

Materials Science and Technology



Teachers Handbook

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Materials Science and Technology Teachers Handbook



**Pacific Northwest National Laboratory
Richland, Washington**

Materials Science and Technology Teachers Handbook



**Science Education Programs
Pacific Northwest National Laboratory*
Richland, Washington**

***Operated by Battelle Memorial Institute
for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830**

Preface

This Materials Science and Technology Teachers Handbook was developed by Pacific Northwest Laboratory, Richland, Washington, under support from the U.S. Department of Energy. Many individuals have been involved in writing and reviewing materials for this project since it began at Richland High School in 1986, including contributions from educators at Northwest Regional Educational Laboratory, Central Washington University, the University of Washington, teachers from Northwest schools, and science and education personnel at Battelle, Pacific Northwest Laboratories. Support for development was also provided by the U.S. Department of Education. This latest version was revised during 1993-1994 by a group of teacher consultants that included Guy Whittaker, Coupeville, Washington; Paul Howard, Richland Washington; Noel Stubbs and Eric Pittenger, Corvallis High School, Corvallis, Oregon; Andy Nydam, River Ridge High School, Lacey Washington; and Len Booth, Lacey, Washington. The following PNL staff members reviewed the guide: Mike Schweiger, Materials and Chemical Sciences Center, Irene Hays and Karen Wieda, Science Education Center; and Jamie Gority and Georganne O'Connor, Communications Directorate. Many other organizations and individuals providing support are noted in the Acknowledgments section.

The curriculum has also been endorsed by the U.S. Materials Education Council and was featured in articles in the MRS Bulletin, the journal of the Materials Research Society in September 1992 and December 1993.



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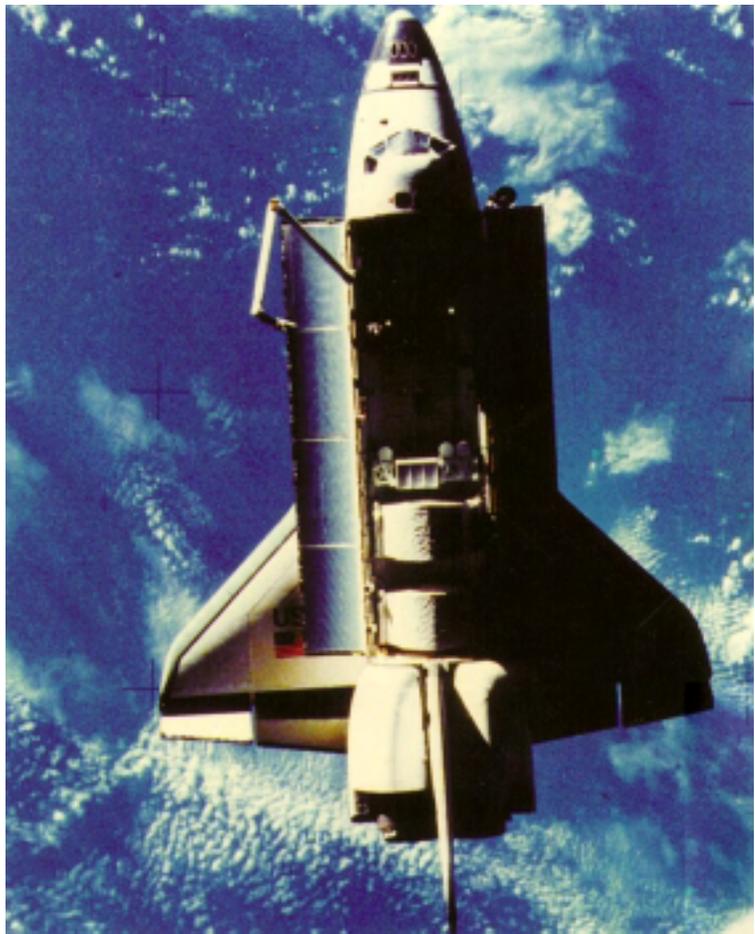
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Introduction to Materials Science and Technology

What is Materials Science?

Materials make modern life possible—from the polymers in the chair you're sitting on, the metal ball-point pen you're using, and the concrete that made the building you live or work in to the materials that make up streets and highways and the car you drive. All these items are products of materials science and technology (MST). Briefly defined, materials science is the study of "stuff." Materials science is the study of solid matter, inorganic and organic. Figures 1.1, 1.2, 1.3, and 1.4 depict how these materials are classified.

Briefly defined, materials science is the study of "stuff."



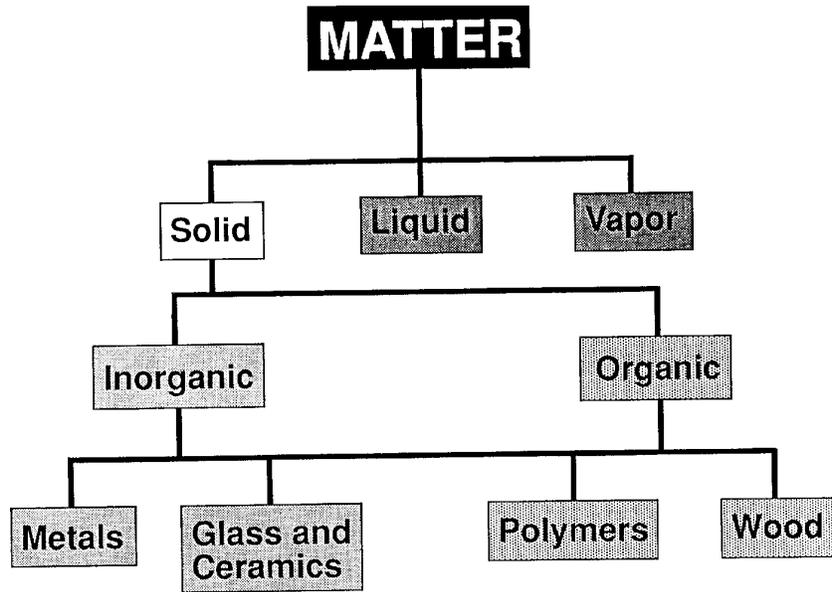


Figure 1.1. Physical Classification of Materials by State

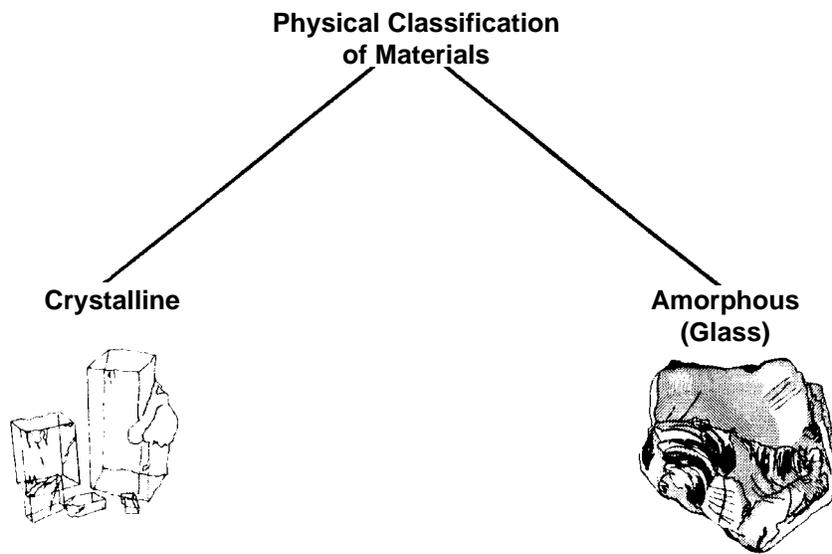


Figure 1.2. Physical Classification of Materials by Morphological Structure

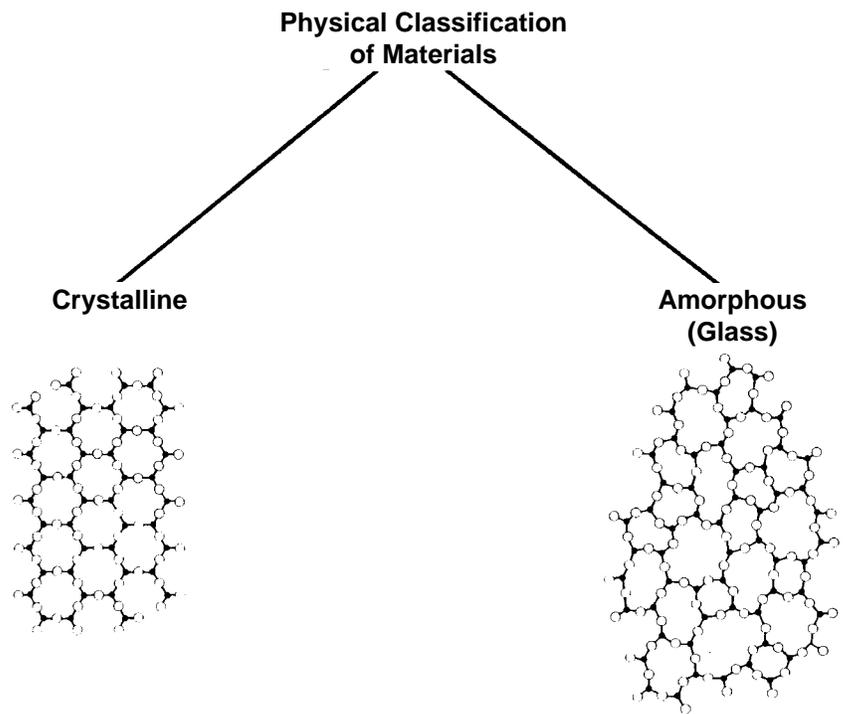


Figure 1.3. Physical Classification of Materials by Atomic Structure

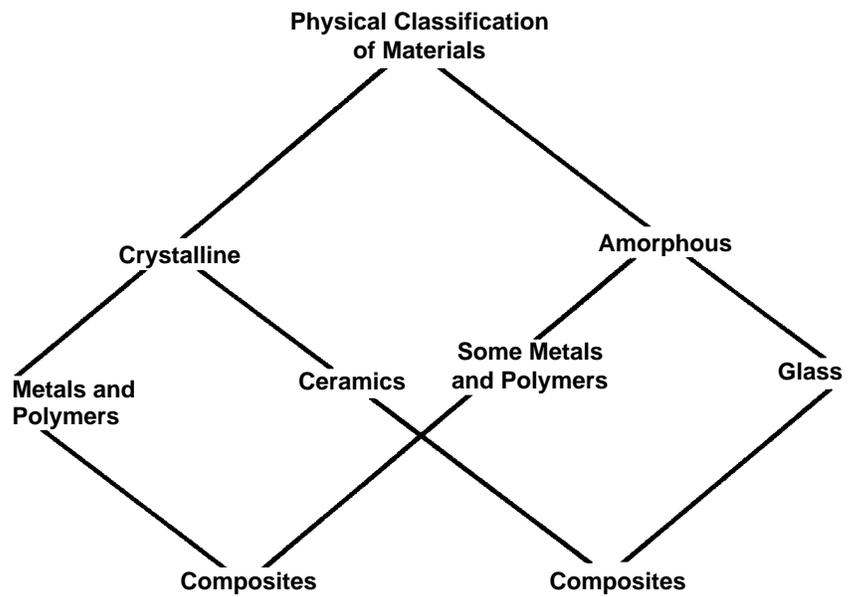


Figure 1.4. Interrelationships Between Classes of Materials

“Technology draws on science and contributes to it.”

**—AAAS Project 2061
Science for All Americans**

Materials science and technology is a multidisciplinary approach to science that involves designing, choosing, and using three major classes of materials—metals, ceramics, and polymers (plastics). Wood also could be used. Another class of materials used in MST is composites, which are made of a combination of materials (such as in particle board or fiberglass).

Materials science combines many areas of science. Figure 1.5 illustrates how materials science draws from chemistry, physics, and engineering to make better, more useful, and more economical and efficient “stuff.”

Because of the interdisciplinary nature of materials science, it can be used both as an introductory course to interest students in science and engineering and also as an additional course to expand the horizons of students already taking science and mathematics courses.

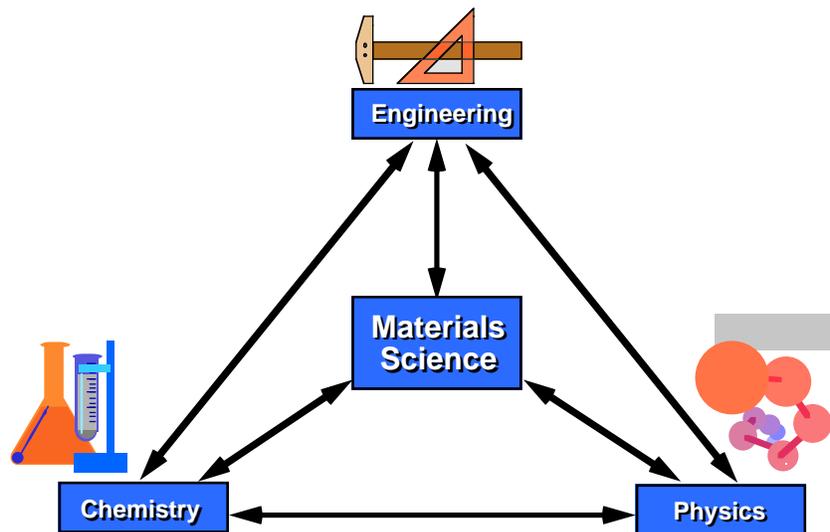


Figure 1.5. Materials Science and Technology—A Multidisciplinary Approach

The Relationship of Science and Technology

In the MST classroom, the boundaries are blurred between science and technology. It is not easy to know where one ends and the other begins. In this way, the learning environment of MST reflects the scientific and technical enterprise where scientists, engineers, and technologists work together to uncover knowledge and solve problems. In the school environment, these overlapping and complementary roles of science and technology are found most often in courses called “technology education.”

Some confusion exists between the labels “technology education” and “educational or informational technology.” Educational technology refers to delivery systems for teaching and tools for instruction such as computers, satellite television, laser discs, and even chalk. It refers to laboratory equipment such as microscopes, telescopes, and calculators. These tools can access and process information and perform numerical calculations that describe physical phenomena—but they are not technology education in the sense we describe.

In a technology education course, technology is treated as a substantive content area, a subject with a competence or performance-based curriculum involving learned intellectual and physical processes and skills. As such, technology is viewed as a part of the essential curriculum content in mathematics and science, and understanding of the principles and practices of mathematics and science is viewed as essential to effective technology curricula. Science and technology as it is practiced in the real-world supports this relationship.

Even though the activities in an MST classroom may not call out the difference between science and technology, it is important to know that they are fundamentally different from each other (see Figure 1.6). Knowing the difference can assist you in designing and delivering the curriculum and in assessing and reporting learning attained by students. The National Center for Improving Science Education makes the following distinction:

Science proposes explanations for observations about the natural world.

Technology proposes solutions for problems of human adaptation to the environment.

In science, we seek the “truth” about, for example, the basic constituents of matter or the reason why the sky is blue. Inherent in the pursuit is the sense that scientific explanations are tentative; as new knowledge is uncovered, the explanations evolve. But the desired goal of this pursuit is an answer that explains the scientific principle (the physics and chemistry, for example), behind the phenomenon.

In technology, no one best answer may exist for a given problem. Humans need protection and food, for example. Or they want to move objects from one place to another, or create objects of beauty to be shared and displayed. Numerous tools, strategies, techniques, and processes can be developed to solve these problems. Trade-offs among constraints and variables lead to one or more solutions. We may develop better ways to solve a problem over time, but we don't expect any given solution to be the one answer in the face of all variables and constraints.

Hand in hand, science and technology help us know enough about our world to make intelligent decisions that impact the quality of our lives and help us solve problems that ultimately impact that quality. Technologists develop tools that help us make new observations that advance science. Science reveals new knowledge that extends our ability to adapt to our environment. Taken together, science and technology in the MST classroom are combined to prepare students who not only create, design, and build, but understand the nature and behavior of the materials used in the building. They have the "know-why (science)" and the "know-how (technology)" that lead to creativity, ingenuity, and innovation.

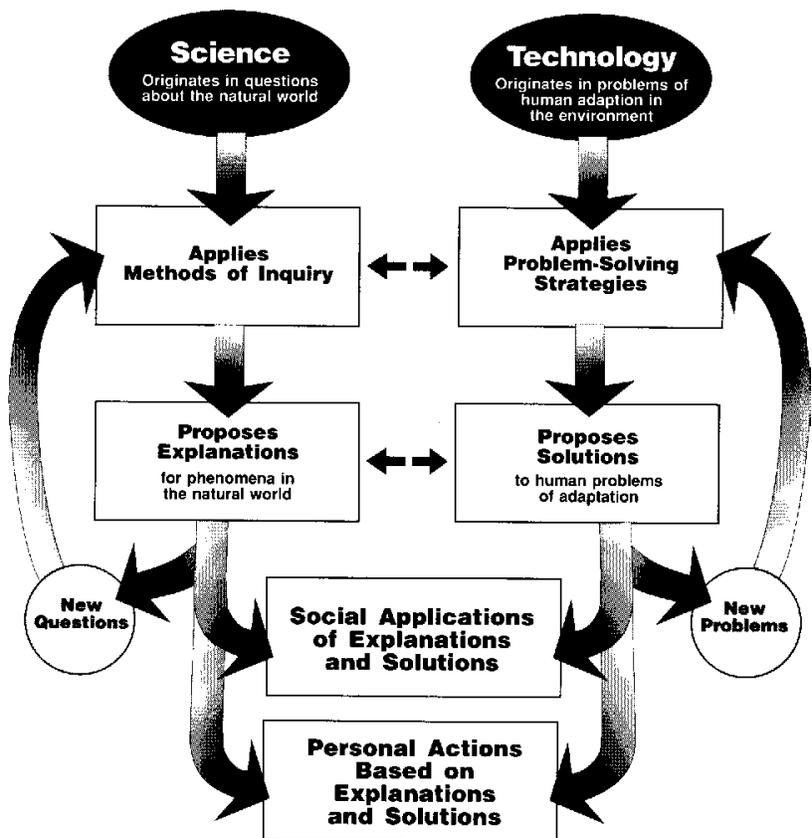


Figure 1.6. The Relationships between Science and Technology, (National Center for Improving Science Education)

How is Basic Science Linked to Everyday Materials?

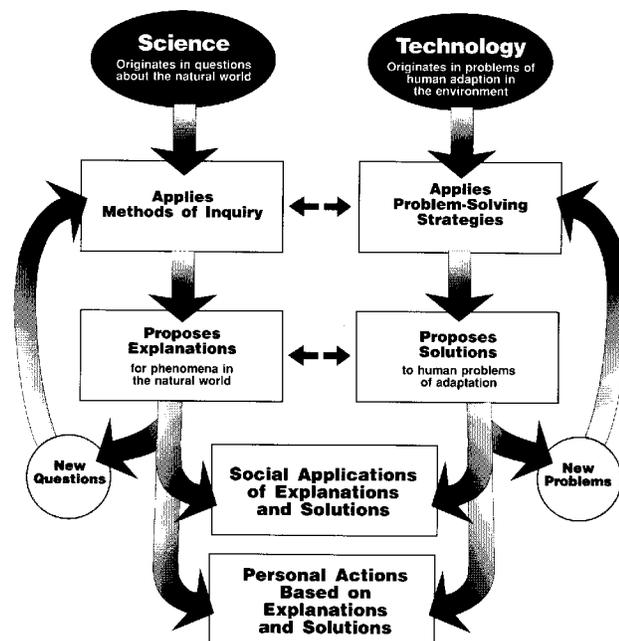
A primary application of materials science is matching the right material or combination of materials to the intended purpose and use of a specific product, such as a car. To do this, materials scientists must consider such things as the weight and strength of a certain material as well as its ability to conduct electricity or insulate the product from heat. They must also consider the material's chemical stability, corrosion resistance, and economy. This is the basic science part.

Table 1.1 shows some of the properties the major classes of materials exhibit. We use observable properties of materials to show the consequences of atomic- and molecular-level events. How atoms in different materials are bonded makes a profound difference in the properties they exhibit.

As students experiment with the different classes of materials, they will discover what terms like ductility mean and what makes these properties important in designing and producing stuff. Take the properties of metal, for example. The shared outer electrons of metal are wholly or partially responsible for high electrical conductivity, high thermal conductivity, and ductility. Ceramics exhibit the opposite properties as their localized, mostly ionic, bonding produces low electrical and low thermal conductivity and contributes to the extreme brittleness of ceramics. Students will also see as they experiment why one class of material is preferred over another for certain products and how they can change or "improve" certain materials.

"The metals, plastics, and glasses every human being uses must be the seed bed from which the periodic table and thermodynamics sprout."

***—Rustum Roy,
The Pennsylvania
State University***



A Short History of Materials Science

Humans have been using materials for at least 10,000 years of recorded history, but the real beginning of materials' use was long before recorded history. The first materials scientists may well have been Grog or Grogette (a fictional character of caveman origin) as Table 1.2 shows. In an initial, or "first," materials science era, men and women used materials just as they found them, with little or no modification. Even in these early times, though, they had reasons for choosing wood or stone objects for certain purposes.

In more recent times, during what is called the second era of materials history, humans learned enough chemistry and physics to use heat and chemicals to process natural materials to obtain what they needed. For example, researchers learned how to separate metals from ore by heat and reduction. These processes made available whole new classes of materials, most of them metals. Table 1.3 shows a longer listing of materials discovery through history (compiled by the *EPRJ Journal*, December 1987).

Table 1.2. A Short History of Materials Science

Initial or First Era

Grog/Grogette—	}	Using things as found or with slight adaptation
The First Materials Scientist		
8000 BC Hammered copper		
6000 BC Silk production		

Second Era

5000 BC Glass making	}	Changing things with heat or chemicals to improve properties
3500 BC Bronze Age		
1000 BC Iron Age		

(Hiatus, as scientific background develops)

Third or Final Era

1729 AD Electrical conductivity of metals	}	Understanding, making new materials
1866 Microstructure of steel		
1866 Discovery of polymers		
1871 Periodic table		
1959 Integrated circuit		
1960 Artificial diamond		
1986 High-temperature superconductors		

Table 1.3. Materials Footnotes Through History

8000	Hammered copper
7000	Clay pottery
6000	Silk production
5000	Glass making
4000	Smelted copper
4000-3000	Bronze Age
3200	Linen cloth
2500	Wall plaster
2500	Papyrus
1000	Iron Age
300	Glass blowing
20	Brass alloy
105	Paper
600-900	Porcelain
1540	Foundry operation
late-1500s	Magnetization of iron demonstrated
1729	Electrical conductivity of metals demonstrated
1774	Crude steel
1789	Discovery of titanium
1789	Identification of uranium
1800	Volta's electric pile (battery)
1824	Portland cement
1839	Vulcanization of rubber
1850	Porcelain insulators
1850s	Reinforced concrete
1856	Bessemer steelmaking
1866	Microstructure of steel discovered
1866	Discovery of polymeric compounds
1868	Commercial steel alloy
1870	Celluloid
1871	Periodic table of the elements
1875	Open-hearth steelmaking
1880	Selenium photovoltaic cells
1884	Nitrocellulose (first man-made fiber)
1886	Electrolytic process for aluminum
1889	Nickel-steel alloy
1891	Silicon carbide (first artificial abrasive)
1896	Discovery of radioactivity
1906	Triode vacuum tube
1910	Electric furnace steelmaking
1913	Hydrogenation to liquefy coal
1914	X-ray diffraction introduced
1914	Chromium stainless steels
1923	Tungsten carbide cutting materials
1930	Beginnings of semiconductor theory
1930	Fiberglass
1934	Discovery of amorphous metallic alloys
1937	Nylon
1940s	Synthetic polymers

Table 1.3. (contd.)

1947	Germanium transistor
1950	Commercial production of titanium
1952	Oxygen furnace for steelmaking
1950s	Silicon photovoltaic cells
1950s	Transmission electron microscope
mid-1950s	Silicon transistor
1957	First supercritical U.S. coal plant
1958	Ruby-crystal laser
1959	Integrated circuit
1960	Production of amorphous metal alloy
1960	Artificial diamond production
1960s	Microalloyed steels
1960s	Scanning electron microscope
1966	Fiber optics
late-1970s	Discovery of amorphous silicon
1984	Discovery of quasi-periodic crystals
1986	Discovery of high-temperature superconductors
1989	Buckyballs (Buckminsterfullerene)

About the time early polymers were introduced in the late 19th century, we had learned enough about organic chemistry to manipulate materials at the molecular level. At this point, it became possible to design specific materials to fit specific needs.

Designed materials constituted much of the accelerating pace of materials science. This has launched us into the third and final era of materials history, which began its accelerated pace in the 1950s. Today, we hear about newly designed materials daily as the demand for new and better materials gives rise to these new products.

Designed materials are probably best illustrated by composites, which allow us to reinforce materials at the right places and in the right amounts to minimize weight and produce the desired mechanical properties. The graphite tennis racquet, golf club shaft, and fishing rod are all products of this designed materials revolution, as are the wings of new high-performance aircraft such as the Harrier.

Advanced materials developed by Battelle and researchers at Pacific Northwest National Laboratory are described in the Resource Appendix.

A New Scientific Frontier

Atomic structure and chemical composition were once major focuses of materials science research. However, over the last few decades, this focus has changed dramatically as analytical chemistry, the electron microscope, X-ray diffraction, and a host of spectrometers have been developed that can analyze materials with accuracy.

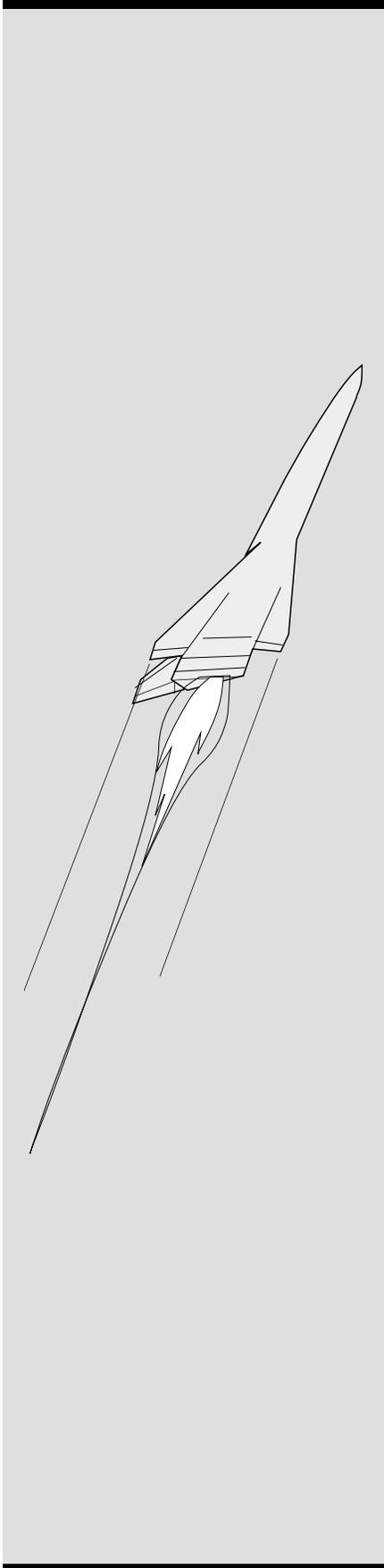
Because scientists can now understand what materials are made of (chemical composition) and how they work (physical properties), the major focus of materials science has shifted to understanding how materials can be improved and what new materials can be developed to meet society's needs. These scientific advances caused a revolution in knowledge in materials. What was known about materials only 50 years ago could be printed in several volumes of books; today's advances fill shelves of books.

Examples of new materials abound and are reported regularly in newspapers and magazines. The space shuttle tile, which is used as a heat shield to protect the aluminum shell on the shuttle, is one example of this development of new and improved materials. When NASA (the National Aeronautics and Space Administration) decided to build a space shuttle that would rocket into orbit and eventually plunge through the atmosphere and land on the ground like an airplane, no known insulating material existed that would protect the flight crew from the fierce re-entry heat, be light enough to coat the entire craft, and be reused a number of times.

So, ceramists (materials scientists who work with ceramics) designed special tiles made from high-temperature glass fibers and sintered them to form a rigid, but almost unbelievably light structure. These tiles are glued to the shuttle with silicone rubber and now do an admirable job of keeping heat away from the crew. The ceramists designed the tiles from "scratch" by adapting their knowledge of glass properties to meet the needs of the space shuttle. (See the Appendix to find out how you can order a space shuttle tile from NASA for your classroom experiments.) Further development continues as less bulky and more reliable materials are being developed to shield the Orient Express, a supersonic transport being developed for near-space travel over long distances around the Earth.

Materials Science in Our Everyday Lives

Another example of the development of new materials is in biomedicine. The recent controversy over silicone breast implants shows how much care must be taken in choosing, testing, and using materials that are used inside human bodies. More successful examples of materials developed for human bodies are such things as hip, knee, and finger joint replacements made from composite materials.



“Technology provides the eyes and ears of science—and some of the muscle, too.”

***—AAAS Project 2061
Science for All Americans***

A modern automobile is a good example of how materials have changed to keep pace with industry and culture. The American car of the 1950s was a durable machine and pretty well suited to its environment. Gas was cheap, metal was thick and lavishly used. The resulting car was heavy, but Americans demanded high performance for use on newly built freeways designed for speeds of at least 75 miles per hour. Engines were correspondingly large, with displacements approaching 500 cubic inches (that’s about 8 liters!). Americans tended to abuse these cars, and they were built to take abuse.

No one ever claimed these cars were fuel efficient. Then came the oil shock of 1973, and cars had to change radically, and have kept changing to meet the demand for more fuel-efficient transportation. In the quest for efficiency, car weight was reduced, and some changes were made in streamlining. Sheet metal used to build car bodies became much thinner and had to be much stronger. Unit body construction provided a way to produce stiffness without all the weight of a separate frame. Plastics and aluminum were used extensively in many parts of the car, and aluminum use increased dramatically.

The electronics revolution has provided onboard computers to manage the fuel and ignition systems of the engine, which now operate much closer to optimum parameters because of the need for both fuel efficiency and reduced emissions. Removing lead from gasoline stimulated use of better alloys for valves and valve seats. Spark plugs no longer exposed to lead deposits last 30,000 miles. Many other changes have occurred to the automobile, and you and your students doubtless know a few more.

However you look at it, materials have become a scientific frontier that continues to develop new and improved ways for people to live and travel now and in the future.

Looking at MST as a Career— “The Field of Dreams”

“In the years ahead, materials science will truly be the field of dreams. The special knowledge and skills of materials scientists will be needed to develop and produce materials that make other things possible....materials that enable us to fulfill our dreams of traveling and working in space, cleaning up the environment, improving the quality of life, revitalizing our industrial complex, restoring our economic competitiveness, and conserving and making better use of our resources.”

***—Adrian Roberts,
Brookhaven, National
Laboratory Associate Director
for Applied Science and
Technology***

Materials engineers and scientists will be required in ever-greater numbers as designs for everything from tennis racquets to space shuttles are driven harder by requirements for ever-higher efficiency in manufacturing and by use and re-use of materials. And, increasingly, the disposal of used materials will require attention with emphasis on recycling these materials. “Environmentally friendly” materials that can be produced, used, and disposed of without harmful effects to the biosphere is a field of study just beginning to emerge. This will require much research in our future. But, whether the need in 2010 is for 1000 materials scientists or 100,000, matters little. The greater need is for technologically literate citizens.

Examples of ways materials science has become a career for a number of people are highlighted in the this section.



Materials Scientists at Work

Mary Bliss

Astronomy was my first love. I joined an amateur astronomy club when I was 13 or 14. What I really liked about it was light and telescopes. At my high school, if you were good in science, that meant biology and you wanted to be a doctor or nurse. Chemistry was taught like history. The labs were set up to reproduce some result, and everything seemed to be known. So, instead of doing a regular senior year of high school, I enrolled in an advanced studies program for high school students at Pace University. I took chemistry and liked it this time. By the time I finished high school, I had 29 college credits.



“One January session I also signed up for a class called Gemstones: Myth and Mystery with a professor in the College of Ceramics. I had a blast! I got to run the transmission electron microscope myself.”

—Mary Bliss

I was in my sophomore-level classes when I arrived at Alfred University with my 29 credits. I wanted to take physics because I was still interested in astronomy. I also took organic chemistry because I figured if I didn't like physics, maybe I would major in chemistry. I never worked so hard in my life. I didn't have the faintest ideas of what was going on in physics. Having a study partner was the only way I could handle those classes. One January session I also signed up for a class called Gemstones: Myth and Mystery with a professor in the College of Ceramics. I had a blast! I got to run the transmission electron microscope myself. We found an error in the literature, and I ended up presenting the paper at a regional society meeting and won an award for the best undergraduate research project at Alfred. So, professors in the Ceramics Department encouraged me to change my major. Besides, in exchange for changing my major, one ceramics professor was going to give me a matched pair of Herkimer diamonds.

I worked the summers of my junior and senior years at Corning Glass Works in Corning, New York. I learned what engineers do all day there. I also met some really good engineers. I liked Corning, but I knew I wouldn't be happy as a production engineer forever. So, I got a master's degree in ceramic science at Penn State University (working on piezoelectric materials). I wasn't very happy with this work so I did my doctorate in the Solid State Science Department doing spectroscopy on silicate minerals. What strikes me most is that I liked spectroscopy even when I was in high school.

“There is something intriguing about making glass out of common, dull elements of the earth and having it melt and then cool into a material that can be clear and smooth.”

—Mike Schweiger

Mike Schweiger

As I was growing up, I had an innate curiosity about bugs, animals, trees, plants, and most anything in nature. I loved incubating eggs and raising chicks. My heart was always broken the day the chicks were taken away to a farm because they had grown too big for the house we had in Idaho Falls. I raised other animals more acceptable to a city environment when I had time, such as ants, frogs, bunnies, snails, caterpillars, and water striders.



As a vivid memory of these years, I retain a large scar on my arm from when I excitedly raced down the hall of our home with a 3-pound glass peanut butter jar full of the latest collection of ants for my ant farm. I tripped on some toys and fell on the shattered jar, severely cutting my left arm. This incident had no effect on my love of living things.

I liked biology and chemistry throughout school. I graduated from college as a teacher with a major in natural sciences. As I taught grade school, students enjoyed learning science, and it was one of my favorite subjects to teach. I found out I wasn't teacher material, and after 5 years in the education field, I joined the Materials Science Department at Battelle as a technician.

I was assigned to the glass development laboratory in the basement of Battelle's Physical Sciences Building. I was determined to take this position so I would have an easier time transferring to the Biology Department. The in-depth study of glass intrigued me, however, and I turned some of my love of nature into studying inorganic materials. There is something intriguing about making glass out of common, dull elements of the earth and having it melt and then cool into a material that can be clear and smooth. This same material can also be heat treated and crystallized, and these crystals are a unique world of their own and a part of nature not readily seen or understood.

