating a glowing effect. The edge-glow dyes are completely soluble and are distributed uniformly within polycarbonate, acrylic, and other compounds. Both heat and light stable, they have no appreciable effect on either processing or performance characteristics of the original resin.

The putter is clad with aluminum, and is manufactured with holes in the side, allowing light to penetrate and be absorbed by the thermoplastic. The light is then emitted along the edge of a 0.04 by 2.0 in (1 by 50 mm) polycarbonate insert, producing a lighted, straight focal point for the golfer.

For more information: RTP Company, Winona, MN 55987; tel: 507/454-6900; Web site: www.rtpcompany.com. **Circle 298** Ram Inc., Cisco, TX 76437; tel: 254/442-1008; Web site: www.raminc-cisco.com.

Snowboards contain tough honeycomb composite core

Snowboards composed of ultralight sandwich materials are made by Hexcel Composites, Austria. The materials consist of a tough honeycomb core made of Baypreg polyurethane from Bayer MaterialScience AG, Germany.

"Winter sports equipment such as skis or snowboards have always been structurally complex products," explains Dr. Marc Schütze of Bayer MaterialScience AG. "Manufacturers have long combined different materials to ensure the ideal balance between stiffness and flexibility required for a safe, high-performance piece of equipment. But the wood frequently used in the core was always associated

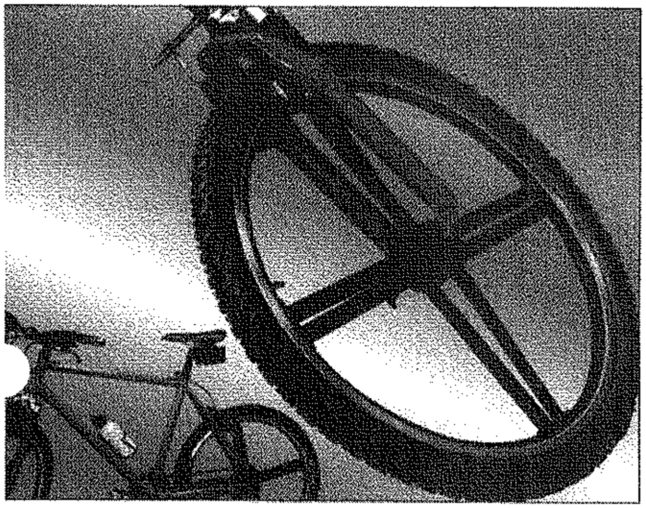
with a significant amount of weight. Modern honeycomb composite materials, like those that can be produced with Baypreg, offer the same high-quality material properties at only a fraction of the weight. Moreover, production is simpler and cheaper."

To make the snowboard, a glass fiber mat is applied to the top and bottom of a lightweight core material, such as a honeycomb made of paper or a thermoplastic material. The glass fibers make up only a small percentage of the snowboard's weight, but efficiently absorb any tensile forces, thus guaranteeing the high stiffness of the product. A liquid two-component system is sprayed onto the glass fiber mats. Then the composite structure (including the core, the impregnated skin layers, and the decorative foils) is then placed in a pre-heated mold and pressed into shape. At an elevated temperature, the polyurethane reacts within just a few minutes, joining all the elements of the composite structure together permanently. The sandwich composite can be removed from the mold after two to three minutes.

For more information: Bayer Polymers LLC, 100 Bayer Road, Pittsburgh, PA 15205-9741; tel: 412/777-2500; Web site: www.bayerpolymers.com. **Circle 296**

◆Injection-molded bike wheel combines rigidity, toughness

An injection-molded four-spoke bicycle wheel for a mountain bike that combines rigidity and toughness has been made of LNP Thermocomp Nylon 6/6 from LNP Plastics, a GE Plastics Company, Exton, Pa. The Nylon 6/6 is reinforced with carbon fibers, which provide high impact toughness. The composite also sustains high shock loads, and is light in weight and easy to assemble. Finally, the composite is lower in cost than traditional thermosets. The mountain bike is made by Gubesch GmbH, Germany. For more information: LNP Engineering Plastics Inc., 475 Creamery Way, Exton, PA 19341; tel: 610/363-4500; fax: 610/363-4749; Web site: www.lnp.com.



The NASA aluminum alloy greatly improves piston durability.

◆NASA develops aluminum alloy for boat outboard engines

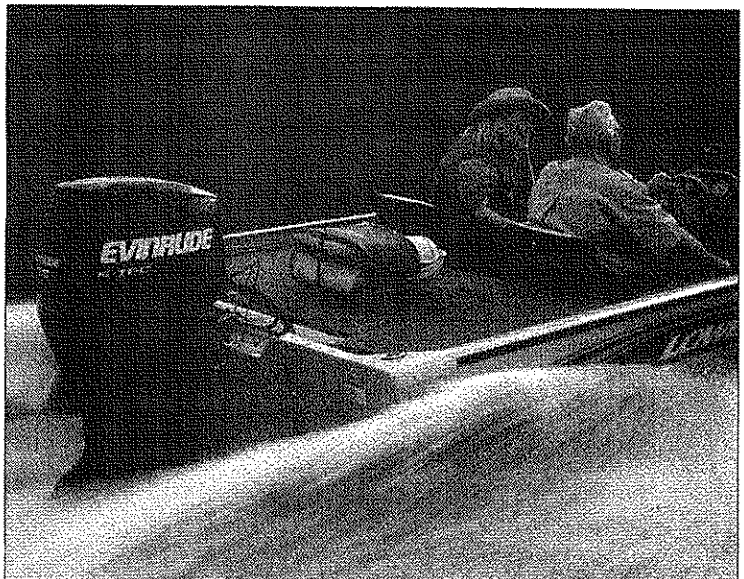
A NASA-patented a high-strength aluminum alloy has been selected by the Boats and Outboard Engines Division at Bombardier Recreational Products, Sturtevant, Wis., for the pistons in its new Evinrude E-TEC outboard engine line.

The alloy, developed at NASA's Marshall Space Flight Center in Huntsville, Ala., is used in a new piston design that reduces the so-called "slapping" sound when pistons slide up and down in the engine's cylinder. The alloy can greatly improve piston durability because it is 2.5 times stronger than conventional cast aluminum pistons at high temperatures, and can be produced with a material cost of less than $1 per pound. It exhibits high strength at temperatures as high as 260 to 370°C (500 to 700°F).

Development of the NASA High-Strength Aluminum Alloy began seven years ago when a major automobile manufacturer approached NASA seeking a solution to reduce the costs of aluminum engine pistons, as well as to lower engine emissions. NASA was also interested in developing an alloy with higher strength and wear-resistance at elevated temperatures for aerospace applications.

Jonathan Lee, a structural materials engineer in the Marshall Center 's Materials, Processes and Manufacturing Department, and co-inventor PoShou Chen, a scientist with Morgan Research Corp. in Huntsville, tackled the project. The result was design of what would become the basis for a new aluminum alloy, MSFC-398 or NASA High-Strength Aluminum Alloy.

The Evinrude E-TEC outboard engine line uses pistons made with the NASA High-Strength Alloy in its mid-power range of recreational boating for its current 40 to 90 horsepower engines. BRP projects it will manufacture several hundred thousand pistons



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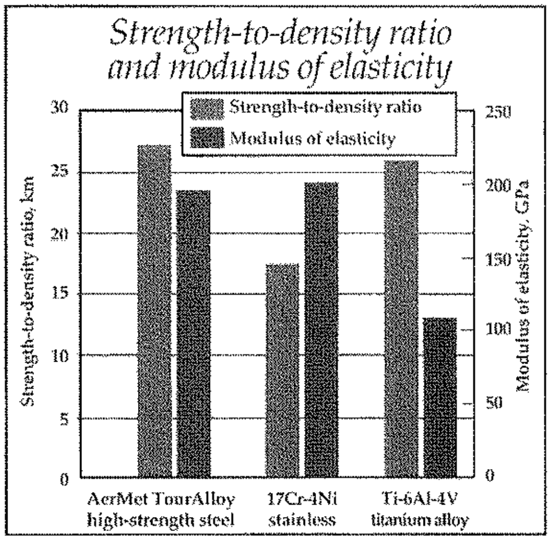
for outboard motors using the NASA High-Strength Aluminum Alloy over the next several years.

For more information: NASA Marshall Space Flight Center, Huntsville, AL 35801; Web site: www.msfc.nasa.gov. Dave Thompson, Bombardier Recreational Products, Sturtevant, WI 53177; tel: 262/884-5399; Web site: www.evinrude.com.

◆High-strength aerospace steel makes better golf club heads

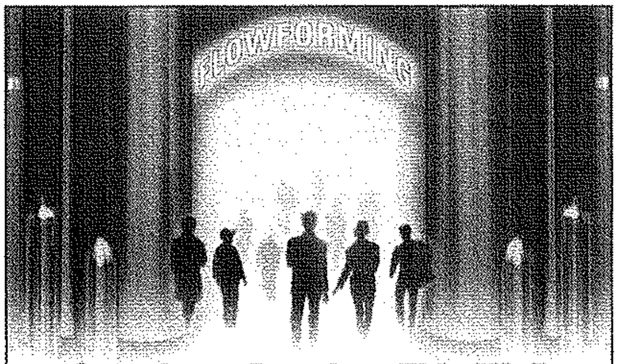
A high-strength steel alloy developed for aerospace applications by Carpenter Technology, Reading, Pa., offers a combination of properties that has improved golf club design and play. AerMet TourAlloy, originally developed as AerMet 100, is a premium-melted, ultrahigh-strength steel with composition Fe, 11.1Ni, 13.4Co, 3.1Cr, 1.2Mo, 0.23C. It offers a unique combination of high strength and hardness, fracture toughness, exceptional ductility, and resistance to both fatigue and stress-corrosion cracking.



AerMet TourAlloy is now used for face inserts in golf club woods and irons. The alloy permits the design of heads that are lighter and larger, and offer greater energy transfer at impact with the golf ball. It compares favorably with two other high-tech materials that have been commonly used in contemporary lines of clubs, titanium alloy Ti-6Al-4V and stainless steel alloy 17Cr-4Ni. The graph compares elasticity and strength-to-density ratio, also known as specific strength.

With their superior hardness and strength, golf club face plates that have been made of AerMet alloy give the ball greater spring and velocity in flight. These two key properties, in combination, allow more of the swing energy to be transferred to the ball. Many golfers, in addition, say they like the crisp sound made by the hard club face when it strikes the ball.

For more information: Carpenter Technology Corp., P.O. Box 14662, Reading, PA 19612-4662; tel: 610/208-2000; fax: 610/208-3716; Web site: www.cartech.com. **Circle 297**



Oobleck

Purpose of the activity:

- making observations
- being open to the unexpected
- looking at properties

Materials:

- 5 oz. Dixie cups or plastics cups
- wood craft sticks
- water
- white powder (cornstarch)

Procedure:

1. Fill the Dixie cup approximately 1/3 to 1/2 full with white powder (cornstarch).

2. Add 1/3 as much water.

3. Stir with craft stick.

4. Consistency should be sort of like thick toothpaste or putty.

5. Go outside and experiment with the material.

Experiment with the substance:

- stir slow
- stir fast
- push the stick down through it - slowly and quickly
- squeeze it in your hand
- roll it into a ball and pull it apart
- hit a ball with a hammer
- play catch with it
- other????????

Journal:

- Describe the material
- How did you make it?
- What did you do to it?
- How did it respond/behave?
- Reflect

This activity demonstrates a non-Newtonian material. It does not "obey" the laws of Newtonian physics. Oobleck displays a property known as dilatancy which is the tendency to become more rigid (solid) when it is stirred or subjected to a shear force or pressure. Let the students experiment with the mixture before telling them what the white powder is. This is a good opening day or first week activity to introduce journaling.

Additional Ideas:

- Have 3 different bowls of "powder" in separate areas of the room. Use cornstarch, flour, and plaster of paris. Do not tell the students that the powders are different. Let them discover that the batches are not all the same and hypothesize and investigate why.
- Make large batches of oobleck and place it shallow pans. Have students slap it with their hands or young children step on it.
- Have students experiment to determine the "perfect" recipe for oobleck while making and recording all measurements.
- Another thixotropy and dilatancy lab may be found in the Battelle MS&T Handbook or CD beginning on page 4.4
- Watch the YouTube video "A pool filled with non-Newtonian fluid" at http://www.youtube.com/watch?v=f2XQ97XHjVw&mode=related&search

Vocabulary:

Non-Newtonian

- does NOT follow the laws of physics as described by Newton

Dilatant

- adding energy (shear force) makes a liquid thicker or more rigid - more viscous
- example - oobleck (cornstarch-water mixture)

Thixotropic

- adding energy (shear force) makes a solid thinner or liquefy - less viscous
- examples - catsup, concrete, some paint, printer's ink

Viscosity

- resistance or opposition to flow of a liquid

"White Powder Lab"

Name:__________________________

Period: _________ Date: __________

Do all liquids behave the same? *Answer all questions completely.*

Procedure:

1. Take one cup with white powder (about 1 tablespoon) and a stir stick. Record observations about the powder below. Does it have an odor? Does it slip between your fingers easily?

2. Slowly add water to the powder until the combination makes a putty-like material. Stir as you add water. Observe how the mixture moves as you stir with the stick. Is it difficult to move? Does it move easier as you stir it, or is it more difficult?

3. Stir rapidly and then stir slowly. Is there a difference in the way the mixture responds to the way you add energy? Record observations below.

4. Try putting the mixture in the palm of your hand. Can you roll it into a ball? What happens if you stop trying to roll it? Record observations below.

Deposit all materials in the trash can.

5. In the space below, define the following terms and give examples of each:

Thixotropic fluids:

Dilantant Fluids:

(by Jill VanGlubt)

22-S

Matter

Any visible lump of matter - even the merest speck - contains more atoms than there are stars in the galaxy. Each type of atom brings a particular quality to every substance of which it is a part, and although atoms are so small, their colossal number in any tangible sample results in our perception of their properties. When we lift an apple we feel the weight of a galaxy of almost weightless atoms. When we hear the ripple of water we are hearing shock waves as a myriad of almost imperceptible molecules crash down and collide with the other molecules. When we dress we pull across our bodies a great web spun from almost infinitesimal dots and held together by the conspiracy of forces between them. When we see a flame we are seeing the release of an almost negligible droplet of energy, but in such a Niagara that the heat sears and consumes.

Molecules
by P.W. Atkins
ISBN: 0-7167-60045

Check out the book list in the appendix.

Material

Webster's definition: the elements or substance or the parts of which something is composed or can be made

Material = Solid Stuff or Solid Matter

Materials Science and Technology

-understanding and using the materials in our daily lives

-study of the materials in our lives and how they can be changed or manipulated

-the study of available materials and the search for new ones

-describes the understanding of solids that emerges from the combined viewpoints of chemistry, physics, and engineering

-4 aspects:
  synthesis and processing
  structure and composition
  properties
  performance

-involves the generation and application of knowledge relating the *composition*, *structure*, and *processing* of materials to their *properties* and *uses*

-materials engineering deals with the synthesis and use of knowledge (structure, properties, processing, and behavior) in order to develop, prepare, modify, and apply materials to specific needs

Materials ID Lab

Goal:

- To assess prior knowledge of students.
- To generate interest in types and properties of materials.
- To help students develop their own definition/description of each material category.
- Practice classifying and justifying (critical thinking).
- Allow students to realize that science and classification aren't always perfect and don't always have a "right" answer.

Method:

1. Have students do a "free" write in their journal:
    - "List anything and everything you know about the 4 categories of materials including definitions/descriptions, properties, examples of the material, uses of the material, etc."
    - The four materials categories are: metals, ceramics, polymers, and composites.

2. Hand out or have students choose an object(s) until all are taken.

3. Each student's task is to classify their object by putting it into one of the material categories and justify (give reasons) for their choice.

4. Generate lists on the board or overhead as students classify their object and give their reasoning. Be encouraging but do not indicate if their placement is correct or incorrect.

5. After all the objects have been classified, ask the students to count up how many objects they think have been put into the wrong category.

6. Go through the lists and make corrections.

7. As a class, generate a list of properties or descriptions for each category.

Notes:

- Students generally feel uncomfortable with this at first. They are not used to thinking out loud or having to give reasons for their answers.
- Rephrase what the student says so they can hear their thoughts.
- Do not give any indication if their answer is correct. The students start listening to each other and it is interesting to see how they are accepting of each other's "opinions" as "facts".
- Do not accept "because" as a reason. Insist that they give you more. Give them lead-in questions if they need help.
- If a student places an item into the polymer category and gives their reason as "because it isn't a metal" – request more information, ask "how do you know it isn't a metal?"
- If a student gives a response along the line of "because it looks like a metal" – request more information, "what does a metal look like?"

- Following is a list of sample items. Use whatever you find sitting around the classroom or home. It is a good idea to include some simple items along with some that are "ringers" (have no correct answer).
- Follow up with a discussion about the history of materials use. (see handout)
- Alternative method:
    - assign each material category a different location in the room
    - give each student an object to classify
    - have the students take their object to the material location they think their object belongs in
    - have the students at each material location decide who belongs/stays and who needs to go to a different category
    - have each group write a description and/or list of properties for their material category
    - share group results with entire class
- Alternative method:
    - spread the objects around the room
    - have the students classify each object on their own
    - place the students in small groups to discuss their "answers" and develop a description and/or list of properties for each material category
    - have a class discussion to develop a consensus on the classification of each object and to develop a final description for each material category

Sample Items:

Metals	**Ceramics/Glass**	**Polymers**	**Composites**
stainless steel foil	glass stirring rod	latex balloon	Mylar balloon
metal scoopula	fiberglass strands (no matrix)	cotton cloth	Formica sample
copper wire	brick	Fed Ex envelope (Tyvek)	cardboard
aluminum wire	calcite crystal	preform	plywood
steel wool	glass bottle	PVC pipe	cut up ski
	pumice	acrylic cube	
	talc	rubber stopper	
	shell*	Styrofoam cup	
	glass foam block**	candle***	

Additional items:

Silicon lump - this doesn't fit into any of the categories. The only materials that are elemental are metals, the rest are compounds or mixtures. Silicon isn't a true metal. This item helps to teach the students that no classification system is perfect or will work for every possible sample. An additional category could have been added such as "semiconductor" or "electronic material".

Light bulb - this isn't a single material, it is an "assembly". It is made up of more than one material and each material has its own function. The different materials are joined together but still are separate unlike a composite.

*shell - based on the type of shell, this could be listed under composites because the layers of ceramic are bonded by polymers. Accept it under either category and have a discussion with the students.

**glass foam block - used to clean grills or shave the "pills" off of sweaters

***candle - the students will want to place it under composite because of the wick. Remove the wick if possible or tell them just to consider the wax. Some scientists would not classify the wax as a polymer because the chains are too short. This is a good point of discussion.

Examples of student generated lists of properties for each category:

Metals

- hard
- shiny (luster)
- variable melt T°
- flexible
- malleable
- ductile
- good conductors
- heavy (dense)
- most are dense
- opaque
- undergo oxidation
- bendable
- strong
- can be elements
- some are magnetic
- fairly high melt T°
- impermeable
- workable
- corrode easily
- come from ores
- can be mixtures (alloys)

Ceramics/Glass

- not conductors
- high melt T°
- brittle
- some are transparent
- fragile
- breakable
- not workable
- formed by heat
- sand or clay based
- fairly high density
- poor conductors
- can be formed
- includes minerals
- can be recycled

Polymers

- plastics (synthetic)
- some are natural
- some are absorbent
- flexible
- low melt T°
- low density
- many are recyclable
- stretchable
- not brittle
- bendable
- rubbery
- expandable
- shrinkable
- elasticity
- some are transparent
- poor conductors
- can be easily formed
- long molecules
- some are hard
- variety of properties
- made of compounds

Composites

- combination of 2 or more materials

The Stuff of History

Lesson to use with the history diagram from Stuff: The Materials the World is Made Of

Have the students do a "free write" after the Materials ID Lab about the history of materials use. Do this before showing them the overhead of the relative importance of materials through history.

History Free Write:

- Which of the material categories has been used the longest by man?
- Why that particular one?
- What did they use it for?

Take a poll of how many students chose each category.

Have a class discussion about what the students wrote.