My 14 years at Battelle have been involved with this small area of materials study. The field is so vast I know I could spend the rest of my life studying glass and still only have understood some of the science of this material. I look forward to the interesting career ahead of me.

“I have learned enough about metals and polymers to be considered a materials engineer.”

—Roy Bunnell

Roy Bunnell

I was raised in Pocatello, Idaho, and developed a keen early interest in chemistry and physics, particularly as they apply to explosives and rockets. I still have 10 fingers and two functioning eyes, through either incredible luck or divine intervention. After I obtained a bachelor's degree in ceramic engineering from the University of Utah in 1965, I came to Battelle. By working on a wide variety of

projects, ranging from nuclear reactors for space propulsion to materials compatibility in high-temperature sodium to amorphous carbon to high-temperature properties of zirconium alloys to nuclear waste glass to new composite materials, I have learned enough about metals and polymers to be considered a materials engineer.



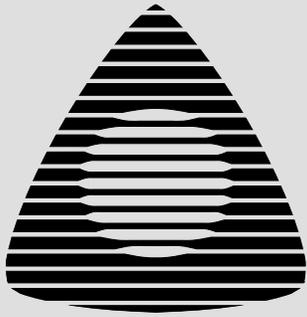
Ross Gordon

Ross attended schools in Richland, Washington, from the 4th grade through high school at a time when scientific education was a priority for the community. He decided in the 9th grade that he was going to become a chemical engineer, even though he wasn't sure what a chemical engineer did. Ross attended Brigham Young University where he received a bachelor's degree in chemistry

and a bachelor of engineering degree in chemical engineering. During Ross' last quarter in school he had an open slot for a class in either metallurgy or plastics. He asked his major professor which would be best. The professor recommended that Ross take metallurgy because he would probably never get involved in plastics. Ross followed his advice and learned a little about metals, which has been a great benefit, even though the professor's prediction was completely wrong. Ross' first job was for Boeing as a plastics' engineer. He worked for 8 years in the aerospace industry in plastics research then came to Battelle where he has spent the last 29 years solving problems and doing research related to plastics.

Ross has learned through the years that the best way to solve a problem is to start with the basic scientific principles (mathematics, biology, chemistry, and physics) that he learned in high school. When these principles are combined with additional education and experience, even "impossible" things can be accomplished. He's also learned that approaching a problem with the assumption that it can be solved is the most effective way to be happy and successful.





Creating an MST Environment

MST Curriculum Philosophy/Rationale

“A combined emphasis on “know-how” and “ability to do” in carrying out technological work transforms mathematical and scientific principles into reality.”

—International Technology Education Association

The philosophy that underlies this introductory materials science and technology (MST) curriculum has as much to do with how things are taught as with what is taught. The instructional approach is based on the idea that students cannot learn through talk or textbooks alone. To understand materials, they must experiment with them, work with their hands to discover their nature and properties, and apply the scientific concepts they learn by “doing” to designing and creating products of their own choosing.

Learning comes, as it has for humankind for generations, from the active pursuit of solving problems. In this case, students learn from solving problems using the scientific process, which is speeded by scientific knowledge. Students get a chance to use and build their mechanical skills as well as mind skills. We call this approach hands-on/minds-on learning.*

Learning by doing is not a new or complicated idea, but it is not common in today’s classrooms. Unlike many mathematics and science classes, students enrolled in MST classes are excited instead of bored. They ask “What happens if ...?” instead of “What’s the right answer...?” Instead of sitting at a desk reading about science and technology, they work on science and technology activities. They’re not memorizing facts about mathematics and science, but using the thinking processes of scientists and mathematicians to become better reasoners, and learning facts and concepts while solving problems relevant to them as they create their projects.

The MST course can only be fostered by good teachers, those who are a regular part of the school system and community members who have mastered their skills and are willing to pass on what they have learned. Teachers must create a learning environment where students are willing to risk and are willing to learn from mistakes they make.

Beyond MST’s basic project approach, other fundamental elements of the program include fostering student creativity, developing journal writing skills, and teaching in teams (science and technology teachers). Peer teaching also plays an important role. Students who have just mastered a skill or gained an idea can be the most convincing teachers.

* “Hands on/minds-on”: this phrase originated with Herb Thier, Lawrence Hall of Science, and refers to experiential learning that physically and intellectually engages the student.

“Do not try to satisfy your vanity by teaching a great many things. Awaken people’s curiosity. It is enough to open minds, do not overload them. Put there just a spark. If there is some good inflammable stuff, it will catch fire.”

—Anatole France

When scientific concepts, thinking skills, and mechanical skills are combined, then science and technology are truly combined, and an atmosphere exists that appeals to a broad range of students. Not just “science smart” students, but also the so-called average students not usually reached by traditional science, mathematics, and technology curricula and also young women and traditionally underrepresented students.

Working with materials appeals to all students because materials are the medium for art, handicrafts, and the myriad of things that surround them. Students enrolled in honors science courses find that MST focuses the science knowledge they have learned in other courses and gives them a chance to use mathematics skills in concrete ways. Other students, more oriented toward applied technology than traditional science, who are not usually adept at memorizing or doing mathematics, often shine in the MST course as they discover how to connect subjects usually taught in isolation. They can apply their abilities and strengths in areas of problem solving in which they do well.

Through the process of working with materials, students begin to understand science as a highly socialized activity. They discover that science is not just facts and figures, but a process that relies on people’s visions and imaginations, as well as their abilities to follow through a step-by-step process. The degree of “handiness”^{*} MST students develop goes a long way toward instilling in them a sense of self confidence. Although few students take advanced materials classes in college, most say MST has changed the way they look at the world.

^{*} “Handiness”: a term contributed by Eugene Eschbach, Manager of Innovation and Technology at Battelle, refers to the ability to solve materials-related problems with available or limited resources (see page 2.15)

MST Multi-Instructional Approach

- Solving Problems
- Creating Student Projects
- Using the Laboratory Journal
- Working in Small Groups
- Developing Handiness
- Fostering Creativity
- Teaching in Teams
- Using Community Resources

Multi-Instructional Approach

Because this MST course is designed to be taught to a wide range of students, we use a multi-instructional approach that includes elements to appeal to many learning styles. In general, we describe the instructional process shown in Figure 2.1 as “observe, correct, and create.” It works something like this: Students ponder, plan, experiment, GOOF UP, correct, discover, and learn in a laboratory setting. These concepts are the principles of the scientific process.* As part of the process, students experiment individually or in groups, record their observations in a journal, and discuss the experiments and their observations in class or small groups. In addition, students read and research, using periodicals and other library resources in relation to the unit of study or their selected project. Students are encouraged to gather information by interviewing or working with those who are familiar with the materials or are experts in the field of study.

The multi-instructional approach focuses on solving problems, creating student projects, working in small groups on open-ended experiments, writing as a means of learning, participating in high-interest demonstrations and activities, using community experts in materials, showing videos, and using a host of written resources. These approaches reach many minds and learning styles, and can interest many students in the learning process.

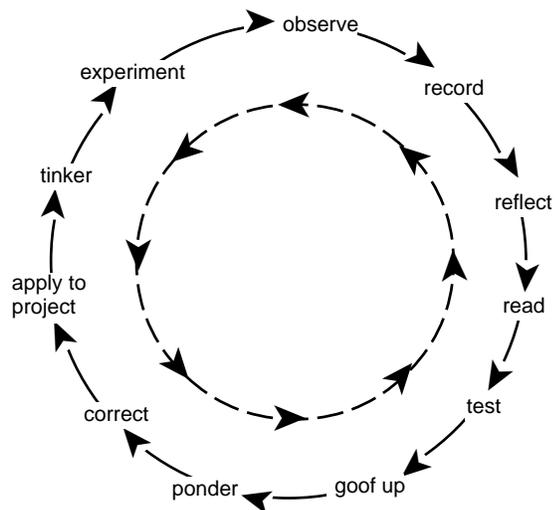


Figure 2.1. MST Learning Process

* The process may be recursive, allowing students to cycle back to gain additional information, even as they move forward.

“As children we were fascinated with ‘tearing’ things apart. As we matured and went through the educational system, the desire or fascination somehow died or was stuffed until only those who could memorize written data and regurgitate it were recognized as being smart or gifted. The so called ‘handy’ student was lost or ran out of places where their skills could be evaluated and appreciated.”

**—Andy Nydam, MST Teacher
River Ridge High School**

Course of Study

Four major units of study form the basis of the MST curriculum. Each unit typically includes the following activities as shown in Figure 2.2. *Note the approximate percentage of time required for each activity.*

Student Experiments—Students conduct experiments individually and in groups (35%). The experiments feed student projects.

Student Projects—Students design, research, create, and build individual or group projects (35%).

Instructor Demonstrations and Presentations—One day per week (20%).

Films, Videos, Guest Speakers, and Visits to Industries and Laboratories—Fostering creativity, developing handiness, and using community resources are also major elements of the MST multi-instructional approach. These elements are integrated into the curriculum through student projects and the instructor’s ability to promote these concepts (10%).

Reading, Writing, and Discussion—These activities are integrated throughout. Students 1) write and sketch in a journal to record observations, procedures, experiments, and progress on projects (information from presentations, guest speakers, tours, readings, and films also is recorded); 2) read and research (through interviews, periodicals, and library resources) in relation to the unit of study or the students’ selected projects; 3) participate in journal writing activities to practice and enhance student writing skills; 4) explore through discussion, writing, and applying the process of creativity, innovation, and scientific inquiry; and 5) study specific occupations that require a special understanding of material characteristics and how these occupations can change as a result of technological change in materials.

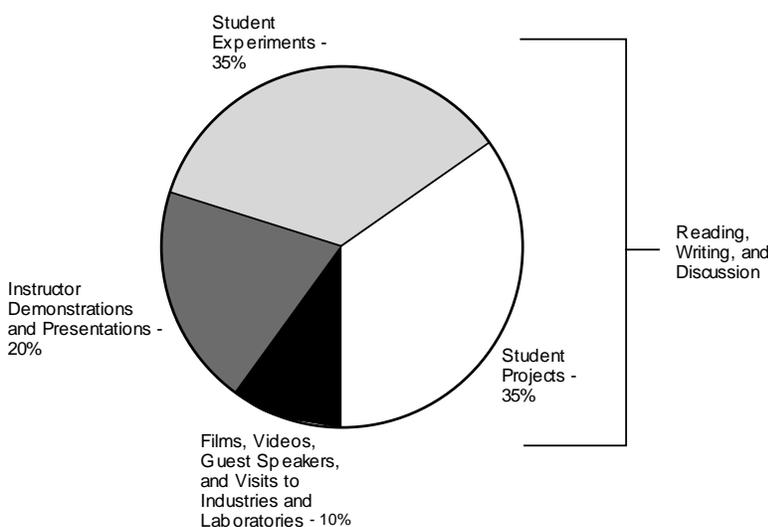


Figure 2.2. MST Activities

“By taking [the MST] class I have really learned a lot. Last year I took a chemistry class and stumbled my way through it. I read the book and did the problems and never really understood any of it. After taking MST, I understood ionic bonding and vanderwalls forces because this class allowed me to take what I learned last year and apply it. Now when I think about chemistry and math I know there is more to it than just numbers, because I can apply this knowledge to real world every day problems.”

***—Tom Gannon, MST Student
Richland High School***

Solving Problems

Engineers and scientists approach materials and materials processing by attempting to solve problems important to society or industry. One good example of a current materials research problem is how cars are designed and built. Right now in the United States materials scientists and engineers are working on how to build a lighter car that will be more fuel efficient and constructed of recyclable materials. This “new” car must have a frame and body as strong as current automobiles. The materials used in its design and manufacture will be revolutionary. That’s a problem. A *big* problem!

How do they go about solving it? First, the auto industry has called in materials experts. In the past, the auto industry’s research laboratories have based most of their research around metals, because they always built cars from metal; but now, to design future cars, the laboratories have had to recruit scientists and engineers who are experts in working with ceramics, polymers, and composites. These experts gather together and brainstorm over what kinds of new materials they might be able to fabricate, what new processes they need to manufacture the new materials, and what kind of new procedures they need to test new materials.

From this “pool of ideas” created by brainstorming the auto industry decides which materials to research, fabricate, and test. These are not all new and revolutionary ideas, however, because some scientists and engineers have been working on similar problems with aerospace crafts for many years. Their expertise proves invaluable in hastening some new materials that will be integrated into future cars.

A Technique Scientists Use to Solve Problems

As materials scientists approach a problem involving new materials, they use statistically designed methods to acquire as much information as they can from a minimal number of experiments. Of course, before doing any experiments, which tend to be expensive and time consuming, they conduct a literature search to look at the reports of the extensive research already done on many materials.

Scientists acquire valuable information from reading what already has been published in scientific and technical journals and reports, which aids them in their research. In some cases, by reading the literature, scientists find that the research they planned to do already has been conducted. The experiment is then designed to aid scientists in narrowing their area of focus to the desired properties and materials they will examine and to learn more detailed information as they study the materials.

The MST course uses problem solving as the foundation of its approach to studying science and technology. One way the course accomplishes this is by having students experiment with materials as scientists do.

“As an MST teacher, you have to develop an attitude that you’re learning too. When you don’t carry an air of knowing it all, students begin to have some ownership and become more willing to share their successes and failures.”

***—Len Booth, former
MST teacher***

The instructional approach allows students to experience specifically how scientists approach a materials problem. Students combine, process, and examine materials as scientists do, then draw scientific conclusions based on what they find. Students learn problem-solving skills by experimenting with materials. They also further this problem-solving process by creating, designing, and building a project of their choice.

Creating Student Projects

Research on teaching and learning shows that people learn best in meaningful contexts and when involved in things they care about. Designing and creating a project is often what draws students to enroll in the MST course, partly because they are attracted to the idea of building something and studying what is current and relevant to them. The project also helps make science, technology, and school relevant to what scientists, engineers, and technologists encounter in their work. The project builds on concepts and skills students learn while experimenting with materials in the classroom. With the project, students get a chance to further use and develop problem-solving skills, demonstrate knowledge of subject material, and follow the scientific process on their own.

The basis of the project is designing, researching, creating, and building an object with materials—a ring, superconductor, belt buckle. Students spend some class time each week working on these objects.

What Constitutes a Project?

Students can choose a project that involves creating some traditional object, requiring traditional tools and equipment (pliers, saw, hammer), or they can focus on an object related to a recent scientific and/or technological advancement, such as a superconductor or foam beam, necessitating laboratory equipment such as a digital scale or balance, beakers, chemicals, and/or a furnace.

For example, a student may decide to make a stained glass window or create a ring from precious metals. Students learn about stained glass in the ceramics unit (amorphous structures), metal alloys in the metals unit (crystalline structures), and the nature and properties of both of these groups of materials. But as students apply this knowledge in a project, they have to connect all the concepts of academic study to real life. These concepts are reinforced by the hands-on/heads-on process involved in the projects. Other student project examples include a honeycomb core stressed-skin composite material, shuttle tiles, a bridge, a polymer/wood cabinet, a radio-controlled airplane, materials testing devices, a chess set, and a belt buckle.

Another Opportunity to Learn

Paul Howard is a master of the teacher as problem-solving facilitator technique. Paul, a goldsmith and artisan in the Richland, Washington, area, visits the MST program at Richland High School several times each week. He is an expert in precious metals and jewelry, and also familiar with what is expected of students in the MST laboratory. Students frequently ask him for help in solving their materials problems.

Paul lets students be the leaders and thinkers. He does this by asking questions and listening as the students talk about their problems. Once, a female student (the vice principal's daughter) had designed a sterling silver ring project, made a wax model of it, invested, programmed and burned out, calculated density, alloyed, centrifugally cast, set a cubic zirconium stone, finished, and added the final polish to the ring, which she planned to give to her boyfriend. She gave the ring to her teacher and he dropped it. Bang! The ring hit the concrete, deforming a corner. While tears rushed down the student's face, the teacher looked for a hole to crawl in. Paul Howard bent down, picked up the ring, and very slowly rolled it over in his hand. Then, he smiled. Paul's answer to this "disaster" was to suggest to the student that she now had "another opportunity to learn." She and Paul decided that the deformation was simply a modification that could be made on the other faces of the ring, providing balance. The teacher learned it is okay to err, and the student continued the learning process by modifying her project.

The Project as a Problem-Solving Tool

Many students choose to design and create metal belt buckles as a project. It would be easy for the teacher to give students a recipe for how to make the metal and directions for what kind of buckle to make, but that would defeat the purpose of MST. Instead, you must guide students in creating a design, selecting the type of alloy they think most appropriate to make their projects, right or wrong, and let them experiment with it. Naturally, in the process of making the buckle, they will encounter problems with the material, such as bubbles forming between the mold and the metal, or the metal deforming too easily because it is too soft or heavy. But these problems are the tools that give students opportunities to develop critical thinking skills, handiness, creativity, and problem-solving techniques.

In using the hands-on problem-solving approach with the metal belt buckle project, for example, students become familiar with the individual elements in the alloy. As students experiment with it, changing proportions of the elements to obtain a metal that is either softer and easier to work, or tougher and more resistant to deformation, they experience alloying first-hand, but they also learn an invaluable lesson about problem solving, how to change materials to meet desired requirements, and they get the personal satisfaction of having worked through a problem.

Teacher as Problem-Solving Facilitator

We see the teacher's role in the project as that of facilitator, a valued resource, someone who encourages students who may need a boost in this open-ended learning process. You have the experience and knowledge to know how to direct students' thought process to help solve problems. You should give students the kind of "help" that will let them solve the problem themselves. Guide students through problems by offering suggestions, not solutions, directing them to ask the right questions, and focusing their direction. In many cases, you may be learning right along with the students.

Projects and the Laboratory Journal

Using a laboratory journal is an integral part of all student projects and other laboratory and class activities. The journal becomes a means for students to explain steps they have taken that may be critical in solving problems they have encountered (see sample student journal entry). When students keep detailed notes, the teacher, or a materials expert or specialist can step in, look at the notes, and perhaps, help assess the process the student is following, and look for areas that may be causing problems in building a project. The journal also gives the teacher a tool for evaluating the unit of study. A more-detailed description of the laboratory journal and tips for how to use the journal follow.

Using The Laboratory Journal

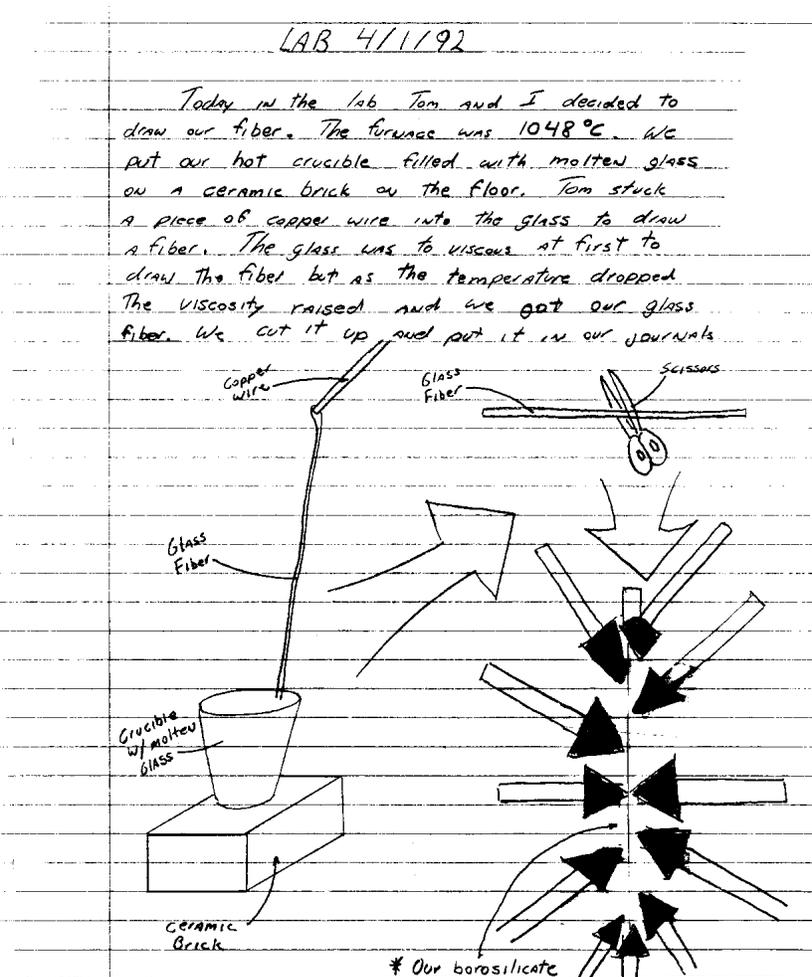


Figure 2.3. Sample Journal Page

Writing is important in the world of science and technology. Many jobs in scientific fields depend on clear written communication. Some say that scientists spend as much as one-half of their working hours writing.

The major tool scientists, engineers, and many others such as doctors, surveyors, architects, or factory production workers use for written communications is the laboratory notebook or journal. This book becomes the permanent record of collected data, experimental results, and conclusions. It is also a tool scientists use to help them in the process of “thinking-out” a problem, for asking questions, making speculations on paper, and clarifying hazy issues or concepts.

Students need to write, too, as part of their exploration of science and technology. They need to practice writing in the journal (see Figure 2.3), not only to record information and observations, but also as an

essential means of learning. Learning to write is learning to think. It prepares the mind for discovery. Students' use of the laboratory notebook can be a novel experience for them. It can also become a symbol of scientific discovery and learning, a way they can relate to and identify with scientists, by having their own scientific "tool," just like a real scientist or technologist. After using the laboratory journal, some students may be motivated to take the scientific concepts they have learned with them and continue the data collection, information gathering, and application process on their own.

Rules for writing in a laboratory journal are not important in this course. The main task is to motivate students to write what they are thinking, observing, or need to remember—information that will be useful for the future. Students can use the journal, as scientists do, to think out a problem, ask questions, or clarify concepts. The important task is to get them to write, draw, think, and collect data in a notebook (see Figure 2.4).

Simply put, students who write about subjects understand them better.

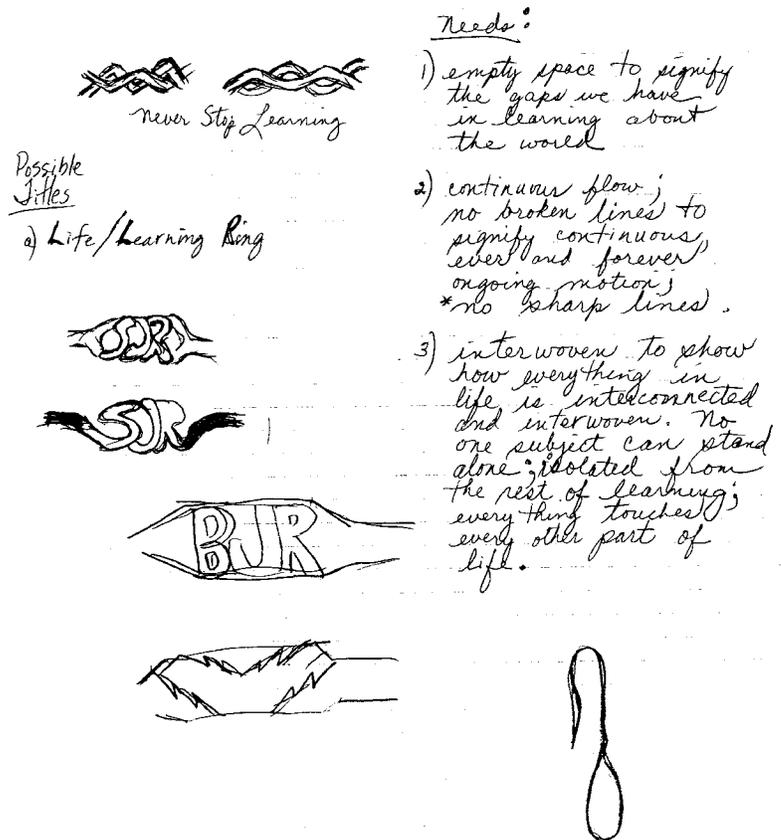


Figure 2.4. Sample Journal Page

Journals used in industry are bound so the numbered pages do not come out. Written items cannot be erased, and generally, any corrections are done with a single line drawn through the deleted word or words. For the practical experience of learning to write, the MST journal may be a loose-leaf three-ring binder. With a binder, students can add extra pages and classroom handouts, or they can take out a specific page and turn it in to the teacher to be read.

Keep in mind that the purpose of the journal is a learning tool. Clear writing promotes clear thinking. The emphasis of writing to learn is on learning content, not on writing skills themselves, although writing skills are likely to improve through practice. In reading student journals, you should not dwell on grammar, spelling, or other technical aspects of language. The general rule should be: "If it does not interfere with clarity of meaning, ignore it."

As students become more familiar with their ability to use their journal, and as they observe other students organizing, writing, and outlining, they will develop an intrinsic sense for the usefulness of their writing and their ability to clearly present what they have learned. The journal will then become for them a reference for following a procedure and for showing other students and the teacher what's been taking place in the classroom and laboratory as well as in a specific experiment. Successful student notebooks are an accountable indication of accomplishment when students have finished the course.

Some MST teachers have emphasized the importance of the journal by assigning a portion of the student's grade to this activity. The journal has also been used in open-book quizzes. Students are a little more motivated to use their journals daily when testing and grading are emphasized as part of the process.

It is essential that you check student journals a minimum of once every other week. Make sure you provide students with written feedback, comments, or advice on their thinking/learning progress.

Benefits of Using the Laboratory Journal

Student Benefits

- Enlarges students' understanding of materials science and technology.
- Encourages participation through a success-oriented activity.
- Helps develop clear thinking.
- Encourages and illustrates the importance of writing across the curriculum.
- Provides an open and risk-free communication with the teacher.
- Provides accountability to teacher for work done.
- Emphasizes the importance of writing whether now or in the real world.

“The daily-logs serve as a record of conceptual difficulties as well as a record of other matters that cause the student to stop and wonder.”

***—Gretchen Kalonji,
Kyocera Professor,
Department of Materials
Science and Engineering
University of Washington***

- Can be used as a resource in an open-journal test.
- Gives students a reason to write.

Teacher Benefits

- Breeds success in the course, encourages teachers.
- Provides insight into students as individuals and their understanding of materials.
- Provides optimum teaching opportunity, i.e., if the students can write about and clearly explain something, teachers know they have taught beyond memorization for a test.
- Promotes “active” teaching; forces teachers to examine course work and their efforts more closely.
- Builds rapport between teacher and student; makes learning a joint effort.
- Provides a future resource for teacher, student, and classmates.
- Provides an effective communication source to encourage students.
- Provides accountability for teacher evaluation for individual students and the entire class.

Journal Writing Activities

You will need to promote using the laboratory journal because many students have learned to think of writing as a difficult task. Daily writing is essential in the MST class for students. A number of activities follow that can be used to stimulate student writing.

Journal Write. *The purpose of this exercise is to get as much information and as many questions onto paper as quickly as possible. Some information may be facts students want to remember, or questions students would like to have answered because an article they read had insufficient information, or the student didn’t have sufficient background to understand it.*

- Distribute a short article (1-2 pages) from a current materials periodical to each student (a list of periodicals is provided in the Appendix). Give students a specified period of time (i.e., 5 minutes) to read the article. At the end of the time period, tell students to stop reading, even if they all haven’t finished the article, and have them begin to write, again, for a specific time period. To help students start writing, give them some writing prompts (see sidebar). You can use an overhead projector, the chalkboard, or hand out the prompts on paper. When time is up, have students count the number of words they wrote, and record them at the bottom of the page.

“Journal Write” Prompts

1. What did you see?
2. What did you read that you didn't know or understand?
3. If you had one question to ask the author, what would it be and why?
4. Why were particular materials used to construct this product?
5. Write down what is bugging you.
6. What things have you seen around you that remind you of this product?
7. What did this article make you think of?
8. What did you learn from this article that you didn't know before?
9. Do you agree or disagree with the article?
10. What would you have done if you had discovered this product?
11. What was the most useful thing you heard in the last 30 minutes?
12. Why do you suppose society wants you to know this stuff?
13. What puzzles you about this article?
14. What made sense to you about this article?

- After a journal write, have students exchange notebooks with a partner. Partners read each other's journals and make comments on the page about the writing (i.e., "Looks good!" or "I wish I could organize my thoughts as well as you did," or "I found the answer to your question a little later in the article").
- Have partners discuss the article or their writing for a short time. These partner activities allow students to learn from other students' strengths and insights as to how they accomplished the task.
- Have the whole class discuss the article and writing experience. Students could be inspired by the article, and learning about a scientific concept or technological process would be a group motivator.
- Use questions evolving from the journal write for student research. Have students find a resource in the community to answer a particular question, or invite a local "expert" to come to class and talk about the question.
- To vary the journal write activity, have students jot down what they already think they know about a topic or article they will read. They can also write questions they hope the article will answer or predict the author's major points. After reading the article, students can then respond to what they wrote.

Daily Write. *The purpose of this activity is to get students to write their thoughts and ideas in the journal. It is also an activity for teaching "thinking on paper," so students become aware of thoughts that occur to them day to day and the thought patterns that might be forming.*

- Ask students to answer the following questions: 1) What did I do in class last time we met? 2) What did I see or learn about MST since the last time we met? 3) If I could ask only one question related to MST, what would it be? Challenge students to find answers to their questions by talking to a local expert or by consulting a resource book such as an encyclopedia, or watching periodicals for a topic on the subject. When the question is sufficiently answered, have students write this information in their journal.

Weekly Summary. *During these weekly reviews, students may discover what learning is taking place over time or what process continues to be a problem. They can sort out some variables of a recurring problem and refocus on a specific answer to a problem (i.e., my glass process continues to be plagued with cracking. I need to learn more about annealing so I can pour uncracked glass). These summaries can also zero in on specific item(s) that may warrant teacher attention.*

- Have students spend 10 minutes each week summarizing their week's work. Use the following journal prompts:

More Prompts for Writing in the Laboratory Journal

I observed...

My idea worked because...

My modification was to...

The experiment was successful because...

I wonder what would happen if...

Next time I'll...

My goal in this project is to...

Before I can go any further I must...

- What did you do this week?
- How did it go, good or bad, and why?
- Who did you work with, and what was the result?
- What did you learn from your work?
- What do you now anticipate? (next steps, needed materials or resources)?
- What are your frustrations and your successes and why?

Writing to Describe a Process. *This kind of writing involves recording the experiment, project, or process in the journal. Students need lots of practice because as they get more involved in making something, they forget to record each step.*

- Have students record all details of a lab they are working on. See sidebar for prompts to help describe a process. Have someone familiar with the process read student entries and make suggestions for how to more accurately describe what has been written.

Resources

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Working in Small Groups

Working in small groups is an essential element of a successful MST program. Small groups develop teamwork and cooperative learning skills, and promote student interactions that allow students with experience and knowledge in specific areas to lead or share with other students.

For example, when a specific experiment requires numbers to calculate chemical batches or explain the chemical bonds, the college preparatory students quickly shine, but typically, the students who learn by doing or applying what they learn do better manipulating and processing materials. In this kind of learning environment, students end up coaching each other, and in the process, learn to respect each other's abilities, and their own (see box).

Working in small groups also gives students a sense of how the "real" work world functions. Often, as we attempt to solve problems, it is not uncommon to find ourselves in content areas with which we are not familiar. Learning to ask for someone's help in solving a problem is a necessary skill in our increasingly complex society.

Building Teams

Bill Howl, an MST student from Olympia, Washington, has had minimal success in school. He still does not read, and he cannot write. Bill chose to make metallic parts from powdered metals as his MST project. He learns best by working with his hands and learning from his mistakes as he worked through the press and sintering processes of making powdered metal parts. When the MST class began working on the powdered metal unit, Bill already knew the process well. So, the students looked to him for help and advice as they learned the procedure. Pretty soon, other students began to recognize Bill as the powdered metal expert, which boosted his self esteem to a level he had never encountered in his school career.

Developing Handiness

“Handiness,”* as we define it, is the ability to solve materials-related problems with available or limited resources. When presented with a problem, without the usual materials to solve it, “handy” people can use their creativity, imagination, and problem-solving skills to come up with a solution that allows them to get a job done.

Handiness is an important component of the MST course. Today, many students are not handy. They lack the ability to solve developmental problems because they don’t understand how to use alternative materials if what they need is not available. The MST course helps students overcome these obstacles by systematically examining many diverse materials, their characteristics, properties, and subsequent uses. By working hands-on with the materials in classroom experiments and on projects, students learn not only about materials, but also techniques to manipulate them—handiness.



A Success Story

The term handiness was coined by Eugene Eschbach, Manager of Innovation and Technology at Battelle. Gene learned to be handy growing up on the family ranch near Yakima, Washington. Gene’s father raised cattle on the open range and was not at home with mechanical things. So, when ranch work was automated, Gene’s brothers had to buy and repair all the machinery.

In the late 1920s, the Eschbach family developed part of their ranch as an amusement park. But Gene’s brothers left the ranch for the military, so Gene had to shoulder many of the responsibilities for fixing things. The park was isolated, a long way from a repair shop, so Gene learned to repair electro-mechanical and electronic devices of all sorts—automated violins, automatic phonographs, and later, the slot machine. He says, “. . . I had an outlet for my creativity, and I was able to reinforce it because the equipment had to work. I was able to implement my ideas, and if I made a mistake, I could fix it without feeling badly because no one noticed my mistakes.”

Gene kept the equipment running, sometimes under much duress, but the work motivated him to be the first in his family to attend college. Even before Gene finished his degree, RCA Laboratories hired him. At RCA, he intensely studied the properties and forming of glass, metals, and ceramics. He was associated with developing what then were highly novel methods of fabricating components. He also helped develop the first large-diameter television picture tube envelope that could be made through mass production techniques. Later, this same design was the foundation of the color television industry. Over the years, Gene has accumulated several patents and hundreds of invention reports. These successes come, in part, from the handiness skills he learned on the ranch as a young boy.

You learn to work with what you get. Sometimes the 'lemonade' is a lot better than the result you planned. Glass-ceramics were an accident. An annealing furnace did not turn off as programmed. Instead of throwing it away, Donald Stookey asked himself, "What is this stuff anyway?" This led to a whole new field within glass making.

***—Mary Bliss,
Materials Research Scientist
Battelle***

Fostering Creativity

Setting up a classroom/laboratory environment where the focus of learning is discovery and exploration provides a unique opportunity for students to develop and enhance their creativity. The MST course's inquiry approach to problem solving, the experimental design model with open-ended experimentation, and projects all help students use their creative skills.