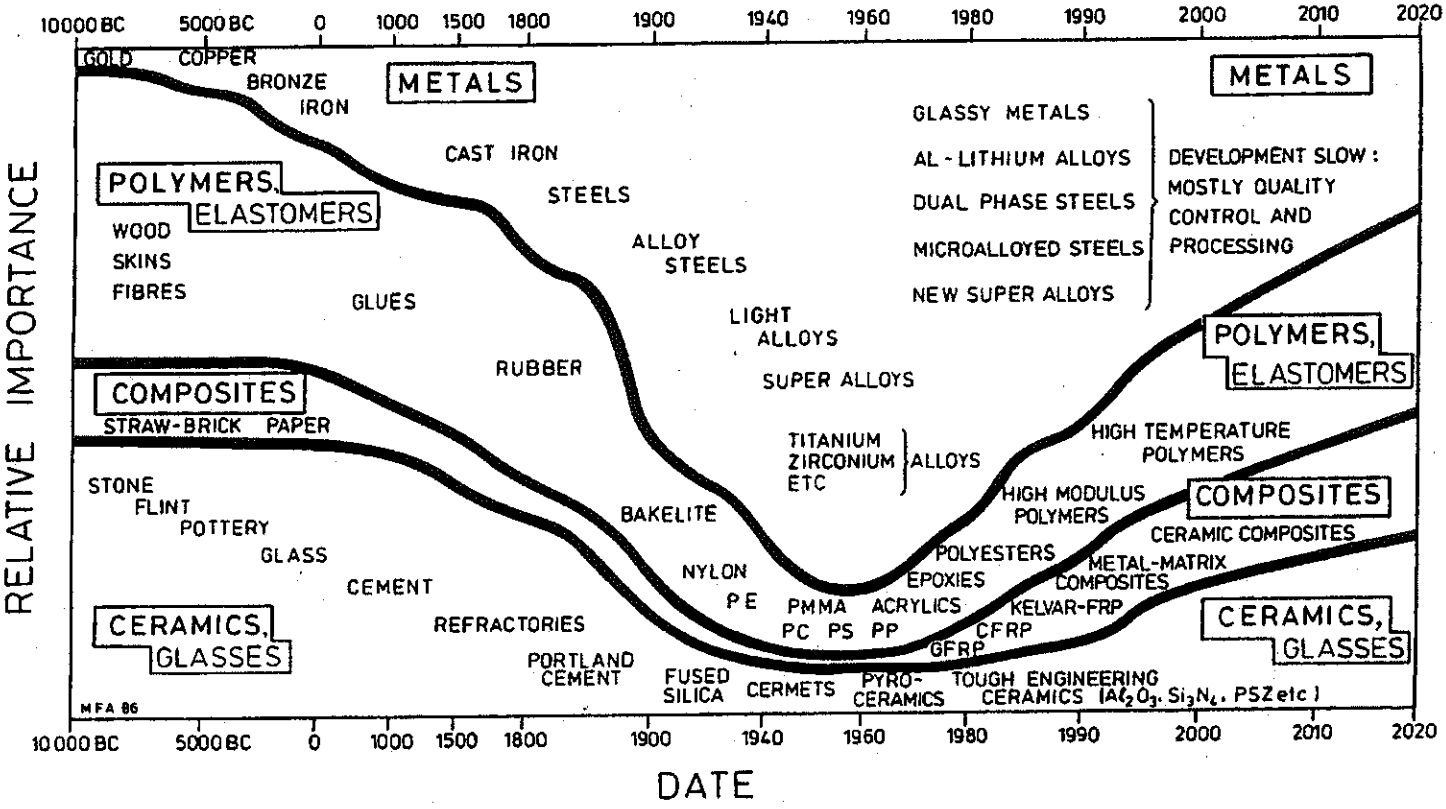
Show the students the history diagram.

Possible points of class discussion about the diagram:

- Discuss the Stone Age, Bronze Age, and Iron Age – relate this to the importance of materials in human lives.
- What would you call today's Age – polymers? Silicon? Composites? Age of Materials?
- Discuss native metals (gold, silver, copper) – "found as pure metals in nature" – other metals are found in ore and have to be reclaimed.
- Discuss the Industrial Revolution – how is it represented on the chart?
- Current trends?

Have students sketch the basic shape of the diagram in their journal – also list two example of each category from earliest times.

The Stuff of History. To follow each of the heavy lines across this diagram is to trace a word-byte history and projection of four major classes of materials - metals, polymers-elastomers, composites (whose properties are derived from two or more materials - such as a polymer with glass fibers as reinforcement - bound into a single overall structure), and ceramics-glasses. The relative importance to humanity of each material class at each historical period is suggested on the diagram by the proportion of the diagram's vertical axis corresponding to each material class. So in 1960, for example, composites were least important while metals were head and shoulders most important. In 2020, however, the four classes of materials are projected to have roughly equal importance.



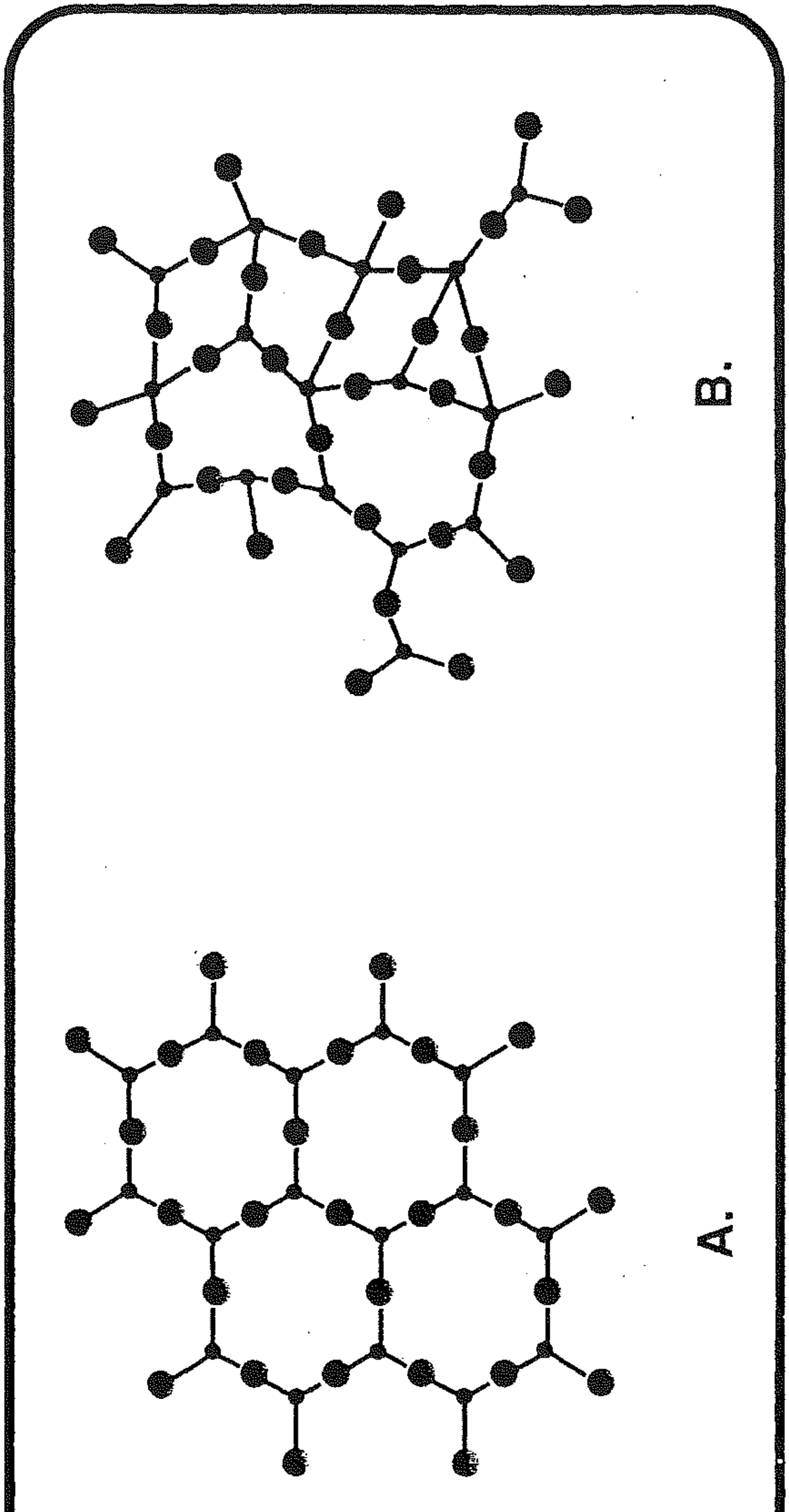
Stuff: The Materials the World is Made Of
by Ivan Amato
ISBN: 0-380-73153-3

30-S

Classification of Materials

Types of matter: element, compound, mixture
Types of elements: metals, nonmetals, semimetals
Types of structure: crystalline, amorphous
Types of bonding: metallic, ionic, covalent, intermolecular forces

	Metals	Ceramics/Glass	Polymers
Type of Matter	*Element or mixture*	*Compound or Mixture of compounds*	*Mostly compounds*
Type of Elements	*Metallic elements*	*Metals with nonmetals OR Semimetals with nonmetals*	*Nonmetals*
Type of Structure	*Crystalline*	*Ceramics = crystalline Glass = amorphous*	*Mostly amorphous with some regions of crystallinity*
Type of Bonding	*Metallic bonding*	*Ionic bonding and network covalent bonding*	*Covalent bonding and weak intermolecular forces*


A.
B.

Subatomic Particles

Name	Protons (p or +)	Neutrons (n)	Electrons (e^-)
Charge	+1	No charge	-1
Location	In nucleus	In nucleus	In shells around nucleus
Mass	~ 1 amu	~ 1 amu	~ 2000 x smaller
"Job"	Determines identity of element	Supplies proper mass to hold nucleus together	Determines bonding/ how it reacts
Number	Atomic #	Atomic mass - atomic # = # of neutrons	Same as # of protons

33-S

Types of Bonding

Type of bonding	metallic	ionic	covalent	intermolecular forces
Type of elements involved	between metals	between metals and nonmetals	between nonmetals	between molecules
Givers &/or takers of electrons	between givers	between givers and takers	between takers	
Description	Valence e^- roam freely between many atoms. Sea of e^- surrounding (+) kernels.	Transfer e^- Makes (+) and (-) ions that are attracted to each other.	Share e^- Forms discrete molecules.	Hold covalently bonded molecules together as a solid.
Type of material formed	solid metals and alloys	ceramics and glass	polymers and some ceramics/glasses	helps form solid polymers
Strength of bond	relatively strong	very strong	very strong	weak
Properties Produced	good conductors, workable, corrode easily	brittle, high melt temps, nonconductors as solids, don't corrode	insulators, don't corrode	help determine a lot of properties of covalent compounds (polymers)

Scope and Sequence for Classifying Matter

Science	**Technology**
-search for knowledge	-how we use the knowledge - application
-"understanding"	-"using"

Matter

-has mass and takes up space
-made up of atoms
-name something you can see that isn't made of matter - a shadow

-If it isn't matter then it is energy - chemistry concentrates more on matter and physics concentrates more on energy. We will do some of both but more chemistry.

Atom

-smallest particle of an element that has the properties of the element

States of Matter

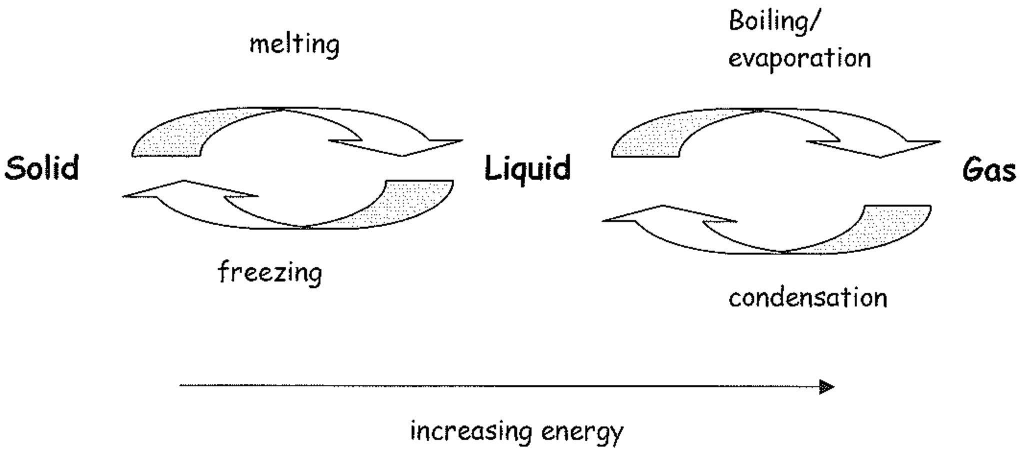
-fill in chart from overhead - solid, liquid, gas
-use Petri dishes with BBs to illustrate packing and mobility

Plasma

-ionized gas
-electrons stripped from nucleus
-occurs at very high temperatures
-mixture of neutral atoms, free electrons, and charged ions
-examples: sun, star, lightning through atmosphere

States of Matter

State	Solid	Liquid	Gas
Volume	*Definite*	*Definite*	*Indefinite*
Shape	*Definite*	*Indefinite*	*Indefinite*
Packing of particles	*Tight*		*Loose*
Particle mobility	*Least*		*Most*



Question for students: Where would plasma fit in the diagram?

Types of Matter

-Start w/ the Flinn "Nuts, Bolts, and Washers" Activity
(See instructions and notes on Flinn Fax)

-Notes:

Element	**Compound**	**Mixture**
-one kind of atom	-2 or more elements chemically combined	2 or more substances physically combined
-basic building blocks		
-on periodic table	-properties different from elements making it up	-components can retain some of their properties
-make up everything		
-over 100	-elements combine in definite ratios	-mixed in any ratio
-represented by symbols	-represented by formulas	-no formula
-examples: Sulfur - S Gold - Au Zinc - Zn	-examples: water - H_2O salt - NaCl carbon dioxide - CO_2	-examples: salt water bronze kool-aid fruit jello brass

Types of Elements

Metals	**Nonmetals**	**Metalloids (semimetals)**
-left side	-right side	-on border between metals and nonmetals (stairstep line)
-most numerous		-fewest # of elements
-solids	-all 3 states	-solids
-lustrous	-not lustrous (dull)	-intermediate properties
-conductors	-tend not to be conductors	
-workable	-brittle	

Ask *students to provide examples of each*
Demo *- Cu, Al, graphite, sulfur, silicon*
conductivity (use meter), luster, workability/brittleness

Types of Structure

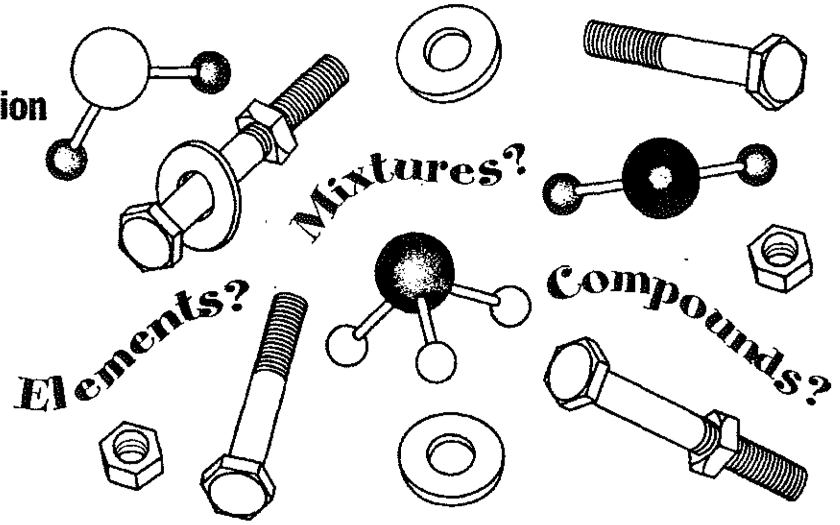
Put BB board on overhead. Ask for a student volunteer to go to the board and circle 2 regions that have different types of structure. Discuss their differences.

Crystalline	**Amorphous**
-orderly arrangement of particles	-random arrangement of particles
-repeating pattern	-no repeating pattern
-predictable	-not predictable

Use overhead to show a diagram of each. Have them copy it into their journal.

Classifying Matter

A "Nuts-and-Bolts" Demonstration



Introduction

Bulk samples of an element, a compound, and a mixture may look similar "on the outside." But when we talk about these concepts with students, we are asking them to see what they look like "on the inside"—we want them to imagine atoms and molecules and mixtures of these and notice how they are different. This "nuts and bolts" demonstration will help your students visualize abstract concepts relating to the classification of matter.

Concepts

- Element
- Compound
- Mixture
- Classification of Matter

Materials

Small bolts or machine screws
Hex nuts and washers to fit bolts
Plastic Petri dishes, 9
Overhead projector

Preparation

Label nine Petri dishes A through I and place the following objects in each:

A. six bolts
B. six nuts
C. six washers
D. three bolts and three nuts (not assembled)
E. two bolts, two nuts, and two washers (not assembled)
F. three "nut and bolt" assemblies
G. two "nut-bolt-washer" assemblies
H. two "nut and bolt" assemblies and two extra bolts or nuts
I. two "nut and bolt" assemblies and two "nut-bolt-washer" assemblies

Procedure

1. Have students prepare a data sheet and label it "Element, Compound, or Mixture" at the top and "A–I" down the side.
2. Select one of the Petri dishes at random and place it on the overhead projector.
3. Tell the students to imagine that *each object* represents either an atom or a compound, then ask them to *silently* identify whether the *collection of objects* in the Petri dish represents an element, a compound, or a mixture. Have the students write down their choice on their data sheet.
4. Repeat steps 2 and 3 with the other Petri dishes. To make students think and keep them guessing, randomly select the Petri dishes from the available set.
5. After all of the Petri dishes have been shown, discuss the findings with the class.

Tips

- An alternative way to conduct this demonstration is to place the dishes on lab benches around the room and have students circulate around the room to examine the samples and complete a data sheet.
- Other questions to ask the students include: Are the contents homogeneous or heterogeneous? Name a real example corresponding to the type of substance in each Petri dish.
- Seal the Petri dishes with tape and reuse them every year.

Discussion

Do not focus on "right and wrong" answers during the classroom discussion. Encourage students to share their reasoning with the class so they can discover the abstract concepts on their own. Petri dishes A, B, and C represent elements, while Petri dishes D and E contain mixtures of elements. Petri dishes F and G represent compounds. Petri dish H contains a mixture of compounds and elements, while Petri dish I contains a mixture of compounds.

Safety Precautions

Although the materials in this demonstration are considered nonhazardous, follow all normal laboratory safety guidelines.

Acknowledgment

Special thanks to Lee Marek, Naperville North High School, Naperville, IL for providing this activity.

Reference

Flinn ChemTopic™ Labs, Vol. 1 Introduction to Chemistry, Flinn Scientific: Batavia, IL, 2002.

Materials for *Classifying Matter—A "Nuts-and-Bolts" Demonstration* are available as a kit from Flinn Scientific. See description on this page.

Catalog No.	Description	Price/Each
AP6253	Flinn ChemTopic™ Labs, Vol. 1 Introduction to Chemistry	$11.95

Classifying Matter

A "Nuts-and-Bolts" Demonstration Kit

The perfect introductory activity to teach elements, compounds, and mixtures! Use this "nuts-and-bolts" demonstration to help students visualize abstract concepts relating to the classification of matter. Your students will be more successful in learning chemistry as they build visual connections between the world they can see and that of atoms and molecules. Teacher Demonstration Notes provided. Kit contains all materials necessary to do the demonstration on this page.

Catalog No.	Description	Price/Each
AP6291	Classifying Matter—A "Nuts-and-Bolts" Demonstration Kit	$18.50

http://dev.nsta.org/ssc/
Scope, Sequence, and Coordination
A Framework for High School Science Education
Based on the National Science Education Standards

Science as Inquiry

A Physical Challenge

Can elements be classified by physical properties?

Overview:

Using some common metallic and nonmetallic elements, students determine their characteric properties.

Materials:

Per lab group:

1 centrigram balance
1 miniature lamp (flashlight)
sand paper
hammer
screwdriver
6-volt battery
25-mL graduated cylinder
3 wire leads
2 alligator clips
1 overflow can (optional)

Sample of materials (two samples of each per group, 3 to 6 g per sample):

iron
aluminum
tin
copper
zinc
magnesium
carbon
silicon
sulfur

Procedure:

Supply students with element samples of metals and nonmetals, and with a "Table of Densities." Samples should not be identified by name but simply labeled A–G. They can vary in mass from about 3 to 6 grams and should be in solid, non-powdered form so that students can obtain the density quite easily. Samples should include both metals (iron, aluminum, tin, copper, zinc, magnesium) and nonmetals (carbon, silicon, and sulfur). Have students make observations of the following properties: color, luster, malleability hardness and conductivity. They should design a data table and record their observations. Have students tap each sample with a hammer to determine if the element is malleable or brittle. Next, they should gently rub each sample with sand paper to determine its hardness, and also record if it is shiny or dull. Have students construct a conductivity apparatus using the materials provided and test each sample for conductivity—recording whether the element is a conductor or nonconductor. Students can obtain the density by obtaining the mass and volume of the sample (the volume can be determined by water displacement using an overflow can or by noting differences in water levels in the graduated cylinder). After completing all tests, students analyze their observations, determine which samples are metals and which are nonmetals—and, from known densities—the name of each element previously labeled A–G.

Background:

Teachers may use any samples of elements that are available to them and suitable for the activity. The test for malleability consists of tapping the sample with a hammer. If it is malleable it will flatten without shattering. If the sample shatters into a number of pieces, it is considered to be brittle. To test metals and nonmetals for conductivity, connect a six volt battery to one side of a miniature lamp. Then connect another piece of wire to the other side of the battery. Then connect another piece of wire to the other side of the miniature lamp. Test for conductivity by touching each wire lead to either side of the substance being tested. Nonmetals will generally not conduct electricity, however if the carbon is graphite, it will conduct because of the free electrons within the structure.

Sample Results

Element	Appearance	Crushing	Conductivity	Density (g/cm^3)
carbon	dull black-gray	brittle	yes (no)	1.8–2.3
zinc	shiny silver	malleable	yes	7.1
silicon	shiny gray	brittle	yes	1.6
iron	shiny gray	malleable	yes	7.9
tin	shiny silver	malleable	yes	7.3
sulfur	dull yellow	brittle	no	2.1
magnesium	shiny silver	malleable	yes	1.7
aluminum	shiny silver	malleable	yes	2.7
copper	shiny gold	malleable	yes	8.9

Variations:

Students may be asked to search for metal and nonmetal objects in the home and list how they are used. Make a list and state why each item is considered as a metal or nonmetal.

Students may be asked to collect food and other product labels. Use the labels to find common elements, write the name of the elements, its symbol and research to find the purpose of using the element in the product.

Adapted from:
American Chemical Society, *Chemunity News*, Vol. 1(3), (2), 2(3), (5), 1991, 1992, pp. 19–20.

Science as Inquiry

A Physical Challenge

Can elements be classified by physical properties?

Overview:

How do we know something is a metal? This activity provides the physical tests to determine this answer.

Procedure:

Obtain element samples labeled A through G. Make observations of these properties: color, luster, malleability, conductivity and density. Make a data table to record your observations, first recording the color and luster of each sample. Next, tap each sample with a hammer to determine if the element is malleable (flattens out) or brittle (shatters). Gently rub each sample with sandpaper. Construct a conductivity apparatus using the materials provided and test each sample for conductivity. Observe and record whether the results indicate that the material is a conductor or nonconductor. Obtain the density of each sample. To get the volume, drop the sample into a graduated cylinder containing water and note the volume difference. Use your observations and the "Table of Densities" supplied by your teacher to determine which samples are metals, which are nonmetals, and the identity of each metal.

Questions:

1. Which lettered samples of elements were metals? Which were nonmetals?

2. What are some common characteristics of metals?

3. What are some common characteristics of nonmetals?

4. Could any of the elements you tested be called metalloids? Which ones? Why did you classify them in this manner?

5. Is there any generalization you can make about the densities of metals vs. nonmetals?

6. Identify the name of each element you tested, e.g., A=iron, B=zinc, etc.

7. Are the other properties you did not report on or test in this activity that might distinguish a metal from a nonmetal?

8. Are there any properties that you observed that might give you a clue why nonmetals are poor conductors of electricity?

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Appendix C

GENERAL COMPARISON OF PROPERTIES: METALS, CERAMICS, POLYMERS

Property	Metals	Ceramics	Polymers
Density	2-22 (ave. ~8)	2-19 (ave. ~4)	1 to 2
Melting points, °C	Low = gallium 30; High = Tungsten 3410	High 4000	Max. serv. temp. ranges from ~45 for ethyl cellulose to ~300 for polyimide
Hardness	Medium	High	Low
Machinability	Good	Poor	Good
Tensil Strength, MPa (ksi)	Up to 2500 (360)	Up to 400 (58)	Up to 140 (20)
Compressive Strength MPa (ksi)	—	Up to 5000 (725)	Up to 350 (50)
Young's Modulus GPa (10^6 psi)	15 to 400 (2 to 58)	150–450 (22–65)	0.1 to 10 (0.00015 to 1.45)
High Temp. Dreep Resistance	Poor to Mediium	Excellent	—
Thermal Expansion	Medium to High	Low to Medium	Very High
Thermal Conductivity	Medium to High	Medium, but often decreases with temp.	Very Low
Thermal Shock Resistance	Good	Generally Poor	—
Electrical Properties	Conductors	Insulators	Insulators
Chemical Resistance	Low to Medium	Excellent	Good
Oxidation Resistance	Generally Poor	Oxides excellent SiC and Si_3N_4 Good	—

Industrial Materials
by: Larry Helsel and Peter Liu
ISBM: 1-56637-815-X

Properties of materials: more than physical and chemical

Structural properties

These aren't really 'properties' – more like definitions that relate to what's under the hood. The goal here is to relate structure to properties.

Composition	The kinds and relative count of elements, ions or other constituents in a material; chemical formula, percent in an alloy, etc. Note that a single composition can have different structures, for instance allotropes of sulfur or polymorphs in iron-carbon systems. The basic starting point is:

	<u>Composition</u>	<u>Bonding</u>
Metals	metallic elements	metallic
Ceramics	metals + nonmetals	ionic & covalent
Polymers	carbon, hydrogen	covalent

Crystal structure	Atomic scale order; the manner in which atoms or ions are spatially arranged. It is defined in terms of unit cell geometry. A material with long-range order is called crystalline (contrasted with amorphous).
Microstructure	The structural features that can be seen using a microscope, but seldom with the naked eye; ranges from glassy to crystalline; includes grain boundaries and phase structures.

Physical properties

These are the standard properties that we teach in chemistry class.

State	Solid, liquid or gas; not as simple as it may seem.
Density	Mass of a material per unit volume. Low density, high strength materials are desirable for manufacturing aircraft and sporting equipment.
Magnetism	The physical attraction for iron, inherent in a material or induced by moving electric fields. Iron, cobalt, nickel and gadolinium are inherently ferromagnetic.
Solubility	The maximum amount of a solute that can be added to a solvent. Solubility is complex in some solid materials, for instance the ones that form eutectic mixtures; a good starting point to discuss complex phase diagrams.
Viscosity	Resistance of a material (usually liquid) to flow. Plastics and glasses become less viscous with increasing temperature.

Mechanical properties

The concepts of stress, strain, elasticity, deformation and failure are necessary to understand and interpret mechanical properties.

Malleability	The ability of a material to be reshaped in all directions (plastic deformation) without failure; related to ductility and sometimes called workability; an important characteristic of metals.
Ductility	The ability of a material to change shape (deform) usually by stretching along its length; closely related to tensile strength.

Strength	Strength is not a precisely defined mechanical property, as there are many types of strength. Collectively, it means the ability of a material to stand up to forces being applied without it bending, breaking, shattering or deforming. A strong material is one able to withstand large stresses before either breaking or deforming. Some materials have different strengths according to the nature of the stress applied. Concrete, for example, is strong under compression but has relatively poor tensile strength.
Tensile strength	The maximum strength, in tension (pulling), that can be absorbed without fracturing, breaking, or snapping. Low tensile strength can be an indicator of defects in crystal structure.
Flexural strength	Applied stress at the time of fracture from a test in which the stress is perpendicular to the axis of deformation (bending); generally used to characterize beams.
Hardness	The resistance to being permanently deformed or bent; measured by distance of penetration into the material. There are several scales used to measure hardness, so mineral hardness (Mohs scale) is not the same as metal hardness (Brinell scale). Metals are often 'worked' or heat-treated to increase their hardness, for instance in the manufacture of tools such as hammers, which really need to be hard.
Toughness	A characteristic of a material that relates to its response to sudden blows or shocks. Toughness can be expressed as the amount of energy required for creating or propagating a crack. Closely related to resilience.
Brittleness	The absence of ductility; failure by sudden fracture (no plastic deformation); characteristic of ceramic materials.
Elasticity	The ability of a material to absorb force and flex in different directions, returning to its original position once the stress is removed. Polymers are desirable for their elasticity.
Plastic deformation	The ability of a material to permanently change shape, without failure, with an applied force. Creep is a specific plastic deformation in which the material is subjected to long-term stresses below its normal yield strength.
Stiffness	A stiff material is one for which a large stress (force applied per unit of cross-sectional area) is required to produce a small strain (fractional change in length). The ratio of stress to strain is known as the Young's modulus of the material.

Electrical properties

For the sake of this summary, electricity is defined as the flow of electrons.

Conductivity	A measure of how easily a material allows electrical current to flow through. Metals like copper, aluminum and iron have much higher electrical conductivities than ceramics, plastics, glass and rubber.
Resistivity	The reciprocal of electrical conductivity; a measure of a material's resistance to the flow of electric current. Resistivity is an important concept in semiconductors; depends on electronic structure, temperature and microstructure.
Dielectric strength	Dielectric properties describe the response of dielectric materials (poor conductors) to applied electric fields and depend on polarization of electric charges. Dielectric strength is the strength of an electric field necessary to cause significant electric flow through a dielectric material.

Chemical properties

Generally, lack of reactive chemistry is desirable for materials; this is a good place to look through those MSD sheets.

Toxicity	A measure of a material's ability to damage or disrupt the metabolism of living tissue; can be acute or chronic; can be administered by contact, inhalation, ingestion, or injection. *The dose makes the poison.*
Chemical resistance	A material's ability to withstand degradation from acids, solvents, water, or oxygen (corrosion is a special process); generally marked by weight change, discoloration, cracking, or change in mechanical properties.
Corrosion resistance	Corrosion is an electrochemical process that is closely related to the activity series. An ion high on the list will replace a metal lower on the list. Mg > Al > Zn > Cr > Fe > Sn > Ni > Cu > Ag > Au Corrosion is strongly dependent on environmental variables.
Combustibility	A material's ability to catch fire and burn; important for organic materials and reactive metals (especially finely divided).
Passivity	The loss of chemical reactivity by some active metals and alloys, frequently by formation of a thin oxide surface coating.
Biocompatibility	Use in or on the human body without eliciting a rejection response from the surrounding body tissues; includes materials made of polymers, metals, ceramics, and composites.

Thermal properties

Think about heating a rod: it gets hot, it expands, it conducts heat, it may soften or melt. These properties are described (in order) below.

Specific heat	The efficiency of a material in absorbing heat. High specific heat means a material heats fast and cools down fast. By definition, the specific heat of a material is the energy required to raise the temperature of 1 g of that material by 1 °C. Water has an anomalously high specific heat.
Thermal expansion	Nearly all materials expand when heated and contract when cooled. The extent to which this happens is the coefficient of thermal expansion. Bridges are designed with expansion joints so they don't buckle due to thermal expansion.
Thermal conductivity	Thermal conductivity is the rate at which heat flows through a material. It depends on the flow of both electrons and phonons.
Glass transition temperature	The point at which a polymer or glass changes between a rigid solid and a viscous fluid (reversible). The rate at which a glass or polymeric liquid cools affects the extent of crystallization and resulting mechanical properties.
Melting point	The temperature at which liquid begins to form as a material is heated. Not all materials have distinct melting points, and many materials have phase transition temperatures in which crystal structure changes.

Optical properties

Optical properties relate to a material's response to electromagnetic radiation, primarily visible light. Light can be absorbed, transmitted, or reflected. Optical properties are important for all materials, not just transparent materials (think photoelectric effect).

Transmissivity	A measure of a material's ability to allow the passage of light; the ratio of transmitted light to incident light.
Absorptivity	A measure of a material's ability to absorb light as is passes through; the ratio of absorbed light to incident light.
Index of refraction	The ratio of the speed of light in a vacuum to the speed of light as is passes through a material; a measure of how much light 'bends' as it passes from one medium to another.
Photoconductivity	Some materials become positively charged when exposed to radiation, due to the ejection of electrons (photoelectrons). Photoconductivity describes the increase in conductivity as a result of incident light; use it to teach quantum mechanics.
Polarization	Orientation polarization results from the alignment (by rotation) of permanent electric dipole moments. As a result, only the incident light that is aligned to the material's 'slits' can pass through. Used to develop sunglasses and LCDs. Note that there are many uses for the word polarization.

Sources of information

William D. Callister, Jr. *Materials Science and Engineering - An introduction*. John Wiley & Sons, New York, NY. Sixth Edition, 2003.

James A. Jacobs and Thomas F. Kilduff. *Engineering Materials Technology*. Pearson Education, Upper Saddle River, NJ. Fifth Edition, 2005.

TechnologyStudent.com. http://www.technologystudent.com/index.htm.
Illustrated properties of materials are found under 'Resistant materials.' Accessed June 2005.

Beginners Guides to Measurement – Materials. http://www.npl.co.uk/publications/materials/. Accessed June 2005.

Sulfur Lab

Safety:

Fire hazard. During this activity, the sulfur may catch fire and burn at the lip of the test tube. Have wet towels readily available to smother the flame. Take care not to burn hands. Take care not to overheat the sulfur. Sulfur dioxide is toxic. Dispose of sulfur in trash can. Refer to MSDS sheet.

Part A: Rhombic Sulfur - Demonstration

1. Add a small scoop of sulfur to 3 mL of olive oil or mineral oil in a 50 mL beaker. Heat gently with stirring for 10 - 12 seconds (do not go over about 80° C). Place a few drops of the warm solution on a watch glass and set aside. Let crystals grow overnight or for several days.

Part B: Monoclinic Sulfur

1. Fill a test tube approximately 1/3 full with sulfur. Keep the sulfur powder off the sides of the test tube.

2. Make a cone out of filter paper and place it in a funnel.

3. Heat the test tube of sulfur VERY slowly - passing it back and forth above the flame. Totally melt to a liquid. (Use Bunsen burner and test tube clamp) (Keep the sulfur yellow)

4. Pour liquid sulfur into filter paper cone. As soon as a surface crust forms, open the filter paper to original shape.

5. Make observations of crystals formed.

6. Clean up!!!!!

Part C: Amorphous Sulfur - Demonstration

1. Nearly fill a 250 mL beaker w/ ice water.

2. Fill test tube about 1/4 full w/ sulfur. (Keep sulfur off the sides of the test tube)

3. Heat sulfur slowly. It will pass through stages:
    - melt to yellow liquid
    - red liquid
    - dark reddish-brown thick syrup
    - dark runny liquid

4. Pour hot sulfur into beaker of water. (quench)

5. Make observations of solidified sulfur.

6. Place in fume hood overnight. Make observations after 24 hours.

7. Clean up!!!!

Describe and sketch each allotrope of sulfur.

Notes:

The sulfur lab introduces:

- allotropes
- ways of forming crystals
- amorphous vs. crystalline structure
- solid state phase change

It is best to do parts A and C as demonstrations. Part B may be done by the students. Make sure the room is adequately ventilated and check for known sulfur allergies ahead of time.

When pouring out the sulfur for Part C, leave some of the liquid sulfur in the test tube. It is possible to observe a reversal of the structural changes that occurred during heating. The liquid will become viscous and thick as it cools, and then runny again upon further cooling. When it gets to this point, pour the remaining liquid into a beaker or cup of water. It should form small balls instead of long strings. The balls are hard and when split open with a fingernail reveal small yellow crystals on the inside.

Expected Results:

- Rhombic sulfur - small diamond shapes that will need magnification to view
- Monoclinic sulfur - long yellow spikes that do not need magnification to view but it is worthwhile to use a stereoscope
- Amorphous sulfur - long, rubbery, amber-colored strands - their surface resembles the scales on hair when viewed under a stereoscope
- Amorphous sulfur after 24+ hours - will begin to turn back to a yellowish color and will become brittle - it is returning to a crystalline state - a solid state phase change is occurring

Sulfur

Sulfur can behave chemically in two ways. First a sulfur atom can acquire two electrons to complete its octet, thereby forming the stable sulfide ion, S^{2-}, with the [Ar] electron configuration. It can also have positive oxidation states, particularly in the presence of such powerful oxidizers as fluorine and oxygen. Thus, as we already know, sulfur readily burns in air to form sulfur dioxide, a pungent gas. In this reaction sulfur forms a covalent bond with oxygen. But since oxygen atoms have a greater affinity for electrons than have sulfur atoms, the shared electrons shift towards the oxygen.

It should now be apparent that the way sulfur behaves in a particular reaction depends upon the nature of the element it combines with. If sulfur reacts with metals (or hydrogen), it is the more electronegative partner in the resulting bonds, and its oxidation number is –2. On the other hand, if sulfur reacts with oxygen or fluorine, its oxidation number can be +1, +2, +3, +4, +5 or +6. Of these, the most common is +4, as in SO_2 and SF_4. However, in the presence of a suitable catalyst, sulfur dioxide will also combine with oxygen to form sulfur trioxide, SO_3, and SF_4 can be reacted with excess fluorine to make SF_6. Interestingly, SF_6 is a very stable gas, and is used as an insulator in high-voltage electrical equipment, whereas SF_4 is a highly reactive compound. This is another example where a compound derives its stability from kinetic rather than from thermodynamic factors. SF_6 is unreactive because the crowded sulfur atom is kept away from nucleophiles by the six tightly-held fluorine atoms.

Properties of sulfur

Both sulfur and oxygen atoms have 6 electrons in their outermost energy levels. It would, therefore, be reasonable to expect that sulfur, like oxygen, would form diatomic molecules, S_2. Actually, sulfur forms diatomic molecules only at high temperatures. At ordinary temperatures it forms a ring of 8 sulfur atoms bound together by covalent bonds (Figure 10-3). The origin of this difference lies in the relative strengths of the single (e.g. O-O vs S-S) and double bonds (O=O vs S=S). Only for the elements of the second period of the periodic table is the bond energy of a double bond greater than the sum of two single bonds.

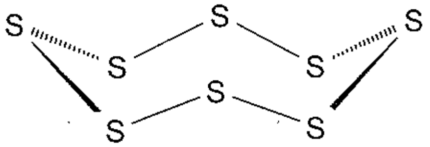


Figure 10-3

The crown shape of the sulfur molecule, S_8

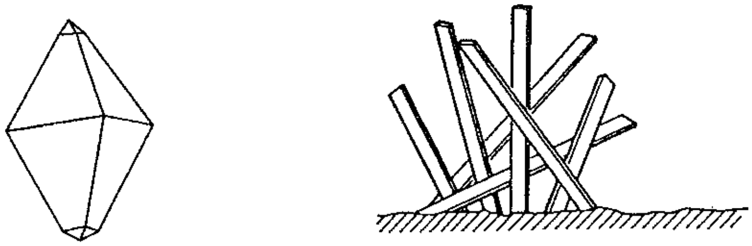
As one would expect, the van der Waal's forces are considerably greater in cyclic S_8 than in O_2. Sulfur molecules are nonpolar. In general we can say that nonpolar molecules mix with other nonpolar molecules but not with polar molecules. Sulfur will dissolve in such nonpolar liquids as carbon tetrachloride, carbon disulfide, and hexane, but not in water.

Allotropes of sulfur

Sulfur has several allotropic forms, the most important being rhombic and monoclinic. Crystals of rhombic and monoclinic sulfur differ only in the internal arrangement of the crown-8 rings with respect to one another. The resulting crystals are observably different, belonging as they do to two different symmetry classes.

Rhombic sulfur consists of yellow octahedral crystals (see Figure 2). It is stable at ordinary temperatures, and is therefore the more familiar allotrope. It melts at 114°C, is insoluble in water, but quite soluble in carbon disulfide. Sizable crystals of rhombic sulfur can be grown by slowly evaporating a carbon disulfide solution of sulfur.

Monoclinic sulfur consists of long needle-shaped crystals (see Figure 10-4). These can be formed by melting rhombic sulfur and then allowing it to cool and crystallize. This is because monoclinic sulfur is stable at temperatures above 96 °C; it is unstable below this temperature and slowly reverts to the rhombic form. A more convenient way of preparing monoclinic sulfur is to let it crystallize from solution in hot toluene.