All students are capable of being creative, but their creativity generally has not been tapped and at times has been stifled by our formal educational process. The standard learning approaches—passively reading textbooks, listening to lectures, and doing cookbook-style labs with "set" results that guarantee the right answer—have created "fearful" students, who are not willing to take risks because they might get the wrong results.

Part of fostering the creative process is letting students make mistakes. Because the MST program emphasizes the learning process over right answers, it takes the pressure off students of always having to be right. The learning environment provides them instead a freedom to experiment with their own hypotheses, make some mistakes, and learn from their failures. Making mistakes means acknowledging unexpected results or unpredicted scientific outcomes. It doesn't mean sloppy experimentation or poor safety practices, ignoring materials or processes that would lead to an injury, fire, or explosion.

Learning from mistakes is key to the scientific process. Battelle's Gene Eschbach is first to admit and reinforce this concept. In an article Gene wrote about his early work experience at RCA Laboratories, he describes his experience related to making mistakes (see box, next page).

Tips for Fostering Creativity

- Create an atmosphere where students are willing to risk and feel it is okay to make mistakes.
- Develop a rapport with students that gives them a feeling of acceptance, trust, and team spirit.
- Remember that some students will be able to express their creativity rapidly, which can stimulate other students whose skills may take a while to surface. At the smallest sign of a creative idea, encourage these students, and let them see they do have abilities.
- Recognize that making mistakes is an acceptable tool for learning within the classroom. But, be very careful in distinguishing between using the mistake as a learning tool and introducing scientific concepts that are erroneous. Continually check your knowledge of scientific concepts, and likewise, be attentive to what students are learning by checking their journals, listening to their discussions, and clarifying the important scientific concepts being developed in the units of materials study.

“Several years ago, a chemistry teacher stopped by the auto shop to ask if I would give a demonstration on the operation of an air conditioning system to sophomore chemistry students. “Sure! What for?” I said with moderate suspicion. (After all, how often do science teachers mix with shop teachers? The science teacher’s response to my question was the genesis of a new direction in philosophy and curriculum in our school toward technology.)”

***—Robert Gauger, Chairperson,
Technology Department
Oak Park and River Forest
High School, Oak Park, Illinois***

An Honor to Err

That it’s OK to err during an investigation or during a learning process was brought home to me again and again by my most illustrious mentor, Dr. Lloyd Preston Garner of RCA. The laboratory by his design was indistinguishable from its support function, namely: the instrument makers, tool and die makers, electricians, and electronics experts, who were all housed among aspiring scientists.

Dr. Garner told all of us on many occasions not to hide our errors but to share them with others because he believed that “our errors are our greatest teachers.” One day he found in a wastebasket a part from an experiment that was damaged. He grabbed the part, called everyone to an informal meeting, and asked who had thrown the part away and why? Then he asked why the rest of our group was not made aware of the error and the mistake. Dr. Garner went on to say that an error was, first, an opportunity to learn, and second, an indication of a possible shortcoming. Moreover, that it was usually a manifestation that “Mother Nature was trying to tell us something,” and not an oversight to be covered up. From then on, Dr. Garner said it would be an honor to err. A 20-ft-long trophy case was placed in his office exhibiting all errors and surprises after they were analyzed.

I was privileged to be with Dr. Garner for 4-1/2 years. And during that time I filled 4 of the 5 shelves with errors, unusual events, and an occasional triumph. “Errors” included events where an experiment did not “come out” as we expected or predicted. Many such “errors” became “happy accidents.” A few years ago I visited Dr. Garner (in his late eighties now), and within 5 minutes of our visit he said (and I was after all in my sixties), “Gene, errors are our greatest teachers, don’t hide your errors, and more importantly, run fast enough to still make them.”

—Eugene Eschbach,
Manager of Innovation and Technology, Battelle

Teaching in Teams

Combining science and technology is an integral element of the MST program. So, we recommend the course be taught by both a science and a technology teacher. Because materials science and technology is a new field of science, bringing with it some unexplored areas in traditional science and technology education, the combined expertise of two teachers enhances student learning, particularly where science concepts are heavily combined with materials processes and application (technology per se).

Students learn from the diversity of teaching styles and from the strengths of each teacher. Teachers also benefit from the interaction, learning from each other’s strengths. We have found that some of the most successful MST courses have been taught with this combination.

Using Community Resources

Community resources are important to the MST program, helping to bring reality to the classroom. Ways to use community resources can vary from inviting local materials experts to visit the classroom and taking field trips to local cement plants, jewelry workshops, and specialized materials application sites to forming local MST advisory committees and developing mentors and partnerships. Remember, anyone who makes “stuff” is a potential resource. The local telephone directory is an excellent tool for locating resources.

Community volunteers can be wonderful mentors if they are properly instructed to help students, guiding them toward the solution to a problem. Mentors should be motivators, answering students’ questions, perhaps with another question, or giving students clues as to where to direct themselves to solve a problem, or showing students a process they know will help them better conduct an experiment or project.

Richland High School MST teacher Steve Piippo, who first developed the MST approach with scientists at Pacific Northwest National Laboratory, describes below how he developed an important relationship with local goldsmith/artisan Paul Howard in the box below.

Community Mentor

About 1985 while teaching in the laboratory a man walked in and very casually asked, “Can I be of any help to you or your students?” The man turned out to be local goldsmith Paul Howard. Paul is an artisan who now volunteers his time in the MST laboratory. He arrives at school without standard teacher attire, attendance responsibilities, or grading responsibility. He looks at each student as an individual who is motivated to create a precious metals project (metal alloys) and experience the feeling of accomplishment and success. Paul requires that each student record questions, ideas, and information in a learning log and that each question be the result of a previous application of research. Paul does not fall into the “tell me what to do next” trap. Each student’s question is followed with, “What do you have in your log,” “Have you checked this reference,” or “What do **you** think would work?” Students quickly learn that Paul does not regurgitate the answer but makes them derive their own individual solutions and apply their ideas as a solution. Every community has businesses that would provide a mentor, if asked. Try calling artisans, rock hounds, model airplane builders, dental technicians, American Society of Materials members, and members of the Society of Mechanical Engineers, Society of Plastics Engineers, junior college or university artisans, boat builders, ceramic and stained glass businesses, and other local businesses.

—Steve Piippo, Richland High School MST teacher

Building a School/Community Advisory Committee

An ideal MST advisory committee membership comprises teachers, administrators, curriculum directors, vocational directors, and representatives from local MST-related industries, who meet monthly to find out such things as 1) what is happening in the MST course, 2) what equipment might be needed, 3) ways local business/industry can assist teachers/students in laboratory activities or arrange field trips to their businesses, 4) and future activities in which students will be involved.

Advisory committee members can help students understand MST and also help teachers stay current in MST by sharing experience, knowledge, journals, information, and videos. Meetings can be held either at a place of business or in the MST lab.

Getting the Advisory Committee Started

We have found several ways that work well to get a local advisory committee started. A few suggestions follow.

1. Have students write an autobiographical sketch that includes what their parents do for a living and for special hobbies. Some parents will have jobs and hobbies that fit in well with the content of MST. Then ask those parents whose jobs/hobbies match your units of study if they would like to be part of your committee. Most people will be motivated to help since they have a vested interest (their son or daughter) in the class.
2. Look through the yellow pages and find any possible MST-related businesses/industries. Call or write a letter to any that sound interesting, inviting them to participate in the advisory committee.
3. Visit local industries, ask for a tour, get acquainted with the people, and tell them about your program. Occasionally, you will get a negative response, but most of the time people want to help their local school system. The following are examples of MST kinds of businesses in your area.

Plastics:

Tub, spa, and swimming pool manufacturers
Boat builder
Plumber
Auto repair
Injection molding corporations
Toy manufacturers

“At first, starting an MST course is really intimidating. It’s like jumping on the highway without a map. Then you begin to become fairly competent.”

—Andy Nydam, Olympia High School MST Teacher

Glass and Ceramics

Artists
Stained glass
Blown glass
Pottery
Glass manufacturer
Bottle recycler
Dental lab
Glass shop
Concrete plant

Metals

Metals shop
Metal fabricating shop
Sheet metal union
Jeweler
Sculptor
Local college or high school metals instructors
Auto body shop
Tool & die shop

Composites

Recreation supply
Sporting goods
Airplane manufacturers
Automotive supply

Woods

Lumber yard
Wood supplier
Paper mill
Plywood mill
Saw mill
Finish carpenter

4. Don't forget state, regional, and national professional societies, such as the Materials Research Council, Society of Plastic Engineers, the American Ceramic Society, and the American Society of Materials.

“The technology education laboratory provides a setting that abounds with opportunities for a broad range of learning activities extending from the concrete to the abstract.”

—International Technology Education Association

Setting Up The MST Classroom and Laboratory

To best facilitate the MST multi-instructional approach, you need two types of facilities: a classroom and a laboratory. A classroom and separate laboratory would be the ideal facility, but, in many places this is impossible. Figure 2.5 shows a design for a typical MST facility.

The classroom provides a formal place for class discussions, instruction, lecture, safety meetings and guest speakers, a traditional school classroom, with desks, chalkboard, bulletin boards, and book shelves. The classroom also should provide a quiet place for students to record journal entries and study complex concepts.

The MST laboratory provides a much different atmosphere. With multiple activities occurring, you hear the chatter of students discussing problems, projects, or the latest news in recent MST periodicals. You hear the buzz of a diamond cut-off saw, the clatter of spatulas, and the growl of the oxyacetylene torch, all common sounds for the MST laboratory setting.

The teacher is the key to helping and training students to work in this open environment, where learning takes place amidst constant busyness. Students learn much through this designed-discovery process. But teachers also need to be sensitive in motivating students who may be frustrated with a problem or insecure in the open-ended MST process. Most importantly, you must maintain accountability in a system that demands students cooperate with each other and at the same time work with safety as a key concern.

In setting up an MST laboratory, don't forget to consider proper storage space. Chemicals, materials, and equipment used periodically or once a year need to be stored in locked cabinets or a storage room. Also consider storage needs for chemicals that must be separated and stored in specific areas because of their flammability or incompatibility.

The design of the facility must provide a safe learning atmosphere. There has to be sufficient space and openness to allow students to freely move around work areas without crowding those who are performing laboratory experiments. It is also important for the teacher to be able to scan the laboratory quickly to assess the safety and performance of all students.

Also, ventilation of specific work locations such as an exhaust canopy over the furnaces and the area where students solder are important considerations. Heat and flammable materials must be properly separated to meet building and safety code. Chemical hazards must also be addressed to ensure students are protected from potential injury.

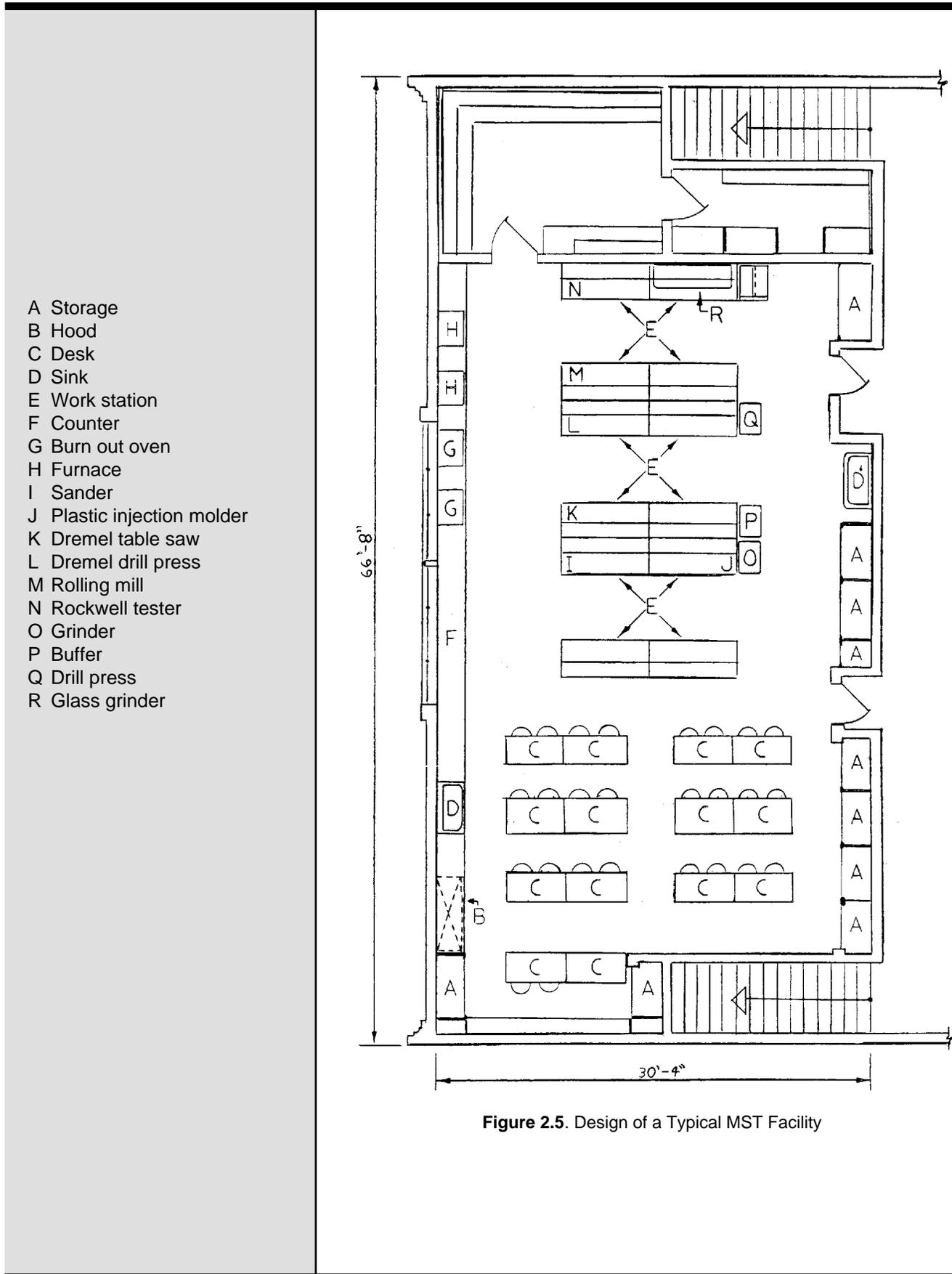


Figure 2.5. Design of a Typical MST Facility

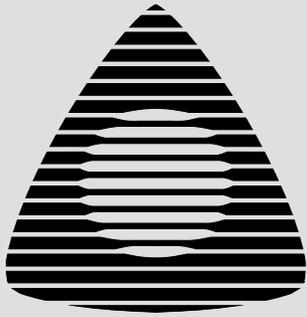
Laboratory Safety

Before beginning any experiment/demonstration, you must discuss safety with students and establish laboratory rules. To perform laboratory procedures without considering student safety can endanger all people in the laboratory. For some students, the MST experiments are their first experience working with testing materials, using laboratory tools, and working in the same space with other students.

You must be aware of your state's safety rules or guidelines for laboratory safety. Training students in how to safely perform laboratory procedures and operate tools and equipment used to conduct experiments and complete their projects is of utmost importance. Please consider the following items when developing laboratory rules.

- **Protect your eyes and students' eyes.** Whenever the classroom is set up in a working (laboratory) mode, or your facility has a dedicated MST laboratory, the first thing students should do is put on their safety glasses—even before setting up the experiment. Those visiting or walking through the laboratory must also wear safety glasses. At first, some students may feel awkward about wearing the glasses, but once everyone wears them, they feel more comfortable and learn the importance of protecting their eyes. Getting into the habit of wearing safety glasses also reminds students to be more safety conscious.
- Ensure that other body parts are protected from possible hazards. Wear gloves, aprons, chemical goggles, and masks, when necessary. Use tongs and other protective equipment, when necessary. Wear long pants (i.e., blue jeans) and leather shoes while working with molten material.
- Students need to know the differences between safety glasses and chemical goggles and use them appropriately. This means they need to have access to both kinds of eye protection.
- Adequately ventilate the laboratory. Make sure vents are not near building intakes.
- Most vaporized metals are health hazards, and exposure should be limited.
- Ensure correct safety labels are attached and safety signs posted in appropriate places. Explain all signs and emergency equipment; do not assume they are self-explanatory.
- Be aware and have a working knowledge of materials safety data sheets (MSDS) reports for materials used in the laboratory.
- Ensure that students working in the laboratory give each other consideration and distance. Make sure students moving from one work area to another are conscious of their surroundings and avoid bumping into other students.

- Make sure students clean up after completing each experiment or day's work.
- Avoid contaminating chemicals or surfaces.
- **Horseplay must not be allowed in the laboratory at any time.** Students need to know the seriousness and consequences of horseplay. Accidents don't happen. They are caused by carelessness.
- Emphasize wearing "proper" clothing. Shorts and open-toed shoes are not appropriate in a laboratory setting. Panty hose can be readily dissolved by acids and/or solvents, causing chemical burns. Long hair should be tied back. Loose clothing should not be worn. Have alternative activities ready for students not appropriately dressed. A study area where these students can work during laboratory time is useful. Or, keep extra safety apparel on hand that students can borrow for the class period.



Standards, Learning Goals, and Assessment

Standards, Learning Goals, and Assessment

This section reports on the development of national education standards in mathematics, science, and technology education. It also provides an overview of the MST course with learning goals for students and suggested strategies for assessing student learning. An overview of the national school-to-work legislation also is provided.

National Education Standards for Curriculum, Assessment, and Teaching Strategies

Just six years ago, the nation's political and education leaders recommended that national education standards be developed for all core subjects. The precedent for this national effort was the National Council of Teachers of Mathematics' (NCTM) *Curriculum and Evaluation Standards for School Mathematics* completed in 1989. In 1991, NCTM issued teaching standards to be used in conjunction with the 1989 standards.

The National Research Council's (NRC) National Committee on Science Education Standards and Assessment (NCSESA), with input from groups such as the National Science Teachers Association (NSTA) and the American Association for the Advancement of Science (AAAS), have developed national standards in five areas of science education: science teaching, professional development assessment, content and science education systems.

Although similar standards for technology education have, to date, been developed only at the state level, considerable discussion has occurred about the role of technology in the national standards for mathematics and science.

National standards are not intended to be pronouncements from on high about what goes on in classrooms. Standards are the goals for which we strive, the "banners" under which we define and teach the curriculum and assess student learning. Standards define demanding but attainable learning goals that impart a vision of what we want all our young people to know and be able to do. But they are not prescriptions; they are suggested guidelines. And they must be backed by a nationwide consensus support.

Why do we want standards? First, standards give everyone a common language to communicate agreement on high-quality education. Standards can identify, reward, and defend best practices. For example, supervisors of innovative mathematics teachers will be faced with a

strong counterargument in the standards if they tell teachers that they must drill students on meaningless computational exercises. And publishers and producers of instructional materials and tests that do not align with the standards will face opposition from teachers aware of national standards. Standards can, and ultimately will, influence the context in which every student and teacher functions.

The National Education Standards and MST

As we continue to develop the MST curriculum and the strategies for teaching and assessing student learning, we are ever conscious of our desire to align with the emerging national standards in science, mathematics, and technology education.

Much of what we are now coming to know as national standards was present from the beginning of MST. For example, the interdisciplinary nature of MST reflects the national standards that address the value of connecting and interrelating the disciplines. Following are passages from the science, mathematics, and technology standards, respectively, that call for connections among the disciplines:

“...include all natural sciences and their interrelationships, as well as the natural science connections with mathematics, technology, social science, and history.”

“...use and value the connections between mathematics and other disciplines.”

“...articulate the concepts of mathematics, science, social studies and the arts in the context of technology education.”

The standards have challenged educators to see the content differently and have led to new understandings of science, mathematics, and technology in the classroom. Commonalities among the three disciplines are evident in the standards. All three call for active learning where all students, not just a talented few, gain an in-depth understanding of the subject. The standards call for varied groupings in the classroom in contexts that model the process of inquiry that real-life scientists, mathematicians, and technologists use to uncover new knowledge and solve problems. MST models this process.

The standards-setting process is very new in our nation, and it is not complete. Therefore, the results of that process are only now becoming widely known. As we learn more about the standards, more will be incorporated in MST.

'We are living in a world where what you earn is a function of what you learn.'

—President Bill Clinton

School to Work Opportunities Act

MST provides an environment where all students can develop knowledge and skills useful in a science and technology workplace. Not only does the course reach those 75% of the student population who do not pursue baccalaureate degrees, it also appeals to students in the so-called academic track. The course integrates academic and vocational learning to the extent that it simulates the environment in which scientists and technologists uncover knowledge and solve problems, the kind of school-based learning that assists students in their transition from school to work.

In combination with structured work-based learning and attention to connecting activities, MST fulfills purposes of the new federal legislation President Clinton signed into law in May 1994. The School to Work Opportunities Act is a national effort to develop a school-to-work system to assist students in making the transition from school to the adult workforce. The goal of the Act is to create well-marked paths students can follow to move from school to good first jobs or from school to continued education and training.

The Act focuses on broadening educational and career opportunities for all students by encouraging state and local partnerships between businesses and education institutions. The partnerships will help students make the connection between what they learn in the classroom and what they will be required to do in the workplace.

Although administered and funded by the U.S. Departments of Education and Labor, the initiative puts the onus on state and local partners (students, teachers, parents, business, labor representatives, community-based organizations) to build school-to-work systems to benefit their communities. Four major types of grants are available to help states and localities build their own customized systems. However, every school-to-work system must include three core elements: school-based learning, work-based learning, and connecting activities to help bridge the gap between school and work—the kinds of activities that are a part of MST.

The School to Work Opportunities Act was introduced as a result of increasing national concern about students who pursue little or no formal education beyond high school. Currently, 75% of students in the nation attempt to enter the workforce directly from high school or following only 1 or 2 years of college. Many are not successful in moving from school to work, particularly in areas requiring knowledge and skill in science, mathematics, and technology. They lack basic academic and entry-level occupational skills necessary to succeed.

Although originally designed to deal with students not earning a college degree, the final version of the School to Work Opportunities Act stressed that a school-to-work transition system serve all students, even those bound for college. MST is an example of a curriculum that serves this purpose.

MST Course Content Outline

The following course outline is one example of content to be included in an MST course. You can develop your own as you create a program that fits your district.

Introduction

- Materials - The basic nature and properties of materials
- Solid state - Materials divided into two categories: crystalline and amorphous

Body of Course

- Nature of metals - Properties and characteristics of metals
- Nature of ceramics - Properties and characteristics of ceramics
- Nature of glasses - Properties and characteristics of glasses
- Nature of polymers - Properties and characteristics of polymers
- Nature of composites - Properties and characteristics of composites

Topics to be Integrated

- Physical Properties
 - Thermal properties of materials
 - Electrical properties of materials
 - Strength of materials
 - Optical properties of materials
- Chemical properties
- Periodic table of elements
- Methods of scientific inquiry
- Significant developments in the history of materials
- Application of materials
- Systems of technology development

Integrating MST into Existing Classes

Because MST is a study of “stuff,” it is a relatively simple task to incorporate much of the MST curriculum into an existing physical science class. Typically, MST materials have been used as an integral part of chemistry, substituting more relevant MST experiments for the recipe format found in a most supplemental chemistry manuals. The following is a brief description of one way to integrate MST materials into sections of a first year chemistry course:

Chemistry Topic	MST Experiments/Demonstrations
Chemical elements	Classification of materials
Metals and their properties	Drawing a wire Crystal structure Alloys Pb/Sn alloy Sterling silver Pewter Metals project
Non-metals	Crystal structure Sulfur and its allotropes Amorphous vs crystalline structure Glass Glass project
Carbon chemistry	Polymers Nylon Soft and hard foams RTV Epoxy Polymers project
Oxidation/Reduction	Raku
Stoichiometry	Formulas for glass Heat change of Zn/Al alloy
Chemistry notebook	MST journal
Chemistry text	MST resources, including teacher guide

Learning Goals

Possible learning goals related to the example content outline are highlighted in the box below. The goals are not meant to be tied to specific units of the MST course.

On completing the course, the student will be able to:

- identify materials specific to our environment
- classify materials as metallic or non-metallic
- classify materials as crystalline or amorphous
- describe through writing and discussion the basic properties of materials: mechanical, thermal, chemical, optical, and magnetic
- characterize materials on the basis of chemical bonding and crystal structure
- demonstrate that the properties of materials can be altered by changing their chemical makeup or physical makeup by treating them in various ways through experiments, projects, and written/oral explanations
- use terms specific to materials science and technology in writing and oral presentations
- demonstrate through writing and oral explanations the application of the powers of observation, measurement, and comparison to analyze materials, their properties, and applications
- demonstrate the basic processes of extracting, preparing, and producing materials used in the course through laboratory exercises and projects
- select materials for specific uses based on the properties, characteristics, and service of the materials
- flourish in an environment of creativity
- demonstrate critical thinking skills through problem solving in manipulating and controlling the materials used in the course
- use writing to record observations, procedures, and experiments and as a tool for thinking, studying, and learning the subject matter
- demonstrate in writing and discussion an appreciation and understanding of significant developments in the history of materials
- select, design, and build a project or projects demonstrating the creative and innovative application of materials
- work in a cooperative group setting to solve problems
- demonstrate practical reasoning, and hands-on/minds-on, problem-solving skills in designing, fabricating, and constructing projects during the course.

Assessment

Assessing student learning and instructional quality is an important part of the MST course as it is for all science, mathematics, and technology education. And for MST, assessment means more than just testing. You would be hard pressed to design a multiple choice or short answer test to measure the outcomes of this course. MST's activity-oriented approach requires that you look at assessment differently.

Because the instructional approach focuses on hands-on/minds-on processes, assessment also should focus on evaluating these processes and thinking skills. Assessment techniques should emphasize asking students to generate their own answers and measure scientific thinking and laboratory skills.

Some common characteristics of this kind of assessment, called "authentic" assessment, include the following:

- asking students to perform, create, produce or do something
- tapping higher level thinking and problem-solving skills
- using tasks that represent meaningful instructional activities
- invoking real-world applications
- using people, not machines, to do the scoring, using human judgment
- requiring new instructional and assessment roles for teachers (Herman et al. 1992, p. 6).*

Using authentic assessment, which mirrors MST's problem-solving approach to teaching, you can assess both product and process. You might ask students, for example, to perform a laboratory experiment or solve a real-life problem, using the equipment, materials, and procedures as they would in class. By observing and asking questions, you can evaluate both the process students use and their understanding of the major concepts involved.

Other approaches you might use to assess process include clinical interviews, documented observations, student learning logs and journals, student self-evaluation (oral or written), debriefing interviews about student projects (where the student explains what, why, and how and reflects on possible changes), and student think-alouds in conjunction with standardized or multiple choice tests.

To assess products, you may use essays with prompts, projects with a rating scale, student portfolios with a rating scale, posters/presentations (which mirror the way scientists often present results), student demonstrations of paintings, drama, dances, and stories with a rating scale, and standardized or multiple choice tests, perhaps with a section for explanations (Herman et al. 1992, p. 7).

*Herman J.L., P.R. Aschbacher, and L. Winters. 1992. *A Practical Guide to Alternative Assessment*. Association for Supervision and Curriculum Development, Alexandria, Virginia.

Recent Trends in Assessment

As approaches to teaching and learning have changed, so has assessment and its role in ensuring effective instruction. Recent trends in assessment, highlighted in the box below (Herman et al. 1992, p. 13), show some of these changes.

- Changes from behavioral to cognitive views of learning and assessment
 - From sole emphasis on the products or outcomes of student learning to a concern for the learning process
 - From passive response to active construction of meaning
 - From assessment of discrete, isolated skills to integrated and cross-disciplinary assessment
 - From behavioral manipulations to attention to metacognition (self-monitoring and learning to learn skills) and conative skills (motivation and other areas of affect that influence learning and achievement)
 - Changes in the meaning of knowing and being skilled—from an accumulation of isolated facts and skills to an emphasis on the application and use of knowledge.
- From paper-pencil to authentic assessment
 - From standardized testing to relevance and meaningfulness to students
 - From single skills to an emphasis on complex skills
 - From single correct answers to multiple solutions
 - From hidden standards to public standards, known in advance
 - From uniform expectations to individual pacing and growth.
- Portfolios: from single occasion assessment to samples over time
 - As a basis for assessment by teacher
 - As a basis for self-assessment by students
 - As a basis for assessment by parents.
- From single attribute to multi-dimensional assessments
 - For recognition of students' many abilities and talents
 - For growing recognition of the malleability of student ability
 - For opportunities for students to develop and exhibit diverse abilities.
- From near exclusive emphasis on individual assessment to group assessment
 - Through group process skills
 - Through collaborative products.

Assessment Techniques

In designing assessment strategies you should keep in mind that the keys to assessment are defining goals to be assessed and the criteria used to assess them. As with other formal assessment, you should ensure that the strategy you use specifies the 1) nature of the skills and accomplishments students are to develop, 2) illustrative tasks that would require students to demonstrate these skills and accomplishments, and 3) criteria and standards for judging student performance on the tasks. You also need to develop a reliable rating process and use your results to refine assessment and improve curriculum and instruction (Herman et al. 1992, p. 8). Some example techniques that have been developed to rate student performance are highlighted below.

Task Sheet

One team of MST teachers developed the task sheet shown in Figure 3.1 to track student progress. All projects and experiments on which students work are listed on the sheet. A five-point rating system is defined for the tasks. When a student completes a task, you check the appropriate column. The point values have criteria assigned to them, which the students should know. One point means the task was completed; three points means the task was completed, and the student can explain the process; and five points means the task was completed, and the student was capable of teaching another student how to do the task.

Task Sheet	Name _____		
Experiment/Demonstration	1 pt	2 pts	5 pts
Crystal Study			
Properties of Metals			
Alloying Copper and Zinc			
Drawing a Wire			

Figure 3.1. Task Sheet for MST Assessment

Scoring Guide

The California Assessment Program 1990 developed a Scoring Guide: Group Performance Task form that can be adapted for the MST evaluation. Figure 3.2 shows the four components and five levels of accomplishment. Each level has been defined so you, the student, and others know the assessment criteria. Figures 3.3 and 3.4 show a CAP generalized rubric and an objectives rating form.

Figure 5.1
California Assessment Program 1990
History-Social Science Grade 11
Scoring Guide: Group Performance Task

	Level I Minimal Achievement	Level II Rudimentary Achievement	Level III Commendable Achievement	Level IV Superior Achievement	Level V Exceptional Achievement
Group and Collaborative Learning 20	(1-4) Exclusive reliance on one spokesperson. Little interaction. Very brief conversations. Some students are disinterested or distracted.	(5-9) Strong reliance on spokespersons. Only one or two persons actively participate. Sporadic interaction. Conversation not entirely centered on topic.	(8-12) Some ability to interact. At least half the students confer or present ideas. Attentive reading of documents and listening. Some evidence of discussion of alternatives.	(13-16) Students show adeptness in interacting. At least 3/4 of students actively participate. Lively discussion centers on the task.	(17-20) Almost all students enthusiastically participate. Responsibility for task is shared. Students reflect awareness of others' views and opinions and include references to other opinions or alternatives in presentation and answer. Questions and answers illustrate forethought and preparation.
Critical Thinking 30	(1-6) Demonstrates little understanding and only limited comprehension of scope of problem or issues. Employs only the most basic parts of information provided. Mixes fact and opinion in developing a viewpoint. States conclusion after hasty or cursory look at only one or two pieces of information. Does not consider consequences.	(7-12) Demonstrates only a very general understanding of scope of problem. Focuses on a single issue. Employs only the information provided. May include opinion as well as fact in developing a position. States conclusion after limited examination of evidence with little concern for consequences.	(13-18) Demonstrates a general understanding of scope of problem and more than one of the issues involved. Employs the main points of information from the documents and at least one general idea from personal knowledge to develop a position. Builds conclusion on examination of information and some consideration of consequences.	(19-24) Demonstrates clear understanding of scope of problem and at least two central issues. Uses the main points of information from the documents and personal knowledge that is relevant and consistent in developing a position. Builds conclusion on examination of the major evidence. Considers at least one alternative action and the possible consequences.	(25-30) Demonstrates a clear, accurate understanding of the scope of the problem and the ramifications of the issues involved. Employs all information from the documents and extensive personal knowledge that is factually relevant, accurate, and consistent in the development of a position. Bases conclusion on a thorough examination of the evidence, an exploration of reasonable alternatives, and an evaluation of consequences.
Communication of Ideas 20	(1-4) Position is vague. Presentation is brief and includes unrelated general statements. Overall view of the problem is not clear. Statements tend to wander or ramble.	(5-9) Presents general and indefinite position. Only minimal organization in presentation. Uses generalities to support position. Emphasizes only one issue. Considers only one aspect of problem.	(8-12) Takes a definite but general position. Presents a somewhat organized argument. Uses general terms with limited evidence that may not be totally accurate. Deals with a limited number of issues. Views problem within a somewhat limited range.	(13-16) Takes a clear position. Presents an organized argument with perhaps only minor errors in the supporting evidence. Deals with the major issues and shows some understanding of relationships. Gives consideration to examination of more than one idea or aspect of the problem.	(17-20) Takes a strong, well-defined position. Presents a well-organized, persuasive argument with accurate supporting evidence. Deals with all significant issues and demonstrates a depth of understanding of important relationships. Examines the problem from several positions.
Knowledge and Use of History 30	(1-6) Reiterates one or two facts without complete accuracy. Deals only briefly and vaguely with concepts or the issues. Barely indicates any previous historical knowledge. Relies heavily on the information provided.	(7-12) Provides only basic facts with only some degree of accuracy. Refers to information to explain at least one issue or concept in general terms. Limited use of previous historical knowledge without complete accuracy. Major reliance on the information provided.	(13-18) Relates only major facts to the basic issues with a fair degree of accuracy. Analyzes information to explain at least one issue or concept with substantive support. Uses general ideas from previous historical knowledge with fair degree of accuracy.	(19-24) Offers accurate analysis of the documents. Provides facts to relate to the major issues involved. Uses previous general historical knowledge to examine issues involved.	(25-30) Offers accurate analysis of the information and issues. Provides a variety of facts to explore major and minor issues and concepts involved. Extensively uses previous historical knowledge to provide an in-depth understanding of the problem and to relate it to past and possible future situations.

Figure 3.2. California Assessment Program 1990 Scoring Guide (from Herman et al.1992, pp. 46, 47)

Figure 5.3**CAP Generalized Rubric**

(California State Department of Education 1989)

Demonstrated Competence**Exemplary Response . . . Rating = 6**

Gives a complete response with a clear, coherent, unambiguous, and elegant explanation; includes a clear and simplified diagram; communicates effectively to the identified audience; shows understanding of the open-ended problem's mathematical ideas and processes; identifies all the important elements of the problem; may include examples and counterexamples; presents strong supporting arguments.

Competent Response . . . Rating = 5

Gives a fairly complete response with reasonably clear explanations; may include an appropriate diagram; communicates effectively to the identified audience; shows understanding of the problem's mathematical ideas and processes; identifies the most important elements of the problems; presents solid supporting arguments.

Satisfactory Response**Minor Flaws But Satisfactory . . . Rating = 4**

Completes the problem satisfactorily, but the explanation may be muddled; argumentation may be incomplete; diagram may be inappropriate or unclear; understands the underlying mathematical ideas; uses mathematical ideas effectively.

Serious Flaws But Nearly Satisfactory . . . Rating = 3

Begins the problem appropriately but may fail to complete or may omit significant parts of the problem; may fail to show full understanding of mathematical ideas and processes; may make major computational errors; may misuse or fail to use mathematical terms; response may reflect an inappropriate strategy for solving the problem.

Inadequate Response**Begins, But Fails to Complete Problem . . . Rating = 2**

Explanation is not understandable; diagram may be unclear; shows no understanding of the problem situation; may make major computational errors.

Unable to Begin Effectively . . . Rating = 1

Words do not reflect the problem; drawings misrepresent the problem situation; copies parts of the problem but without attempting a solution; fails to indicate which information is appropriate to problem.

No Attempt . . . Rating = 0**Figure 3.3.** CAP Generalized Rubric (from Herman et al. 1992, p. 56)

Figure 5.7
PART II: Objectives Rating Form — Individual

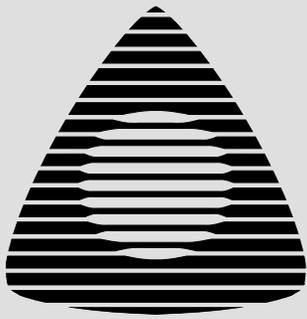
Title of the Task: _____ Task # _____ Student ID # _____

Teacher ID #: _____ Date: _____

The group should be able to...	Where to Find Evidence				E	G	N.I.	*
1. Identify and apply physical and/or chemical properties for the purpose of identification.					<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	
2. Identify information and steps needed to solve a problem.					<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	
3. Communicate the strategies of a study through written means.					<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	
					<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	
					<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	
					<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	
					<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	
					<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	
* Check if students' work is a strong and clear example of rating given.								

(Connecticut Department of Education 1990) E = Excellent G = Good N.I. = Needs Improvement

Figure 3.4. Connecticut Department of Education 1990 Objectives Rating Form (from Herman et al. 1992, p. 56)



Experiments/ Demonstrations

Introductory

Introductory

Introduction

These introductory experiments are some of the laboratory experiments and demonstrations designed to grab students' attention, pull their minds from predictable everyday classroom activities, give them something to look forward to, and teach them some simple principles and properties used by materials scientists. The experiments range from the corn starch experiment (thixotropy/dilatancy), messy but exciting, and the water-lock demonstration, to the free exploration with properties of metals experiments. The demonstrations and experiments are meant to be high-motivation experiences, high visibility, showing the fun of scientific experiments and that's it! Some theory of scientific principles can be taught here, but that is not meant to be the purpose of these experiments.

Guest speakers, field trips, and video tapes can be used with these introductory activities or with any of the experiments to help keep student interest and expectations elevated. There may be times when dissolving polystyrene in acetone or crunching on a marshmallow cooled by liquid nitrogen could be interjected into the agenda because you decide students need a change—a break in the routine. The activity may not have anything to do with the current course of study, but simply be a change.

Many other introductory or “grabber” labs have been developed that are not written up in this section but will be demonstrated during the Institute. It will be your responsibility to record these activities in your journal. This will put you in the position of student and learner. It will help you practice using a journal, giving it importance and relevance, and help you have a sympathetic attitude toward your students as they write up labs during the school year.

Before you immerse yourself in MST experiments and projects, remember that science and technology are not history. They are not meant to be taught from a textbook as if they were history. Similarly, experiments are not meant to be followed as recipes; use them as a means to solve problems students encounter in their projects or as they study a material. Materials research is conducted to find out what is not known. For students, some materials are unknowns. Use experiments as a way to let students discover, make mistakes, and learn about new or better ways to perform a procedure or process. Remember, in science there are no bad results, only poorly designed experiments and another chance to learn!

Water Lock

Instructor Notes

Reliability

This demonstration always works.

Estimated Time for Activity

One class period.*

Teacher Tips

1. Source of sodium polyacrylate: *Flinn Scientific*
2. Sodium polyacrylate (water lock) is a superabsorbent polymer. This powder can instantly absorb more than 800 times its weight in deionized water. The more ions present in the water, the more sodium polyacrylate will be needed to absorb the liquid. This material is commonly used as the absorbent material in disposable diapers. It is also used in potted plants to help the soil store water.
3. The quantity of sodium polyacrylate needed to demonstrate the application of this material depends on the size of the beaker of water. Before the demonstration, determine the amount of water lock necessary to perform this demonstration. Simply add known amounts of water lock, and stir until the liquid gels.
4. Note how such a simple idea is of such large commercial value. You could include a discussion of the economics of engineering, i.e., how much money was spent last year on disposable diapers, paper towels, and newsprint.
5. You may also want to consider the “cradle-to-grave” history of this material. Where does it come from? How do we dispose of it? Can it be recycled?
6. Use this as a journal write activity. Have students write possible uses they think this material is good for.
7. In a class or small group discussion, have students share their ideas about this material. They can hypothesize about how the water lock works. Have the students compare their hypotheses to what actually happens when you explain the scientific principle that applies to this demonstration in a classroom discussion at the end of this activity.

* One class period is approximately 1 hour.

Demonstration: Water Lock

Student Learning Objectives

At the end of the activity students will be able to:

- record observations in their journals
- discuss observations
- suggest explanations.

Materials

- Water
- 400-mL beaker

Equipment

- Spoon or scoop
- Sodium polyacrylate

Procedure

1. Show the class the beaker of water and have someone verify that it is water.
2. Take a small amount of sodium polyacrylate (Use about 1/2 teaspoon for a 400-mL beaker of water) and stir it quickly into the water.
3. Almost immediately, invert the beaker to show that the water is “all tied up.” (You might even try inverting the beaker over a student once you have developed some confidence in the demonstration.)
4. Pass the beaker around the classroom to allow students to observe and/or touch. Record their observations and thoughts in their journal.

Classification of Materials

Instructor Notes

Reliability

This activity involves all students and will begin to establish students' concepts of materials, their characteristics, and how this relates to function.

Estimated Time for Activity

One class period.*

Background

1. There are many places to get samples of materials. You can use old appliances, or go to junk yards, flea markets, or various industries. Materials are all around us. Know what the samples you have selected are. Be sure to include fibers like Kevlar, glass wool, fiberglass, and composite materials. Mylar and reflective mylar can be used to give students something to think about in classifying them.
2. Metals have identifying characteristics such as shine, hardness, ductility, and they conduct heat and electricity.
3. Ceramics tend to be hard, but brittle, stiff, and do not conduct heat or electricity as a rule.
4. Polymers are usually flexible, have a low density, are insulators, and burn.
5. Composites are combinations of any of the above materials. In some cases, no material by itself (metal, ceramic, or polymer) has the characteristics required for a particular use, so a combination of materials (composite) is used.
6. Classification is a higher level thinking skill. As students justify their placement of materials into certain categories, it gives them a chance to reinforce their ability to think critically about choices.
7. If you use pieces of glass or other objects with sharp edges, it may be wise to dull the edges using an abrasive. Warn students to be care-ful of sharp edges.
8. Once you have gathered samples, keep them in a box to ensure you retain good samples for next year. As you obtain different material samples, you can add them to the box, as appropriate.

* One class period is approximately 1 hour.

Activity: Classification of Materials

Student Learning Objectives

At the end of the activity students will be able to:

- place a randomly selected material(s) into one of three categories: metal, ceramic, or polymer
- give the rationale for placing their material(s) into the category selected.

Materials

- An assortment of different materials taken from various sources in the environment. Examples include parts of appliances, fabrics, bottle fragments (both glass and plastic), nails, wires, fiberglass, and insulating materials. Be sure to include a few items that are composite materials so students will have to ponder where to place them. It is best to have at least one sample per student.

Procedure

1. Display the materials on a table or desk in front of the classroom.
2. On the table or desk, set aside space for three areas labeled metals, polymers, and ceramics where students may place an object after they have identified the material.
3. Have students, one at a time, select an object of their choice and place it in the category they feel is appropriate.
4. After students have categorized all objects, select various samples and have the students who classified those objects justify why they were placed in certain categories.

Material Systems

Instructor Notes



Estimated Time for Activity

Approximately two class periods.

Teacher Tips

1. This activity may seem very elementary, but it is designed to stimulate the students' thinking in areas of handiness, creativity, and the knowledge of materials.
2. Stress and strain are two terms that are often confused. Stress is defined as the resistance offered by a material to an external force. Although this is correct, stress is usually defined as the applied load. It is measured in terms of force exerted per unit force (N/M^2 or Pa in the metric system or lb/in^2 in the English system). Strain is the amount of deformation (bending, twisting, stretching) resulting from the stress. When a stress-causing force is applied, a strain results. If the strain exceeds the elastic limit of the material, the material has permanent deformation (bends, stretches, breaks).
3. Appliances of 20 or 30 years ago can be compared to modern appliances to evaluate changes in equipment design. One way to do this is to disassemble appliances that have 20- to 30-year differences in manufacturing time, and then compare the materials categories for any changes in types of materials used. You

can also check for changes in design (i.e., vacuum tubes to transistors, mechanical switches to electronic buttons). This will help students grasp some of changes that have taken place in the past few decades.

4. Before beginning the project, instruct students in the safe use of screwdrivers. These instruments should be used only for the intended purpose of the experiment (in this case, only for disassembling appliances). When the student is not using the instrument for this purpose it should be at rest at the workstation. Students should not move around or carry the screwdriver; it can be as dangerous as a knife. Also instruct students to keep their free hand away from the tip of the working screwdriver. Demonstrate how to determine where to put the free hand to hold the part and keep it away from areas the screwdriver might jab toward if the screwdriver should slip from the screw being worked on.

Caution: Cut all electrical cords from electrical appliances and properly dispose of them before students work on appliances to ensure no electrical shock will be encountered.

5. Testing electrical equipment should always be done with battery-operated equipment, never by plugging the appliance back into the wall circuit.
6. Also warn students of the shock hazards that can be encountered when working with or dismantling television sets or microwave ovens. These appliances have capacitors that retain electricity long after the appliance is unplugged and can be an electrical shock hazard for those who do not know how to work on them. Do not dismantle these types of appliances in the classroom.
7. TV tubes are vacuum tubes and will implode with great force if fractured or broken, sending glass and shrapnel across the room. This is a serious eye hazard. This can be frightening and dangerous. Students should know this for their own safety.

Safety

See individual activities.

Activity: Materials Science Applied to Household Appliances

This is a project to give the students experience with materials that they are around every day. It provides an opportunity for them to explore, discover, and handle the inner makings of common household items.

Student Learning Objectives

At the end of the activity, students will be able to:

- dismantle a small appliance and organize and/or categorize materials from within the appliance into groups of materials, categories of physical properties, or types of materials used in engineered systems
- demonstrate the correct use of screwdrivers and pliers while working with these tools.

Equipment

- Old appliances such as toasters, irons, hair driers, wind-up toys, clocks, curling irons, cameras, mechanical or electrical toys,
- Screwdrivers, Phillips and straight edge (Most screws can be undone with mini-screwdrivers, but you will want to have some large-handled screwdrivers to loosen hard turning screws.)
- Pliers
- Wire cutters
- Candle
- Containers (plastic or paper bags)
- Permanent marker pens
- Ohm meter or continuity device
- Safety glasses

Caution: Everyone in the proximity of the work area as well as workers with materials or tools must wear safety glasses at all times during this experiment.

Procedure

1. Dismantle the appliance using the tools needed to remove the appliance's casing and inner parts.
2. Place disassembled parts into containers labeled metals, ceramics, polymers, and composites.
3. Discuss the quantities of materials gathered in each container. Name some reasons certain materials are more commonly used than others. Could there be a better material to use than what is found in your appliance? Why do you think the manufacturer decided to use the material currently used in the appliance?
4. Record observations about the disassembled appliances in the laboratory record book. Is there a particular part or mechanism that could be drawn to show special details of this appliance? Record your observations in your journal. Details could include the following
 - drawings of appliances or specific parts
 - type of appliances worked on
 - types of material the major parts of the appliance are made from (What parts are made of metals, ceramics, polymers, composites?)
 - reasons why materials were chosen for specific purposes of the appliance
 - possible reasons the inventor or manufacturer used some unusual materials to make some parts of the appliance.

Additional Activities

The following suggested projects could be "springboard" activities to allow some students to spend extended periods of time testing and discovering different areas of materials science.

Caution: Safety glasses need to be worn at all times.

Activity: Property Testing

A number of tests are briefly described in this section. You may want to use or create additional tests to aid in exploring property testing. By no means are all testing areas covered, but these tests will give you some ideas of where to start.

Strength

A crude test for strength would be to lodge the material to be tested between two bricks and then to stack six to eight bricks on the material and measure how much it deforms the original shape (see Figure 4.1). There are other ways of doing strength tests too.

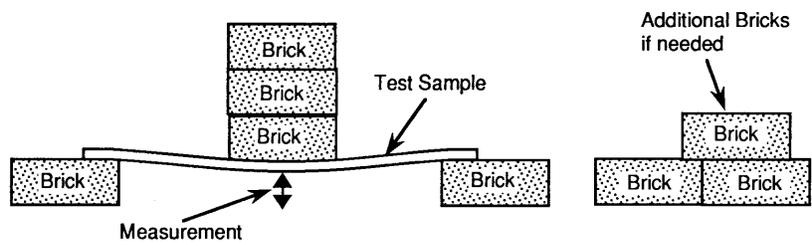


Figure 4.1. Strength Test

Stress and Strain

Using the strength of your hands, try bending the material and then observing the effects of stress on it. Is the material brittle? Does it flex easily and go back to its original shape? Does it permanently bend (deform) when flexed? At what point does it break, or to what extent do you stress and strain it before it finally fractures?

Caution: Be careful. Materials may break, throwing fragments into the air. Wear safety goggles. Keep away from other students to prevent injury.

Hardness

From a measured height, drop a steel ball or a large marble on different materials obtained from the appliances. Observe and record the height the ball rebounded and the size and depth the ball dented the material being tested. Be sure the test sample is resting flat on a hard, solid object (i.e., a concrete floor) so you are truly testing the hardness of the material and not some other property.

Electrical Conductivity

Using a flashlight bulb, a battery, and three pieces of wire, measuring about 6 in. per wire, set up an electrical continuity device to check if electricity will conduct through some materials (see Figure 4.2). The light will

light up if the material is electrically conductive and will remain off if no electricity passes through the material. (This a crude continuity device.)

An ohm meter would also be useful to check the electrical resistance of materials. The experience of working with the ohm meter is valuable.

Caution: Be careful when working with the ohm meter so as not to destroy some of its internal parts. This would happen by touching the leads to a system that already has a voltage applied to it.

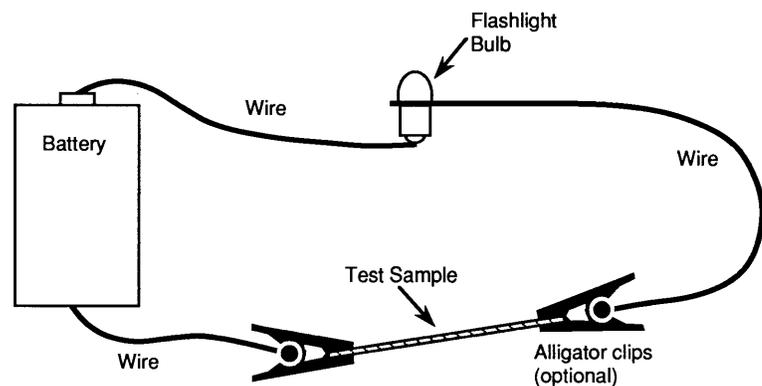


Figure 4.2. Electrical Conductivity Test

Thermal Effects

Obtain several liters of liquid nitrogen. Dip the dismantled materials in it and see if or how the cold temperature affects their strength. Polymers and composites will be most affected by the temperature; metals and ceramics will experience the least amount of change. Wearing leather gloves, flex the material being tested to observe if cold has changed the strength and flexibility of the material.

Heating material will provide valuable information about many materials. Using a burning candle, Bunsen burner, or propane torch, pass each material slowly through the flame, and determine the effect of heat on the material. Most polymers can be identified by burning them and observing their smoke, smelling the fumes (carefully), and observing how it burns in the flame. Use caution because some materials will melt, drip, and splatter hot liquid. Other materials may oxidize and some materials may not be affected at all.

Caution: Melt or burn unknown materials only in an area with direct exhaust to the outside. Some materials may burn and produce irritating, choking, and/or toxic fumes.

Do not heat containers or electrical devices (i.e., capacitors) that may have a potential to explode.

Activity: Magnification

To greatly enhance the students understanding of some materials, examine the materials using a microscope—a dissecting microscope that can magnify up to 50 times is more than sufficient. Many things can be learned from observation under magnification.

Activity: Inventing Appliances

From the array of parts, pieces, and electrical and mechanical devices available from the appliance dismantling activity, give students the opportunity to invent a contraption or appliance of their own making.

1. Challenge students to invent something using their unusual ideas and aspirations. If some students have a difficult time coming up with ideas, suggest they build a simple telegraph, microphone, or intercom. Other suggestions would be to make motorized advertisements, clocks, or automated levers with used electric motors. Switches and lights could be added to operate simple switching devices. This would be an excellent learning experience for students to build, operate, and understand how appliances work.
2. Allow students to trade, borrow, or give away parts.

Caution: Do not allow student to make any electrical devices except those that can be operated using dry cell batteries.

Activity: Making a Poster Board Display

For some students, displaying materials from a particular appliance they have dismantled on a poster board would be a desirable educational project. Materials could be mounted by category in a visually appealing manner. Labels and short, descriptive explanations could be added to the poster board beside each material. As part of the display, the student could research a material, then describe how it was produced or manufactured.

Other types of poster board displays could be used. For instance, a diagram of an appliance could be the focus of a display. Actual parts could be used to explain the mechanical or electrical function of certain appliance devices. Let students be creative. They will be able to suggest other themes that could be used on these displays.

Additional Activities

While students are dismantling appliances, they could also try to figure out how an appliance's electrical wiring works or how certain mechanical devices operate as they are pushed or turned. While they are working, students could also consider if they would like to make something like an appliance, boat, or automobile as a job or career. Would students like to be one of the engineers, inventors, manufacturers, or workers that helped make these appliances?

Crystal Study

Instructor Notes

Reliability

This experiment consistently works. The only drawback is the possibility of breaking the glass squares by dropping them or when dismantling the glass-stuff-glass “sandwich” while the stuff is still molten (easily repaired though).

Estimated Time for Activity

One class period.

Teacher Tips

1. The purpose of this lab is to provide students an opportunity to 1) observe macro crystalline growth, 2) observe how crystals grow together and form grain boundaries, and 3) compare various kinds of crystals. This knowledge can then be transferred to metals and ceramics, which form crystalline structure in the same manner as observed except on a micro scale.
2. It is recommended that the teacher prepare the glass slides for this activity. The instructions for doing this are given below. The student activity includes only the procedures for warming and cooling the plates once they are made. Once these glass sandwiches are made, they can be re-used many times and stored from year to year.
3. Suggested materials that may be used to crystallize include the following:
 - phenylsalicylate, also called salol
 - thymol, strong “listerine” odor
 - benzoic acid
 - urea, crystal growth is very small, but large grains appear, (teaches grain boundaries and grains)
 - naphthalene
 - naphthol (also may want to use magnification to study crystals and boundaries)
 - p-dichlorobenzene (fumes).

4. Suggested materials which will make an amorphous structure as a comparison to the crystalline materials:

- paraffin
- stearic acid

Note: No crystals form with these chemicals.

5. To make glass plate sandwiches

- Put plates on cold hot plates and warm them slowly.
- Sprinkle a few grains of chemical on the plate, and allow them to melt. Form a small puddle of molten chemical in the center of the plate.
- Take a second warm plate, and carefully cover the puddle. To reduce air bubbles, place the top plate on edge at one end of the bottom plate and slowly lower it to cover the molten chemical evenly and force the air out the sides.

Caution: If the chemical is forced from between the two glass plates, it can drip onto the hot plate and cause smelly or harmful fumes to volatilize.

- Allow the sandwich to cool slowly.
- Make a third plate, which is a mixture of two chemicals (make sure they are compatible i.e., naphthol and naphthalene are okay), and observe how the mixture behaves under slow and rapid cooling. A series of three plates can be made with different concentrations of the two chemicals.
- Cool the plates under a gradient. Insulate one-half of the plate so it cools more slowly than the other half. Compare the slow and fast cool regions and the transition zone. Note the shape and size of the crystals relative to how the plate was cooled. Repeat this with the plates that have two chemicals mixed on them.

6. Why does crystal growth matter? Many people and industries rely on controlled crystal growth. The manufacturers of sugar and salt, for example, must produce uniformly sized grains tons at a time. They need to know about how quickly the grains grow and how to make them all the same size. You may want to compare your crystals grown from molten solutions to those made from aqueous solutions.

Drug companies also care about crystallization. Crystallization can be used to purify chemicals. Think about the plates that had a mixture of chemicals on them. Can you think of a way to "unmix" them first by heating and cooling?

The structure of a single crystal can be used to help identify the compound.

How would you make large single crystals for further analysis? (see Figure 4.3 attached.)

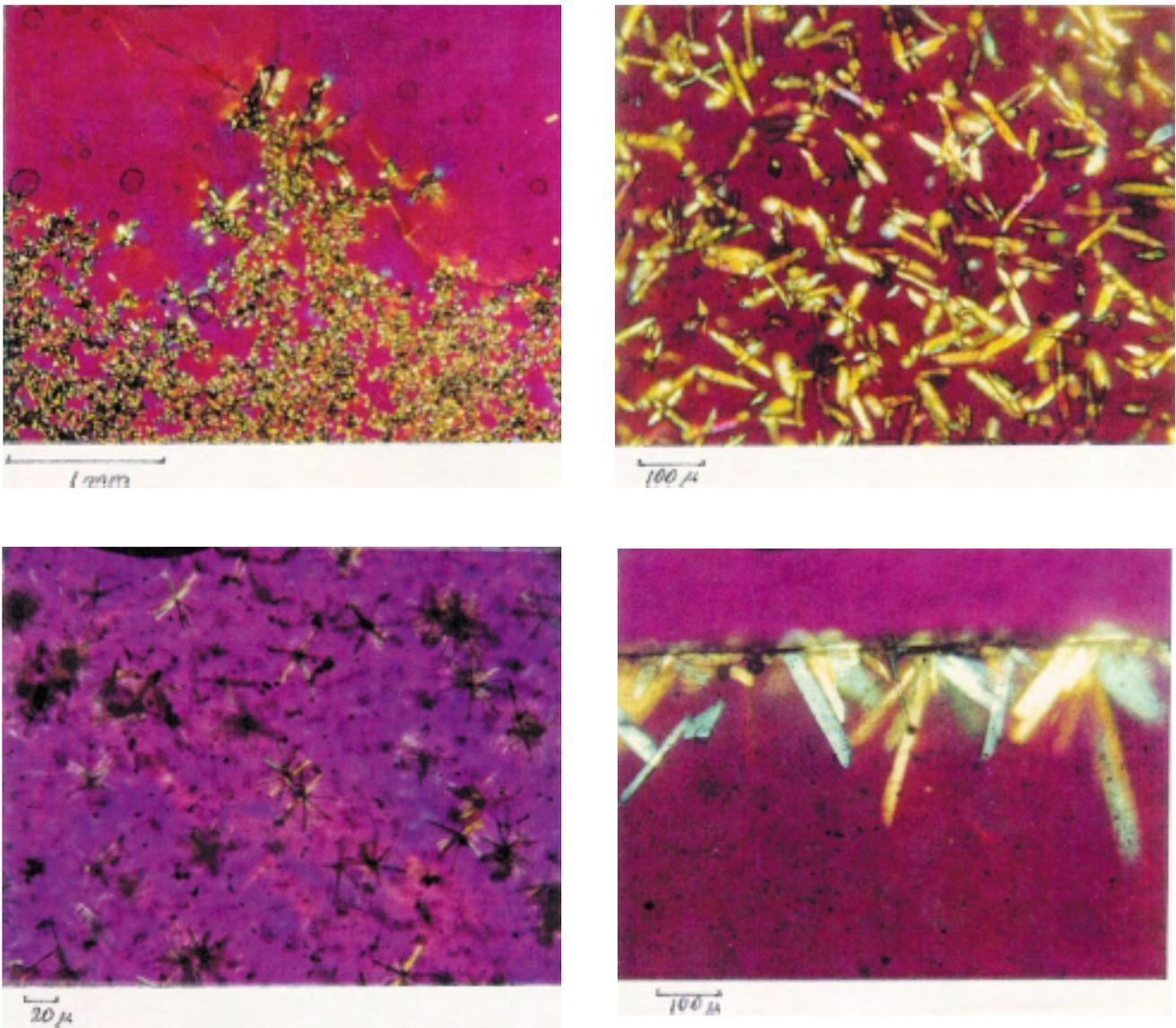


Figure 4.3. Varied Crystals Growing in Chemical Solutions

Notes on Polarized Light

1. Works very well when observing transparent materials that are crystalline or have areas of stress.
2. Polarized light is used a number of ways in MST. This activity is an introduction to the concept. It provides background information that can be used in the Crystal Study Lab and for making glass (Ceramics section).
3. Light travels as a wave, much like sound. If you were to look at a light wave as it travels along, you would see a regular rise and fall in intensity and a constant distance between peaks and troughs, commonly known as a sine wave. (See Figure 4.4).

If you were to look at a bunch of light waves end-on, they would look pretty messy. This is because the waves are not all in the same plane. The general effect would be something like Figure 4.5.

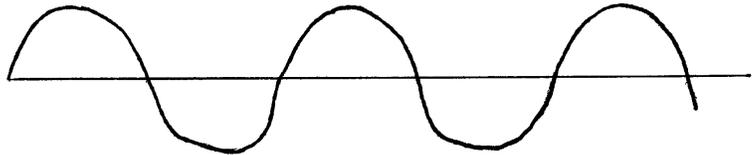


Figure 4.4.

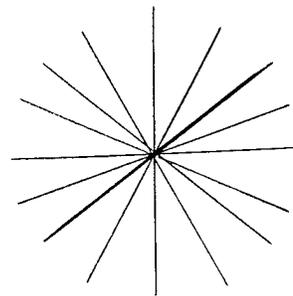


Figure 4.5.

4. If we could get some light waves all lined up in the same direction, some neat things could be done with them. This effect can be accomplished by using a polarizer, which is a material that looks like a picket fence to a light wave. Only the light waves oriented parallel to the picket fence are able to pass through it, and if a second polarizing filter is held with its axis perpendicular to the first, no light can pass through the pair.
5. Polarizing films can be made by heating a sandwich made from needle-like crystals of iodoquinine sulfate between two sheets of plastic. As it cools, the plastic sheets are pulled in the opposite direction to line up the crystals. This alignment produces the picket-fence effect as described above.

6. Light that is reflected from shiny surfaces is polarized to some extent. That is why polarized sunglasses work to cut glare, because the lenses in these glasses are oriented to filter out much reflected light. These lenses can be taken apart and used as a source of polarized film for the experiments involving stress visualization or crystallization.
7. In this handbook, polarized light is used to observe two phenomena, crystal orientation and stress. In some crystalline materials, polarized light is transmitted in some directions better than in other directions. This difference in crystal orientation can be observed when viewing these crystals between cross-polarized film. This process is explained in this experiment.

Polarized light also interacts with certain transparent materials under stress. As the polarized light passes through the area of stress, it is slightly rotated causing color bands to be generated, which can be observed through another polarized film. This process is used to observe stress in transparent glass and plastics as discussed in the Ceramics section of this handbook.
8. Reference: Wood, E.A. 1964. *Crystals and Light, An Introduction to Optical Crystallography*, Van Nostrand, New York.
9. Devise a way to measure the crystals, and have students put a scale in their sketches.
10. How does polarized light work?
11. What other materials can be analyzed with polarized light?

Extension Activity

1. This would be an opportune time to invite a “rock hound,” jeweler, geologist, mineralogist, or earth science teacher to visit your classroom to discuss and show various crystalline materials.
2. Other variations to this lab follow.
 - a) As the glass slides are cooling, and crystals have not yet formed, place an aluminum rod on the top glass plate. The aluminum acts as a heat sink. Observe how this changes previously run samples.
 - b) Have a sample in a glass sandwich where one surface of the glass is scratched. Observe how this scratch affects results of crystal growth.
 - c) On a single plate of glass, melt a small pool of suggested material. As this molten pool cools, drop a small “seed crystal” of the same material into it. Observe how the seed crystal affects crystal growth.

3. Examine the plates using transmitted light and a microscope or hand lens.
4. Have students practice sketching what they see in their journals. Have them pay special attention to how “regular” the crystals are. They are easy to draw because there are so many straight lines. Why is this? Before the structure of the atom was known, early mineralogists thought crystals were made of building blocks. What shape blocks would you need to make your crystals? How thick are they?

Compare your flat plates to salt, sugar, or even rock candy. See if you can get the students thinking about crystals as three-dimensional objects.

If you live in an area with cold winters, discuss or examine frost, snowflakes, ice, and the variety of shapes crystalline water can take. It’s all water! Guess the shape of the building block.

Safety

1. Use Pyrex or other thermal shock-resistant lab glass for glass plates. Thin plates (1/8 in. or less) are better than thicker plates. Microscope slides work well.
2. *Prepare these plates in advance.* This is most easily done by placing the glass plate on a hot plate set on low temperature in the hood, melting the chemical on the warm glass plate, and placing the second plate on top. To reduce breakage of the glass plates, warm all the plates slowly on the hot plate, and handle them with tweezers.
3. You need to consider ventilation. Some substances produce irritating fumes; others produce slightly toxic fumes or fumes that will make many light-headed. Note: thymol, naphthalene, and naphthol produce fumes and strong odors. Benzoic acid has very irritating fumes, phenylsalicylate has toxic fumes. **Use these chemicals cautiously!** Don’t spill them on the hot plate’s surface. Handle only small quantities around the hot plate.
4. Hot plates can cause burns.

Activity: Crystal Study

Student Learning Objectives

At the end of the activity students will be able to:

- follow a procedure that allows the study of crystal growth, size, and shapes
- demonstrate their observation and recording skills through journal writing and discussion.

Materials

See Instructor Notes

Equipment

- Prepared glass plate sandwiches, 5 cm x 5 cm, 2 ea.
- Colored pencils
- Polarized film, 5 cm x 5 cm
- Magnifying lens
- Hot plate
- Tweezers/tongs

Caution: Do not overheat glass plates. Do not put your head directly over the hot plate when heating chemicals. Avoid breathing fumes.

Procedure

1. Obtain two different glass plate sandwiches, one marked "A," the other marked "B."
2. Obtain two pieces of polarized film.
3. Place glass "A" on a cold hot plate and turn on hot plate to a low setting ("2" is typical). (DO NOT TURN TO A HIGHER SETTING.)
4. Carefully observe the crystal formation between the two pieces of laminated glass. When the crystals START to melt, immediately remove the glass from the hot plate using tweezers. Turn off hot plate. Continue observations.
5. Record observations in your journal. Include sketches of crystals.

- Place glass between polarized film with a light source behind it. Turn or rotate pieces of the film 90° and observe (see Figure 4.6). The two pieces of film can be arranged to either transmit or block light. View the glass plate with the film in both positions and without the film. Illustrate what you see in your journal using, if needed, colored pencils.

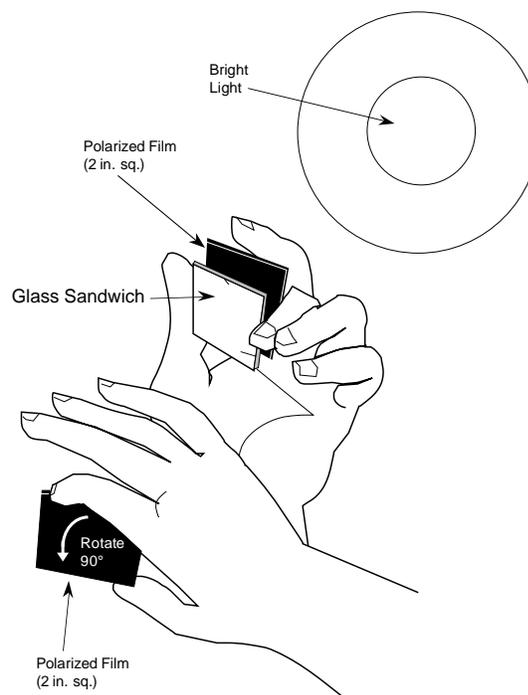


Figure 4.6. Use of Polarized Film for Analyzing Crystal Structures

- Repeat steps 3 - 6 using glass "B."
- If time allows, repeat steps 3 - 7, using samples with different chemicals.

Additional Activities

- Cool the plates slowly, and sketch what you see.
- Cool the plates rapidly, and compare to the slow-cool method.
- Observe other materials and light sources using the polarized film to better understand polarized light.

Iron Wire

Instructor Notes

Reliability

This experiment works every time if wire is of high enough iron content and is heated enough for it to get above phase change temperatures. You may have to try several kinds of wire to see which gives the best results. It will not work if iron is not nearly pure, wire is not heated enough, or wire is not long enough to expand and contract to observe phase change.

Estimated Time for Activity

One class period.

Teacher Tips

1. A local hardware store is a good source of iron wire.
2. The iron wire will smoke temporarily as it is first heated because of oil and grease introduced during the manufacturing process or subsequent handling. Do not worry about this.
3. The wire will oxidize as it is heated. The oxide will cause the wire to become increasingly brittle if the heat cycling is repeated many times. Also, if the wire is heated repeatedly, most of the cross section of the wire may become oxidized, and the wire may break under the gravitational force of the weight. The oxide is an insulator, and the wire will stop conducting when it has oxidized all the way through (if it has not broken before that). Check to see if tempering is also occurring.
4. This lab uses electrical resistance to heat the wire. Electrical engineering and physics can be introduced with this lab. The wire's resistance varies with the diameter. Smaller wires will heat faster to higher temperatures. Have someone from a stereo store come and talk about how to select the gauge of stereo speaker wires or have a household electrician come to talk about overloaded circuits and how electrical fires can happen.
5. A regular, repeating three-dimensional alignment or arrangement of atoms defines what is called a crystal structure. The types of "crystal structure" that a material has depends on many factors, such as temperature, atom size, and types of atoms making up the crystal.
6. Many crystalline materials have the same crystalline structure over the entire temperature range from room temperature to the material's melting point, i.e., aluminum.