Typical habit of rhombic sulfur crystals

Typical habit of monclinic sulfur crystals

Figure 10-4 Common appearance of the two main allotropes of sulfur, both containing S_8 rings

Near its melting point, sulfur is a mobile liquid, which is consistent with the interpretation that at this point it consists almost entirely of S_8 rings and that these rings interfere only slightly with each other's motion. However, as the temperature is raised, the kinetic energy of the molecules increases, causing bond-breaking and re-forming to occur. Thereby the rings become entangled and the viscosity of the liquid increases dramatically. As the temperature is raised still further, more extensive bond-breaking occurs, and a variety of short-chain sulfur molecules are formed. This allows some of the entangled chains to free themselves, and, as a result, the viscosity decreases. Finally, if the hot liquid is suddenly chilled by cold water, the chains again become so entangled that the sulfur solidifies and becomes rubber-like in texture. On long standing, the entangled chains eventually revert to S_8 rings, and this so-called plastic sulfur reverts to the rhombic crystalline form.

These notes came from:
http://classes.uleth.ca/200501/chem28101/Expt10-Grp16.pdf

Other websites to check out:
http://www.woodrow.org/teachers/chemistry/institutes/faraday/lab5.html

http://www.columbus.k12.oh.us/walnut_ridge/Sulfur%20(Expt%2024).html

http://dev.nsta.org/ssc/pdf/v4-0961s.pdf

Ways of Forming Crystals

1. From a solution as the solvent cools or evaporates

   Examples:
   - growing single crystals lab – copper sulfate or potassium alum
   - sodium acetate demo from Flinn
   - sulfur lab – part A – rhombic

2. Cooling a liquid from a melt (freezing)

   Examples:
   - sulfur lab part B – monoclinic
   - phenyl salicylate demo

3. Grow as a precipitate from a chemical reaction

   Example:
   - silver nitrate on copper wire

$AgNO_3$	+	Cu	------->	Ag	+	$CuNO_3$
Silver nitrate	+	copper wire	--------------->	silver crystals	+	copper nitrate

Growing Single Crystals

Day 1

1. Measure amount of water it takes to fill jar $\frac{3}{4}$ full. Record the volume in mL.

2. Determine amount of chemical needed to make a supersaturated solution.

   Copper sulfate ($CuSO_4$) = mL of water x .43 g/mL

   Potassium alum = mL of water x .16 g/mL

   Record the mass in grams.
   Describe appearance of chemical.

3. Mass the proper amount of chemical into a 100 – 150 mL beaker using a balance.

   Define the term "tare" in your journal.

4. Add the amount of water from step #1 to the beaker.

5. Use a hot plate to heat the contents of the beaker until all of the chemical is dissolved. Stir as you heat.

6. Pour a small amount of the solution into a watch glass. Place remaining solution into your jar and loosely cap. Record observations.

Day 2

1. Select a seed crystal from your watch glass. Cut 20 – 25 cm of thread and use it to tie a knot around the see crystal. Draw and describe the seed crystal in your journal.

2. Run the thread through the hole in the jar lid and tape it down so that the seed will suspend in the middle of the solution.

3. Clean the seed crystal and thread by gently and quickly dipping them in a beaker of water a couple of times.

4. Suspend the seed crystal in the jar of solution.

Journaling for Day 2:

- Look at your watch glass under a stereoscope and find examples of each of the following:
  - single crystal
  - grains
  - grain boundary

- Make a labeled sketch of each of these structures.

- Choose a seed crystal - sketch it actual size and mass it.

Day 3+

1. Check the crystal daily. Record observations, sketches, and describe "maintenance" techniques used.

2. If crystals appear on bottom of jar - reheat the solution to re-dissolve the chemical. Use a beaker. Allow solution to cool before replacing the crystal.

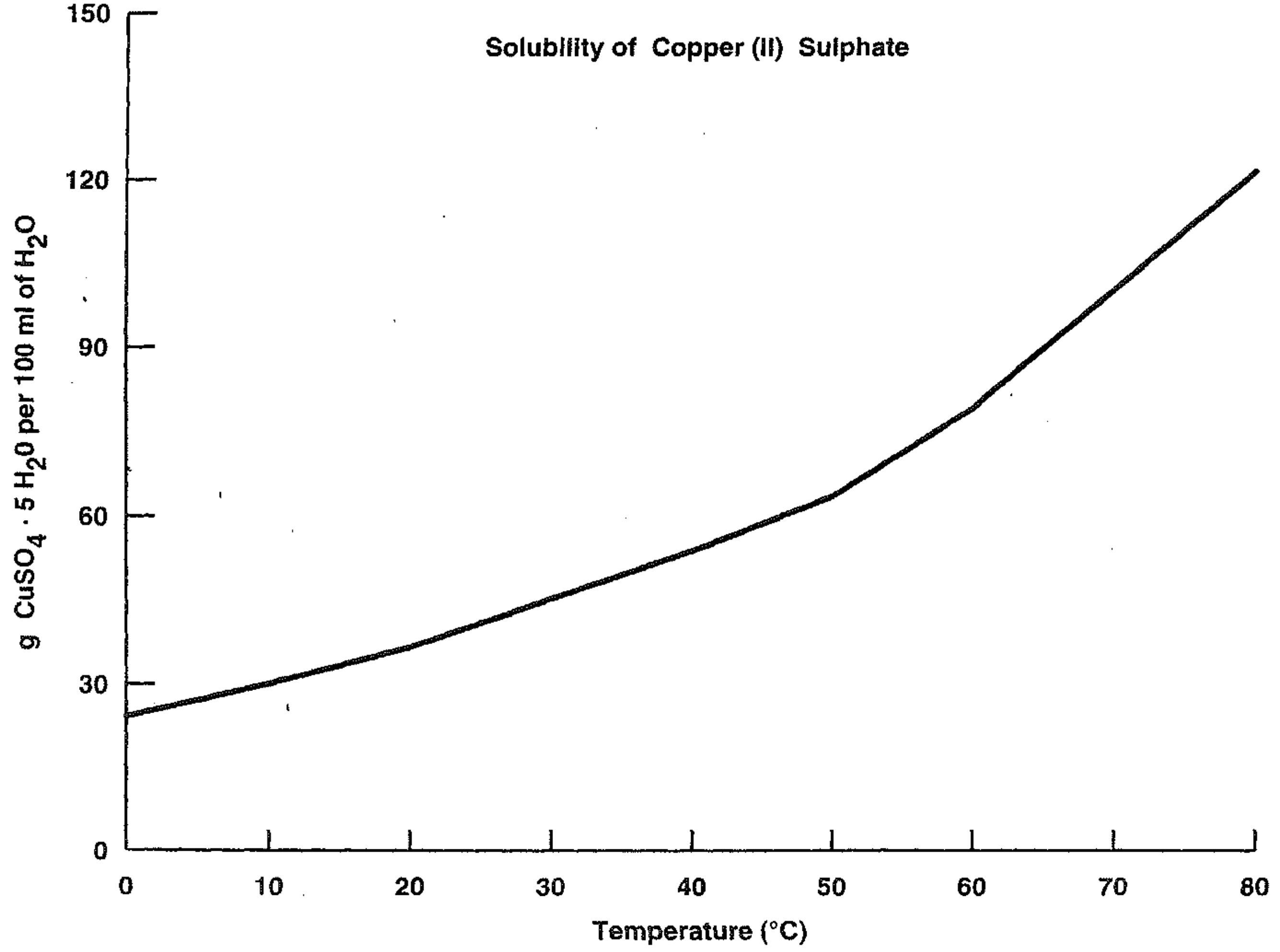
3. If extra crystals grow on the suspended crystal or thread try to remove them.
   -use forceps
   -dip in water
   -?????????

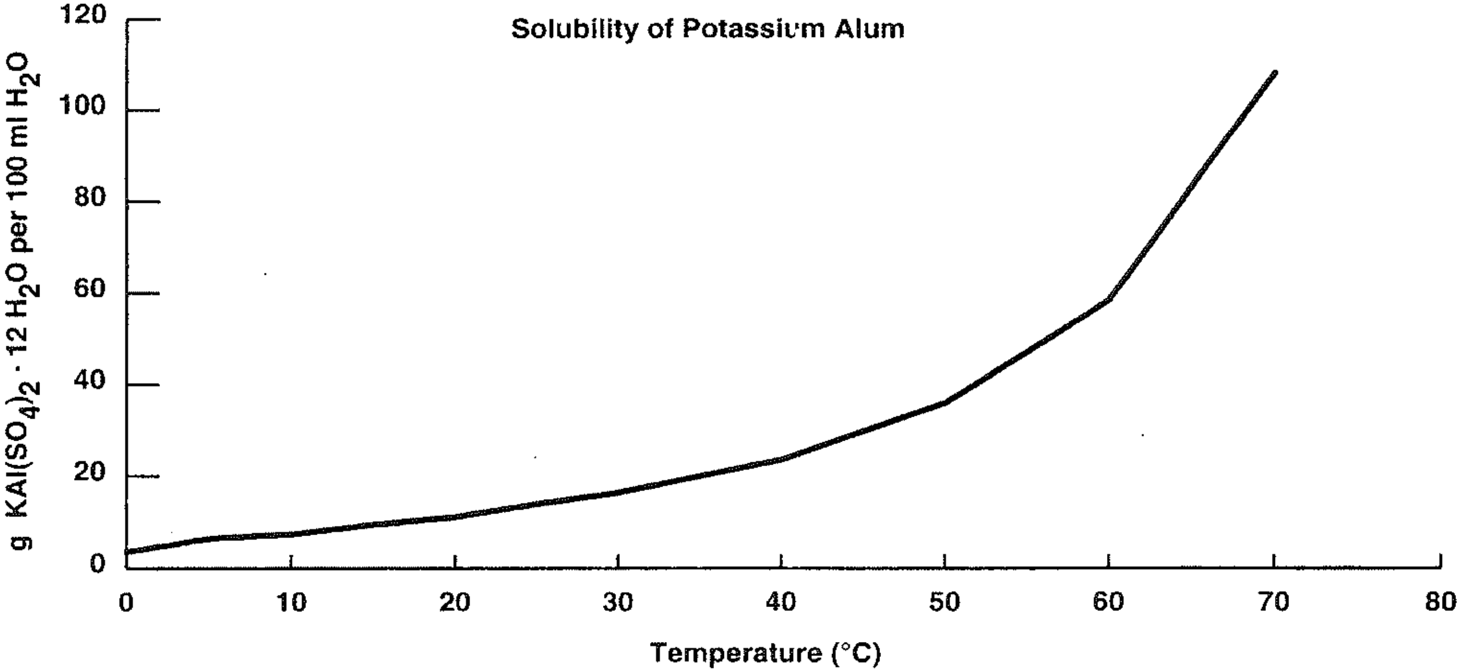
4. If the crystal stops growing, re-supersaturate the solution. Add 2 or 3 grams of chemical for each 100 mL of solution and reheat in a beaker to dissolve. Let solution cool before replacing the crystal in solution.

Final Journal Write

- Discuss problems you encountered in growing a SINGLE perfect crystal and remedies you tried.
- Why does the crystal eventually stop growing? How can you fix this?
- How many times did your crystal increase in mass?
- How well did your crystal keep a perfect shape?
- What have you learned? (about solutions, about crystals, etc...)
- What would happen if you placed a potassium alum seed crystal in a supersaturated $CuSO_4$ (copper sulfate) solution? Why?
- What is your opinion of this lab? What did you enjoy the most? What did you like the least?

Note: 5 oz. plastic cups, toothpicks, and plastic wrap can be used instead of glass jars with lids.


Solubility of Copper (II) Sulphate
g $CuSO_4 \cdot 5 H_2O$ per 100 ml of H_2O
150
120
90
60
30
0
0
10
20
30
40
50
60
70
80
Temperature (°C)


Solubility of Potassium Alum
g $KAl(SO_4)_2 \cdot 12\ H_2O$ per 100 ml H_2O
120
100
80
60
40
20
0
0
10
20
30
40
50
60
70
80
Temperature (°C)

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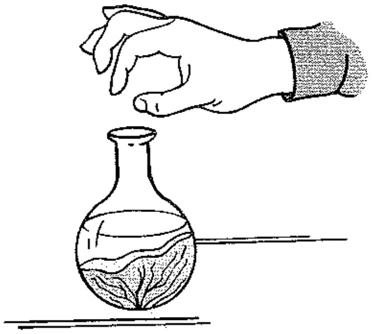
Instant Crystals

Supersaturated Solution

Publication No. 700



Introduction

Snap your fingers over a clear solution and, presto, the solution instantaneously crystallizes. The flask can immediately be turned upside down without spilling a drop. Is it magic? Not exactly! It's science at work.

Chemical Concepts

- Supersaturated solutions
- Crystallization

Materials

Sodium acetate, trihydrate, $CH_3CO_2Na{\cdot}3H_2O$, 160 g

Distilled or deionized water, 30 mL

Erlenmeyer flask, 500-mL, Pyrex®

Parafilm M® or 100-mL beaker, to cover the flask

Graduated cylinder, 100-mL or 50-mL

Stirring rod, glass

Washing bottle filled with distilled water

Balance

Hot plate or Bunsen burner

Ring stand set-up, if using a Bunsen burner

Heat-resistant gloves or tongs

Safety Precautions

Sodium acetate is slightly toxic by ingestion, inhalation, and skin absorption. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Wear heat-resistant gloves or use tongs when handling the hot flask. Consult current Material Safety Data Sheets for additional safety, handling, and disposal information.

Preparation

1. Weigh out 160 g of sodium acetate trihydrate in a 500-mL Erlenmeyer flask.
2. Using a graduated cylinder, measure out 30 mL of distilled water, and add it to the flask of sodium acetate trihydrate.
3. Heat the mixture on a hot plate or over a Bunsen burner, stirring occasionally until all of the solid is dissolved. (This may take 15 minutes or so.) Make sure the sides of the flask are free of solid sodium acetate. To remove crystals from the sides of the flask, rinse them down with small squirts of water from the washing bottle.

56-S

4. Cover the flask with Parafilm or with a 100-mL beaker. Allow the solution to cool to room temperature undisturbed or, to speed up the cooling process, run cool water over the sides of the flask making sure no tap water gets into and contaminates the solution. The flask can now sit undisturbed until you are ready for the presentation. Take care not to disturb the solution as even slight movement may cause crystallization to occur before you're ready.

Procedure

1. While holding a single sodium acetate trihydrate crystal over the open mouth of the flask, snap your fingers and allow the crystal to drop into the flask. You might want to say some magic words like "abracadabra presto" as you snap your fingers. The single crystal should start a chain reaction of crystallization.
2. Immediately turn the flask upside down as crystallization occurs. The crystallized sodium acetate will not fall out.
3. Feel the sides of the flask. The flask will be warm since this is an exothermic process.
4. The solution may be used over again by reheating it to redissolve the sodium acetate.

Tips

- Use caution if substituting a non-Pryex® hydrometer cylinder for the flask in this demo. The temperature differential may crack the cylinder. Use a Pyrex cylinder instead or allow the supersaturated solution to cool slightly before pouring it into the cylinder.
- The addition of too much water will result in leftover liquid after recrystallization.
- This demonstration can be performed for a larger audience by using 640 g sodium acetate trihydrate and 120 mL water.
- Topics of discussion may include saturated solutions, supersaturated solutions, crystallization, and exothermic processes.
- Uses for supersaturated sodium acetate solutions include hot packs and hand warmers.
- Variations of this demonstration include performing the crystallization in a 500-mL graduated cylinder or placing a single crystal in a shallow container and pouring the solution onto the crystal. A buret may also be used to release the solution onto the crystal. These two variations can produce fairly tall columns of the recrystallizing sodium acetate.
- Use a Flinn ChemCam™ or other video microscopy unit to provide a close-up view of the crystallization process.

Discussion

A supersaturated solution of sodium acetate trihydrate (the clear solution) will recrystallize by the addition of a single crystal of the solid. A supersaturated solution is a solution which contains a greater amount of dissolved substance than is present in a saturated solution at the same temperature. A saturated solution is a solution which contains the maximum amount of a dissolved substance at a given temperature.

A supersaturated solution can be made by gradually cooling a saturated solution without agitation so that crystals do not form. Supersaturated solutions are extremely unstable and will precipitate, or crystallize, upon addition of just one crystal of the solute. Even slight shaking or agitation may be enough to cause crystallization to begin.

Disposal

The sodium acetate solution may be re-used or flushed down the drain with excess water. Please consult a current *Flinn Scientific Catalog/Reference Manual* for proper disposal procedures.

Materials for *Instant Crystals—Supersaturated Solution* are available from Flinn Scientific, Inc.

Catalog No.	Description	Price/Each
S0036	Sodium acetate, 100 g	Consult Your Current *Flinn Catalog/Reference Manual.*
S0037	Sodium acetate, 500 g	
GP3050	Erlenmeyer Flask, 500-mL	

57-S

Phenyl Salicylate Demo

Purpose:
- grow crystals from a melted substance
- demonstrate the formation of grains and grain boundaries

Materials:
- phenyl salicylate - enough to cover the tip of a small spatula
- glass microscope slide
- match
- light microscope
- projection system

Procedure
- Place a small amount of phenyl salicylate in the middle of a glass slide.
- Heat gently with a match from underneath until it melts. (wipe off carbon residue)
- Focus under a microscope.
- Add a single crystal of phenyl salicylate to the melted puddle. Crystallization should start to occur.
- If the added crystal melts, the puddle is still too warm. Wait a minute or two and try again.
- Move the stage to follow the growth of the grains.
- The grains should be rhombic in shape.

Student Journal
- Describe the basic procedure.
- Describe the formation of grains and grain boundaries
- Draw and label examples of grains and grain boundaries

Growing Silver Crystals

Purpose:
- grow crystals from a chemical reaction
- illustrate the concept of dendrites

Materials:
- copper wire - approximately 20 gauge or finer - flattened with a hammer or rolling mill
- .1M silver nitrate solution
- microscope slide
- stereoscope

Procedure:
- Place a flattened 1" piece of Cu wire on a microscope slide.
- Focus one end of wire under stereoscope.
- Have the teacher drop $AgNO_3$ (silver nitrate) on the wire.
- Make observations:
    - low and high power
    - light from above and below

Journal:
- sketches
- written description
- definitions

Crystal
-group of atoms that form a particular repeating pattern
-no breaks in alignment

Dendrites
-crystals growing out from other crystals
-crystal branches

Grains
-multiple crystals in a solid
-start growing in different places and meet up

Grain Boundary
-where grains meet up in a solid
-smaller crystals have more grain boundaries
-affect physical properties

Notes:

Use overhead of grains and grain boundaries

Use BB board to illustrate grains and grain boundaries

Use videoflex to point out silver dendrites

Analogies on size of crystals and # of grain boundaries:
- -jigsaw puzzle - 12" x 12" - 10 pieces vs. 100 pieces
- -U.S. States - instead of 48 - just 25 - fewer state lines - combine KS and MO into one state

Students can pair up but have each one focus on a different end of the wire. Have the students look through the eyepiece as the silver nitrate is dropped onto the wire.

Models of Crystals

Students do the "Models of Crystals" lab. They build 4 different unit cells using toothpicks and polystyrene balls. A recommendation is to use 1 ½" diameter spheres - the smaller ones tend to fall apart quickly after using just a few times. They build the most basic one (simple cubic) and the 3 most commonly found in metals (BCC, FCC, HCP). See the lab sheet the students fill out.

Permanent models made out of ping-pong balls and hot glue are very useful. These help the students compare the different models in terms of packing and slip planes since they dismantle their models before building the next one. It is also helpful to build planes of atoms and then stack them. This helps the students to see that the layers are all actually the same in a model; they are just "offset" when stacking them together to make the unit cell. This is also great to see the overall 3-D pattern of the crystal shape. This works especially well with FCC and HCP. If you make 3 planes for each, then the students can also try piecing them together into one layer instead of stacking them into 3 layers to make a unit cell. By building a bigger plane from smaller ones, the students can pick out the "section" that is used in each of the different layers in the unit cell. The repeating pattern is much more noticeable.

After the students have finished building the models and writing in their journals, ask the students the following question:

- "Why do we care what particular crystal structure a metal has?"
    - *because crystal structure affects properties of the metal*

Have the students rank the crystal models from "most closely packed" to "least closely packed".