7. Many materials may take on one crystalline structure at room temperature and another crystalline structure at different temperatures. This behavior is known as polymorphism or allotropy. The chemistry is the same; only the atomic-level structure changes. Poly = many; morphism = shapes or forms; i.e., iron, quartz (silica), and the aluminum-zinc alloy.

8. As materials heat, the atoms in them vibrate and effectively increase their unit cell volume; this is thermal expansion. Metals have a larger thermal expansion than ceramics, which is why running hot water on a metal cap on a glass jar “loosens” it.

As the amplitude of the atomic vibrations increase the crystal structure gets so big the atoms rearrange themselves into a less dense structure. This is a high-temperature phase change. The atoms will eventually vibrate so much the chemical bonds between them will be broken, and the material melts.

9. The light that gets emitted from the iron wire is called “black body radiation.” When the electrons in the material absorb energy from the heat, they release it in the form of light. The hotter the material, the shorter the wavelength of light. That is why the color of the wire changes from red to white.

Ask a jeweler, blacksmith, metal sculptor, or welder to come to your class or allow you to visit their workplace to discuss the appearance and “feel” of hot metals. How does the metal “work” at various colors.

The colors you see can be accurate measurements of the temperature of the material. This is how astronomers determine the temperatures of stars. Ask an amateur or professional astronomer to come and talk about the stars.

Other activities of interest in this area would be to find a local business or industry that uses optical temperature measurement to detect heat. Have an engineer demonstrate how this equipment works. Some fire departments and public utilities have infrared cameras that can see heat before your eyes do. Ask them to come and use their cameras in your class. Maybe they can detect the hot wire before it emits light.

Description of the Teacher Demonstration

1. A length of wire is stretched between two ring stands on a non-conducting surface. A weight is suspended from the wire by means of a hook (see Figure 4.7). The wire is heated in a controlled fashion past the points at which phase changes occur in the iron. The motion of the suspended weight is observed as the wire heats. The wire gradually expands by thermal expansion, goes through the phase change, then continues to expand. The expansion and contraction of the wire should be observed by the

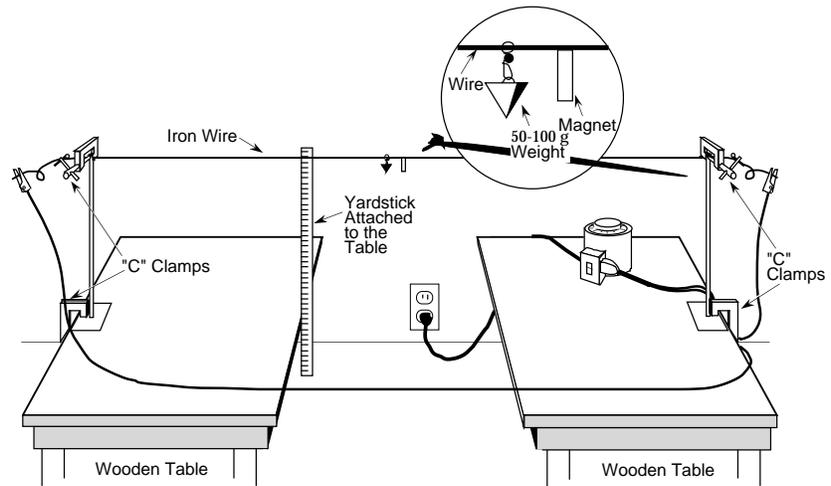


Figure 4.7. Iron Wire Demonstration

suspended weight lowering and raising. The effects of the phase change should be seen as the wire is both heated and cooled. The effect, however, is most easily noticed as the wire cools.

2. A corollary experiment consists of observing iron's. The wire is then heated and cooled in the same manner as above, while the behavior of the magnet is observed. The room temperature phase of the iron is ferromagnetic. When the current is turned on, the magnetic field set up by the current in the wire exerts a force on the magnet. The interaction of the two magnetic fields will be greater than the ferromagnetic attraction between the wire and the magnet, especially since the wire loses its magnetic strength as it is heated. The temperature at which iron is no longer ferromagnetic, the "Curie temperature," is 770°C . The magnet will fall at this temperature even though the wire will look hotter than that. This occurs because the magnet acts as a heat sink for the section of wire it is attached to lowering the temperature of the wire around the magnet.

Explanation of the Phenomena Observed

Iron is polymorphic (or allotropic), exhibiting three phases in the temperature range between room temperature and its melting point. (See Table 4.1 and Figure 4.8. Also see, for example, Robert Reed-Hill, *Physical Metallurgy Principles*, Van Nostrand, 1964, pp. 319-320; and Albert Guy, *Elements of Physical Metallurgy*, Addison-Wesley, 1960, pp. 134-136.)

Table 4.1. Crystal Structures of Iron

<u>Iron Phase</u>	<u>Temp. Range, °C</u>	<u>Crystal Structure</u>
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 (BBC) less dense, paramagnetic

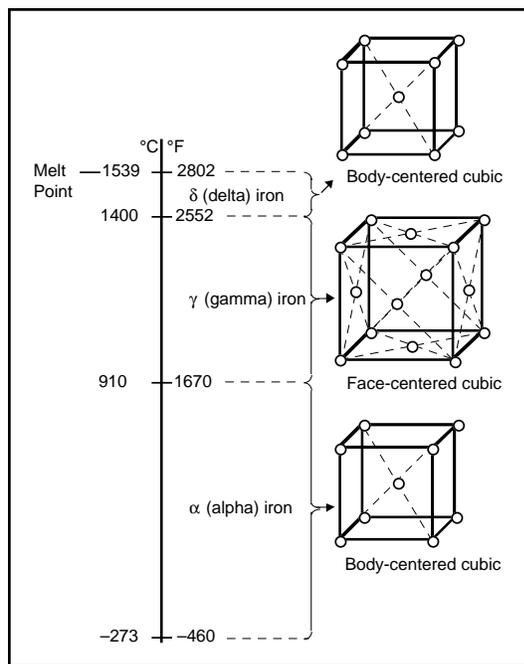


Figure 4.8. Polymorphism of Iron (From Guy, A. *Elements of Physical Metallurgy*, Addison-Wesley Co., 1960, pg. 135.)

Safety

1. Use extreme caution because an electrical shock can occur when contacting the clamps, stands, alligator clips, or wire when electrical source is plugged in. Be certain electrical source is disconnected before working with equipment.
2. The equipment may be very hot on completion of the experiment. Use caution. Wear leather gloves, to avoid burns.
3. If heated high enough, the wire can melt and splatter to the ground. This can be a fire and burn hazard if not safely set up over a cement floor or an insulated ground cover such as a ceramic fiber blanket or a sand trap. This also will prevent the hot magnet from scorching the floor when it falls off the wire at about 770°C.
4. Students should be a minimum of 8 ft from the experimental equipment at all times to ensure their safety.
5. Be prepared! Sudden surges of electricity from turning the variac too quickly can cause circuit breakers to fail. Be familiar with the janitor's whereabouts during this demonstration or where the breaker can be reset if the need should arise. *By slowly increasing the power through the variac, this problem can be avoided.*

Disposal

Make sure all wire is cool before throwing it in the trash.

Activity: Iron Wire

Student Learning Objectives

At the end of the activity students will be able to:

- explain thermal expansion as it occurs in this activity through writing and drawing in journals and through discussion
- describe phase changes through discussion, writing, diagrams, and models
- explain that thermal light is emitted when the temperature is high enough, and that the color and intensity of the light depends on the temperature
- explain why the oxidation of iron takes place more rapidly when iron is heated
- describe the interesting interaction occurring between the electromagnetic field set up by a current in a wire and a permanent magnet suspended in that electromagnetic field

Materials

- Iron wire (18 - 24 gauge, 12 - 15 ft long). Inexpensive wire works best, generally of a high iron content.

Equipment

Power source:

A.

- A 110-volt, 15 amp, or larger, variable transformer, commonly called a "variac."
- 10-ft power cord (which has been split to reach to both ends of the iron wire), with an AC male plug on one end (to connect to Variac) and alligator clips on the split end, one for each end of the iron wire.

or

B.

- 2 well-charged 12-volt batteries (connected in series)
- Rheostat rated at 25 volts and 15 amps or more
- Single wires, each equivalent in weight to one side of a power cord, to connect the batteries to one side of the rheostat and the other side of the rheostat to one end of the iron wire, with an alligator clip. The other end of the iron wire is connected to the other side of the pair of batteries. See Figure 4.9.

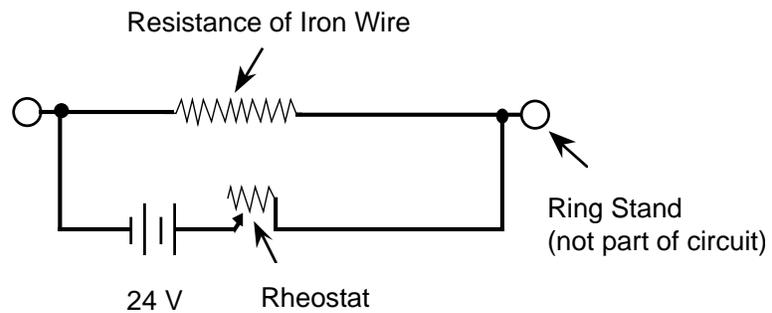


Figure 4.9. Wiring Diagram for Circuit with Batteries

- Two wooden (non-conducting) tables or benches adjacent to each other, one movable
- Two ring stands
- Weight, from 50 - 100 g, with a hook for hanging
- Magnet no larger than 10 g (preferably a bar magnet).

Procedure

1. Mount the two ring stands on the table(s) far enough apart to make the wire between them taut (See Figure 1). Attach the wire to the ring stands, and adjust the distance between stands as needed to stretch the wire. For greater safety, to prevent energizing the ring stands, the ring may be wrapped with insulating tape where the wire is to be attached.
2. Hang the weight on the wire in the center between the stands.
3. Attach the electrical leads (alligator clips) to the two ends of the wire near the ring stands. Do not attach the alligator clips to the ring stands, as the paint and oxide on the rings are non-conducting and will prevent good connections.
4. Dim the lights in the room.
5. Slowly increase the voltage to the wire until the wire glows bright orange. Observe the movement of the weight.
6. Reduce the voltage rapidly while again carefully observing the weight.
7. Repeat steps 5 and 6 and measure the wire displacement with a rule next to the weight.

Caution: The wire, when hot, can cause burns, shocks, and even start a fire!

Caution: Eye hazard. Wear safety glasses. Be careful not to increase the temperature of the wire much beyond the second phase change, to avoid getting close enough to the melting point that the weight breaks the wire, allowing the ends to rebound in random directions.

8. Attach the magnet near the weight. Repeat steps 5 and 6. Observe the motion of the magnet.
9. Draw diagrams of this demonstration in your journal. Record observations. A class discussion should be encouraged to theorize the phenomena observed. Summarize the correct scientific principles at the end of the discussion.

Paper Clip Destruction

Instructor Notes

Reliability

This experiment works all the time.

Estimated Time for Activity

One class period.

Teacher Tips

1. This experiment is designed to show that materials will fatigue and fail when distorted. It is also intended to show that not all objects fail equally, but failures can be plotted, and the probability of failure can be predicted. The experiment is also a good introduction to destructive testing compared with non-destructive testing.
2. Heating, cooling, and areas of impurities within a batch of paper clips will cause them to have different kinds of failures and varied rates of failure even though the paper clips may have been manufactured with the same quality assurance, procedural specifications, and from the same batch of material.
3. Quality control is a major concern in mass production. When a typical sample is taken from a batch of materials and tested for fatigue failure, the samples do not fail under equal stress or number of deformations. This distribution of failure may be used to predict product reliability.
4. When making parts from a particular material, the degree of forming is limited. Severe forming requires material with adequate ductility or formability. Tests for failure distribution functions help establish bounds of expected formability with a particular batch of material. Analysis of forming operations and degrees of shape-changing provide data about the ductility/formability needed for each particular part. Conditions of actual material ductility and specific shape-forming severity need to be adjusted to produce parts that can be joined together as component of a total product. Production limitations necessarily enter into the details of product design; one aspect is wrapped up in the other. Designing and manufacturing a new product is costly!
5. Formability is only one example of metal failure by fatigue or (usually) overload. Examples more applicable to paper-clip bending would be axles or crankshafts on cars. Other practical examples include airplane propellers and highway bridges.

6. Students need to share their data and make a bar graph for each type of paper clip. These graphs can be used to discuss reliability and safety.
7. Direct students in a classroom discussion on destructive testing. Areas to consider in the discussion follow:
 - How can you use your data to estimate the strength or reliability of the untested paper clips?
 - Since testing destroys the clips, how many can you afford to test? People who crash test cars and airplanes can't test each one. There wouldn't be any left to sell!
 - How sure do you need to be about the strength of your clips?
 - How would you design for a larger safety factor if designing an airplane?
 - Think of other situations where testing is important.
 - Discuss why the paper clip finally broke. Did anyone notice it got harder and harder to bend the clip? What was happening *inside* the material?

Extension Activities

1. Take a shoe box lid and put enough marbles in it to cover one fourth of its surface area. Tilt the lid so all the marbles move to one corner. Note the arrangement of the marbles, the rows, layers and areas of dislocation where the marbles lose their patterned arrangement. Tap the side of the lid, and note how the marbles. The ways the marbles move in "steps" or "bumps" are how atoms move when metal is bent or deformed.
2. In school each student is tested. This is not destructive (or shouldn't be!) Imagine if one student was tested and that was the grade for the class! Ask a quality control engineer to come and talk about sampling and testing, or ask someone from an advertising agency to talk about market research.

Activity: Paper Clip Destruction

Student Learning Objectives

At the end of the activity students will be able to:

- follow instructions to perform a destruction test
- perform a destructive test sequence on paper
- plot a distribution chart
- check for bias in testing
- describe the results of the testing by using appropriate formats.

Materials

- Paper clip, standard size (10 ea.), 2 different brands or styles of paper clips (there are various types of clips that can be used, smooth, ridged, small diameter, large diameter) or other suitable material.

Equipment

- Twister, heavy card stock (approximately 1 in. x 2 in. folded in half into 1 in. x 1 in. square to help protect the fingers while twisting the paper clip)
- Safety glasses

Safety

No safety problems are apparent with this activity. However, it is possible that broken clips might be sharp or have rough edges, which can cause cuts.

Depending on the speed of the twist, the broken end might be hot. This would not be hot enough to hurt anyone. If it hurts a little, one more thing has been learned.

Procedure

1. Lay a paper clip flat on bench, and hold the smaller loop with your left hand. Grab the larger loop with your right hand, and rotate the clip open, one quarter turn, keeping it flat the entire time to form an L-shape (see Figure 4.10).
2. Grasp the larger loop between the thumb and index finger of your dominant hand, and fold a piece of card stock over the smaller loop to hold it firm and provide a cushion.

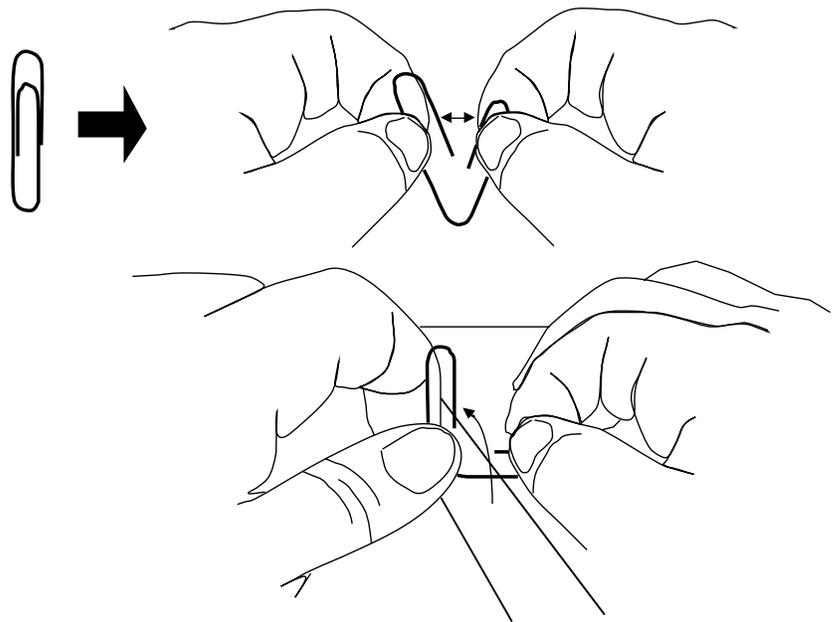


Figure 4.10. Paper Clip Destruction Test

3. Twist the larger loop with the thumb and forefinger of your dominant hand, keeping the small loop at a right angle to the larger loop.
4. Count each half turn in the same direction. Record in your journal, to the nearest quarter-turn, the number of twists you made to break or fracture the paper clip.
5. Repeat with a different brand of paper clip.
6. Share data with other students.
7. Make bar graphs as directed.

Ceramic Mantle

Instructor Notes

Reliability

This demonstration always works.

Estimated Time for Activity

One class period.

Teacher Tips

1. This demonstration is designed to help students become aware that a lantern mantel is made of a ceramic material. The mantle possesses properties of ceramics such as a high melting point and brittleness. The demonstration is used also to help show that compromises must be made when selecting materials for a specific application.
2. Contained in the mantle is a material consisting mainly of yttrium oxide. This material can withstand temperatures of up to 2400°C (4352°F). Yttrium oxide is a ceramic and very brittle as a mantle material. For shipping and handling purposes, the yttrium oxide is impregnated in a lacy sock of rayon. When placed in the lantern and ignited, the rayon burns off, leaving an ash of yttrium oxide that is so brittle, a fly could pass through it.
3. The lantern operates on hydrocarbon fuels (white gas, propane, etc.). The higher the temperature you heat this material, the more light it will emit. Energy deposited on a small amount of material produces a concentration of heat and light. Reducing the size of the material and holding the energy constant produces a brighter light. This is why the mantle fibers are so thin.
4. Very few high temperature materials can be used as mantle material. Most materials do not produce visible light at these temperatures. Instead, they emit in a very narrow wavelength of light in the infrared or ultraviolet range.
5. In the past, thoria was used at the lantern mantle. It is radioactive. A choice was made to use it because it was relatively inexpensive, could withstand high temperatures, and produced the best quality light. If you have an old thoria mantle you may want to demonstrate the radioactivity of this mantle using a Geiger counter or other radioactivity detector (see description in box on following pages.)

Safety

1. Thoria, if used, is radioactive.
2. Use safety gloves and glasses.
3. Lanterns and fuel can be dangerous. Use proper igniting techniques recommended by the manufacturers.

Why Coleman Mantles Make Your Geiger Count

Let's start with the history of lighting. Obviously, the first source of light for man was the sun and the moon. At some point in history, fire was discovered. This gave us both heat and light. This always involved the burning of vegetable matter such as wood, leaves, etc.

By the time of recorded history, our ancestors were rendering from their animals to get fats and oils that could be used in candles and lamps. Lard candles and whale oil were commonly used as late as the 1800's.

When Colonel E. L. Drake successfully drilled for petroleum in Pennsylvania in 1859, the patent **office** was swamped. An average of eighty applicants per year for petroleum lamps were made for the next twenty years.

Gas from oil and coal became available in the 1800s also. The results were a number of lighting devices using those gases.

All of these lighting devices (candles and lamps) were successful because of the incomplete burning of the fuel. Thus, the unburned carbon was heated to incandescence. The result was a dim yellow light.

In 1855, R. W. Von Bunsen invented a burner that would take coal-gas and premix it with air. The resulting flame was non-luminous because of the complete burning of the fuel. Early attempts to make incandescent mantles had failed, in part, because of the luminous flame.

A number of attempts were made to make light with the bunsen flame and metal oxides or platinum metal. All failed but one. A spotlight was made by heating a cylinder of lime (calcium oxide) with a reflector behind it. Its only application was the stage; thus, we still say we are in the limelight.

In the 1880s, two new sources of exceptional light were invented. First, Thomas Edison invented the electric light and second, Auer Von Welsbach invented the thorium incandescent gas mantle. The gas mantle was by far the most successful. Whereas the light bulb was dim, required much capital to build power plants, and was not portable, the mantle was cheap, portable, and by far, the brightest light man had ever made. When you read literature from the time, it refers to a wonderful light or 'the marvelous power of emitting light'. Of all of the great cities of Europe, some became lighted by the greenish white light of the gas mantle.

As the light bulb improved, electrical power became more available, and the demands for electrical devices such as toasters, fans, refrigerators, etc. increased, the demand for the gas mantle declined. With FDR's Rural Electric Association (REA), the mantle was to be used only by people in remote areas, campers, lighthouses, and people of the developing world.

This decision to go to electrical power has had its price. In fact, electrical power kills 14,000 persons each year. When we look at the risk statistics of Americans, we find that swimming kills 3,000 annually, X-rays kill 2,300, contraception 150, commercial aviation 130, high school and college football 23, and vaccinations 10. In 97 years, no deaths have been attributed to the radioactive or chemical properties of thorium in an incandescent gas mantle.

Fourteen years after the first thorium mantle was patented, the English physicist Rutherford discovered the material was radioactive. Thus, we have been aware of this radioactivity for 83 years. The decay is well-known and measured.

A Milwaukee newspaper reported that a college student measured the activity of a package of lantern mantles and found it to be 300 to 700 millirems.

Actually, one mantle measures less than 0.1 millirem/hr or 1/3000 to 1/7000 of the value reported in Milwaukee.

The box of 1000 mantles is less than 0.5 millirem/hr.

If we remove the beta shield, the value increases 0.9 to 1.35 millirem/hr on the 1000 pack.

If we were to use a Geiger Counter, the alpha radiation measures about 4,500 counts/minute. This is counts of particles, not millirems. Alpha radiation from thorium and its daughters are very weak. In fact, an inch of air, a sheet of paper, or the dead cells of the skin (the epidermis) is enough to stop them.

We can conclude the following from experts in the field such as Robley Evans, Frank O'Donnell, and Theodore Fields:

1. Thorium and its daughters are naturally occurring radioactive materials. They were formed when the earth was made. In fact, about as much thorium found in a mantle is also found in every cubic foot of rock, soil, dirt, concrete, etc.
2. A commercial jet airplane will increase the exposure of each passenger in one flight from New York to Los Angeles to the same dose received by an average camper using one mantle.
3. Moving from the first floor of a dwelling to the third floor will increase the exposure of the occupant to the same dose received by an average camper using one mantle.
4. The natural radiation per year from the earth, air, and from outer space is at least 50,000 times more than from a mantle.
5. A camper who received the greatest expected dose from using one mantle would have to camp for 4000 days per year to equal the average annual medical dose.

Therefore, we have a long history of safety with the mantle. And, we have shown that even an unrealistic exposure (such as camping 4000 days per year) will make only a fraction of the annual dose we receive every year from the earth, the air, outer space, and medicine.

Gilbert J. Addison, Design Engineer, The Coleman Company, Inc.

Demonstration: Ceramic Mantle

Student Learning Objectives

At the end of the activity students will be able to:

- explain why energy delivered to a small amount of material at a constant level results in heat and/or light
- explain that thoria is a ceramic, which is used because of its high melting point
- explain that choices must be made when selecting materials. List those choices for which thoria was selected.

Materials

- Coleman lantern mantle

Equipment

- Pyrometer at least 3300°C (optional)
- Lantern, Coleman type, fueled either with propane or white gas

Procedure

1. Show a Coleman lantern mantle to students (Teacher Tip 2).
2. Light the lantern and measure the mantle's temperature using a pyrometer (Teacher Tip 3) (see Figure 4.11).
3. Turn off the lantern.

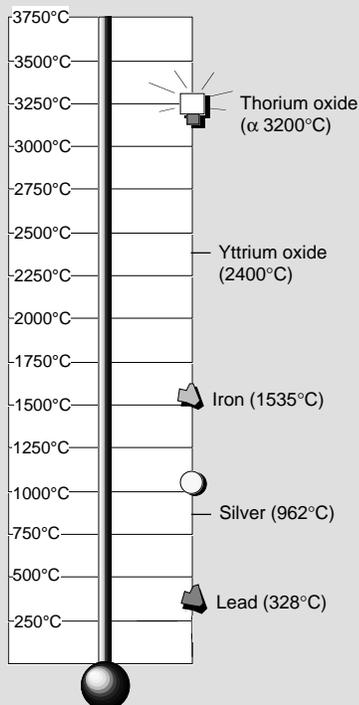


Figure 4.11. Relative Melting Temperatures

Light Bulb Filament

Instructor Notes

Reliability

This experiment always works.

Estimated Time for Activity

One class period.

Background

1. Since about 1730, serious experiments have been conducted in developing the electric light bulb. Thomas Edison's work in the 1870s contributed to the development of the filament. He used carbonized thread to make an incandescent light bulb that burned for 40 hours. Currently, the filament is made of tungsten because this filament may reach a temperature of 2500°C, which enables it to glow white hot. Incandescent means glowing with heat.
2. The glass envelope is the part of the bulb that prevents the filament from oxidizing (see Figure 4.12). When the light bulb is manufactured, the envelope is filled with a non-reactive gas to prevent the tungsten from burning (rapid oxidation—the tungsten combining with the oxygen in the air to form tungsten oxide). Even in the envelope the filament does not last forever because as it reaches its high temperature some of the tungsten vaporizes (changing from a solid to a gas or vapor which is called sublimation), and the filament gets thinner. Eventually, the filament gets so thin it breaks.
3. Filaments also exhibit thermal shock, breaking because they are heated too fast. This is why lights usually burn out when you first turn them on.
4. When electricity is run through the filament after the envelope is removed, the metal oxidizes and forms tungsten oxide. Tungsten oxide, a ceramic, exhibits characteristics that are common to ceramics, many of which are unlike those of a metal, including brittleness, non-metallic color, and poor electrical conductivity.
5. Smoke is observed as the tungsten is burning (oxidizing). This occurs because one of the oxides of tungsten has a very low melting point and is being vaporized from the hot filament.
6. Distribute copies of light bulb diagram—one per student (see Figure 4.13).
7. You need one bulb and socket for each student group.

Extension Activity

1. Compare this lab to the previous lab. Lantern mantles can burn in air because they are ceramic, but they are very fragile (brittle).

Activity: Light Bulb Filament

Student Learning Objectives

At the end of the activity students will be able to:

- label the parts of an incandescent light bulb on an appropriate drawing
- describe through writing and discussion the purpose of a light bulb's envelope and filament
- explain through writing and discussion the changes in the properties of the tungsten filament when it is exposed to air.

Materials

- Light bulbs, standard base, 110 volt
- Water

Equipment

- Hammer
- Towel
- No. 10 can
- Safety glasses
- Safety face shield
- Leather gloves
- Glass cutter or file
- Bunsen burner
- 110 volt socket with plug (see Figure 4.12)

Procedure

1. Study Figure 4.13, which is labeled with the correct terminology for a typical incandescent lamp.
2. Carefully remove the glass bulb (envelope) from the lamp using one of the following methods:
 - a. Wrap the bulb with a towel and hit it with a hammer lightly to break **only** the glass envelope.
or
 - b. Use a glass scribe to etch around the base of bulb. Tap etching to crack open the bulb.
or
 - c. Heat bulb in bunsen burner flame. When it is hot, plunge into No. 10 can of water.

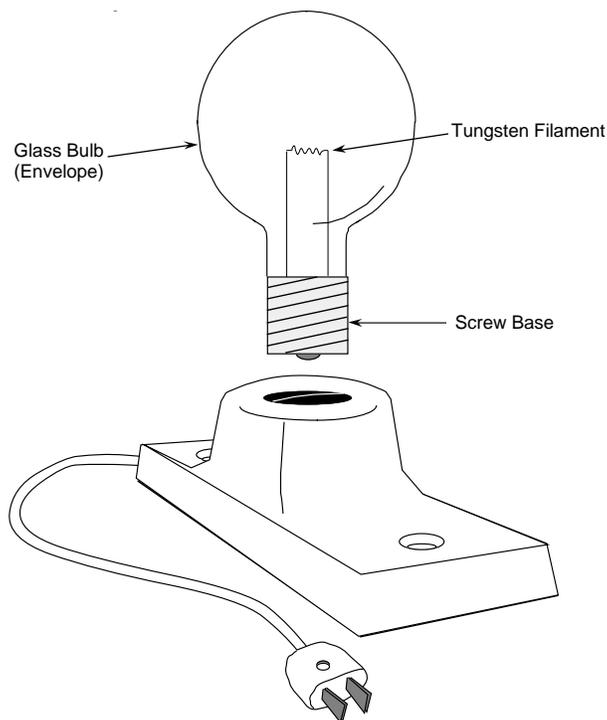


Figure 4.12. Typical Incandescent Lamp

Caution: Be sure you wear safety glasses, a safety face shield and leather gloves to protect yourself from being cut by broken glass.

3. Identify the parts of the dissected light bulb using Figure 4.13.
4. Observe the tungsten filament. Note its color and flexibility. Most filaments are coiled, and many even have two coils, an outer coil and a tightly wound inner coil. (Today's technology uses the terms 1st and 2nd generation coils for these types of coils.)
5. Analyze the tungsten filament and glass bulb to determine why and how those materials were combined for a light source.
6. Screw the base of light bulb into the **unplugged** electric socket.

Caution: Electric shock hazard. Check to make sure socket is unplugged.

7. Plug into socket, and observe filament from a safe distance (>2 ft.). Keep hands away from socket.
8. **Unplug** the socket, remove the base from the socket. Observe filament remnants and record observations in your journal.

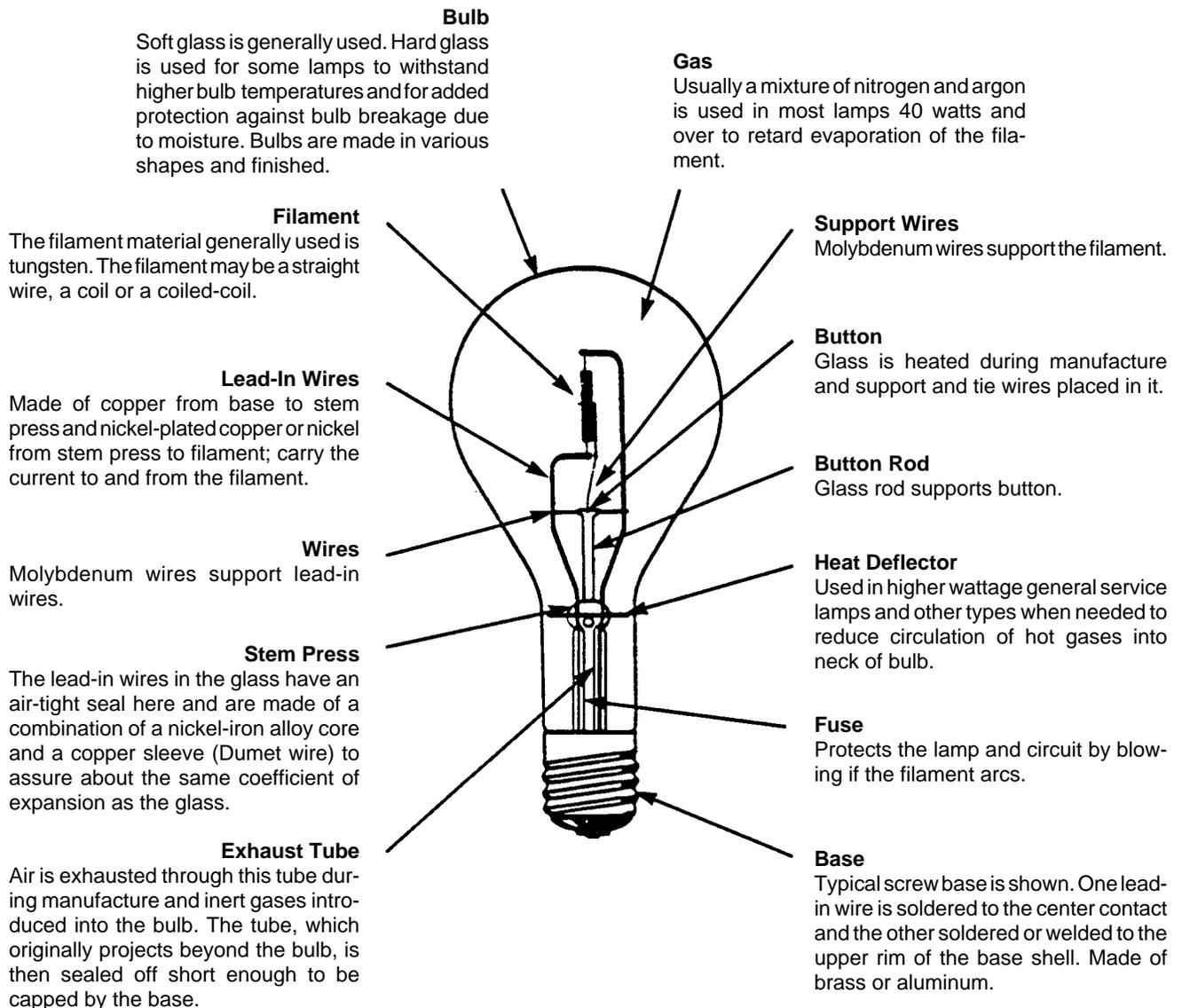


Figure 4.13. Typical incandescent lamp bulb. This type produces a high lighting level over a relatively long period of time. Longer lasting lamps can be produced but the light output is lower. Additional light is produced at the expense of lamp life. Modern incandescent lamps strike a balance between light intensity and lamp life. Bulb blackening is the result of depositing of tungsten particles on inner surface of the bulb. (Sylvania)

Thixotropy and Dilatancy

Instructor Notes

Reliability

These experiments work all the time. The mixed quantities of water and cornstarch can and do give varying results, though. A rule of thumb that appears to work well is to have a ratio of about 5:2 parts cornstarch to water by volume.

Estimated Time for Activity

Two class periods.

Teacher Tips

1. Viscosity, thixotropy, and dilatancy are three closely related terms that describe the flow behavior of liquids and mixtures of liquids.
2. Viscosity measures the force required to make a material flow. Fluids that have a high resistance to flow are said to have a higher viscosity than those that flow more easily. For example, honey and molasses have much higher viscosities than water. We are describing viscosity when we use words like “thick,” “thin,” “runny,” “goosey,” and “syrupy” to describe liquids and mixtures. The scientific unit for measuring viscosity is the poise, which is kilograms per meter per second.

Water has a viscosity of 1.005 centipoise at 20°C. Motor oil is approximately 1 poise and honey about 100 poise at room temperature. A display of common fluids could be easily made for the classroom to illustrate this. Several variables affect the viscosity, including temperature, concentration (for solutions, size of the molecules or particles, and shape of the molecules or particles).