1. *HCP - "most closely packed"*
2. *FCC*
3. *BCC*
4. *simple cubic "least - closely packed"*

Ask the students:

- *"Which type of crystal structure allows a metal to be more workable, one with many slip planes or one with fewer slip planes?"*
- *"Which type of crystal structure allows a metal to be more workable, one that is closely packed or one that is loosely packed?" ("One that has a lot of 'gappiness' or one that has little 'gappiness'?")*

The students almost always get the answer to the first question right. It is logical that a crystal structure with many slip planes will be more workable. However, the answer to the second question isn't as obvious. At least half of the students always say that more loosely packed crystal structures (ones with more open space) make a metal more workable. By workable we mean malleable or ductile. I then use the "chalk demo" to illustrate the answer.

Chalk demo:

- Materials:
    - 5 pieces of chalk laid side by side with an ~ $\frac{1}{8}$" gap between each piece (use hot glue to attach them to a piece of clear plastic)
    - 5 pieces of chalk laid side by side with no gaps between them (attach to plastic)
    - one piece of chalk to roll across the top of the other pieces

Give the students the following scenario:

You are riding your 4-wheeler in the country and you come to a deep ditch that someone has built a log bridge across. Which type of bridge would be easier to go across?

Then roll the single piece of chalk across the "chalk bridges" - first the one with gaps and then the one without gaps. Which one is harder to do and requires more energy? They will all agree that the one without gaps is easier.

Now tell the students you are going to ask them the original questions AGAIN:

- *"Which type of crystal structure allows a metal to be more workable, one that is closely packed or one that is loosely packed?"*
- *"Which one is easier for the planes of atoms to slide past each other?"*

The students get it. Common sense wants to tell us that having more "open space" in a crystal makes it easier for atoms to move around so the metal is more workable. But this isn't the case with planes of atoms. More 'gappiness' allows the atoms to fall into these spaces and makes it harder to keep them moving to work the metal.

- more tightly packed = more workable
- more slip planes = more workable

Workable - changing the shape of a solid (while remaining a solid) without it cracking or breaking (malleability and ductility)

Based on the above information, have the students reason out which crystal structure should be the most workable. Since FCC is both tightly packed and has many slip planes, it is the most workable.

Have the students fill in the following table:

Type of crystal structure	Closely-packed?	Many slip planes?	Workability
FCC	*Yes*	*Yes*	*Highest*
BCC	*No*	*Yes*	*Medium*
HCP	*Yes*	*No*	*Lowest*

Ask the students if there is a way to figure out if the packing and the slip planes have an equal effect on the workability or if one of the two factors has more.

Since BCC and HCP both have a "yes" and a "no" and HCP is the least workable, reasoning would dictate that the number of slip planes has more effect on the workability than how closely packed the atoms are.

Now ask the students to predict which familiar metals should have an FCC crystal structure. They can usually correctly name several such as gold, copper, aluminum, lead, etc...

Then compile a list of some common metals and their crystal shapes.

BCC	**FCC**	**HCP**	**Other**
chromium	aluminum	cobalt	tin
iron (<910 °C)	copper	magnesium	
tungsten	gold	titanium	
	iron (>910 °C)	zinc	
	lead		
	platinum		
	silver		

Iron appears in two different columns because it is allotropic. This concept will be further developed in the Iron Wire Demo. But the students should be able to grasp the idea that blacksmiths pound on a piece of iron when it is glowing red hot and stop when it loses its color since FCC is a more workable crystal structure than BCC.

I provide my students a copy of the Sargent-Welch periodic table. It has a tremendous amount of info for each element including crystal structure. It is a very useful tool for students of materials science.

This is a great place to demo the tin cry. Students love it. They may not be able to see the individual crystals move but they sure can hear their collective noise. IASCO is a great source of tin – a one pound bar is about $10.

A sheet of copper and a sheet of titanium are also useful for demonstrating the difference in the workability of an FCC metal and an HCP metal. Simply hold down one end of the metal against the edge of a table, push down on the other end and release. The copper is very workable and easy to bend and will not completely return to its original shape. The titanium takes more force to bend and will spring back to its original shape.

Models of Crystals Lab

Terms:

crystal:

unit cell:

slip plane:

Name and abbreviation of unit cells that will be constructed:

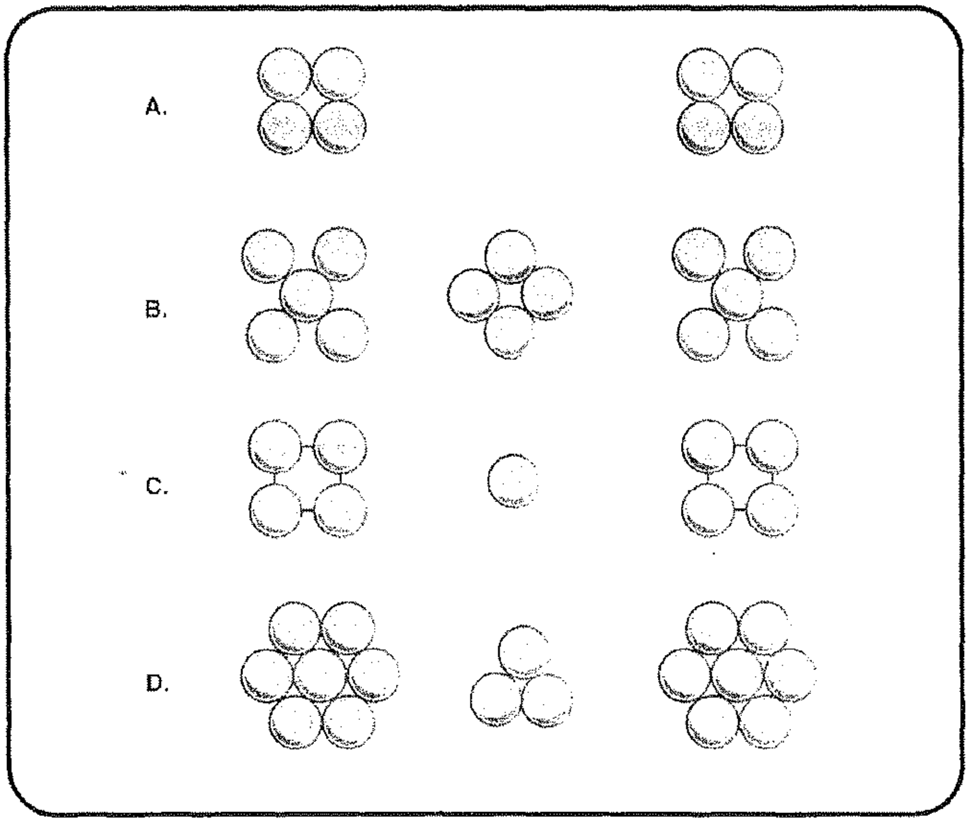
Brief Method:

Construct the crystal models one at a time as pictured "a" through "d" in the figure on the next page.

Journal the following for each model you build:

- sketch of unit cell
- label with name and abbreviation
- describe the packing and slip planes
    - examples: close, tight, loose, "gappiness", many or few slip planes

Before dismantling a model and building the next one, as a class, try to assemble the individual unit cells into a bigger crystal. The teacher will assist with this.



- Pay close attention to spacing and alignment.
- For example, the spheres in layer 1 of model C do not touch each other. The center sphere in model C should touch all the spheres of the 1st and 3rd layers but none of the other spheres should touch each other.
- When stacking the layers to build each model, be sure the orientation is the same as in the diagram.
- Use the fewest number of toothpicks possible.

Models of Crystals Lab

Terms:

crystal: *-an object with a regularly repeating arrangement of its atoms*
-it often has external plane faces

unit cell: *-the simplest and smallest arrangement of atoms that can be repeated to form a particular crystal*

slip plane: *-a surface along which layers of atoms can slide*

Name and abbreviation of unit cells that will be constructed:

Simple cubic
Body-centered cubic - BCC
Face-centered cubic - FCC
Hexagonal close packed - HCP

Brief Method:

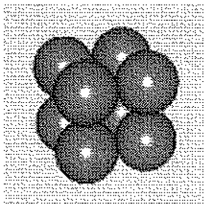
We are going to make models of 4 different crystals using toothpicks and Styrofoam balls.

Construct the crystal models one at a time as pictured "a" through "d" in the figure on the next page.

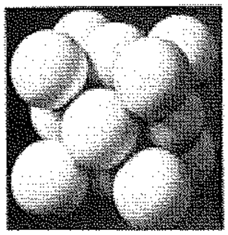
Journal the following for each model you build:
- sketch of unit cell
- label with name and abbreviation
- describe the packing and slip planes
    - examples: close, tight, loose, "gappiness", many or few slip planes
    - (Hint: cubic structures have many slip planes)

Before dismantling a model and building the next one, as a class, try to assemble the individual unit cells into a bigger crystal. The teacher will assist with this.

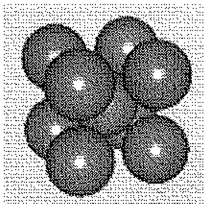
a. simple cubic
    -loosely packed, lots of "gappiness"
    -lots of slip planes



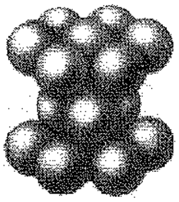
b. face-centered cubic
    -tightly packed, much less "gappiness"
    -lots of slip planes



c. body-centered cubic
    -loosely packed, more "gappiness"
    -lots of slip planes



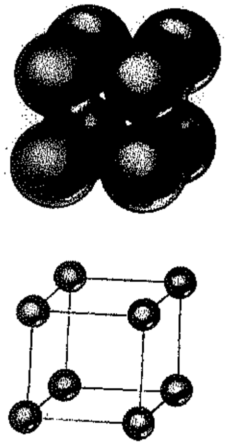
d. hexagonal close-packed
    -tightly packed, not much "gappiness"
    -few slip planes



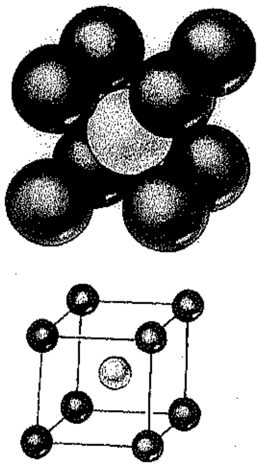
Type of crystal structure	Closely packed?	Many slip planes?	Workability
FCC	*Yes*	*Yes*	*Highest*
BCC	*No*	*Yes*	*Medium*
HCP	*Yes*	*No*	*Lowest*

BCC	FCC	HCP	Other
chromium	aluminum	cobalt	manganese
iron (<910 °C)	calcium	magnesium	tin
molybdenum	copper	titanium	
sodium	gold	zinc	
tungsten	iron (>910 °C)		
	lead		
	nickel		
	platinum		
	silver		

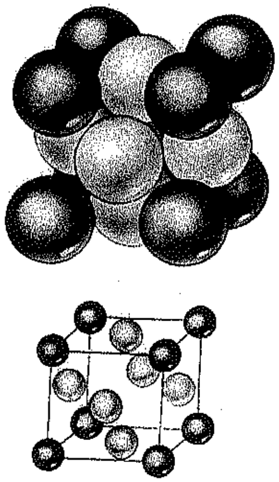
Cubic Unit Cells



In a **simple cubic** unit cell the atoms or ions are at the corners of an imaginary cube.



In a **body-centered cubic** unit cell the atoms or ions are at the corners and in the center of an imaginary cube.



In a **face-centered cubic** unit cell the atoms or ions are also in the center of each face of the imaginary cube.

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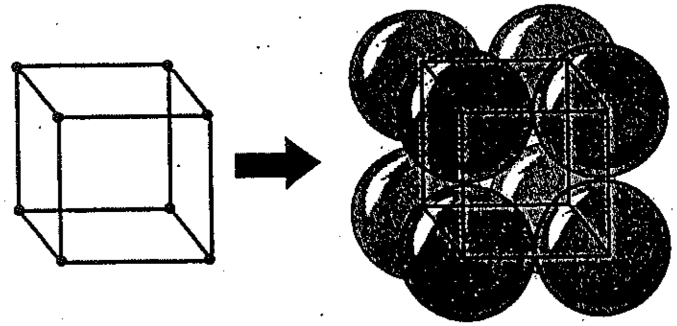
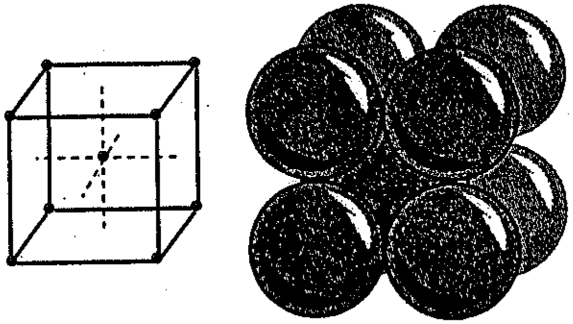
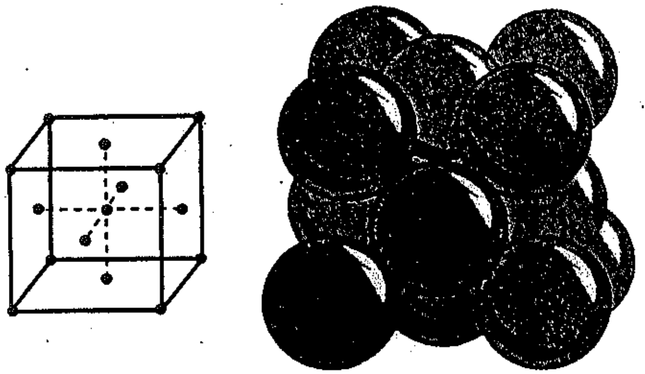


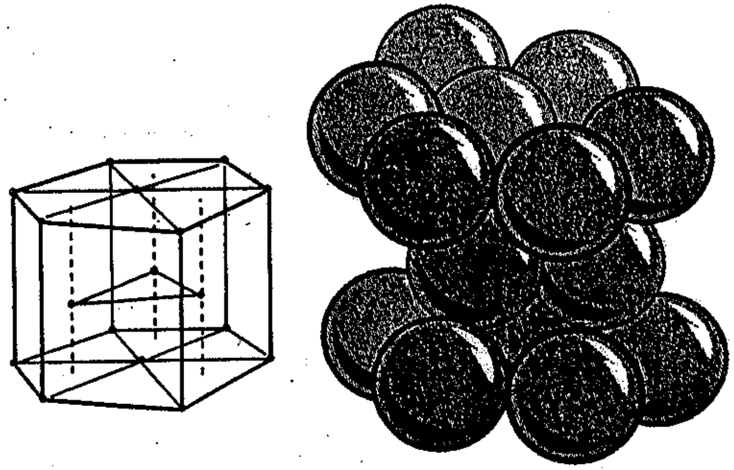
A.



B.



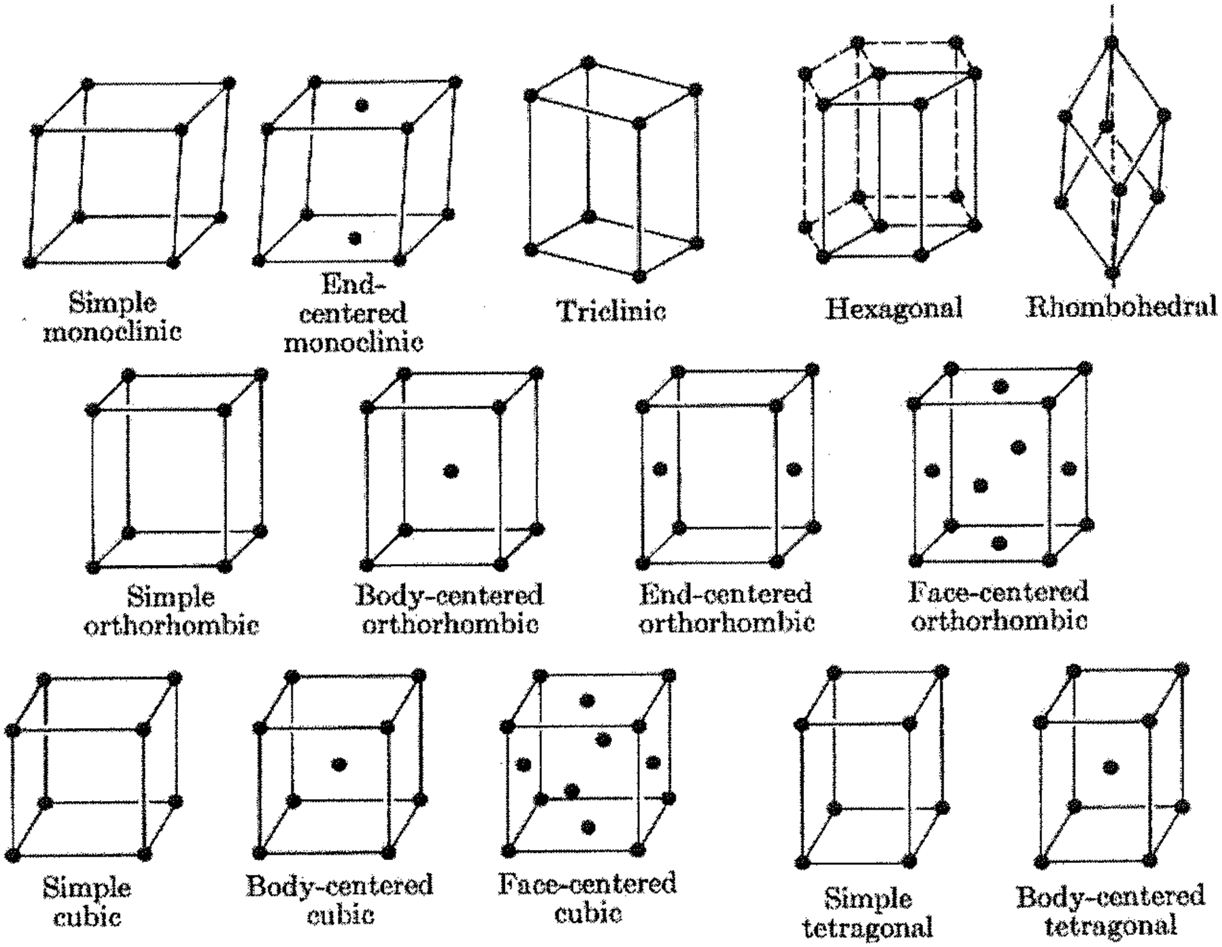
C.



D.

Structure

Crystal Structures



71-S

DEMONSTRATION SO-3 Iron Wire

Purpose

This demonstration is designed to show the student the following:

A. Abrupt solid-state phase changes can occur in allotropic materials.

B. Thermal expansion occurs when metals are heated.

C. Light is emitted when metals are heated hot enough.

D. Iron tends to oxidize more rapidly when it is heated.

E. Magnetic properties are lost when iron is heated beyond a certain temperature called the Curie temperature.

Reliability

Excellent.

Time Required

15 - 20 minutes.

Recommended Placement

Do after Experiment 3-2: Formation of Solids.

Material and Equipment

- Iron Wire, #24
- Variac, 110 V, 15 Amp
- Power Cord, Modified
- Ring Stands, 2
- Buret Clamps, 2
- Mass, 50-200 g
- Magnet, Small
- "C" Clamps
- Meter Stick
- Thermal Wire Adapters, 2

Safety Concerns

1. The wire gets extremely hot. Treat it with care. It also becomes brittle with repeated use and can break unexpectedly.
2. The amount of electrical current is large enough to produce a substantial shock. Care should be taken not to touch the wire when the electricity is turned on.
3. When the magnet drops from the wire it is very hot. You should have a fire resistant surface for it to fall onto. Also, let it cool before picking it up.

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Procedure

☐ 1. Use the "C" clamps or bench clamps to firmly mount the two ring stands on nonconductive tables about ten feet apart. Place clamps on the stands and use the thermal wire adapters to attach the wire. Adjust the distance between the ring stands to make the wire fairly taut. You do not want to put any tension on the wire.

☐ 2. Hang the weight on the wire in the center between the stands.

☐ 3. Attach a small magnet about half way between the weight and the end of the wire. The placement is not really critical.

☐ 4. Attach the clamped ends of the electrical leads to each end of the iron wire. Do not attach the electrical leads directly to the ring stand.

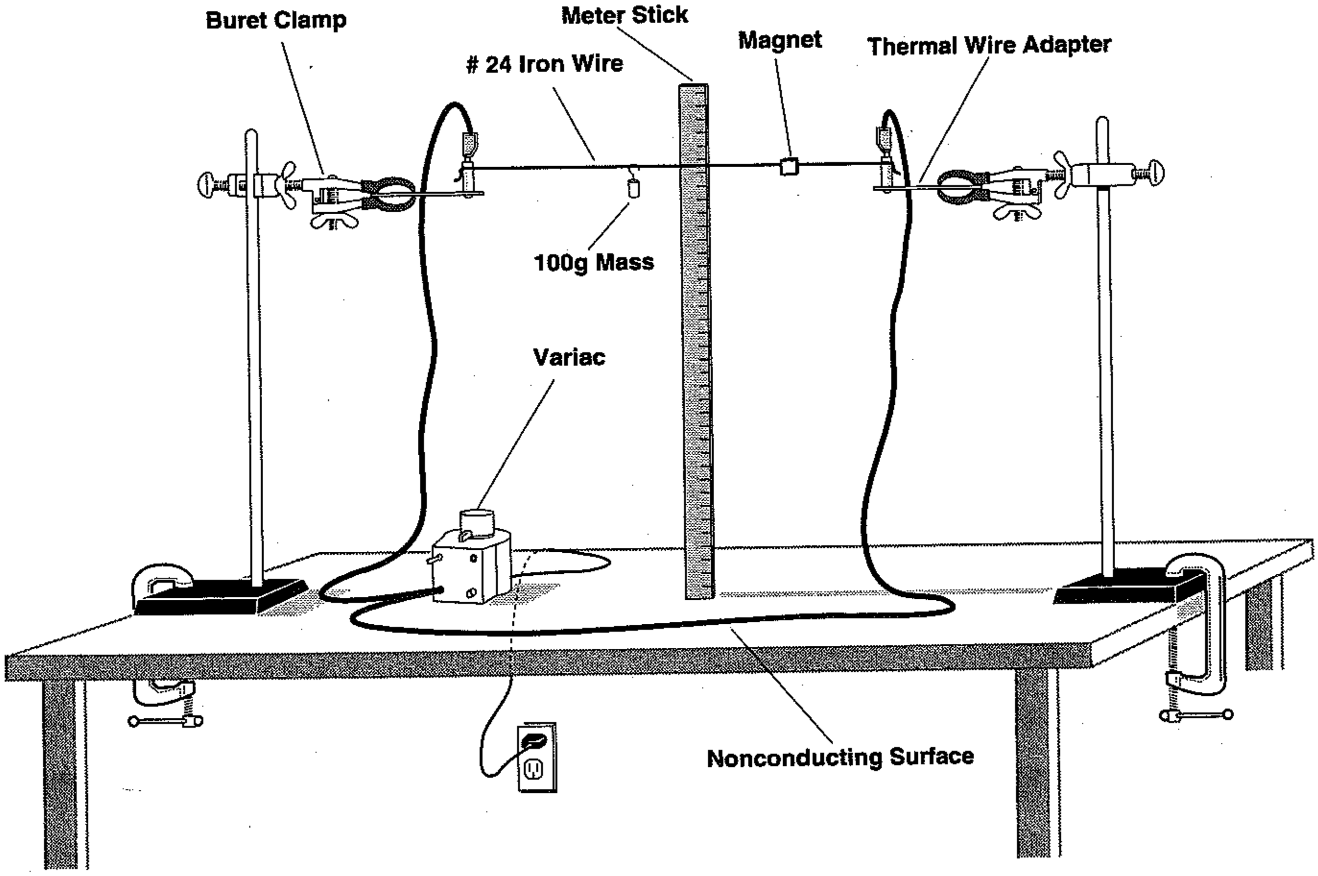

Figure 2
Iron wire demonstration setup

☐ 5. Have the students list observations they make during the next few minutes in their journals.

☐ 6. Use the variac to slowly increase the voltage to the wire until the heat from the electrical resistance causes the wire to expand noticeably. Reduce the voltage back to zero and discuss thermal expansion.

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☐ 7. Dim the lights in the room.

☐ 8. Use the variac to slowly increase the voltage to the wire until the wire glows bright orange. The magnet should drop off during this interval.

☐ 9. Rapidly reduce the voltage while carefully observing the weight.

☐ 10. Repeat steps 8 and 9. This time put a meter stick vertically right behind the weight.

☐ 11. Have the students share their observations. Discuss these. Then repeat steps 8 and 9 once again.

Instructor Tips

1. If you have new wire, it usually comes in a coil and may have kinks in it. Running electricity through the wire will remove the kinks and make the wire sag. You may need to adjust the ring stands after doing this.
2. Frequently, the wire that is purchased will have a protective coating of oil. The first time it is heated the wire will "smoke" as this oil is vaporized.
3. It is strongly recommended that you do a trial run on this demonstration before presenting it.
4. As the wire is used, it will gradually oxidize. This causes the conductive portion of the wire to become thinner. Under these circumstances, the thinner portions of the wire will get hotter and radiate brighter light. The wire is most likely to break at these thinner points.
5. Use an inexpensive magnet. Some ceramic magnets are damaged by the heat.
6. Both the magnet and the mass will act as heat sinks. The wire will not be as hot where they are touching.
7. Careful observation is needed to see the phase change in the wire. The iron wire changes from BCC to FCC as it is heated and passes the 910 °C point. This is virtually impossible to detect. Upon cooling, the reverse occurs. Since FCC is more densely packed, the wire actually expands (rather than continues to contract) as it cools through this point. This is detected by seeing the attached weight dip.
8. The temperature at which iron loses its ferromagnetism is about 770 °C. This is called the Curie temperature. Because the magnet acts as a heat sink, most of the wire will be much hotter before the magnet drops.
9. The longer the wire, the more apparent the phase change.

10. Students frequently have difficulty understanding this demonstration because they do not realize that both heat and a solid state phase change are affecting the length. Therefore, be sure to do step 6 to show and discuss thermal expansion of the wire.

11. A #24 iron wire requires about 100 volts to provide the required current of approximately ten amps to heat the wire sufficiently. A larger gauge wire would require less voltage but more current. A shorter wire requires less voltage, but the phase change is less noticeable.

This write-up was taken from:
Material Science
Solids, Metals, Ceramics, Polymers, Composites
Published by Energy Concepts, Inc.
By Len Booth
ISBN: 1-55756-163-X, 1-55756-164-8, 1-55756-165-6, 1-55756-166-4, 1-55756-167-2

The Iron Wire Demo is an example of a solid state phase change. Examples of other labs and demos that show a solid state phase change are:

- Sulfur lab
- Nitinol demo
- Aluminum/Zinc alloy lab

Summary of observations made by students:

- Heat makes metals expand - thermal expansion
- Metals con get hot enough to give off light - incandescence
- Heat increases the rate of oxidation (rusting)
- Ferrous metals lose magnetism at a certain temperature - Curie temperature is ~770°C
- Solid state phase change occurred at 910°C. This was observed as a "dip' (bounce) by the wire as it was contracting while cooling.

Iron at room temperature is BCC - more spread out
Iron above 910°C is FCC - closer packed
Dip was caused by changing from FCC to BCC at 910°C

After running the demo a couple of times, turn the power off (unplug the variac) and

- use steel wool to "clean" an inch of the wire **OR**
- have a couple of volunteers bend the wire back and forth a few times.

Turn the power back on and redo the demo. The areas on the wire that were cleaned or bent will be visibly brighter. Ask the students what is causing this phenomenon. The rate of oxidation is greatly increased due to the heating of the wire. The oxidation is a ceramic material which insulates the wire. Cleaning or bending the wire removes the oxidation which is brittle. This allows the wire to glow brighter (hotter) the next time the demo is performed.

After the wire cools, cut it up into pieces approximately 4 to 5 inches long and give one to each student. Have them bend it back and forth over a piece of white paper. The oxidation that formed on the outside of the wire is a ceramic material and therefore very brittle and it will readily flake off exposing malleable metal underneath.

This demonstration can also be found in the Battelle MS&T handbook (starting on page 4.22) and the MAST modules (starting on page 41 in the metals unit).

Table 4.1. Crystal Structures of Iron

Iron Phase	Temp. Range, °C	Crystal Structure
α- Fe (ferrite)	<~912	Body-centered cubic (BBC) less dense, ferromagnetic at low temperature, but loses ferromagnetism on heating
	770	Temperature at which Fe loses its ferromagnetism = "Curie temperature"
γ - Fe (austenite)	~912 - 1394	Face-centered cubic (FCC) more dense, paramagnetic
δ - Fe	1394 - ~1538	Body-centered cubic (BCC) less dense, paramagnetic

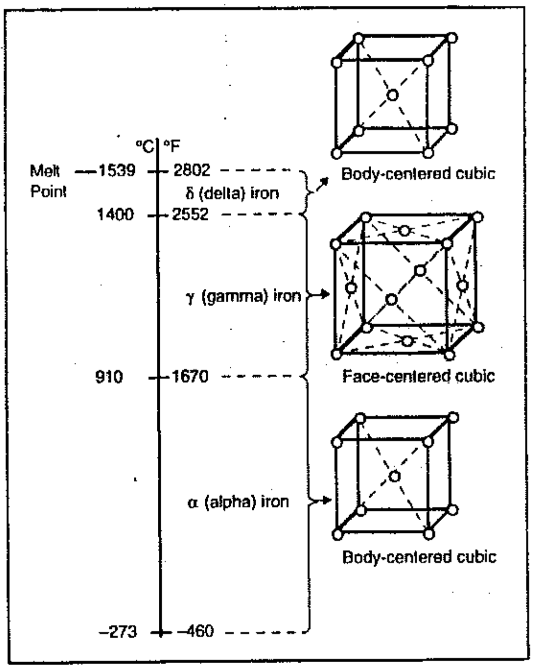


Figure 4.8. Polymorphism of Iron (From Guy, A. *Elements of Physical Metallurgy,* Addison-Wesley Co., 1960, pg. 135.)

Crystal Defects and Imperfections

-impurities and disruptions in the pattern of atoms
-affect many physical properties

3 Main Types of Defects

Ask the students what comes to mind when you hear the word "defect". They usually say something "bad" or "unwanted" or "negative". When discussing that point defects can be used to make alloys point out that we create "defects" on purpose because they result in useful changes in properties. Reinforce the idea that defects can lead to positive changes when discussing that line defects can increase the hardness or strength of metals.

1. **Point Defects** – single atom defects
   Use overhead to illustrate the types of point defects – have students draw them in their journal.

   a. **Vacancy** – atom is missing (void)
      -move around in crystal by diffusion
      -*use BB board to illustrate*

   b. **Interstitial** – extra atoms inserted in the gaps between the regular atoms
      -used in making alloys – ex. steel

   c. **Substitutional** – replace some of the original atoms with different atoms
      -used in making alloys

2. **Line Defects – dislocations**
   -regions in crystals where atoms are not perfectly aligned - *use overheads to illustrate*
   -can move
   -a small number make a metal more workable – a large number make a metal harder to work
   -when working a metal, dislocations can get "jammed" or "pinned". This can make the metal harder = work-hardening

3. **Interfacial Defects**
   -grain boundaries
   -3-D
   -affected by size of grains

"Working a metal"
- changing its shape while a solid
    - Ex. - pounding
    - bending
    - stretching
    - rolling

Copper Wire Activity

Work-hardening and Heat-treating

Students bend ~ 6" - 8" piece of copper wire in the middle feeling the strength it takes to bend it. The wire needs to be fairly thick-gauged. Then they try to bend it back exactly the way it was - straight. Once again noticing the strength it takes. They do this several times. Students should notice that it is practically impossible to bend the wire back to its original shape - perfectly straight. It will appear to have small "kinks" or "bumps" in it. The wire will want to bend in a location to the side of the original bend. The students should also notice that it takes an increasing amount of strength to bend the wire. This is called "work-hardening".

Have the students hammer one end of the wire. Then compare the strength it takes to bend the hammered end versus the unhammered end.

Ask the students if they can hypothesize why the wire changes - what is going on inside.

They are increasing the number of dislocations when they "work" the metal - bending or hammering. The dislocations are also attempting to move through the metal. The dislocations get "pinned" or "jammed" when they meet up coming from different directions. This causes an increase in the strength or hardness of the metal. It decreases the workability and can make it more brittle.

Now have the students heat-treat the copper by holding it in the flame of a propane torch or Bunsen burner (using pliers to hold the metal). Have them heat the hammered end holding the metal vertically in the flame so that part of the middle where it was bent will also be heat-treated. The wire should be heated until it is red hot. The wire can then be cooled - either slowly in air or by quenching it in a can of water.

Have students bend the heat-treated end of the wire and compare it to the feel of the work-hardened wire. It should be noticeably softer and more workable. If they continue to bend it, it will once again work-harden and they will feel the difference in stiffness.

Ask the students to explain how or why the heat changed the metal.

The heat gave the atoms enough mobility to re-grow the crystals in the metal. Dislocations were eliminated (decreased) and bigger crystals with fewer grain boundaries may form. This results in a softer, more workable metal.

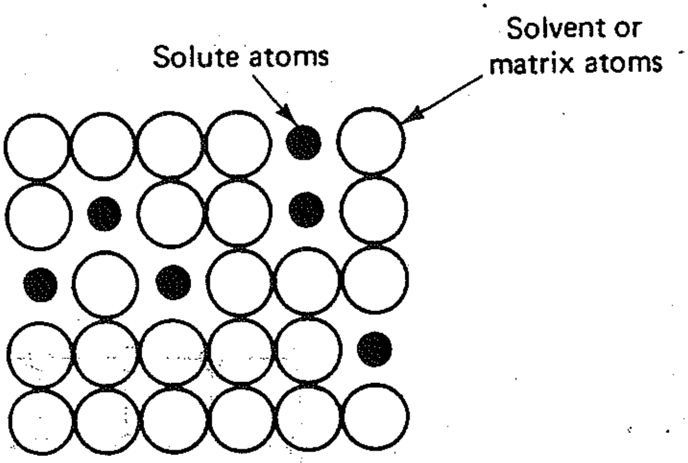


Figure 3-44 Substitutional solid solution.

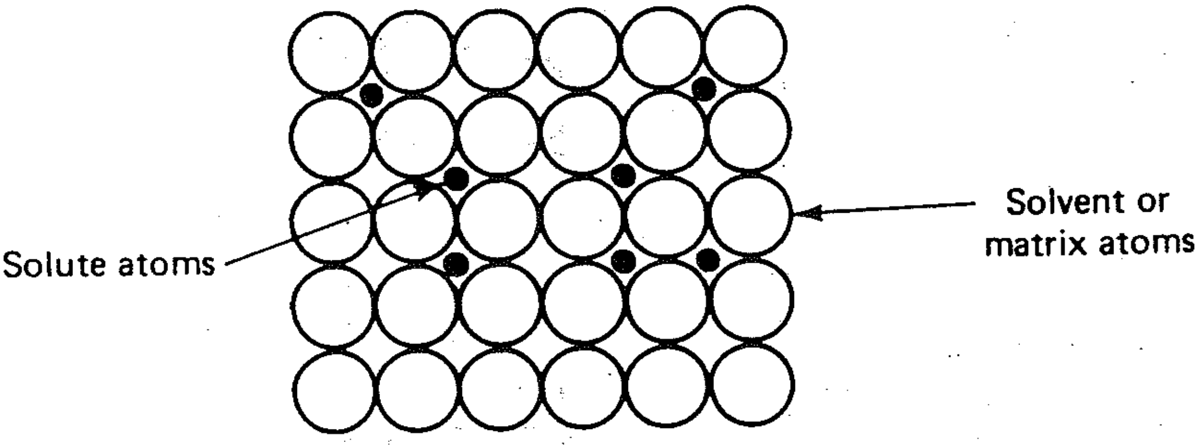


Figure 3-45 Interstitial solid solution.

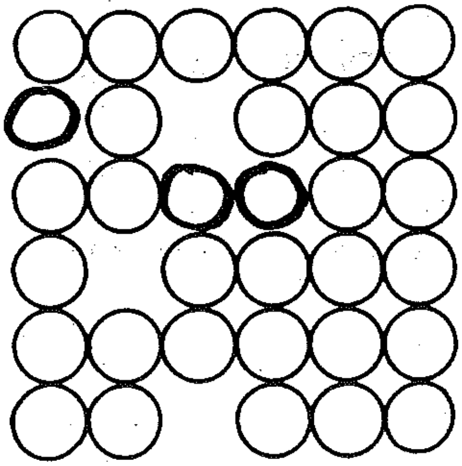


Figure 3-46 Point defects (vacancies).

Jacobs & Kilduff,
ENGINEERING MATERIALS TECHNOLOGY, 3/e

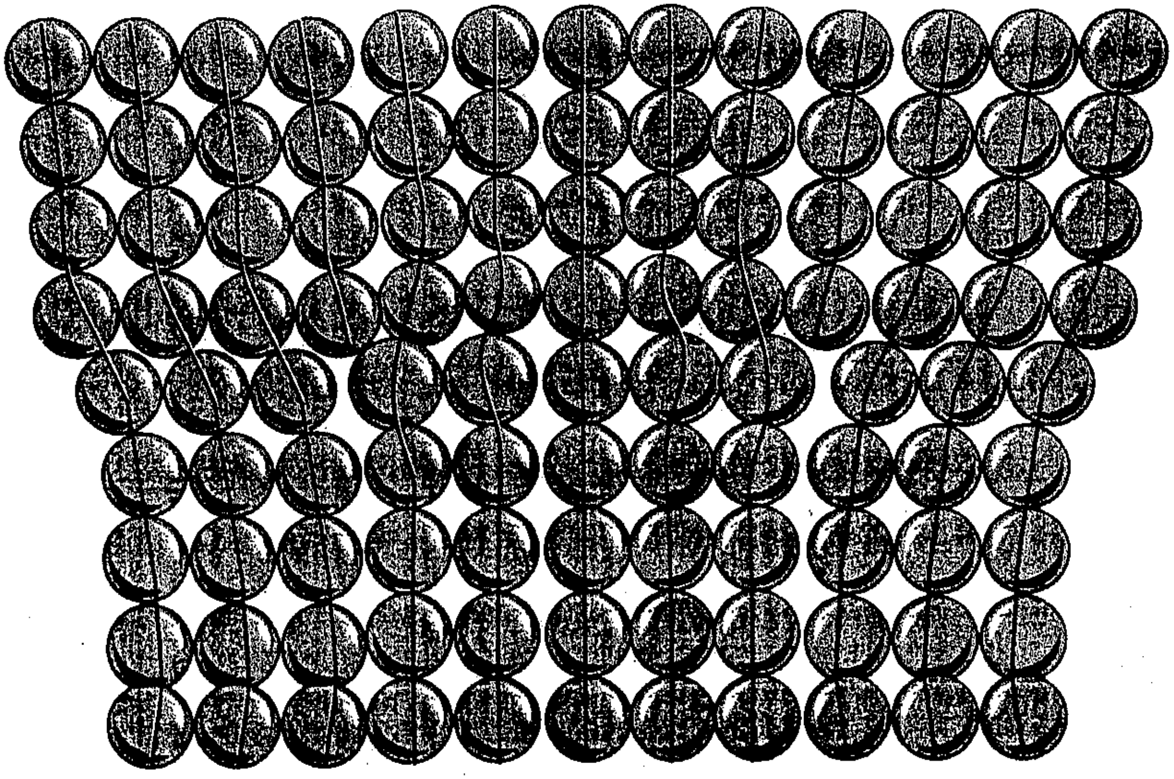
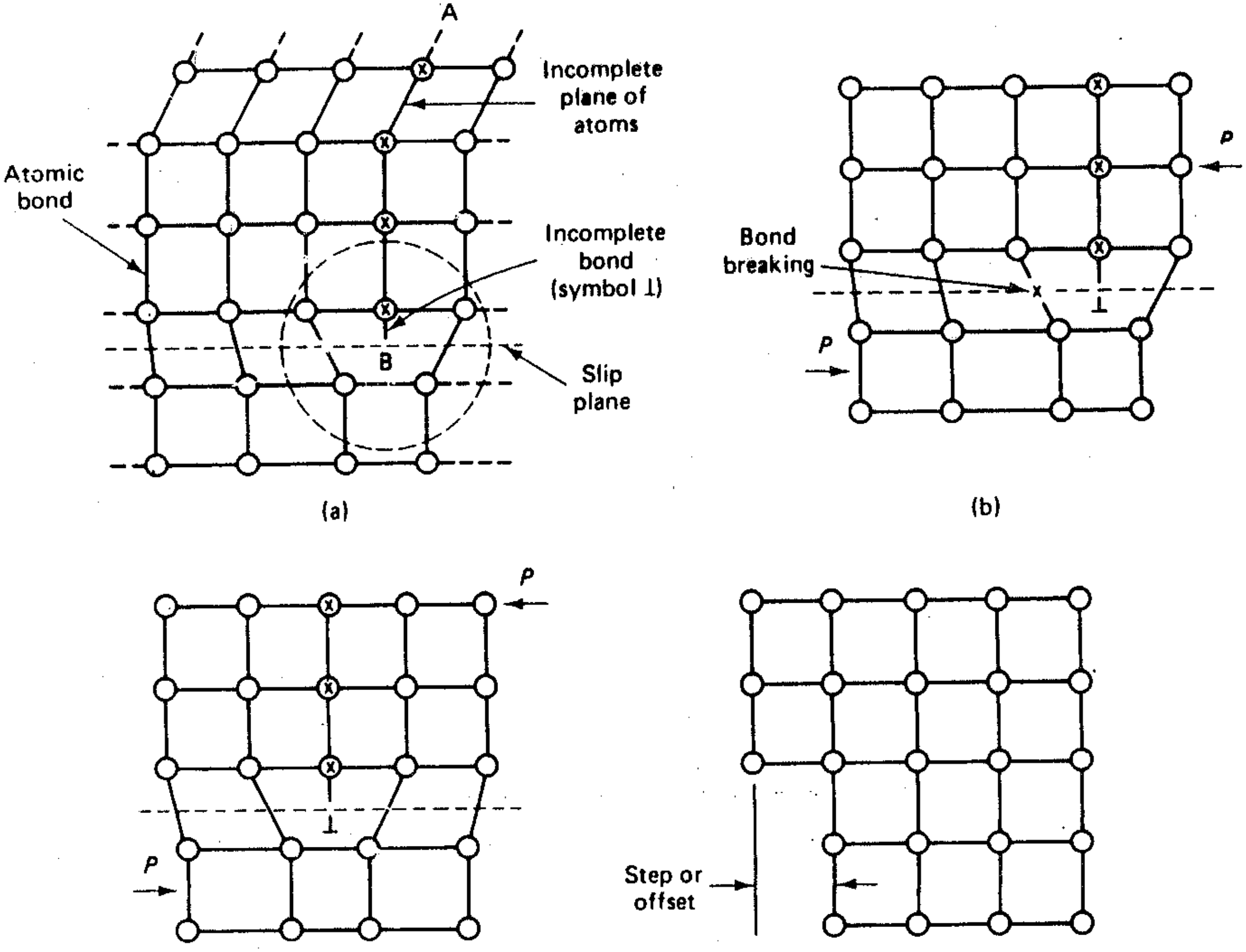