The viscosity of most pure fluids is not changed by the physical energy that is applied to the fluid to get it to flow. Doubling the force applied to the liquid doubles the velocity or flow rate. This simple relationship follows the equation given above and is called Newtonian because it was first described by Isaac Newton.

Some liquids and mixtures do not do as predicted according to Newton's Laws. These liquids exhibit non-Newtonian behavior. One example is catsup. When catsup is mixed or stirred, its viscosity becomes lower, and it flows more easily. This is an example of what is known as thixotropic behavior. Thixotropic is derived from the Greek words “thixis,” meaning “the act of handling” or touch, and “trope” meaning “change.” Therefore, thixotropy means to change by touch.

A characteristic nearly the opposite of thixotropy is a property known as dilatancy. A dilatant substance is one where the viscosity increases with stirring (or by exerting a "sheer" force). The mixture of cornstarch in water exhibits this behavior.

3. Example of non-Newtonian fluids:

<u>Material</u>	<u>Behavior</u>
Quicksand	Thixotropic
Cornstarch-water mixture	Dilatant
Lipstick	Pseudo-plastic
Toothpaste	Bingham plastic
Ready-mix concrete	Thixotropic
Mayonnaise	Thixotropic

4. The quantity of cornstarch and water is not really critical. If the mixture appears too runny, have students add more cornstarch; if the mixture is too stiff, add more water. It is recommended that the amounts of cornstarch not be weighed or massed, but experimentally mixed with water.

5. The "more expensive" the catsup, the better the experiment works.

6. References: Walker, J. 1978. "The Amateur Scientist," *Scientific American*, pp. 186-198 .

GEMS, Oobleck, Curriculum, Lawrence Hall of Science, Berkeley, California.

Suggested Questions

7. What other fluids are thixotropic? Dilatant? Test them.
8. Under what circumstances would you want a material to be thixotropic? (Hint: house paint)
9. When would you want a fluid to be dilatant?

Activity: Dilatancy

Student Learning Objectives

At the end of the activity students will be able to:

- mix a material to demonstrate a mechanical/physical property named dilatancy. (When mechanical energy is applied to a material it becomes thick and solid-like; and when the energy decreases it becomes runny and liquid-like.)
- observe and record the behavior of dilatant material
- outline the theory of how particles behave under shear stress related to mechanical and fluid behavior
- list several materials that exhibit dilatancy behavior.

Materials

- Cornstarch
- Water

Equipment

- 100-mL beaker
- Ring stand with small ring
- Mirror
- Steel ball, approximately 6 mm in diameter (marbles)
- Stirring stick
- Watch, stop watch, or timer

Procedure

Note: It is up to the student to experiment with the amount of cornstarch to add to water.

1. Put cornstarch into the 100-mL beaker.
2. Put water in a 6-oz cup, and add it to the cornstarch.
3. Stir mixture until a runny, putty-like material develops.
4. Let the mixture sit for 30 sec, then stir rapidly.
5. Observe and record results in your journal.
6. Set the beaker on the ring stand, and place the mirror under it so you can see the bottom of the beaker.

7. Drop a steel ball into the cornstarch mixture from about 3 cm above the surface. Time how long the ball takes to touch the bottom of the beaker.
8. Stir cornstarch for 1 min.
9. Drop the ball and time its travel, as you did in step 7.
10. If you have conducted the thixotropy lab, compare with the results of this lab, and record your thoughts in your journal.

Extension Activity

1. Before the cornstarch mixture is cleaned up, you may want to take 1 or 2 spoonfuls of it in your hand, roll the mixture into a ball, and then let it rest in your open palm so you can observe it.

Activity: Thixotropy

Student Learning Objectives

At the end of the activity students will be able to:

- follow directions in performing a test on thixotropic materials, including recording data generated during the test process
- graph the data and draw conclusions from the plotted data
- list several materials that exhibit thixotropy.

Materials

- Catsup, 500 mL

Equipment

- Beaker, 600 mL
- Ring stand with small ring
- Mirror
- Steel balls, 10 each, approx. 6 mm in diameter (marbles)
- Stopwatch
- Stirring stick
- Course sieve
- Container for used catsup

Procedure

1. Pour the catsup into the 600-mL beaker.
2. Set the beaker on the ring stand, and place a mirror under the beaker so the bottom of the beaker can be seen.
3. After at least 5 min, drop one of the steel balls into the catsup from about 3 cm above the surface. Time how long the ball takes to touch the bottom of the beaker.
4. Repeat with four more balls. Compute the average of the five data points. Be sure to drop balls into different areas of the catsup to avoid the balls traveling down same paths.
5. Stir catsup for 1 min.
6. Drop ball number 6 and time its travel. Continue to drop and time balls 7 through 10 at 1-min intervals.

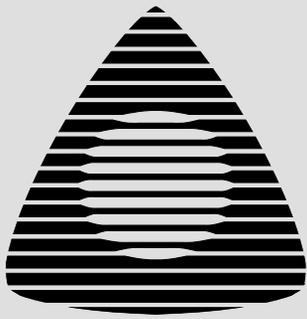
7. Pour catsup through coarse sieve into container reserved for used catsup.
8. Wash steel balls, beaker, stirring stick, and any other equipment that has been used with catsup. Dry thoroughly.
9. Return all equipment to its proper place, and clean your working area.
10. Graph the change in time traveled versus minutes after stirring.
11. If you have conducted the dilatancy lab, compare the results with this lab, and record your notes in your journal.

Vocabulary—Introductory*

Allotropy
Amorphous^(x)
Atomic weight^(x)
Atoms^(x)
Chemical compounds^(x)
Chemical formulas^(x)
Continuity
Crystal^(x)
Crystalline^(x)
Dilatancy
Electromagnetic field
Element^(x)
Filament
Glass envelope
Grain^(x)
Grain boundary^(x)
Incandescent
Melting point^(x)
Mole^(x)
Molecule^(x)
Newtonian
Oxidation
Oxide^(x)
Phase change^(x)
Poise
Polarized
Polymorphism
Shear
Thixotropy
Thoria
Viscosity

*Instructor may vary vocabulary to suit particular content presented.

^(x)Also covered in other units of study.



Experiments/ Demonstrations

Metals

Metals

Metallurgy: The Science of Metals

Introduction

Metallurgy is the science of making metals and alloys in forms and with properties suitable for practical use. It has played a unique role in human history, having brought us out of the Stone Age into the Bronze Age and then into the Iron Age. The seemingly miraculous conversion of dull earths into shining metals was the very essence of the art and magic of alchemy. No science of metals existed in medieval times to understand and explain the secret methods used to make and form metals and alloys.

Some of the mystery over metallurgy still lingers today. Science fiction novels and movies depict space ships and other objects constructed of “wonder metals” with amazing properties. Such usages are believable because of the remarkable achievements of the modern metallurgist during this century in developing new metals and alloys for jet engines, electronic circuits, and other advanced engineering systems. These successes were not achieved based on the art of the past, but by the application of scientific principles. Metallurgy is now a disciplined applied science focused from a clear understanding of the structures and properties of metals and alloys.

Metallurgy can be separated into three basic components: chemical, mechanical, and physical. Chemical metallurgy deals primarily with the making of metals and alloys from their naturally occurring ores. Most metals are present in the Earth as compounds of some sort, such as oxides or sulphides. Metals must be extracted from these ores for practical use. The first metals were discovered accidentally more than 5,000 years ago. Metals such as copper, lead, and tin melted at low temperatures and were probably formed at camp fires. Great advances came in metal production as furnaces were created to control the ore-melting and metal-forming process.

The importance of metals in history stems primarily from their mechanical behavior and use as construction materials. Metals combine the properties of high strength with the ability to change shape without breaking. This enables them to be shaped into a wide assortment of components, including car bodies, cans, and girders. Mechanical metallurgy deals with testing mechanical properties, the relationships between properties and engineering design, and the performance of metals in service.

The final critical component of the science of metals is physical metallurgy. This aspect deals with the internal world of metals and how internal structure can be designed and produced to give the best

properties. Although metals look like inanimate objects, internally electrons dash about within them, and atoms can move and exchange places while the metal is in solid form. As a result, changes in temperature can cause atoms to rearrange and prompt significant changes in properties. The ability to control these internal changes has led to dramatic improvements in the properties of metals. High-strength steels for building supports, stainless steels for corrosion-resistant applications (water pipes, pans, pots, etc.), and aluminum alloys for high-strength, light-weight airplane skins would not have been created without the ability to control and modify internal structure.

Properties of Metals

Instructor Notes

Reliability

This lab will work very well and is an excellent introduction to metals.

Estimated Time for Activity

One class period.*

Teacher Tips

Note: *This lab is meant to be set up at stations or tables. Students in small groups can spend a designated amount of time at each station and then rotate to the next station. The following lists are items needed at each station.*

Station #1: *Electrical Conductivity: Conductive vs. Non-Conductive*
Use an electrical conductivity meter or continuity device (see Figure 4.2 in Materials Systems in the Introductory Experiments Section) and a variety of conductive and non-conductive materials. Objects might include a pencil, chalk, ruler, glass, can, etc.

Station #2: *Electrically Conductive Materials*
Use an electrical conductivity meter or continuity device. Use several pieces of metal, including aluminum foil, lead sinkers, paper clips, coins, etc.

Station #3: *Magnetism*
Use similar objects at this station that you used at Station 2. Many Canadian coins (especially pre-1984) are magnetic.

Station #4: *Physical Appearance of Metals*
Use pieces of brass, bronze, copper, and steels.

Station #5: *Identifying Metals*
Use two pieces of aluminum very different in size and a piece of steel. You could also use continuity devices and magnets, a balance and a graduate cylinder to determine volume in case some students are familiar with the measurement of density.

*One class period is approximately 1 hour.

Station #6: *Metal Processing Techniques*

Use cans that have been formed using different processes: soldered and welded seam cans, also molded cans such as aluminum cans or some tuna and cat food cans. Discuss how each was processed and how bottoms, tops, lids, and flip-tops are made and applied. If you can't find a local technical resource find a beer can collector to discuss how cans have changed.

Station #7: *Expansion and Contraction of Materials*

Use ball and loop thermal expansion device available from scientific supply catalogs (for example, Sargent Welch, Item# 1661, ball and ring or Fisher EMD, Item# S41702). Many students expect the hole to get smaller when heated.

Station #8 *Deformation of Metals*

Use paper clips or any piece of wire that can be used to illustrate fatigue.

Safety

1. Station #7: Use caution with open flame to avoid burns. Also, the metal ball remains hot; be careful with it. Quench it in a can of water to cool.

Activity: Properties of Metals

Student Learning Objectives

At the end of the activity students will be able to:

- list some of the characteristics of metals
- list some of the characteristics of nonmetals
- compare and classify different materials as metals and nonmetals
- develop a reference chart in the journal for properties of metals and nonmetals for use at a later time.

Materials

- Assorted metals and other materials

Equipment

- Electrical continuity tester
- Magnet
- Burner
- Ring and ball device

Procedure

You and your lab partner will rotate among eight different stations and perform a variety of activities. You may start at any station and rotate to any other one. Write observations that you make at each station in your journal. Be sure to note in your journal at which station you are working, and clearly indicate what you have observed.

Station #1: Use the conductivity device to determine if the materials at this station conduct electrically.

Station #2: Test the different types of metals at this station for electrical conductivity.

Station #3: Test the different types of metals to see if they are magnetic.

Station #4: Compare the color and appearance of the pieces of metal. What differences/similarities do you observe?

Station #5: Compare the three pieces of metal. Are they the same type of metal?

Station #6: Compare the cans. How do they differ? How were they made? Were the manufacturing processes different?

Station #7: Pass the metal ball through the hole and remove it. Then heat the ball with the burner, and attempt to pass the ball through the hole again.

Station #8: Bend the wire until it breaks.

Alloying Copper and Zinc

Instructor Notes

Reliability

This lab works very well. It is a real excitement generator for students.

Estimated Time for Activity

One class period.

Teacher Tips

1. Before 1982, pennies were made of copper. Since 1982, pennies have been made of zinc with a thin copper foil covering them.
2. This lab demonstrates diffusion of a metal. The plated zinc on the penny's surface diffuses into the copper and forms a brass surface.

Safety

1. Hot NaOH solution is very caustic. An appropriate "caution" note is added to the activity sheet.

Disposal

1. If NaOH is not reused, react it with HCl to neutralize the solution, then dispose by pouring down a drain. React slowly and carefully to avoid getting solution *hot*.
2. Once the lab has been done you can keep the beakers of NaOH and store for use again. This eliminates disposal problems.

Activity: Alloying Copper and Zinc

Student Learning Objectives

At the end of the activity students will be able to:

- describe through writing and discussion the process and results that occur when an alloy is made.

Materials

- Pennies, pre-1982 and post-1982, 3 ea.
- Zinc (Zn), 1 g, granular
- Sodium hydroxide (NaOH) solution, 3M, 25 mL
- Distilled water, 75 mL
- Tarnish remover solution, 10 mL, or steel wool

Equipment

- Safety glasses
- Chemical goggles
- Hot plate
- Bunsen burner
- Striker
- Beaker, 250 mL
- Beaker, 100 mL
- Tongs/forceps

Procedure

1. Obtain three pre-1982 pennies and three post-1982 pennies. Clean the pennies by dipping in tarnish remover or rubbing with steel-wool. It is very important that all tarnish be removed so the metal is in direct contact with the NaOH solution.

Caution: Sodium hydroxide (NaOH) is very caustic. It can damage eye tissue very rapidly. **When working with NaOH wear chemical goggles.** If you do get some of the NaOH solution in your eye, flush the injured eye **immediately** with cool flowing tap water. Have someone get the teacher to evaluate the situation, and arrange for medical help. Keep flushing the eye with running tap water for 20 minutes (minimum).

- Carefully pour 25 mL of NaOH solution into a 250-mL beaker (the one specifically identified and labeled for NaOH).
- Weigh a 1-g sample of zinc. Pour it into the NaOH solution.
- Gently heat the beaker on a hot plate. A hot solution works best, but do not allow the solution to boil. Continue to heat gently.

Caution: Do not allow sodium hydroxide to boil. Do not breathe vapors. Avoid any skin contact. Immediately flush skin with cool flowing tap water, and notify instructor if you come in contact with the solution.

- Using tongs, carefully add two pennies from each of the two sets to the hot solution. Do not drop the coins so as to cause a splash. Set the third penny aside for comparison. Be sure to remember which set the coins came from.
- Observe and record any changes in the appearance of the coins in your journal until no further changes are noted.
- Place 75 mL of distilled water into a 100-mL beaker.
- With forceps or tongs, remove the pennies from the solution. Place them in the beaker of distilled water. Turn off the hot plate.
- Using forceps or tongs, remove the coins from the beaker of water. Rinse them under running tap water. Dry the coins with a paper towel.
- Gently heat one set of treated coins in the outer cone of a Bunsen burner flame, holding it vertically with the forceps or tongs as shown in Figure 5.1.
- Continue heating the coin for 1 to 3 seconds after its appearance changes. **DO NOT OVERHEAT.** Immediately plunge the coin into the beaker of distilled water. Record your observations in your journal.
- Remove the coins from the beaker of water. Dry them with a paper towel.
- Repeat steps 5-12 for the other set of coins.
- Arrange the coins back into their pre- and post-1982 sets and observe the appearance of the three pennies from each set. Record your observations.
- When finished, clean up your work station following the instructions given to you by the teacher.

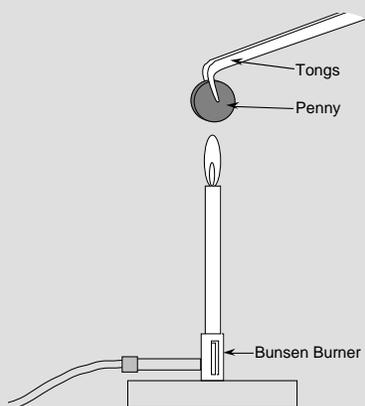


Figure 5.1. Alloying Copper and Zinc

Alloying Tin and Lead

Instructor Notes

Reliability

This experiment works 90% of the time, but it could work all the time if students measure correctly.

Estimated Time for Activity

Two class periods.

Teacher Tips

1. Most vaporized metals are health hazards, and exposure should be limited. Use ventilation and minimum melt temperatures to keep metal volatilization low.

Caution: Do not allow students to put their faces over the evaporating dishes. They must look from an angle to avoid harmful vapors.

2. Because of the toxicity of lead, a zinc-tin alloy or a bismuth-tin alloy could be made using the same procedure. Phase diagrams (Figures 5.2 and 5.3) are included if you decide to use either of these alternatives.
3. An electronic digital thermometer would be the best choice for measuring temperature. Do not use mercury thermometers because glass breakage would lead to highly dangerous mercury vapors.
4. For more uniform heat distribution while heating the samples on the hot plate, a sand bath can be used.

Safety

1. Safety glasses must be worn.
2. Masks must be worn. Note: The masks are not meant as dust or particulate eliminators, but are used as a tangible reminder to students not to breathe directly over the hot plate. You must make it clear to students that the masks do not stop fumes.
3. Molten metal can cause severe burns.
4. Do not breathe directly over evaporating dish when molten metals are present. Ventilate room!
5. Do not allow **any** food into the room; leave lunches outside.

Disposal

1. Product will be used for soldering projects.

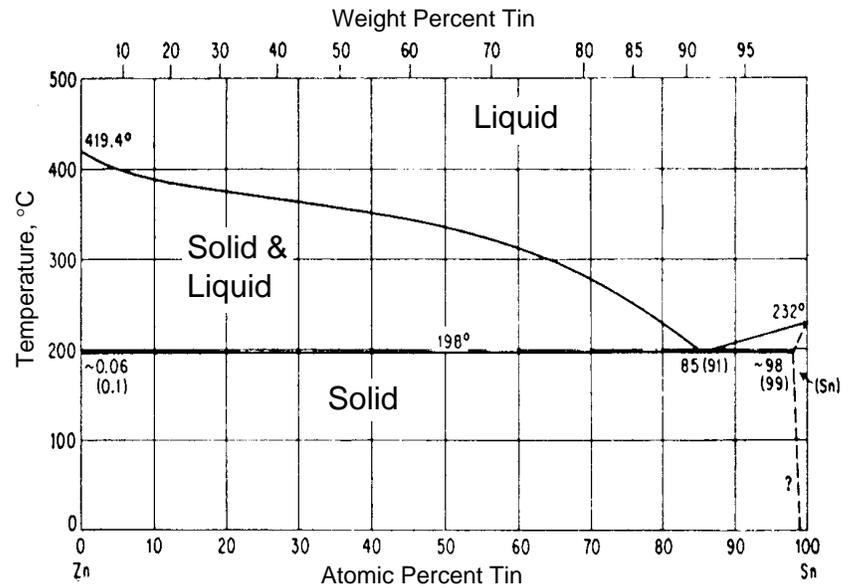


Figure 5.2. Sn-Zn Phase Diagram

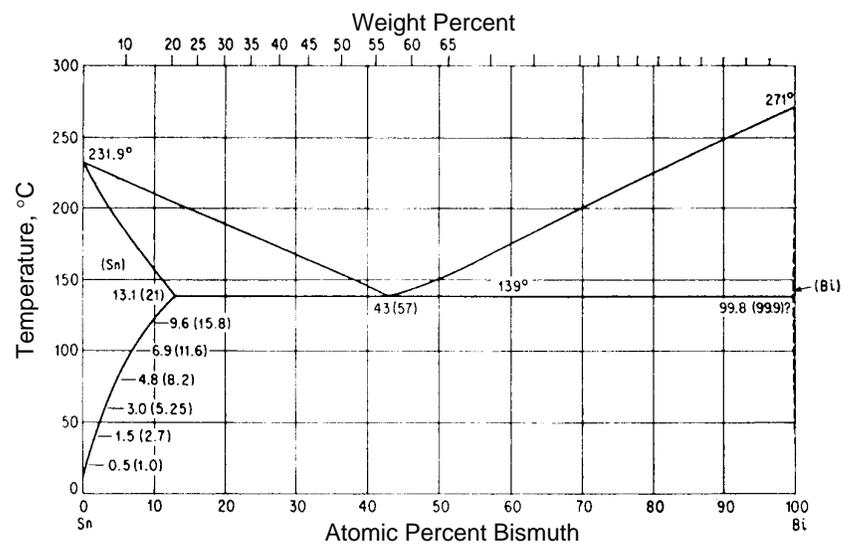


Figure 5.3. Bi-Sn Phase Diagram

Activity: Alloying Tin and Lead

Student Learning Objectives

At the end of the activity students will be able to:

- follow instructions to make an alloy
- make an alloy to meet specific properties such as melting point and “wettability” (low fluid viscosity)
- describe the effect of various percentage mass ratio alloys of lead and tin on melting point, using appropriate formats
- use an alloy’s phase diagram and eutectic point to describe the observations and data obtained during the exercise
- make an alloy (50/50 solder) useful for joining copper foiled stained glass pieces.

Materials

- Lead (Pb) (50 g max per group depending on mix ratio)
- Tin (Sn) (50 g max per group depending on mix ratio)
- Water (tap water for quenching alloy into beads)
- Paper cup (3), 6 oz.

Equipment

- Balance/scale (which ever is available)
- Porcelain evaporating dish (or any assay container that will tolerate 400° C)
- Thermometer (at least 400° C), alcohol type or electronic
- Hot plate (at least 400° C or Bunsen burner)
- No. 10 can/stainless-steel beaker (or any container that will tolerate 400° C)
- Magic marker or high temperature china marker
- Tongs (small ones for picking up evaporating dish)
- Safety glasses (important that they be worn)
- Mask (important that it be worn)
- Fish weight mold
- Metal plate with ledge (1 ft x 4 in. x 1/2 in.)

Caution: This molten alloy can cause severe burns. Metal vapors are a health hazard; do not breathe directly over evaporating dish. Do this experiment in a well-ventilated area.

Procedure

Part I

1. Your group will be assigned a particular weight percentage mix for your tin-lead alloy. See Table 5.1. Record this in your journal.

Table 5.1. Weight Percentage Mix for Tin-Lead Alloys

<u>Group</u>	<u>%Tin (Sn)</u>	<u>%Lead (Pb)</u>
1	100	0
2	90	10
3	80	20
4	70	30
5	60	40
6	50	50
7	50	50
8	40	60
9	30	70
10	20	80
11	10	90
12	0	100

2. Obtain a porcelain evaporating dish. Write your group number with magic marker in four places high on the inside and outside edge of the dish.
3. Obtain a paper cup 1/4 full of tin and a paper cup 1/4 full of lead.
4. Using the scale/balance and an empty cup, weigh out the correct amount of lead and tin to make 50 g of your alloy.
5. Return all unused tin and lead to the **correct** containers.
6. Pour the mixed lead and tin into a porcelain dish. Place on hot plate set at maximum temperature.
7. Using Figure 5.4, estimate the melting point of your mix.
8. Just as melting begins, measure temperature. Continue heating until all metal has melted. **Do Not Overheat.**
9. Record melt temperature and the alloy's appearance in your journal. Allow the alloy to cool.
10. **Clean the thermometer with a paper towel.**
11. When the alloy is cool, give your alloy to the group one number higher than yours.

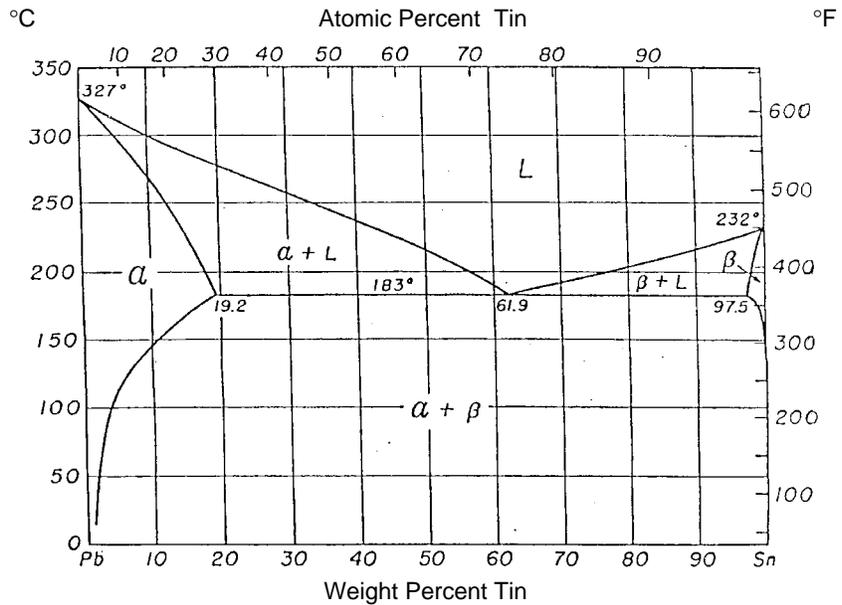


Figure 5.4. Phase Diagram for Tin-Lead Alloys

12. Record the group number and the percentage mix.
13. Repeat steps 6-11 until you have done all of the groups or until the instructor tells you to stop.
14. Draw a lead-tin solid/liquid percent by weight versus temperature graph. Identify the melting points of pure lead, pure tin, and your estimate of the eutectic temperature (lowest melting point).

Note: Part II may be done at this time or you may continue on to Part III. The purpose of Part II is to observe the melting points of all the lead-tin alloys as they are heated simultaneously.

Part II

1. Pour all the molten metal from your evaporating dish into a 1-1/2-oz fish-weight mold. You will be able to make one complete weight and one partial weight. The mold is used to reduce oxidation during the pour process; other processes have been used to do this same experiment. Be creative.
2. Place weights back into evaporating dish, and mark dish with alloy percentage.
3. Place on hot plate in order of percent (see Figure 5.5). Heat the hot plate to 200°C. Slowly begin to raise the temperature of the hot plate. Watch for indications of an alloy melting. Hold the temperature steady when melting begins to occur with any sample.
4. Measure the melting point of the melting sample with a thermometer. Record melt temperature in your journal.

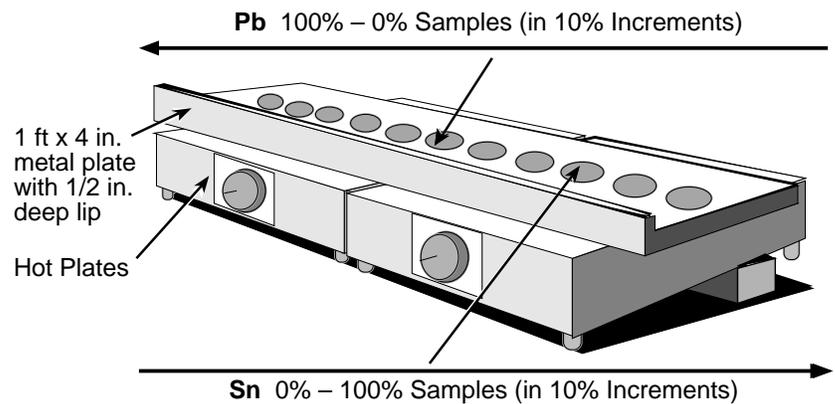


Figure 5.5. Alloying Tin and Lead

5. Compare your results with the phase diagram (Figure 5.4).
6. Return evaporating dishes to original group to continue with Part III.

Part III

1. Add or subtract 6 to your group number and get together with that group. There is no group number higher than 12.
2. Combine the alloy made by each group into one evaporating dish and melt. Allow it to cool. Calculate the lead-tin weight percent of the new alloy.
3. Remelt the alloy. Measure the melt point temperature. What should the melting temperature be? Record in your journal. **Clean the thermometer.**
4. Once your alloy just melts (Do Not Overheat), pour it very carefully and slowly from a height of approximately 2 ft. into a No. 10 can half full of cold water.
5. Retrieve your droplets of lead-tin alloy from the can and dry.
6. Weigh your droplets and record. What should the weight be? Did it weigh what it should have? If not, why not?
7. Turn in your 50/50 alloy to the instructor for use in a future student project.
8. Clean and return equipment to its proper place.

Drawing a Wire

Instructor Notes

Reliability

This lab will work very well. However, as the wire gets smaller some students will experience some difficulty (with breaking, getting started in draw plate, work-hardening, etc.) based on their abilities to work with their hands and with tools.

Estimated Time for Activity

One class period (depending on number of draw plates available).

Teacher Tips

1. The process of drawing a wire (making it smaller in diameter) is a common practice in the manufacture of various types of wire. Whether the purpose of the wire is conducting electricity, bailing hay, or fencing, the process is basically the same. For all of these types of wire, a large diameter (approximately 5/16 in.) metal rod generally in a coil is pulled through a series of continually smaller dies (holes) until the desired diameter is obtained.
2. In the process of going through the dies, certain changes take place in the metal. The crystal structure of the wire changes, and the diameter decreases, but the length increases proportionally, while generating heat because of friction (see your text for in-depth study or Jacobs, pages 158-165).
3. As the wire is formed into a taper by peening, it becomes work-hardened, and therefore, brittle and tends to split or break.
4. Because of friction caused by the wire going through the draw plate and the crystal structure being reshaped, heat is generated.
5. As the wire decreases in diameter, the length of the wire increases inversely proportional to the square of the diameter.
6. The density of the material remains the same.
7. As the wire gets smaller, it gets stiffer, but this is hard to tell because of the smaller diameter.
8. When the wire was annealed it was easier to bend and to form the taper on the end.
9. If you use the lead/tin solder as a drawing activity, be sure you do not transfer materials to other wires drawn with the same plate. This is especially true if you are going to draw silver wire for a later project. Using a suitable lubricant will help prevent problems.

Suggested Questions

10. What happens to the wire as youpeen the end?
11. How did the wire feel after immediately pulling it through the die?
12. Explain the changes in the wire's dimensions.
13. What conclusions did you arrive at because of the lab?
14. Did the density change during drawing? Why?
15. Was the wire stiffer after drawing?
16. What changes took place when the drawn wire was annealed?

Safety

1. Be sure no one is standing behind the person pulling the wire. Pliers could slip or the wire could break, and someone could get hit by an elbow.

Activity: Drawing a Wire

Student Learning Objectives

At the end of the activity the student will be able to:

- demonstrate that drawing a wire work-hardens the wire
- describe compression and tangled dislocations and how this work-hardens metals
- demonstrate plastic deformation, causing friction and heat.

Materials

- Copper (Cu) wire 12 ga, 6 in., or solid core tin/lead solder wire or silver wire
- Lubricant (grease)

Equipment

- Safety glasses
- Vise grip pliers/draw pliers
- Bench vise
- Draw plate
- Micrometer
- Ruler
- Tape measure
- Balance
- File

Procedure

1. Measure the length of your wire using a rule, and the thickness using a micrometer. Weigh the wire. Record the data in your journal.
2. Clamp draw plate with its long edge going horizontally in the bench vise. (Be sure the small openings of the draw plate are on the side from which the wire will be pulled, see Figure 5.6.)
3. Taper one end of the wire using either a ball peen hammer or a file (see Figure 5.6).
4. Pass wire through the largest hole in the drawplate that the taper will go through. Apply lubricant to the wire and friction area of the drawplate.

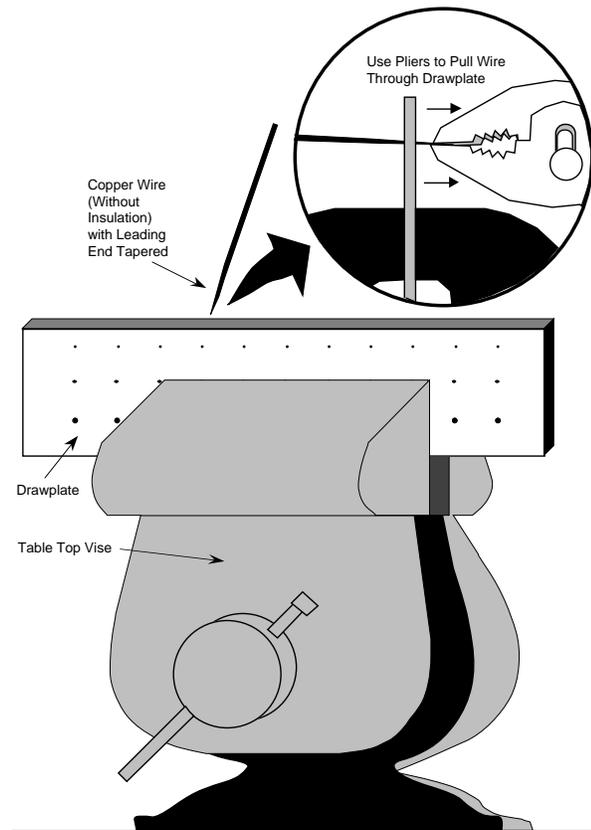


Figure 5.6. Drawing a Wire

5. Grasp the tapered end of the wire with vise grip pliers. Pull the wire smoothly and completely through the drawplate without jerking, if possible.

Note: After a few passes, wire may work-harden. Annealing wire may be necessary.

6. Repeat drawing process until you have drawn the smallest wire possible. Do not hurry the process; reduce wire through gradually smaller gauge holes.
7. Measure the wire's final length, thickness, and mass. Record data in your journal. Calculate the percent change for all dimensions.

Aluminum-Zinc Solid-State Phase Change in Metals

Instructor Notes

Reliability

This lab works as far as making an alloy. A problem may occur when making a noticeable phase change; this works only about 90% of the time. Increasing the annealing temperature about 25°C may make this experiment work 100% of the time (see Teacher Tip 5, for more details).

Estimated Time for Activity

Two class periods.

Teacher Tips

1. This experiment demonstrates the concept that certain metals and alloys undergo a structure change while in the solid state, with a consequent change in their properties. When the structure changes, heat is discharged.
2. Experience indicates that annealed ingots may spontaneously transform back to their stable state. It is recommended that ingots not be stored while in their metastable state; anneal the ingots, do the phase change experiment, then store the ingots.
3. Have oven and furnace at operating temperature to save time.
4. Metals that have the same crystal structure (like silver and gold) are usually completely miscible (they don't separate into two or more phases* upon cooling). When alloys are made from metals with different crystal structures, a tendency usually exists for different phases to form in the alloy upon cooling. The aluminum (Al)/zinc (Zn) alloy studied in this experiment is an example of a material that undergoes a phase transformation upon cooling or heating (see Figure 5.7). Aluminum has a face-centered cubic crystal structure, and zinc has a hexagonal-closest packed crystal structure (see Figure 5.8).

The alloy composition used in this experiment (22 weight percent Al, 78 weight percent Zn) is called an eutectoid composition. Eutectoid means that one solid phase transforms to two solid phases

* A single-phase alloy is uniform throughout in chemical composition and physical state; it is homogeneous. A two-phase alloy, if polished and examined microscopically, has regions of different appearances that are chemically different.