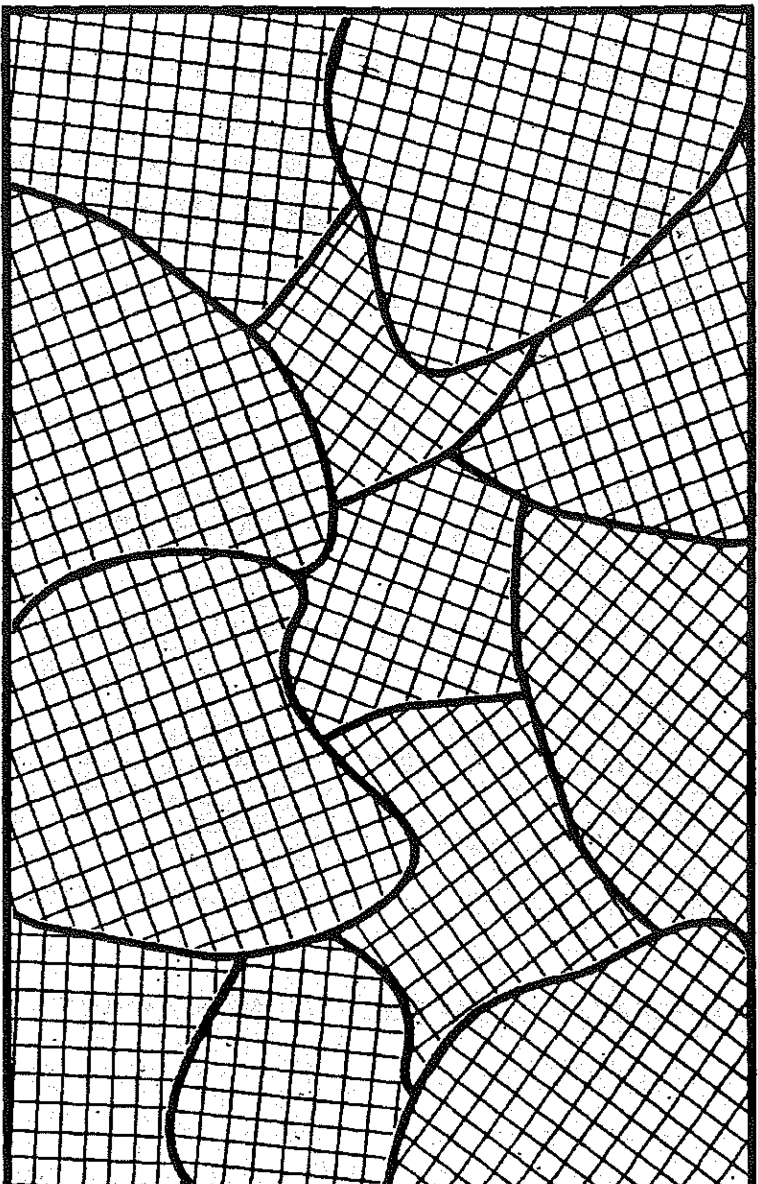
Figure 3
Examples of line defects in a crystal



(a) (b) (c) (d)

Edge dislocation movement (slip).

S-18



82-S

Heat-Treating Steel

Materials:

- 4 bobby pins
- 4 large paperclips
- Heat source - Bunsen burner or propane torch
- Container of water for quenching
- Tongs or pliers

Procedure:

1. Set aside one bobby pin and one paperclip for comparison. (Control)

2. Heat the loop of one bobby pin and a loop of one paperclip red hot and slowly lift out of flame. Slow cool. (Anneal)

3. Heat 2 of each red hot and quench in ice water. Quick cool. (Quench)

4. Take one of each from step #3 and heat again in the top of the flame for a few seconds. Do **NOT** let it get red hot. (Temper)

5. Make a data table for comparison of properties when the heat-treated area is bent.

6. Test the bobby pins one at a time by slowly pulling the ends apart. Record observations.

7. Test the paperclips one at a time by pulling the heat-treated loop open. Record observations.

8. Propose reasons for any differences in results.

Notes:

- Don't heat beyond red hot – too much heat and you start burning out the carbon.
- Bobby pins are high carbon steel and paper clips are low carbon steel.
- This lab is usually done after the iron wire demo so that students have been exposed to the idea of allotropes and solid state phase changes in regards to iron.
- This lab is also usually done after the work-hardening and heat-treating of copper lab.

Typical Results:

	control	anneal	quench	temper
bobby pin	"normal"	softer, easier to bend, lost the springiness	snaps in two, brittle	feels much like the control
paperclip	"normal"	softer, easier to bend	varies depending on the paperclip, sometimes harder, sometimes more like the control, but is NOT brittle, doesn't break	doesn't feel much different than the other paperclips

Heat Treating Iron

Name: ______________________
Date: ___________ **Period:** _____

Objective: examine the properties of iron as it encounters a variety of heating and cooling techniques

Materials:

Iron wire (4 pieces)
Bunsen burner
Tweezers or pliers
Cold water (in container or from faucet)
pencil or pen
fine grit sandpaper

Procedures:

1. Take your piece of iron wire and cut it into 4 equal pieces, each about 4.5 inches long. Using a pencil or pen to wrap the wire around, form each piece into a spring. Make each spring the same length with the same number of turns.
2. Test the springiness of one of the wires. Does it return to its original shape after being compressed? After several compressions, does it return to the original shape? Record your observations in the table below. Be specific. Set this piece aside for comparison later.
3. Take a second spring and heat this to red hot in a Bunsen burner flame, then let cool slowly to room temperature. Test the springiness of this piece in the same manner that you did the piece in #1 above. Record your observations in the table below and set this piece aside for later comparison.
4. Take a third spring and heat this spring in a Bunsen burner until red hot and then quickly place the spring in cold water. This is called "quenching". The result is that you freeze the atoms of the material in whatever position they were in at the hot temperature. Test the springiness of this piece of wire just like you did in the previous examples. Record your observations. Place this piece aside for later comparisons.
5. Take the fourth spring and heat this spring in a Bunsen burner until red hot and then quench it in cold water. Clean off the oxide coating the surface of the wire. Using a fine grit sandpaper. Carefully reheat the spring in a Bunsen burner flame until the metal just shows a bluish colored surface. **DO NOT GET THE SPRING RED HOT.** Slowly move the spring out of the flame making sure not to over heat the sample and loose the blue coloring. Test the springiness of this sample as you did in the previous steps. Record your observations. Place this spring with the others to compare later.

Data Table:

Spring #	Observations	
1	Return to original shape after 1 compression?	After several compressions?
2		
3		
4		

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Analysis:
Answer the following question in complete sentences.

1. Which spring showed the most springiness?

2. Which spring returned to its original shape after being compressed several times?

3. Which spring showed the least springiness?

4. In your opinion, which spring is the toughest? Explain your answer using observations from the experiment.

5. Which spring would be the most expensive? Explain your answer.

6. How do the properties of iron compare with those of copper, before and after heating?
Before:

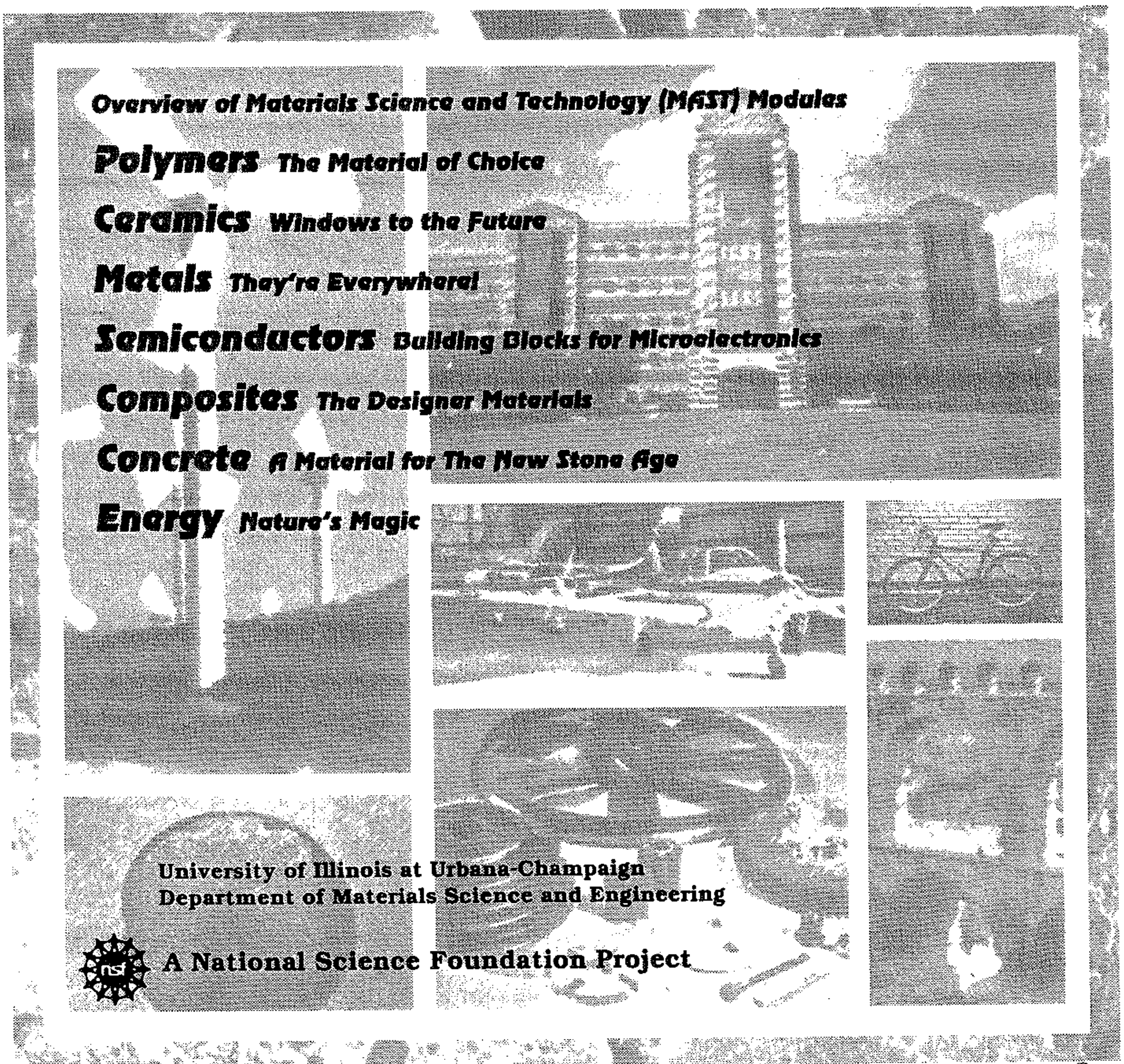
After:

7. Why does one piece of iron show more springiness than another?

8. Pull the ends of each spring to straighten them out. Which one(s) have the most memory?
(this means, which ones "remember" the spring shape and attempt to remain in that form?)

1996
A MAST MODULE

Materials Science and Technology



Overview of Materials Science and Technology (MAST) Modules

Polymers The Material of Choice

Ceramics Windows to the Future

Metals They're Everywhere!

Semiconductors Building Blocks for Microelectronics

Composites The Designer Materials

Concrete A Material for The New Stone Age

Energy Nature's Magic

University of Illinois at Urbana-Champaign
Department of Materials Science and Engineering

A National Science Foundation Project

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Overview of Materials Science and Technology (MAST) Modules

Introduction

The MAST modules are intended to introduce both teachers and students to the exciting world of materials science and technology. There are eight modules (including this overview), covering ceramics, metals, polymers, semiconductors, composites, concrete, and energy. This module provides a brief overview of the modules, defines the different classes of materials, and discusses materials processing and selection.

The modules can be used in part or in whole to supplement physics, chemistry, general science and tech prep classes. **Teachers are encouraged to photocopy any part of the modules for their classroom use.**

Coverage:

Every module includes the following items:

- Introduction
- Initial discussion questions
- Historical overview and future trends
- Scientific Principles (this is for the teacher and advanced students)
  Summary of Scientific Principles (this is for the students)
- References and Resource List
- Laboratory demonstrations and experiments, including:
    - Master equipment grid
    - Student lab hand-outs
    - Teachers guide
- Assessment activities
- Glossary

Descriptions of individual modules:

This section gives a brief description of what topics are covered in each module.

Metals

Structure of Metals:	Describes the crystal structure of metals.
Mechanical Properties:	Discusses the typical mechanical properties of metals.
Processing:	Describes how metals are made into useful products.
Alloys:	Describes what an alloy is.
Corrosion:	Discusses the conditions and chemistry of corrosion.
Metal Ores:	Describes how metals are removed from their ore.

Ceramics

Atomic Bonding:	Discusses the way ceramics are bonded.
Classification:	Discusses the classification of ceramics.
Thermal Properties:	Describes the thermal properties.
Optical Properties:	Describes different optical properties.

Mechanical Properties:	Discusses brittleness, stress, and strain.
Electrical Properties:	Discusses dielectric and superconductivity.
Ceramic Processing:	Describes different methods to form products.

Polymers

Polymerization Reactions:	Describes the different reactions used to make polymers.
Polymer Chemical Structure:	Discusses different chemical configurations.
Polymer Physical Structure:	Talks about the crystalline structure of polymers.
Members of Polymers:	Defines thermosets and thermoplastics.
Polymer Processing:	Depicts the many processing techniques.
Recycling:	Describes recycling and why it is important.

Semiconductors

Conductors, Insulators, and Semiconductors:	Explains the electrical characteristics of materals.
Application and Research:	Discusses how p-n junctions work.
Properties and Processing:	Describes the processing and properties of semiconductors.

Composites

Structure and Composition:	What they are made of and how the components are arranged.
Matrices:	Describes the functions of the matrix.
Reinforcements:	Talks about the different forms of reinforcements.
Properties:	Tells of the different properties obtainable with composites.
Microstructure:	Details the interface between the matrix and reinforcement phase.
Fabrication:	Talks about how composites are made.

Concrete:

What is This Stuff?:	Defines concrete and cement.
Properties of Concrete:	Brief properties discussion.
Hydration of Cement:	Reviews the chemical changes of concrete.
Strength of Concrete:	Explains how different things determine the overall strength of concrete.

Energy

Basic Energy Principles:	Includes the laws of thermodynamics, energy storage, and conversion.
Fossil Fuels:	Defines what they are and talks about the pros and cons of them.
Renewable Energy Sources:	Gives several examples and talks about their pros and cons.
Nuclear Energy:	Describes radiation, fission, waste, and safety.

Experiment 3

Processing Metals

Making Metals Strong

Objective:

The objective of this lab is to demonstrate the effect of cold-working (strain-hardening) and annealing on the ability of wires of the same metal to support a load.

Review of Scientific Principles:

Because plastic deformation results from the movement of dislocations, metals can be strengthened by preventing this motion. When a metal is deformed, new dislocations are produced. As dislocations are generated and move, the metal can be bent or shaped without cracking. As the number of dislocations in the crystal increases, they will get tangled or pinned and will not be able to move. This will strengthen the metal, making it harder to deform. When this is done at or near room temperature, the process is known as **cold-working**. When cold-worked metals are annealed (heated gently), new grains form from the cold worked structure and grow until they replace it with new, soft crystals. Steels (alloys of iron with up to 1% carbon) can also be hardened by **heating** and **quenching**. At high temperatures (red hot), iron has an FCC structure which can dissolve carbon. At low temperature, the iron changes to BCC which cannot dissolve carbon, so it precipitates as an iron-carbon compound. If quenched, this compound does not have time to form, the carbon is trapped and distorts the BCC crystal structure to create a new, hard and brittle structure called **Martensite**. If Martensite is gently heated, the carbon can precipitate giving a strong, tough structure.

Applications:

The properties of metals can be altered by processing. Since the properties of a material are dependent upon its structure on the atomic level, altering its structure should alter its properties. Common treatments include cold-working and heat treating.

Time:

50 minutes, part I; 50 minutes, part II; 30 minutes, part III

Materials and Supplies:

Hammer
Bunsen burner and tongs
16 or 18 gauge solid wire of copper (or aluminum)
16 or 18 gauge solid wire of other metals
high carbon steel wire or bobby pins
Pair of 3" C-clamps (or other size if 3" not available)
Wire gauze

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General Safety Guidelines:

- Take precautions to avoid burns when using the Bunsen burner to heat the metal.
- Make sure all fingers are out of the way when hammering the wires.

Procedure (Part I):

1. Hammer one of the pieces of copper wire until it is about half its original thickness.
2. Bend it and the other piece of wire back and forth several times. Observe.
3. Heat the flattened (work hardened) piece of copper in the burner flame until red hot.
4. Let it cool slowly on the wire gauze.
5. Label and save for experiment 4.
6. Repeat procedures 1 - 5 for the other wires.
7. Label and save the wires for later.

Procedure (Part II):

1. Obtain 7 samples each of high carbon steel wire (bobby-pins) and other metals.
2. Bend one of the wires until it breaks. Count and record the number of bends needed to break the wire.
3. Heat the second and third steel wires in the middle until they are red hot. Let them cool slowly in air.
4. When the wires are cool, bend one of them back and forth as before. Count and record the number of bends needed to break this heat treated wire. Label and save the other wire for later.
5. Fill the beaker with cold water.
6. Heat the fourth and fifth wires in the flame until they are red hot and immediately plunge it into the water in the beaker.

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7. When the wires are cool, bend one of them as before and record the number of bends needed to break it. Label and save the other.

8. Heat and quench the last two wires as in procedure 6. Heat them again but cool them slowly in air. This process is called tempering. As before, note the properties of the tempered wire. Label and save one.