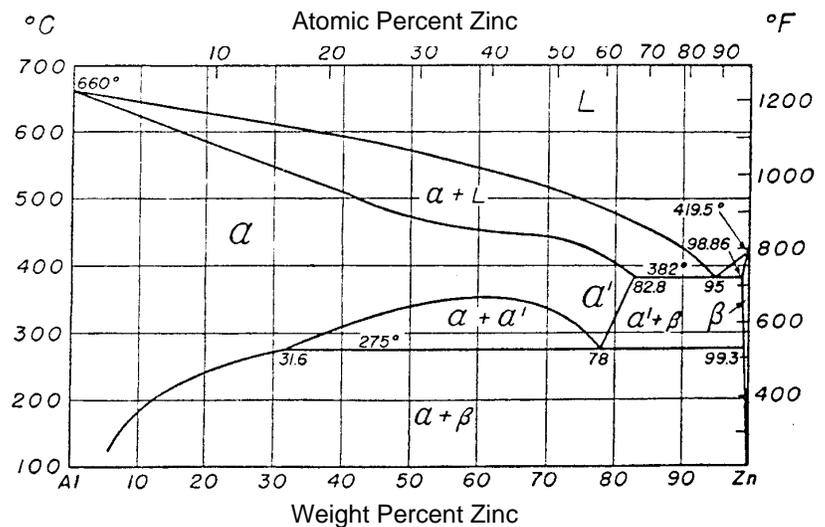


Figure 5.7. Phase Diagram for Aluminum and Zinc

upon cooling. In this experiment, one phase will be mostly Al and the other phase will be mostly Zn.

When the alloy is cooled rapidly from above 275°C (at which point it is single phase) to room temperature, it is metastable (it wants to separate into two phases), but the atoms are frozen in place. Some energy is necessary to allow the transformation to start; this energy is provided by heating the alloy a few degrees in your hand. This particular phase transformation is exothermic (releases heat). Any transformation to a more stable phase releases some heat.

After the phase transformation is complete, the metal can be reheated to above 275°C. At this temperature, only one phase exists (face-centered cubic, like Al), so the transformation is reversed.

5. The temperature of 275°C is used as the annealing temperature of this alloy. This is taken directly from the phase diagram located in the student activity section. In reality and practice, it is suggested that 300°C or greater be used as the annealing temperature for two reasons.
 - a. Temperature gradients exist in most furnaces, and the actual temperature of the furnace may be quite different from the temperature readout or controller in the furnace ($\pm 25^\circ\text{C}$ is not uncommon).
 - b. Compositional variations of the alloy can also occur because of impurities in purchased materials, incorrect or imprecise measurement of source materials, and the loss of zinc because of oxidation during the melt process. As observed on the phase diagram, these minor changes in composition cause a rapid increase in annealing temperature.

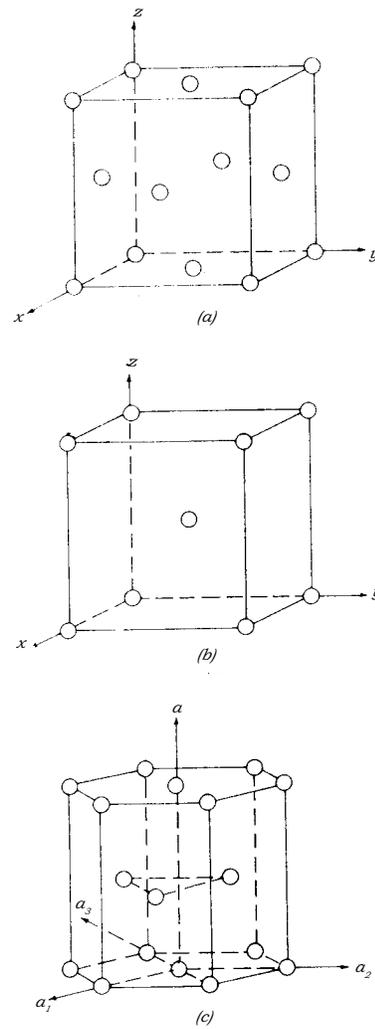


Figure 5.8. Crystal Structure of Metals: (a) Face-centered cubic, (b) Body-Centered Cubic, (c) Close-Packed Hexagonal

6. Adding ice to the water used to quench the ingots is suggested. The quicker the sample cools, the more dramatic the heat release during the phase change. More of the metastable phase will be solidified when the alloy is rapidly cooled.
7. Students will record weights of the crucible and materials before and after the alloying. This is one more chance to let students observe that mass is conserved. Steps 3, 19, and 20 in the student activity directly apply to this.
8. This is an experiment where crucibles can be used year after year. Label the crucibles with a number or figure using an underglazed pencil or a heat-resistant marking product as described in item 9. Students can then choose their own labeled crucible to do the experiment.

9. Heat-resistant marking material can be made quickly. In a small 5 to 10 mL cup or beaker, add 1 to 3 g of iron oxide powder (Fe_2O_3). Mix into the powder just enough water to make a paste or slurry. Use a fine-tipped paint brush to mark or label the crucible with the paste. Bake on the label at 75°C for about 5 min.

Suggested Questions

10. Did crucible gain, lose, stay the same? Why?
11. Did total weight gain, lose, or stay the same? Why?

Safety

1. Do not use aluminum or zinc powder. The powders can be explosive. Use sheet or shot material.
2. Use extreme caution with molten metal alloy. Especially do not overheat zinc because poisonous zinc fumes are created.

Disposal

1. Keep alloy for Caloric Output Lab.

Activity: Aluminum-Zinc Solid-State Phase Change in Metals

Student Learning Objectives

At the end of the activity students will be able to:

- follow directions in the lab to form an alloy
- form an alloy that releases heat when it changes its internal crystal structure
- explain how heat is released from the alloy because the particles are changing from one allotropic form to another.

Materials

- Clay crucible, numbered
- Water (H₂O), ice water recommended
- Aluminum, 22.0 g
- Zinc, 78.0 g
- Paper cup, 3 oz.

Equipment

- Safety glasses
- High temperature hot plates (2)
- Oven (for annealing)
- Furnace (for melting)
- Crucible tongs (large)
- Crucible tongs (small)
- Gloves, leather
- Gloves, heat resistant
- Casting sand mold or sinker mold
- Scale (balance)
- No. 10 can or stainless steel-beaker
- File

Procedure

1. Preheat furnace to 500°C (932°F).
2. Obtain materials, numbered crucible, zinc, alumina, and paper cups. Label the crucibles.
3. Weigh the crucible, and record its mass in your journal.
4. Tare weight of paper cup. Add 78.0 g +/- 1.0 g of zinc. Pour zinc into crucible.
5. Using tongs, place crucible in furnace at 500°C for 15 min.

Note: *Whenever you put materials in or take them out of ovens and furnaces, always use correct tongs and gloves, and have your partner operate the door. Door should be opened for as little time as possible. (If underglaze pencil is used, steps 2 and 5 may be omitted. These steps are needed to bake on heat-resistant glaze markings.)*

6. Tare weight of paper cup. Add 22.0 g +/- 1.0 g of aluminum.
7. Remove crucible from furnace (zinc should be in a liquid state, if not, return crucible to furnace for an additional 5 min). To keep the molten zinc from splattering, add the aluminum VERY CAREFULLY.
8. Return the crucible to the furnace, and increase the temperature to 725°C. Allow the two metals to become an alloy by soaking for 15 min.
9. Prepare casting mold by cutting three holes, 2 in. deep in the casting sand with a 3/8-in. hole-cutting tube. Identify your holes by writing your number in the sand with your pencil.
10. Remove crucible from furnace, and quickly pour molten metal into the mold. Place crucible on a surface intended for hot crucibles. Allow the ingots to cool to room temperature, then remove them from the mold.
11. Using a file, remove any rough surfaces from the ingot and make ends smooth. Remove as little as possible. Add pieces of filed metal to the crucible.
12. Identify your ingot by stamping or engraving your number and/or initials in the end of the ingot.
13. Anneal the ingot by using small tongs and placing the ingot in the oven at 370 – 380°C for 1/2 hour.
14. Fill a No. 10 can with cold water (ice water works even better) and place near the oven.
15. Using small tongs, rapidly remove one of your ingots from the oven and quench it in water using a figure 8 motion for 15 sec to ensure rapid cooling. Then drop the ingot to the bottom of the can. Repeat until all ingots have been quenched.

16. Remove ingots from the water and handle carefully (DO NOT BANG OR DROP). Squeeze the cold (annealed) ingot in the palm of your hand (see Figure 5.9). Squeezing the ingot allows better surface contact, which gives more heat transfer from your hand to the ingot. This heat transfer is what will trigger the phase change. In less than 2 min, a transformation will occur accompanied by the discharge of heat. This excess energy released by the ingot will cause its temperature to rise to as high as 60°C (140°F). (Caution—this may be hot enough to burn your hand.)
17. Annealed ingots must be stored in a cool place or the transformation may occur on its own. This is not recommended, though, because many of the ingots will change to a more stable state on their own.
18. Once an annealed ingot has undergone transformation, it can be reused by repeating the heat treatment in steps 13 – 15.
19. Weigh crucible and record results in your journal. Compare weight in step 3.
20. Weigh ingots and record. Add weight to crucible weight and compare to total weight in steps 3, 4, and 6 .

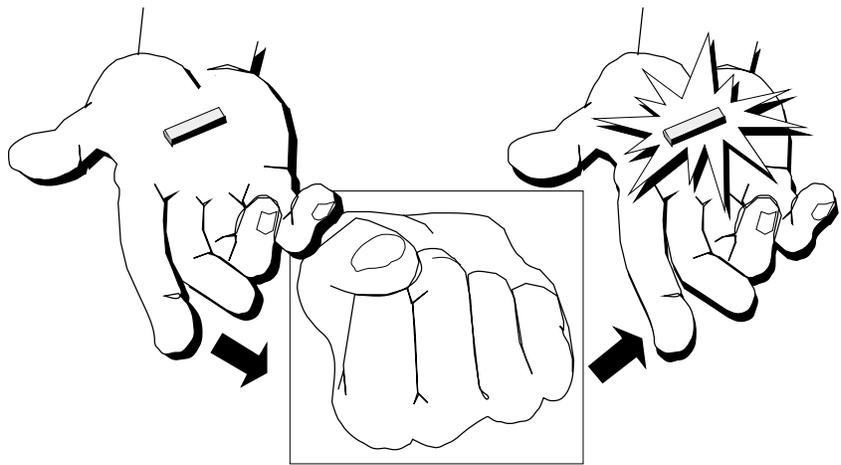


Figure 5.9. Annealed Ingot

Caloric Output of Al-Zn: A Solid State Phase Change in Metals

Instructor Notes

Reliability

If the ingots made in the Aluminum-Zinc Solid State Phase Change lab work, this measurement routine has produced numbers by students ranging from 2 - 25 cal/g, but the accumulative and average has been around 8 cal/g.

Estimated Time for Activity

One class period.

Teacher Tips

1. Once the ingots of Al-Zn have been made and tested, it is possible to measure the approximate amount of heat given off by the phase change. This change is observed in other ways than just heat. For example, visually, the original annealed ingots have a shiny appearance. This changes to a dull gray following the phase change. Also clicking sounds and faint high-pitched whining sounds have been heard during the phase change. It may be interesting to listen to the transforming alloy using a stethoscope
2. A simple calorimeter may be constructed with an 8-oz styrofoam cup, a measured mass of water, and a fairly sensitive thermometer (digital, or mercury, sensitive to the nearest 0.1°C).

The calculation is described in the activity procedure, step 13.

$$\begin{array}{l} \text{heat produced} \\ \text{per gram of ingot} \\ \text{(cal/g)} \end{array} = \frac{(\text{weight of water, g}) (\text{temperature change, } ^\circ\text{C})}{(\text{weight of ingot, g})}$$

3. A styrofoam cup inside a plastic cup is a better insulator than two styrofoam cups together, but just a single cup will work.
4. Collect student results from year to year, and have these data available so students can compare their results.

Suggested Questions

5. Why did the ingots change to dull gray?
6. Why do the ingots make clicking and whining sounds?
7. What does squeezing the metal do to the ingot?

Safety

1. Wear safety glasses.
2. Handling the ingots while they are being annealed could burn you because of the heat in the ingots and the temperature of the oven or furnace.
3. Overheating the ingots can cause the material to vaporize creating poisonous zinc fumes.

Disposal

Water can be poured down drain.

Activity: Caloric Output of Al-Zn

Student Learning Objectives

At the end of the activity students will be able to:

- follow directions in the lab to measure heat
- measure and compute the caloric output of an Al-Zn alloy that has been tempered as it goes through a phase change.

Materials

- Styrofoam cup, 8 oz.
- Plastic cup, 8 oz.
- Cold water
- Al-Zn alloy ingot
- Permanent marker

Equipment

- Safety glasses
- Thermometer
- Furnace
- Crucible tongs (small)
- Graduated cylinder
- No. 10 can or stainless-steel beaker
- Balance

Procedure

1. Preheat furnace to 350°C.
2. Place ingot into furnace for a minimum of 60 min.
3. Obtain styrofoam cup (8 oz), plastic cup (8 oz). Write your work-station number or name on both cups with a permanent marker. Then place the plastic cup inside of the styrofoam cup.
4. Weigh both cups together and record the results in your journal.
5. Using a graduated cylinder, measure 50 ml of water and pour it into the plastic cup.
6. Weigh both cups together with water, and record the results in your journal.

7. Measure the water temperature, and record it in your journal.
8. Take your ingot out of the furnace, and quench it in a No. 10 can filled with cold water until the ingot is cool.
9. Immediately squeeze the ingot in your hand (approximately 3 sec), and place the ingot in the plastic cup containing the cold water.
10. Stir the water gently with thermometer, and read every 30 sec. Record readings until maximum temperature is obtained.
11. Measure the maximum temperature of the water, and record it in your journal.
12. Dry ingot, weigh it, and record the value in your journal.
13. Determine how to measure the amount of heat produced by the ingot as it went through its phase change.
14. Calculate the calories per gram produced by the ingot as it went through its phase change.

Alloying Sterling Silver

Instructor Notes

Reliability

This lab works very well.

Estimated Time for Activity

One class period.

Teacher Tips

1. Silver is most economically purchased in 1 troy oz (1 troy oz. = 31.1035 g) silver pieces at a local coin store. It is *less expensive* there than through a mail order catalog.
2. The alloy, when removed from water at the end of the experiment, may be discolored by oxidation. The oxidation may be removed using a pickling solution as discussed in the lost wax casting lab.
3. Sterling silver is an alloy that contains 92.5% silver and 7.5% copper (by legal definition).
4. The melting point of sterling silver is approximately 962°C (1764°F).
5. To anneal (soften) sterling silver, you heat it to 770°C (1418°F) and quench (cool) it quickly.
6. To temper (harden) sterling silver, it can be heated to 300°C (572°F) for 30 min and then cooled by either quenching it in cold water or just cooling it in open air. By heat-treating sterling silver, the hardness of the metal can be doubled.
7. Students need to calculate the amount of alloy needed (after sprued model weight is obtained) before this lab if they are going to do a project.
8. Phase diagram and information on copper/silver alloy start on page 200 of Jacobs' text.
9. Student questions are discussed in Jacob's text also.

Suggested Questions

10. Why does copper make silver harder?
11. How could you determine if heat-treating the alloy makes it harder?
12. If you doubled the heat-treating temperature what do you think would happen? Why?
13. Why does the sterling have to be water-quenched after melting? What happens if the sterling is allowed to cool slowly? How hard is it when cooled slowly compared to quenched alloy?

Safety

Caution: Watch for splattering hot water and steam as you pour the alloy into the water-filled beaker.

Activity: Alloying Sterling Silver

Student Learning Objectives

At the end of the activity the students will be able to:

- calculate the amount of copper and silver needed to make a specific quantity of sterling silver
- follow directions in making sterling silver
- explain the step-by-step procedure necessary to make sterling silver
- observe changes that take place as the alloy is being made
- explain why sterling silver alloy is used rather than other alloys of silver and copper.

Materials

- Silver (Ag), 99.9%
- Copper (Cu)
- Sodium borate/boric acid (flux)
- Water

Equipment

- Oxyacetylene torch, propane, or natural gas
- Crucible with handle
- Carbon stir stick
- Stainless-steel beaker or No. 10 can (2/3 full of cold water)
- Balance
- Tin snips

Procedure

1. Determine the amount of sterling silver alloy needed for your project (See steps 4 through 6 of the "Lost Wax Casting" lab).
2. Calculate the amounts of silver and copper needed by:
 - a. Multiplying the amount in step 1 by 0.925 to get the amount of silver.
 - b. Multiplying the amount in step 1 by 0.075 to get the amount of copper. (The amounts of silver and copper added together should total the amount of sterling silver needed in step 1.)

3. Weigh out the amount of copper and silver needed to alloy your sterling silver. (You may need to trim a piece or two from metal chunks to achieve desired weight.)
4. Cut silver and copper into small pieces (1/4-in. chunks are sufficient).
5. Preheat and flux crucible. Put the copper in the crucible and cover it with the silver metal chunks. (The silver on top helps prevent the copper from being turned into a metal oxide during the heating process to melt the metals.)
6. Adjust torch to a neutral or carbonizing (yellowish) flame and apply constant heat in a circular motion directly onto the material in the crucible.
7. Sprinkle a small amount of flux onto the alloy to inhibit oxidation.
8. Use the carbon rod to stir mixture once it has melted entirely. The carbon rod also helps to reduce oxides. The metals are now being mixed into an alloy known as sterling silver.
9. When the alloy is thoroughly homogenized and lump free, pour it into the stainless-steel beaker of water.

Use caution when pouring hot metal into water. When pouring more than 30 g of alloy, pour *slowly* to prevent danger of a steam explosion.

10. Extinguish torch. Be careful when removing the silver as the water may be quite warm.

Lost Wax Casting: Investment/Centrifugal Casting Instructor Notes

Reliability

This is a complex procedure, and might have to be repeated more than once. Results are often a boost in students' pride and provide a sense of success and accomplishment.

Teacher Tips

1. The creative design of the wax model takes time. Assorted wax forms can be purchased commercially, if desired for test runs.
2. The instructor should allow the student 1-2 weeks of class time to complete the casting. Model design or student creativity will lengthen the time required to accomplish this lab (see Figure 5.10 for topics and activities related to lost wax casting.)
3. The project can be completed by pairs of students.
4. Refer to Bovin and Murry, *Centrifugal or Lost Wax Jewelry Casting*, for additional background.
5. Show films on the following: wax casting, wax set-up, centrifugal casting, and vacuum casting.

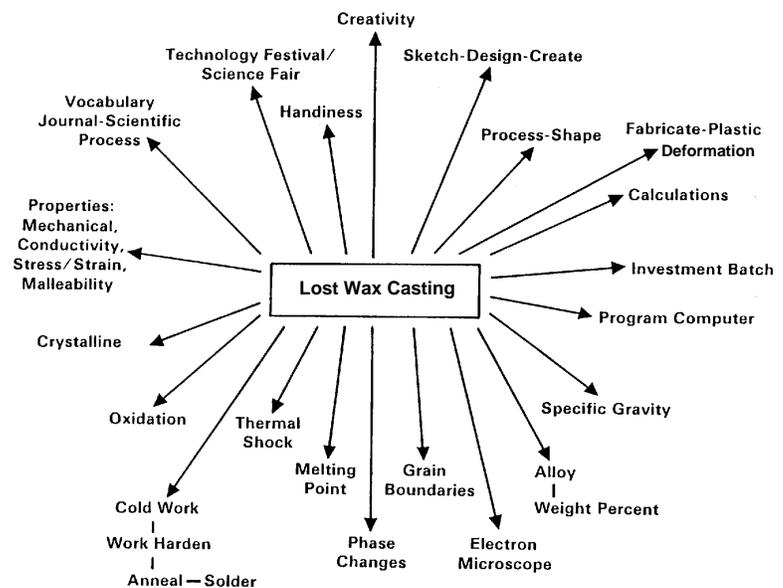


Figure 5.10. Lost Wax Casting

Safety

1. Students should wear gloves, aprons, and safety glasses.
2. Torch can be hazardous. Follow proper procedures with this equipment.
3. When adding flux, make sure students work in a vented area.
4. Use a shield when doing centrifugal casting (this usually is a part of the centrifugal equipment).
5. Burnout program must have cycled.
6. Flask should be $900^{\circ}\text{F} \pm 8^{\circ}$ ($422 - 477^{\circ}\text{C}$)
7. Check for cracking of investment. Exit of sterling at high speed in liquid form is not desired. Review vacuum procedure for cracked flask recovery technique.

Activity: Lost Wax Casting: Investment/Centrifugal Casting

Student Learning Objectives

At the end of the activity students will be able to:

- design and fabricate a project using the process of investment casting by either the centrifugal or vacuum method using a silver/copper (Ag/Cu) alloy.

Materials

- Investment plaster
- Wax, modeling and sprue
- Sterling silver
- Debubblizer (no bubble solution)
- Sodium borate ($\text{Na}_2\text{B}_4\text{O}_7$) or boric acid (H_3BO_3)
- Pickling solution

Equipment

- Gloves and safety glasses
- Burn-out oven
- Wax-forming tools
- Oxyacetylene torch or propane/oxy or natural gas
- Beaker (for pickling solution) (crock pot is safer)
- Centrifugal or vacuum casting apparatus
- Tongs, flask, and copper tweezers
- Rubber mixing bowl (1.5 qt)
- Plastic spatula (wood absorbs water)
- 5-gal bucket
- Jeweler saw

Procedure

1. Sketch in your journal preferably three variations of a design of a wax model you want to make.
2. Fabricate a wax model using techniques demonstrated by instructor with material that leaves no debris. Paraffin is not recommended.
3. Attach sprue to the wax model with inlay, sticky, or welding wax.

4. Weigh the wax model and sprue.
5. Multiply mass of the model and sprue (step 4) by 30%. Add this amount to the mass of the model and sprue to compensate for the soon to be attached sprue button.
6. Multiply mass from step 5 by 10.3 (density of sterling silver) which gives amount of sterling silver necessary to cast your model, sprue and button.
7. If investment requires, paint or dip model with debubbler to reduce surface tension of wax. Allow 20 minutes to dry.

Note: *If investment has built-in surface tension reducer, this step can be skipped.*

8. Secure flask on sprue base making sure model is 3/4 in. away from wall, and approximately 1 in. below top of flask.
 9. Use the Table of Flask Dimensions to determine amounts of water and investment plaster for the particular type you are using.
 10. Measure out the investment and water carefully, add the investment to the water (72°F or room temperature), and mix thoroughly following time schedule. Mix in a clean rubber mixing bowl. Any dried investment will cause a change in cure time.
 11. Use the vacuum chamber to degas the investment in the mixing bowl for about 90 sec with glasses on during which time it will rise, fall, and froth.
 12. Place the sprue base on the casting flask and pour investment carefully down the inside of the flask until wax model is covered by at least 1-2 cm (1/2 in.) of investment.
 13. Place this casting flask in the vacuum chamber and degas for another 90 seconds.
 14. Add remaining investment mixture to the top of the flask. For centrifugal, leave space if using vacuum technique.
 15. Set the flask aside to set for prescribed time.
 16. Scribe your initials lightly onto the top of the investment, when set, to identify your project.
 17. Program furnace for a burnout cycle for particular investment (if not already done). See attached sheet "Science of Burnout" for further details.
 18. Place flask into furnace and allow time for burnout.
- At this point go to the lab "Alloying Sterling Silver."*
19. Prepare for casting by reading the directions for centrifugal casting or vacuum casting that follow, and mentally prepare yourself to follow the process.

If you are going to do centrifugal casting, follow steps 20a - 20l, then skip to step 22. If you are going to do vacuum casting, skip to steps 21a - 21i.

20. If casting with a Centrifugal Casting Machine, follow this procedure
 - a. Put your flask in the machine and balance with counter weights. Return flask to oven.
 - b. Wind casting arm and lock on stop rod.
 - c. Preheat and flux crucible; add metal.
 - d. Remove flask from furnace and place in cradle with open cone-shaped sprue end toward crucible.
 - e. Push crucible carrier tight against flask with tongs. If the machine is a broken arm horizontal centrifugal caster, move arm back away from direction of travel.
 - f. Melt metal as directed, fluxing lightly when necessary. Stir with carbon rod.
 - g. When metal "rolls," have another person hold counterweight arm firmly from above while releasing stop rod. Continue heating the metal.
 - h. Simultaneously raise the torch heat from the metal, and release the casting arm.
 - i. Allow machine to spin to complete stop. Do not stop it.
 - j. Remove flask with tongs. Hold until button loses glow (~5 min), or set down for 5 min.
 - k. Remove flask with tongs and quench in a bucket of water, wearing glasses. Observe thermal shock.
 - l. Clean off investment residue with brush and water.
21. If casting with a Vacuum Assist Machine, follow this procedure
 - a. Connect vacuum pump and casting unit. Turn on vacuum pump. Check vacuum setting with finger.
 - b. Preheat and flux long-handled crucible or electrically heated graphite crucible. Add metal melt, flux, and stir with carbon rod.
 - c. Remove flask from furnace and place on casting table, sprue hole up.
 - d. Turn on vacuum pump: verify full reading on gauge.
 - e. Pour molten metal into sprue hole.
 - f. Direct flame on sprue button for several seconds, when using gas torch.
 - g. Release vacuum and turn off machine.

- h. Remove flask, and set on fire brick until button loses glow, or 5 min.
 - i. Clean off investment residue with brush and water.
22. Let cool in air for 5 min after making casting, then submerge into a bucket of water.
23. While water is bubbling, reach in with your hand and hold onto the flask. Keep flask under water. You will be able to feel the thermal shock of the investment material.
24. Break up investment and remove casted part. *Discard investment material into appropriate waste container and clean up your mess!!*
25. Place casting in pickling solution with copper tweezers to remove oxidation. **Caution:** Be sure to follow directions for pickling safety.
26. Remove sprue and button from casting using a jewelers saw or diagonal cutters.
27. Return sprue and button to instructor.
28. Rough casting procedure complete.

Note: Casting process can take place in 1 hour; however, burnout must go according to the schedule of the specific investment.

Science of Burnout

Several scientific facts about burnout are described in the following paragraphs. This is general information. Burnout will vary based on investment furnace temperature.

The flasks are heated slowly to 400° F. Why? The investment is mixed with water and water turns to steam at 212°F. The water as moisture can escape through the pores of the investment if heated slowly; if heated very quickly, the formed steam expands before it can escape and some of the investment around the cavities formed by wax eliminating may be loosened, resulting in damaged castings.

Water that is chemically combined with some of the chemicals in the investment as water hydration will be driven out at approximately 375°F.

Flasks should never be allowed to sit in a cold burnout furnace for an extended period of time or else they will dry out. If the investment is heated dry, it can act as a sponge and draw the wax into its pores. It is recommended that the burnout furnace be preheated to 300°F before placing the flasks inside the chamber. At 200°F to 300°F, most of the wax immediately melts and flows out through the sprue openings. The steam from the water in the heated moist investment helps to push the wax off the walls of the pattern cavities in the investment. Most commercial burnout furnaces do not have to be preheated since they are still warm from the previous day.

It takes approximately 1 hour for the wax to burn out and become "lost." The wax will crackle and sizzle as it melts. Smoke and steam escape through the furnace's vent.

Wax that does not flow out turns to carbon (a black powder) at 1000°F. The carbon is completely eliminated above 1400°F by combining with oxygen in the air to form the gas carbon dioxide (CO₂). The carbon dioxide is eliminated through the sprue opening and also through the pores of the investment.

Some of the carbon probably is not completely oxidized and turns into carbon monoxide (CO). This odorless, poisonous gas ignites and burns with a blue flame.

Note: The furnace temperature will rise faster (be hotter) than the temperature of the wet investment in the center of the flask. The difference in temperature can be more than 100°F. To permit the furnace temperature and flask temperature to equalize, the furnace temperature, when it is dropped to casting temperature, should be held for at least 1/2 hour.

If the flask is heated over 1500°F., the gypsum binder (calcium sulphate, 2CaSO₄ • H₂O) begins to break down into sulfur dioxide (SO₂) and sulfur trioxide (SO₃) and, if a casting is made over 1500°F., these gases will discolor (form sulfides with) the cast metals. (Source: Bovin, M. *Centrifugal or Lost Wax Jewelry Casting*. Bovin Publishing New York.)

Making a Light Bulb

Instructor Notes

Reliability

This experiment always works.

Estimated Time for Activity

One class period.

Teacher Tips

1. Electricity flowing through the filament encounters resistance, just as water flowing through a pipe. The resistance causes an energy loss, which appears as heat, and the heat makes the filament glow.
2. Incandescent can be described as the property of producing light as a result of heat. The word incandescent means “glowing with heat.”
3. A filament can be described as a high-resistance wire that glows yellowish-white to produce light and/or heat. The filament is a coil of thin wire made from a strong metal called tungsten. This metal can withstand high temperatures without melting. The filament reaches the temperature of about 4500° F (2482° C). Each time the filament gets hot enough to glow, a little bit of the metal evaporates.
4. Some lamps have more than one filament. These filaments may be turned on individually so that the lamp produces different amounts of light (3-way bulbs).
5. By looking at a few numbers for electrical resistance and melting point; students get a sense of why tungsten is used as a filament material instead of nichrome or copper.

<u>Metal</u>	<u>Melting Pt, °C</u>	<u>Electrical Resistance, ^{ohm-cm}</u>
Copper	1083	$\sim 2 \times 10^{-6}$
Nichrome (80 Ni - 20 Cr)	1500	100×10^{-6}
Tungsten	3400	6×10^{-6}

Although nichrome has high resistivity, it wouldn't be very useful as a filament because we couldn't use it much above 1200°C. The light would be red-orange, not very intense.

6. Odd Facts: One of the tiniest bulbs ever produced was called the grain-of-wheat bulb because it was about the size of a single grain of wheat. It was 0.33 in. long and weighed 0.05 g. Doctors used the grain-of-wheat bulb to help them perform delicate surgical operations on children.

The world's largest bulb never had practical use. It was created for display in 1954, in honor of Edison's development of the first practical incandescent bulb. It weighed 50 lb. The tungsten filament uncoiled was 12.5 ft. You could not safely look at the bulb directly. To view it, spectators had to turn their backs on the bulb and look at its reflection in a special window. This single bulb gave off as much light as 2,875 sixty-watt bulbs burning simultaneously and enough heat for almost 20 houses.

Suggested Questions

7. How long did your three filaments burn?
8. What color does the filament glow?
9. How does the brightness differ from the incandescent lights in your home?
10. Why does the brightness differ with home lights?
11. Besides light, what other kind of energy did the bulb produce?
12. How can you prove the answer to question 3?
13. Why do you think the filaments burn out so much faster than commercial light bulbs do?
14. What would happen if you changed the length of the filament?
15. Does it make a difference if you do not coil the filament?
16. Why do they coil the filaments in commercial bulbs?
17. What happens if you change the size of the baby bottle (bulb)?
12. Will the light still burn if you remove the bulb?
18. Why do light bulbs have glass envelopes?
19. How can you make a longer burning light bulb?
20. How many different types of light bulbs can you think of that might be in the average home?
21. What do you think the total number of light bulbs you have in your house?
22. How many watts does a light bulb use?
23. How many light bulb watts do you think your home has?

Safety

1. Students should not touch the filament when connected to the battery. It can cause serious burns.

Activity: Making a Light Bulb

Student Learning Objective

At the end of the activity students will be able to:

- explain how a light bulb works through writing and discussion
- build a working model of a light bulb.

Materials

- Nichrome wire, 32 ga, 3 ea.
- Modeling clay, silver-dollar size
- Insulated copper wire, 18 ga, 20 cm, 2 ea.
- Standard size pencil

Equipment

- 12-volt battery
- Small baby food jar
- Cutting board
- Wire cutter/stripper
- Needle nose pliers

Procedure

1. Mold modeling clay into a flat shape approximately 10 mm larger than the diameter of the baby food jar.
2. Remove 2 cm of insulation from each end of both pieces of 18 ga copper wire.
3. Form a 4-mm loop on one end and an 8-mm loop on the other end of the two wires.
4. Form a 90° bend 2 cm from the end of the 4-mm loop.
5. Stick the two 4-mm looped ends of the wires through the center area of the flattened clay, approximately 3 cm apart, to the bend in the wires (see Figure 5.11).
6. Press the wires flat into the clay and seal the clay around the wire.
7. Wrap a single strand of nichrome wire around a standard size pencil to form a coil (now called the filament). Leave 2 cm of straight wire at each end.

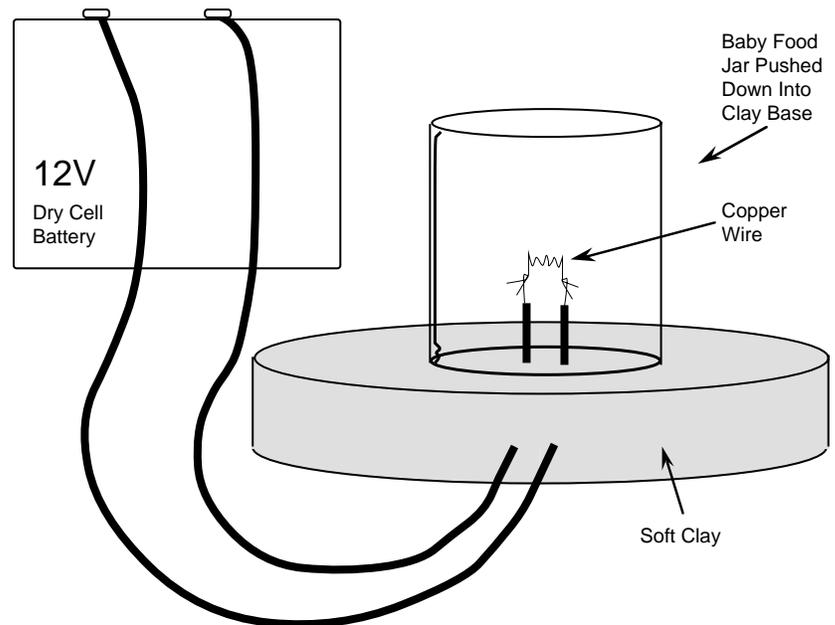


Figure 5.11. Making a Light Bulb

8. Connect the ends of the filament to the 4-mm loops by tightly wrapping the connecting wires together using pliers.
9. Place model clay assembly onto cutting board near the center, and place baby food jar over the wire sticking through clay. Press into the clay to form a seal.
10. Connect one of the wires to one terminal of the battery, and connect the other wire to the other terminal. The filament wire should glow. Time how long it glows.
11. If the filament does not glow, check 1) to see if the filament wire is still touching the connecting wires, and 2) that the connecting wires are not touching each other.

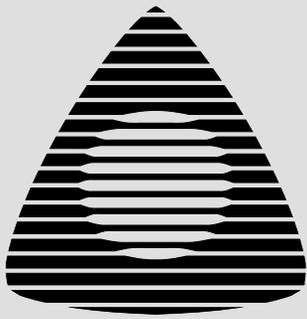
Caution: Do not touch the filament when connected to the battery, it can cause serious burns!