9. Repeat steps 1 - 8 for the other metal wires.

10. Save the extra wires for Experiment 4.

Procedure (Part III):

1. Using a pair of 3" C-clamps attached to the ends of the wire stretch a section of annealed copper wire by 5% and another by 10%.

2. Repeat for the other metal wires.

3. Save these wires also for Experiment 4.

Questions:

1. What is the hammering in Part I, procedure 1 called?

2. In Part I, procedure 2, what did you observe about the ease of bending for each wire? Why were they different?

3. In Part II, procedure 2, how many bends were required to break the wire? Did it break easily? Briefly describe the mechanical properties for this sample.

4. What term describes the heat treating method used in Part II, procedure 3 (heating, slow cooling)?

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5. In Part II, procedure 4, how many bends were required to break the wire? Did it break easily? Briefly describe the mechanical properties for this sample.

6. What is cooling the hot metal rapidly as in Part II, procedure 6 called?

7. In Part II, procedure 7, how many bends were required to break the wire? Did it break easily? Briefly describe the mechanical properties for this sample.

8. In Part II, procedure 8, what were the properties of the tempered wire?

- You might have good success in stretching the wire if you wrap the ends of the wire around the treads of the C-clamp and then tighten the clamp on the ends of the wire.
- A convenient way to stretch the right amount is to mark a 10 cm section of wire with a dark colored marker. Then you can easily measure the amount of stretch between the marks (1 cm increase = 10%). Make sure the students understand that this is another way to cold-work metals.

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Processing Metals

- Processing metals with heat followed by quenching and cold-working should harden them. However, strong heating and quenching will only affect steel. Some aluminum is precipitate hardened with small amounts of copper. Heating these alloys strongly will soften them by causing the copper to form large precipitate particles which have little hardening effect. Most aluminum wire, however, is soft.

Answers to Questions:

1. Cold-working
2. The hammered wire was harder to bend, but broke more easily. The hammering produced many dislocations which became tangled, inhibiting the sliding of planes of atoms.
3. Answers will vary. The unworked wires should be easier to bend, and should bend more times before breaking.
4. Annealing.
5. Annealing the wires should soften the metal allowing it to bend more easily and more times before breaking.
6. Quenching.
7. The quenched wires whould be harder and bend fewer times before breaking. Briefly describe the mechanical properties for this sample.
8. The tempered wire should bend more times than the quenched wire did before breaking.

Experiment 4

Tensile Strength Test for Various Metals

Stretching Wires

Objective:

The objective of this experiment is to demonstrate the elastic and plastic properties of metals.

Time:

50 minutes

Review of Scientific Principles:

Wires of the same gauge, but made of different metals typically support different loads (masses) before going through the point at which they change from being elastic to being plastic. Elastic deformation is recoverable after the load is removed. Plastic deformation is not recoverable.

Applications:

In order to use metals in particular applications, it is sometimes necessary to know their tensile strength. To avoid failure, the right metal must be used.

Materials and Supplies:

15 to 20 cm long pieces of 16 or 18 gauge wire of copper, aluminum, steel, etc.
wires saved from experiment 3
ring stand
adjustable single-burette clamp
meter stick
small paper cup (a 1-oz paper cup works well)
variable masses (lead shot or small ring-washers)

Procedure:

1. Clamp the solid copper wire in the clamp and attach the small cup to the end of the metal wire. See diagram of setup.
2. Adjust the wire so it extends horizontally about 8 to 10 cm beyond the edge of the clamp.
3. Measure the height of the end of the wire above the surface of the work area. This height, h_o, will be your reference height.
4. Carefully place 3 small washers (approximately 3 g) into the cup and again measure the height of the end of the metal wire above the surface of the work area. Record this mass and the new height.
5. Using your hand, gently support the cup and show the students how to check to see that the wire returns to approximately its original height, h_o.

6. Continue increasing the mass in the cup by 3 washers at a time, recording both the mass in the cup and the height of the end of the wire above the surface of the work area, until the wire no longer returns to approximately h_o. Record this value of mass. We shall refer to this maximum number of washers (mass) that the wire can support as its critical number, W_c.

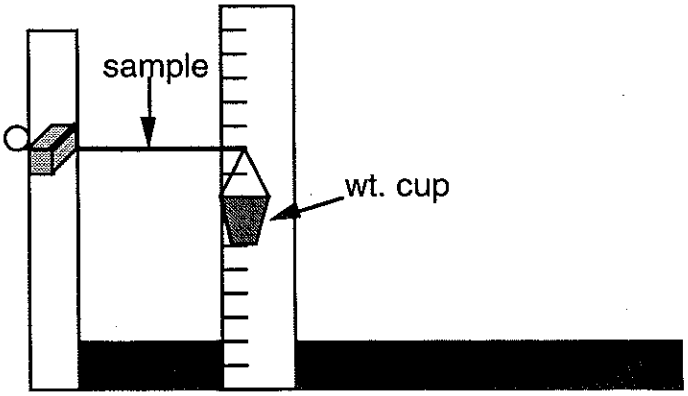
7. Now take 3 or 4 more sets of data on this wire after straightening it.

8. Replace the original copper wire with annealed copper wire of the same gauge.

9. Replace the annealed copper wire with the piece of copper wire that has been annealed and then stretched (cold-worked) by 10%.

10. Repeat procedures 1-8 above for the other wires, time permitting. Be sure the distance from the clamp to the point where the weights are attached is the same for the annealed wire as it was for the original wire.

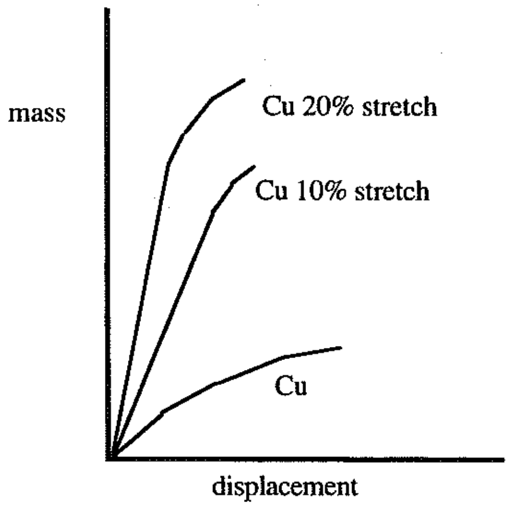
Diagram of Set-up:



Sample Table:

mass	ht.	disp.

Sample Graph:



Analysis:

1. From your data collected in Part III, generate a data table for each wire; including the values for mass, height, and displacement (height - h_o).

2. Plot a graph of mass (on vertical axis) versus displacement for each of the different types of wires. Note that the slope of the curve represents the relative stiffness of the wire represented by the curve. See sample graph.

3. For each of the types of metal wires, find the maximum mass for which the curve remained basically a straight line (the slope was constant). This defines the yield strengths of the metal.

Questions:

1. What is happening to the bonded metal atoms during elastic deformation?

2. What is happening to the bonded metal atoms during plastic deformation?

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3. Give the maximum mass placed on [illegible] before permanent deformation occurred.

4. Why would an engineer be interested in the yield strength of a metal for a particular application?

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Teacher's Guide - Experiment 4

Tensile Strength

- It is advisable to test this experiment beforehand to be sure the particular gauge wire that you have chosen undergoes sufficient deformation with the masses you are making available to the students.
- One way to save time on this lab is to have different groups do different metals.

Answers to Questions:

1. The bonds between the atoms are stretching.
2. Metal atoms are sliding past each other.
3. Student answers.
4. In most applications, it is not desirable to exceed the yield strength of the product. If the yield strength is exceeded the object will be permanently deformed and likely will no longer be useful.

Properties of Materials

-characteristics used for identifying a material

-Have students do a free write to differentiate between chemical and physical properties. Have them attempt to name several examples of each.

Chemical Properties

- how a material interacts with another material
- "social" behavior
- response to other matter (or lack of one)
- *reactions*

Examples:

- burning
- reaction with acid
- reaction with water
- corrosion/rusting/oxidation
- others????

Physical Properties

- characteristics it possesses by itself *(in and of itself)*
- "personal" traits
- response to energy

Examples:

- color
- density
- size
- magnetism
- texture
- boiling point
- melting point
- odor
- solubility
- crystalline structure
- luster
- viscosity (resistance to flow)
- electrical properties *(conductor or insulator)*
- optical properties - response to light
  - index of refraction

    - transparent - light passes through
    - translucent - light passes through but no distinct image
    - opaque - no light passes through
        - *show examples of all 3 - use glass or plastic*
- thermal properties - response to heat
    - conductivity *(students will use conductometer later during properties of metals lab)*
    - specific heat - *how easily it changes temperature - metals have low specific heat*
    - thermal expansion *(remind students of iron wire demo)*

Thermal expansion demos:

ball and ring

- show the students how the ball just fits through the ring
- ask the students to predict what they think will happen if the ball is heated with a torch - students will usually predict that the ball will expand and not fit through the ring
- heat the ball with a propane torch or Bunsen burner
- show the students how the ball will not fit through the ring
- quench the ball in a container of water
- show how the ball now fits through the ring again
- ask the students to predict what they think will happen when the ring is heated with a torch or a burner - the students are often split on whether the center hole will get bigger or smaller - often the majority will say smaller
- heat the ring with a torch or burner
- show how the ball now fits more easily through the ring - the center opening in the ring has gotten bigger - this can be surprising to a lot of students so some explanation is in order
- what happens when a material is heated?
- the atoms gain energy and want to spread out from each other
- where could the atoms go when the ball was heated?
- the atoms moved outward from the center in all directions
- where could the atoms go when the ring was heated?
- confusion can occur at this point - all can agree that the atoms on the outer edges of the circle will move outward - the question is: can the atoms on the inside edge of the ring move towards the center? "common sense" will tell some people "yes" - there is nothing there - why can't the atoms "spread" into that space. Do a "physical demo" to illustrate what actually happens.
- have a group of volunteer students form a circle - facing inward - by linking elbows. Their feet should be equidistant from each other and from their neighbors' feet
- now tell the students that heat has been added - they have to "expand" - how can they do it? Because their elbows are linked, they can accomplish an "expansion" by stepping backward and moving their feet farther apart. The whole thing has to expand as a unit - thus some people can't scoot their feet forward into the "open space of the inner circle" while others move their feet back which is what a lot of students envision when guessing that the opening will become smaller with heating.
- ask the students what would happen if the ring was cut open and straightened out into a bar-shaped piece of metal?

- the bar shaped piece of metal would show expansion in ALL directions
- it is the shape of the piece of metal that doesn't allow expansion towards the center of the circle
- the atoms move in planes because of the crystalline nature of metals

bimetallic strip
piston and sleeve

Mechanical Properties

- subgroup of physical
- response to force or stress
    - force – a push or a pull
    - stress – force causing a deformation or distortion (force per unit area)

Examples:

- workability
    - malleability – can be flattened *(show students a rolled penny)*
    - ductility – can be drawn into wire (stretched) *(show drawn wire)*

- brittleness – breaks instead of deforming when stress is applied – (*snap a piece of chalk)*

- hardness – resistance to denting or scratching *(pass around talc)*
    - *(do a metal hardness test demo – dent metal plates using a heavy weight with a ball bearing attached – make a shading of the dents and measure their width with a caliper – rank the metals)*

- elasticity – ability to return to original shape after being deformed by stress *(rubber ball or piece of elastic)*

- plasticity – retains new shape after being deformed by stress *(wet clay ball or piece of saran wrap)*

- toughness – ability to absorb energy *(toss a metal piece, plastic water bottle, unglazed dried clay (in a baggie), a test tube (in a baggie), Corelle plate) – metals and polymers tend to exhibit more toughness than ceramics or glass – Corelle is an exception, it is a glass-ceramic that exhibits a higher degree of toughness than traditional ceramics*

- strength – resistance to distortion by stress or force

4 types of stresses/forces:

(use overheads to illustrate)

1. tension - pulling

   ex. tug-of-war, slingshot

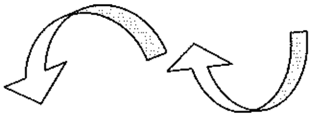
2. compression - pushing together or squeezing

   ex. bed springs, trash compactor, vise

3. torsion - twisting

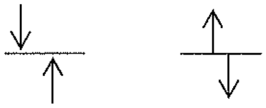
   ex. wringing out a wet towel

   (demo - break a piece of chalk w/ torsion)



4. shear - opposite forces not lined up

   ex. scissors, pin in a wagon tongue, shear pin in machinery



Stress-Strain Curve

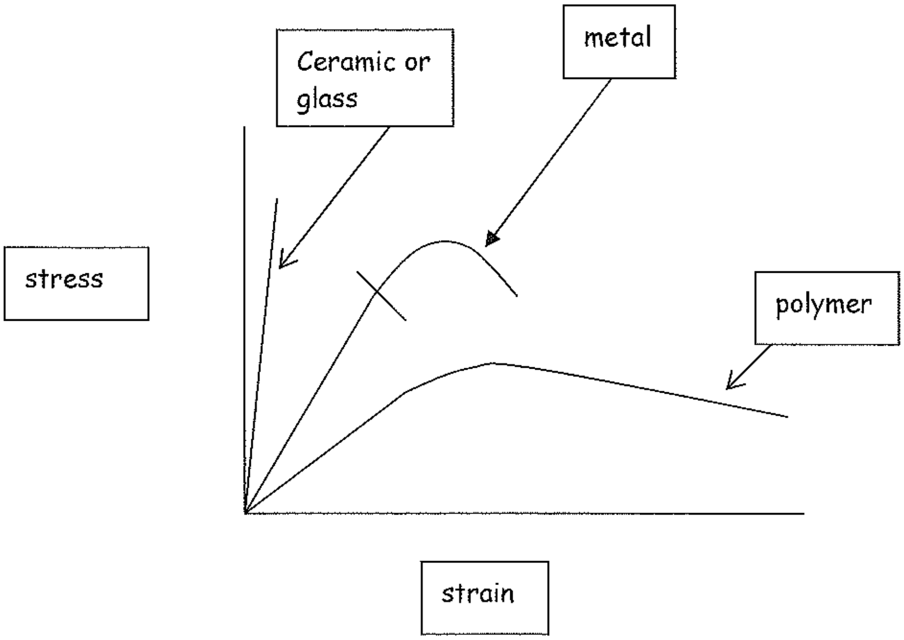
Stress - (cause)

-force causing a deformation or distortion

Strain - (effect)

-change caused by stress (ex. elongation)

-straight line = elastic region
-curved line = plastic region



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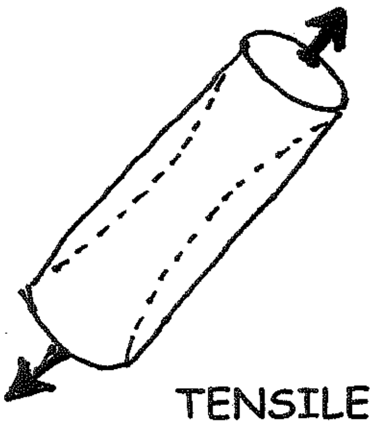
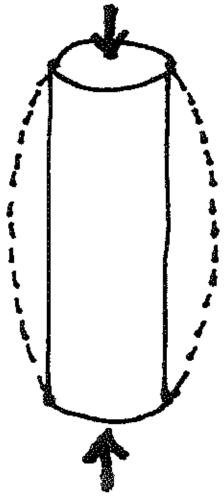
MECHANICAL PROPERTIES

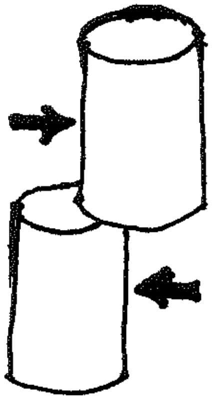
THOSE PROPERTIES DETERMINED BY MECHANICAL STRESS



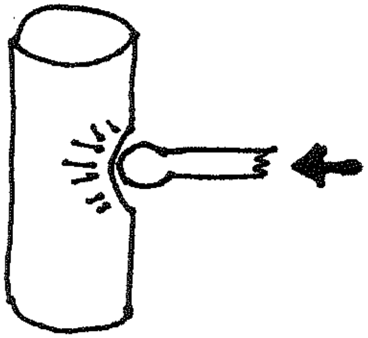
TENSILE STRENGTH



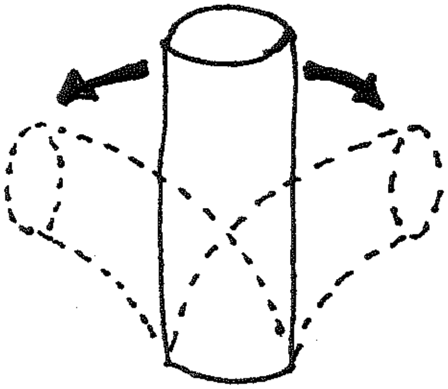
COMPRESSION



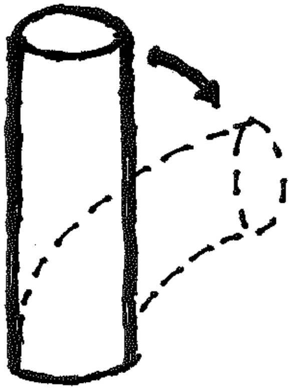
SHEAR



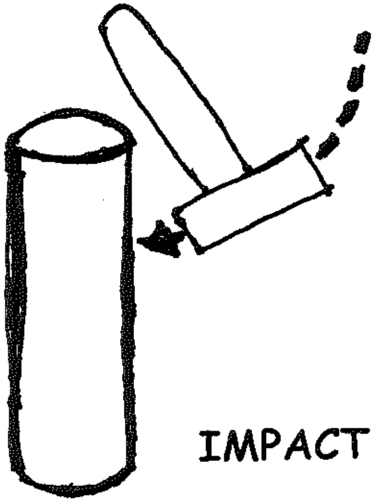
HARDNESS



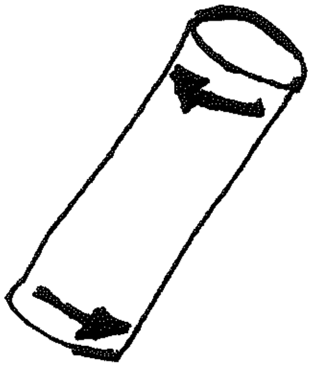
FATIGUE



FLEXURE



IMPACT



TORSION

Glossary

Ceramics: Ceramics are mixtures of non-metals with other metals or non-metals, with ionic and/or covalent bonding.

Composites: Composites are physical mixtures of two different materials

Creep: Creep is the slow deformation of materials under applied stresses at high temperatures

Ductility: The amount a material can be deformed before breaking

Fatigue: The slow nucleation and growth of cracks, usually during repeated applications of modest stresses

Metallic Alloys: Mixture of primarily metallic elements with some metallic or non-metallic elements. The bonding is primarily metallic, so that conductivity decreases as temperature increases.

Metallic Elements: Elements in which the valence electrons are free to flow.

Metals: A general term which includes both metallic elements and metallic alloys.

Polymers: Polymers are long molecular chains, composed of repeating units (poly = many, mer = unit).

Semiconductors: Materials with electrical conductivities intermediate between that of conductors and insulators

Stiffness: The inherent resistance of a material to small stresses

Strength: The critical stress required for permanent deformation of a material

Stress: Force per unit area

Toughness: The energy required for a crack to break a material apart

Wear: Removal of material from a surface by rubbing against another surface .

Solids

Task Sheet

Instructions: Your instructor may ask you to fill in the last two columns of this task sheet and present it to him/her whenever you have completed an activity. This will allow a point value to be assigned to that activity.

Do not lose your Task Sheet. It will need to be turned in to your instructor periodically and at the end of the unit.

Task	5	3	2	1	Activity	Date Completed	Journal Page #
1-1					Equipment Introduction		
2-1					A Property of Materials – Dilatancy		
2-2					Material Safety Data Sheets (MSDS)		
2-3					Identification of Materials		
2-4					Material Systems		
3-1					Models of Crystals		
3-2					Formation of Solids		
3-3					Crystal Study		
3-4					Growing Single Crystals		
4-1					Destructive Testing of a Paper Clip		
4-2					Simple Iron Reactions Using Steel Wool		
4-3					Reduction of Copper		

Scoring:
3 - Did a good job of completing and understanding the task.
2 - Needed some help to complete the activity.
1 - Needed much help to complete the activity; little understanding.
5 - Helped another student learn about and complete the activity after previously receiving credit.

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