12. Repeat steps 8 - 10 with the other two nichrome wires. Note: the nichrome wire length should be a constant length and diameter so results can be compared.

Vocabulary—Metals*

Alloy
Annealing
Burnout
Centrifugal
Creep
Drawing
Fabrication
Flux
Gauge
Grain
Heat treating
Investment
Liquid
Melting point
Noble metals
Oxidation
Phase
Phase diagram
Pickle (boric acid)
Plastic deformation
Sintering
Slurry
Solid
Super alloys
Surface tension
Tempering
Volume
Work hardening

*Instructor may vary vocabulary to suit particular content presented.



Experiments/ Demonstrations

Ceramics

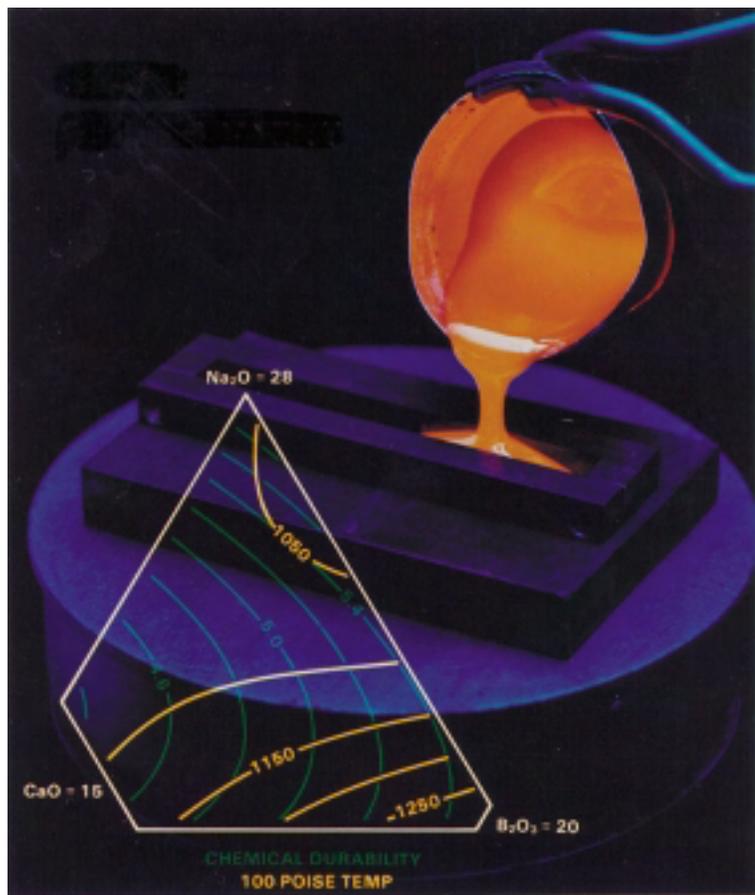
Ceramics

Introduction

Ceramics are non-metallic and inorganic and are made from raw materials that are either mined from the earth or chemically synthesized. They are hard, generally resistant to heat and most chemicals, and lighter than most metals.

Traditional ceramic materials include glass windows, insulating bricks, pottery, and china. However, the fiber-optic phone lines that provide today's clear voice communication are also ceramic, products of high-technology glassmaking. Likewise, the space shuttle is insulated against the searing heat generated as it returns from near space through the earth's atmosphere. Its aluminum hull is shielded by incredibly light bricks made from tiny glass fibers.

Ceramics are compounds that are generally formed by reacting a metal with other elements such as oxygen, nitrogen, carbon, or silicon.



The bonding is usually ionic and is very strong, making ceramics comparatively stable chemically. (Ionic means the joining of a positively charged atom to a negatively charged atom, usually metal atoms to non-metallic atoms.) This ionic bonding occupies the outer electrons of the metal, making the electrons incapable of moving in an electric field; thus, most ceramics are poor conductors of electricity. Ceramics also include glasses, which are composed of metals, oxygen, and silicon. By their nature, glasses do not crystallize as other ceramics do. As they cool from the liquid state, they become progressively stiffer until they are solid, which gives them different properties from other materials, such as not having a definite melting point.

Where resistance to extreme temperatures or molten metals is desired, ceramic materials emerge as extremely important. Without ceramics, it would probably be impossible to melt or cast metals; other materials will not resist the heat or chemical environment, and other materials allow heat to leak away, because they are not effective insulators like ceramics.

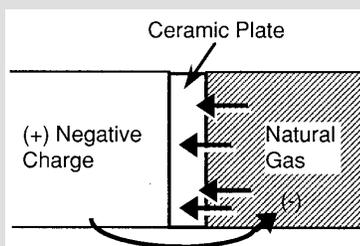
The powerful bonding forces in ceramics have some negative features, one of them being brittleness. Ceramics cannot be bent like metals or most other common materials, and they tend to break without warning. Tiny surface defects, too small to cause much of a problem with a metal, can greatly reduce the strength of a ceramic material. In a metal, flow at the defect location would reduce the effect of that defect; this flow is not possible in a ceramic. So cracks stay sharp and ceramics break instead of bend. (Metallic flow is the movement of one plane of atoms over another.)

Humankind first made ceramics in ancient times. Fire, probably at that time a relatively new discovery, was used to make clay vessels less likely to revert to a gooey mess when contacted by water. During this firing process, materials in the clays reacted, forming small amounts of glass that cemented the rest of the materials together. Glass was born in similar fireside experiments, and in Roman times, was more precious than gemstones and used similarly for decoration.

The future of ceramic materials is even more interesting. Scientists have created ceramics that, while not as tough as metals, are many times tougher than those made just a few years ago. These tough materials are being used increasingly as parts in automobile engines because of their lightness and resistance to wear.

Other ceramics have been made electrically conductive or able to allow oxygen ions to penetrate them. Both of these characteristics are needed for high-temperature fuel cells that can convert fuels such as natural gas directly to electricity more efficiently than any other method (see Figure 6.1).

Ceramics are being formed by methods similar to those used for mass production of plastic parts, so that increasingly intricate parts can be made cheaply. All these developments combined ensure that ceramics will continue to play important roles in modern life.



Oxygen atoms (-) negative charge flow through ceramic to combine with (+) positively charged particles. An electric potential is created and electricity is "birthed."

Figure 6.1. Electrically Conductive High-Temperature Fuel Cell

Thermal Shock

Instructor Notes

Reliability

This experiment works well if the materials are the same as what is described herein.

Estimated Time for Activity

One class period.*

Teacher Tips

1. Thermal shock is a mechanism often leading to the failure of ceramic materials. Many uses for ceramics involve high temperature. If the temperature of a ceramic is rapidly changed, failure may occur. Thermal shock failures may occur during rapid cooling or during rapid heating. As an example, consider rapid cooling, which is easier to visualize. If a ceramic material is cooled suddenly, the surface material will approach the temperature of the cooler environment. In doing so, it will experience thermal contraction. Because the underlying material is still hot, the skin material stretches and so experiences tensile stress. If the resulting strain is high enough (0.01% to 0.1% for most ceramics), the ceramic will fail from the surface, and cracks will propagate inward. Even if these cracks do not cause immediate failure, the ceramic will be severely weakened and may fail from mechanical overload of forces it would normally withstand.
2. When comparing different ceramics for thermal shock applications, it is common to use a figure of merit or index of thermal shock performance. This is a number (ratio) that is useful for both choosing materials and for visualizing the thermal shock process. Because the index should be high for a thermal shock resistant ceramic, its numerator should contain properties that are numerically large when good thermal shock performance is exhibited by a material. Tensile strength (S) and thermal conductivity (K) are therefore placed in the numerator, the former for obvious reasons and the latter because a high value of thermal conductivity tends to decrease thermal gradients, other factors being equal. The denominator of the thermal shock index is composed of the thermal expansion coefficient (A) and Young's Modulus (E), which is a measure of

*One class period is approximately 1 hour.

the stress resulting from a given strain. These numbers should be a low value for good thermal shock performance. Combining these factors,

$$\text{Thermal Shock Index (TSI)} = \frac{SK}{AE}$$

Where the units of measurement should be consistent within a given comparison.

In the case of common glasses, all the properties except thermal expansion fall into a relatively narrow range. By choosing a glass with low thermal expansion, thermal shock failure can be avoided in most cases. See, for example, the index values for soda-lime glass, borosilicate glass, and fused silica in Table 6.1. Note the large difference between the thermal shock indices of aluminum oxide and graphite. This difference is backed by experience; it is extremely difficult to cause graphite to fail by thermal shock, principally because its Young's modulus is so low and its thermal conductivity is high.

Table 6.1. Thermal Shock Index (TSI) for Some Common Ceramic Materials

Material	$K,^{(1)}$ W/cm-°C	S, MPa	A, °C ⁻¹ , x 10 ⁻⁶	E, GPa	TSI
Soda-lime-silica glass	2E-2	68 ⁽²⁾	9.2	69	2.1
Borosilicate glass	2E-2	68	3.3	63	6.5
Fused SiO ₂	6E-2	68	0.6	72	94
Aluminum Oxide	3E-1	204	5.4	344	33
Graphite ⁽³⁾	1.4	8.7	3.8	7.7	416

(1) Thermal conductivity and expansion coefficients from *Thermophysical Properties of Matter*, Y. S. Touloukian, ed., Plenum Press, New York, 1970.

(2) Because glass tensile strength is so dependent on surface condition, a single "reasonable" value was chosen for all glass strengths.

(3) Values are typical of nuclear-grade graphite, from *Industrial Graphite Engineering*, Union Carbide Corp., 1959

Teacher Tips for Demonstration

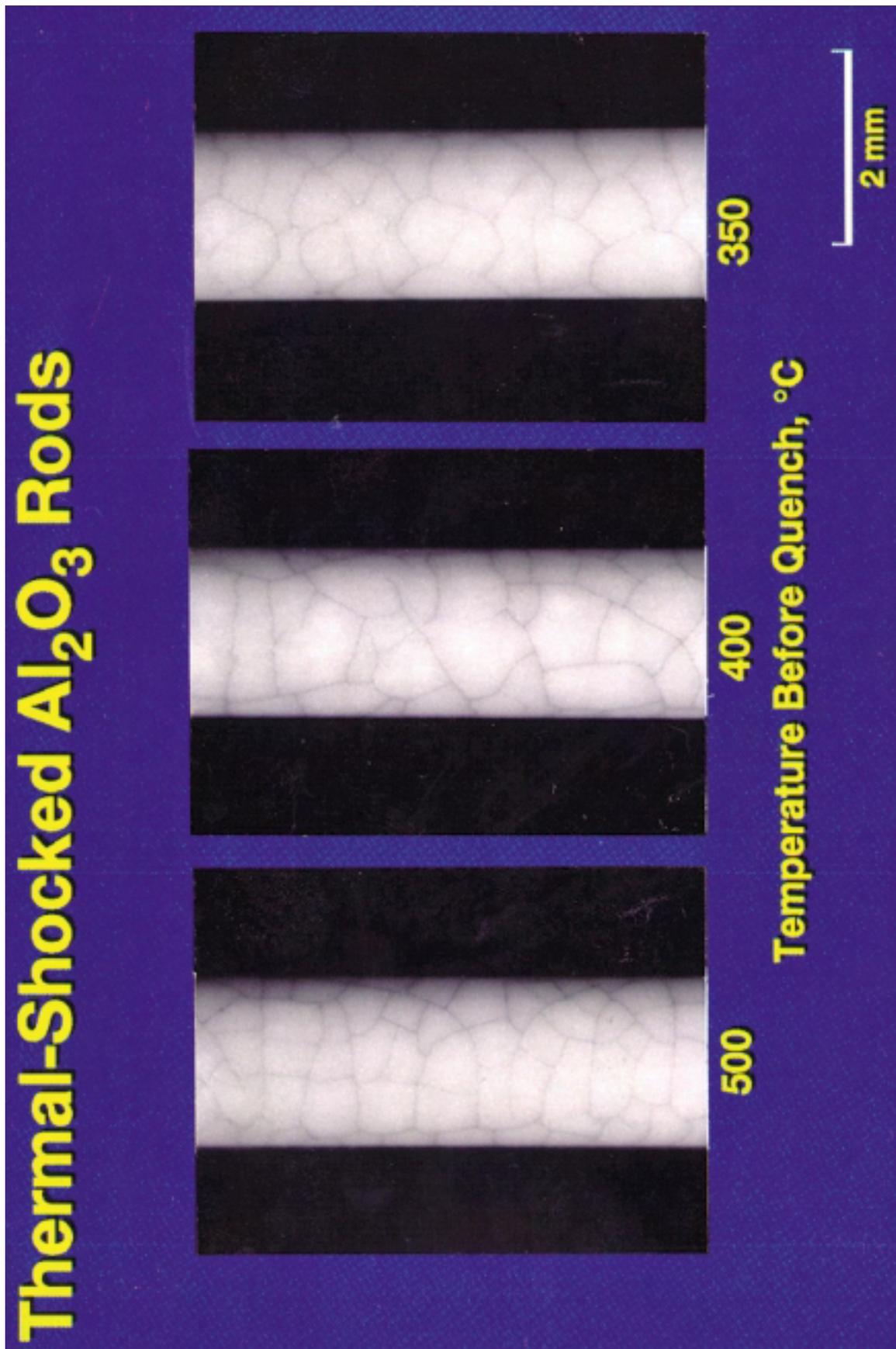
1. Thrown into water (quench), the water changes to steam.
2. Steam forms at the surface of the specimen, absorbing energy (539 calories per gram).
3. This causes the surface to cool to 100°C, almost instantly.
4. The result is a shrinking surface encasing a large, hot specimen, causing thermal shock and cracking.
5. The temperature difference and coefficient of thermal expansion of the material determines the amount that the material will crack.
6. The larger the TSI value, the more likely the material will withstand thermal shock.

Extension Activity

A similar thermal shock experiment to demonstrate follows:

Place about 10 aluminum oxide rods, 3 mm x 10 cm in length, into a stainless-steel beaker or a small metal pan and heat to 500°C in a suitable furnace. Remove the container from the furnace, and quickly quench the rods in a bucket of water. Dry them overnight at about 100°C. The following day, dip the rods in ink, which acts as a crude dye penetrant to make any cracking visible. Wipe excess ink from the rods, handling care-fully to avoid breaking. Note, if broken, the partial penetration of the ink shows that the cracks do not extend into the centers of the rods. This is because the cracks start at the surface in a tensile stress area, but propagate into regions of lower stress until they stop. When a quench is performed on rods heated at lower temperatures (down to about 300°C) crack density is lower and crack depth is shorter (see attached Figures of Al₂O₃ rods). A quench temperature that is lower still will not result in any detectable damage. This temperature is not a constant, but is a function of both configuration and material heated at designated temperatures and quenched). The alumina should be >95% dense, but can be of any purity greater than 95%.





Demonstration: Thermal Shock

Student Learning Objectives

At the end of the activity students will be able to:

- use in writing and discussion the following terms related to the thermal shock index (TSI)

Strength
Thermal conductivity
Coefficient of expansion
Young's modulus

- explain in writing and discussion the effect of varying rates of expansion and TSI on different kinds of materials.

Materials

- Pyrex glass
- Window glass
- Corning ware
- Fused silica glass (optional)
- Water

Equipment

- Lindberg furnace
- Tongs, long-handled
- Bucket
- Safety glasses

Procedure

1. Cut equal sized pieces of each of three or four materials.
2. Preheat Lindberg furnace to 800°C. Place pieces of materials into the oven.
3. About 5 min after the pieces become luminous, quickly remove them with tongs, and plunge them into a bucket of water.
4. Observe each material's reaction to the quench. Record your observations in your journal.
5. On the blackboard or overhead, diagram the formula for TSI:

$$TSI = \frac{KS}{aE}$$

Definition of symbols.

K = thermal conductivity

S = strength

α = coefficient of expansion

E = Young's modulus

6. On the blackboard or overhead define:

- a. *Thermal conductivity*—How well a material transmits heat.
High number—better thermal conductivity.
- b. *Strength*—How well a material resists being broken. Expressed in load bearing capacity as pounds per square inch (PSI) or pascals (Pa), using international units for measurement.
- c. *Coefficient of expansion*—The ratio of the change of length per unit length, or change of volume per unit volume, to the change of temperature.
- d. *Young's modulus*—Stress divided by strain. How hard was the material and how far did it stretch?

Glass Bead on a Wire

Instructor Notes

Reliability

Several problems occur with this experiment: 1) the molten beads fall off the wire, 2) the wire gets too hot, and it melts, and 3) students do not melt the crystals completely and, therefore, don't get the colorful effects that they desire. All these problems can be overcome by following the directions carefully and trying the process several times.

Estimated Time for Activity

One class period.

Teacher Tips

1. The glass bead on a wire test was used by early miners to determine types of ore found in mineral deposits.
2. The wire used in the "Drawing a Wire" activity can be used to make a glass bead on a wire. If you do not want to draw copper wire out, purchase 16-18 gage wire.
3. To get different colors, use dilute solutions of nitrate salts of Ni, Co, Cu, Fe, or Mn. Make the solutions by adding 5 g of the salt to 100 g of water. Dip the nichrome wire with a glass bead into a solution and reheat.

Safety

1. Wear safety glasses at all times.
2. Warn students of hot glass beads. They fall off the wire, splatter, and can cause burns.

Activity: Glass Bead on a Wire

Student Learning Objectives

At the end of the activity students will be able to:

- make a glass bead with ordinary household materials and equipment
- describe through writing and discussion the effect of some metal oxides on glass.

Materials

- Nichrome wire (0.81 mm)
- Copper wire, 12 ga
- Borax, 20 Mule Team or sodium borate ($\text{Na}_2\text{B}_4\text{O}_7$)
- Grease

Equipment

- Propane torch/bunsen burner/oxy-acetylene torch
- Draw plate
- Wire cutters
- Needle nose pliers
- Vise grip pliers

Procedure

Caution: Wear safety glasses at all times. Wear leather gloves when working with the hot, molten chemicals.

1. Cut or obtain a 12 cm to 15 cm length of nichrome wire.
2. With needle-nose pliers, form a closed, oblong loop on the end of the wire approximately 7 mm long and 3 mm wide (see Figure 6.2).
3. Heat loop end of wire with available torch until it begins to turn red in color. Note: If the wire gets too hot it can melt.
4. Dip heated end into borax, then carefully heat with torch until glass bead is formed. If bead is too small or incomplete, then dip it in borax again and heat until desired bead is formed. Continue melting the bead until it forms a droplet that is glassy and transparent. To keep the bead from dripping, gently rock or rotate the wire. Note: Overheating will evaporate the borax, do the melting in the cool, outer portion of the flame as demonstrated in Figure 6.2.

5. Obtain a length of copper wire from the instructor, and draw it through the draw plate using a pair of vise grips until it is approximately 0.81 mm. (for details, see Metals section, *Drawing a Wire Lab*). If you have a piece of copper wire approximately 0.81 mm in diameter, you may skip the drawing process.
6. Repeat steps 2-5.
7. Record your observations in your journal. Compare the beads, and describe any other observations you made while making the glass bead, i.e., what differences did you notice in color and why? What differences did you notice in the wires?

Extension Activity

Using nichrome wire, from a molten glass bead following steps 2-5 above, then dip the hot glass in solutions of metallic salts of nickel (Ni), cobalt (Co), copper (Cu), iron (Fe), manganese (Mn), etc.

Your instructor will assist you with preparing the solutions or let you know where they are located in the laboratory.

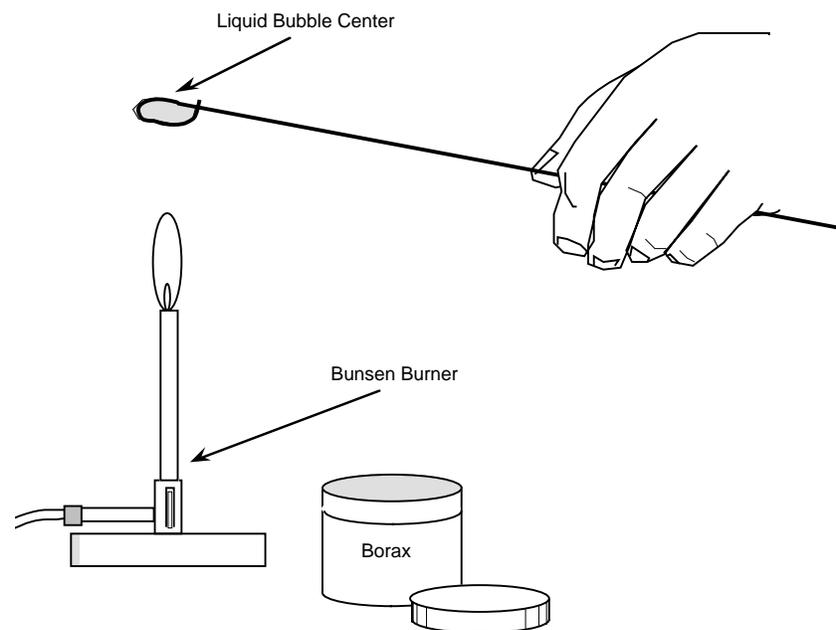


Figure 6.2. Glass Bead on a Wire

Glass Bending and Blowing

Instructor Notes

Reliability

Students really enjoy this experiment, and it works well. The only part that sometimes causes disappointment is blowing the glass, it is difficult to do.

Teacher Tips

1. Buy an inexpensive variety of glass rod or tubing such as flint glass, which has a low melting point. The 6-mm glass tubing works well. Other types of glass such as borosilicate glass (laboratory glassware) and soda-lime-silica glasses (glass containers that food products come in and window glass) have melting points above 500°C and are difficult for most people, except skilled glassblowers, to work with.
2. Bunsen burners usually do not get hot enough to be successful in blowing glass. Propane burners are hot enough to do some glass blowing. If students blow too hard, two things frequently happen, either they blow a bubble too large and thin that it collapses, or they blow a hole in the glass.
3. Encourage students to discover that you really don't "blow" glass. Professional glassblowers know that hot air expands. They "puff" air into the tube that has been sealed on the other end and use their tongues or fingers as plugs. With the volume of the tube sealed, they reheat a portion of the glass to soften it. The expanding hot air inside pushes out a bubble. They repeat this cooling, sealing, and reheating process until they get the shape they want.
4. Optical fibers are thin fibers, usually glass or plastic, used to transmit light. Have the students try making a glass fiber as they are working.
5. Glass may be remelted and/or recycled.
6. Glassblowers use wooden tools soaked in water. Why?

Safety

See Activity.

Disposal

See Activity.

Activity: Glass Bending and Blowing

Student Learning Objectives

At the end of the activity students will be able to:

- heat glass to make it soft enough to manipulate
- make a smooth right-angle bend and fire polish the ends
- cut glass tubing using a file
- draw tubing to make a pipette
- blow a small bubble with at least twice the diameter of the original tubing
- melt a piece of glass rod to make an optical fiber
- describe and demonstrate how polarized film may be used to detect stresses in glass
- use the expansion of heated air to work the glass.

Materials

- Glass tubing, 5 mm
- Glass rod

Equipment

- Safety glasses
- Burner
- File
- Polarized film
- Light table (or overhead projector)
- Laser or other bright light
- Container for finished glass pieces

Procedure

Observe the demonstrations given by your instructor.

Caution: Wear safety glasses and leather gloves at all times during this activity. Potential for serious burns exists when working with hot glass. It cools slowly and cannot be quenched in water like metal. Keep all hot surfaces on a heat-resistant, ceramic pad until cool.

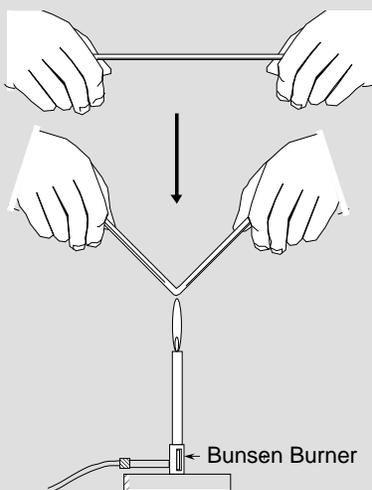


Figure 6.3. Glass Bending

Glass Bending: Use a file to cut a 15- to 20-cm piece of glass tubing. Use the burner to heat the glass near the center (see Figure 6.3). Rotate the glass as it is heated. When the heated portion is soft, remove the glass from the heat. Bend the ends of the glass upward. Cool, then fire polish the ends.

Caution: Heated portions retain heat and require several minutes to cool before handling.

Making a Pipette: Cut a second piece of tubing 10- to 30-cm long. Heat as you did above; when hot, remove the tubing from the heat, and pull the ends apart (as demonstrated). You must pull vertically. Cut the pipette. Carefully fire polish it after the glass has cooled.

Blowing a Glass Bubble: Obtain a third piece of tubing at least 20 cm long that is fire polished and has cooled on the end. You may need to fire polish this yourself. Heat the end of the tube you will blow until molten, then seal the end with pliers. Reheat the sealed end, then blow into the cool end. Continue to rotate the tubing as you blow. This process may need to be repeated several times until you have a bubble with at least twice the diameter of the tubing. Try “blowing” glass and the “puff, seal, and reheat” technique described by your teacher and used by professionals to “blow” glass.

Note: Propane burners get hotter than bunsen burners and may enhance this step.

Making an Optical Fiber: Obtain a piece of glass rod. Heat it as demonstrated and form an optical fiber. You may want to try both the gravity and pulling techniques demonstrated to form an optical fiber. Let the glass cool, then use the laser (or bright light) to see if your fiber acts as an optical fiber (transmits the light).

Glass Disposal: Throw all glass into a special collection container labeled clearly: BROKEN GLASS—CAUTION

- Use polarized material to check your glass pieces for stress (as demonstrated). First hold the polarizers against each other, and rotate them until no light is transmitted through them. Then insert the glass between the polarizers in this orientation.
- As you clean up, place your bend, pipette, blown glass, and optical fiber in a plastic bag or container that has your name on it.
- Write a summary of this lab in your journal. Include not only what you did, and how, but your thoughts and responses to the activity.

Caution: Hot glass can cause incredibly thorough burns on skin, lab benches, books, and back packs! Place all hot glass on a heat-resistant, ceramic surface to cool.

Standard Glass Batching

Instructor Notes

Reliability

This experiment works well. Students always get some kind of glass. The quality depends on student accuracy. Encourage students to be patient when calculating. It takes time to feel comfortable with the numbers.

Estimated Time for Activity

One class period.

Teacher Tips

1. Ziplock bags can be used.
2. Washing soda is a cheap source of Na_2CO_3 . Borax can be used for a boron and sodium source. Both are inexpensive at local grocery stores in the laundry section. Boric acid is available in drug stores.
3. If you use borax ($\text{Na}_2\text{B}_4\text{O}_7 \cdot x \text{H}_2\text{O}$), you get $\text{Na}_2\text{O} + 2\text{B}_2\text{O}_3$. Be sure and account for the ten water molecules in each Borax compound that will be driven off when heated. You can heat the borax in an oven at 80°C overnight to remove most of the water.
4. The silica (SiO_2) from Fisher (240 mesh) works very well. Coarser materials take longer to melt and can cause other problems.

Suggested Questions

Have students show their work where math is required.

5. If each candy bar weighs 2 lb and we have 30 lb of candy bars, how many candy bars do we have?
6. If a certain size of nail weighs 0.04 lb, and we need 500 nails, what weight of nails would we buy?
7. How many nails would we have if we had a mole of nails?
8. Your girlfriend calls you "mole breath." How many breaths would you have to take to have a mole of breaths?
9. Tell how much a mole of each of the following weighs: uranium (U), table salt (NaCl), copper (Cu), and carbon dioxide (CO_2)
10. Why are chemicals measured by weight?
11. You want 3 moles of silica (SiO_2). How much would that weigh?
12. Your friend asks you how many pennies are in a huge pile. How could you easily determine this fairly accurately?

Safety

1. Be careful when mixing to avoid creating dust. Breathing fine dust particles of any kind is a health hazard. Ventilation of batching area is recommended.

Background Information: Mole Percent

When batching glasses, you need to perform calculations to figure out the weights of various chemicals needed. The concept of the “mole” needs to be developed before these calculations are done. The following background information will help you understand the mole.

Three ways of buying things commonly exist: volume (gallons of gasoline), number (dozen eggs), and weight (pounds of oranges). Volume is fairly good for liquids, and it is convenient, but it isn't very reliable for solids because of such things as air gaps and irregularities. Also, volume changes with heat and pressure. Number is fine for regular things, but it is unfair to sell apples by the number since some are large and some are small. (Some of us have the same feelings about shoes and shirts too!) Most things are sold by weight, although these are usually pre-packaged, so we really buy them by the number of packages. Most of the things we buy by weight are “bulk” items. A few examples are bananas, grapes, candy at a candy store, coal, and nails.

One of the reasons nails are sold by weight is because small ones would be too boring and time consuming to count each time they are sold. If this were done, the price would also rise. In general, things are measured by weight to determine their number if things are too small to be conveniently handled. Two formulas that are used are:

$$\#1 \quad \text{Number} = \frac{\text{total weight}}{\text{weight of one}}$$

$$\#2 \quad \text{Total weight} = (\text{weight of one}) (\text{number})$$

These ideas and formulas are also used with chemicals. Atoms combine to form chemical compounds. For example, experiments enable us to know that two atoms of hydrogen combine with one atom of oxygen to form one molecule of water (H₂O). Unfortunately, atoms are far too small to be counted. Therefore, we use weight and the above formulas to determine numbers of atoms.

Because two atoms of hydrogen combine with one atom of oxygen to form one molecule of water, it follows that two dozen atoms of hydrogen combines with one dozen atoms of oxygen to form one dozen molecules of water. Also, 200 atoms of hydrogen combine with 100 atoms of oxygen to form 100 molecules of water. Atoms are far too small to see hundreds, millions, or even trillions of them; so, a new number called a “mole” is used with atoms. It is huge! A mole is 602,000,000,000,000,000,000,000. This can also be written: 6.02×10^{23}

Therefore, two moles of hydrogen atoms combine with one mole of oxygen atoms to make one mole of water molecules. Mole is a number that works just like “dozen” but is much larger. The mole seems like a weird number, but it was selected because it works with the atomic weights that are found on the periodic table. For example, carbon has an atomic weight of 12.0, and one mole of carbon atoms has a weight of 12.0 g. It so happens that one mole of any element equals its molecular weight.

To determine the weight of molecules in a material or a chemical, each element that is part of the molecule must be considered. Just as 1 dozen watermelons does not weigh the same as 1 dozen doughnuts, so 1 mole of carbon atoms does not weigh the same as 1 mole of oxygen atoms. They are equal in number, but not in weight. To determine how much a mole of atoms of a chemical weighs, we add up the atomic weights of all of the atoms in the formula for the chemical. For example, sodium hydroxide (NaOH) and ammonia (NH₃):

<u>Chemical</u>	<u>Element</u>	<u>Atomic Wt.</u>	<u>Number of Atoms</u>	<u>Total Wt.</u>
NaOH	Na	23.0	1	23.0
	O	16.0	1	16.0
	H	1.0	1	1.0

Wt. of 1 mole NaOH = 40.0 g

NH ₃	N	14.0	1	14.0
	H	1.0	3	3.0

Wt. of 1 mole NH₃ = 17.0 g

Therefore, one mole of NaOH molecules weighs 40.0 g, and one mole of NH₃ molecules weighs 17.0 g, although there are equal numbers of each chemical.

Remember, a mole is just a term to represent a very large number. If we know the type of chemical, we can use the periodic table to determine how much a mole of that chemical weighs. Therefore, moles allow us to use weight to determine numbers of atoms or molecules.

In the glass batching lab, the concept of the mole will be used to determine the amount of each chemical to add to the glass. The calculations are explained in the following section.

Loss on Ignition

In this lab, almost 140 g of source chemicals are required to produce 100 g of glass. When you melt your glass, check to see how close you come to 100 g, and explain any differences. This loss of weight when melting material is called "loss on ignition" and must be accounted for when preparing the glass.

You may want to check to see how this loss on ignition works by performing a simple decomposition experiment. Gently heat a known amount of boric acid (H₃BO₃) or Twenty Mule Team Borax (Na₂B₄O₇*10H₂O) above its decomposition temperature, and then re-weigh the material after it cools. Compare the loss on ignition you measure to the one you calculate. If there are differences they may be caused by extra moisture in the sample, impurities in the sample, or vaporization of the sample. In most cases, the differences will be minor.

Activity: Standard Glass Batching Calculations

Student Learning Objective

At the end of the activity students will be able to:

- use two equations:
 1. $\text{Number} = \frac{\text{total weight}}{\text{weight of one}}$
 2. $\text{Total weight} = (\text{weight of one}) (\text{number})$ in problem solving
- state how large a mole is
- apply the mole concept in determining molar masses
- describe why the mole concept is used
- use the mole concept in problem solving
- complete a chart in their journal that includes the precise amount of source chemicals to combine in producing glass of a specific composition
- use the process of conversion from a glass formula to the actual amounts of source chemicals for a glass batch.

Materials

- Periodic chart
- Sample reagents

Procedure

Note: *This procedure takes you through the entire process for calculating a glass composition. As you become familiar with these calculations, you will be able to quickly extract parts of these calculations to use in determining a glass composition. Be patient, it may take some time to understand all the concepts presented. After batching a number of glasses you will become familiar with these calculations.*

1. The desired glass composition to be produced must be expressed as a mole fraction of each constituent. For example, a simple borosilicate glass could be expressed as $\text{Na}_2\text{O} \cdot \text{B}_2\text{O}_3 \cdot 2 \text{SiO}_2$. This chemical formula simply states that glass formers will exist in the glass in the ratio of one mole of Na_2O (sodium oxide), to one mole of B_2O_3 (boron oxide), to two moles of SiO_2 (silicon dioxide or silica).
2. Determine from the periodic table the weight of one mole of each of the oxide components of the glass expressed as grams per mole (grams/mole). This is a process for obtaining the molecular

weight of a compound or chemical. For example, in determining the molecular weight of B_2O_3 , we find the molecular weight of boron to be 10.81 g, and the molecular weight of oxygen to be 15.99 g. The weight of one mole of B_2O_3 is equal to $2(10.81) + 3(15.99)$, which is 69.62 g/mole. The calculations for all three glass components are shown below.

Na_2O	Na = 22.99 g/mole, O = 15.99 g/mole $Na_2O = 2(22.99) + 15.99 = \underline{61.98 \text{ g/mole}}$
B_2O_3	B = 10.81 g/mole, O = 15.99 g/mole $B_2O_3 = 2(10.81) + 3(15.99) = \underline{69.62 \text{ g/mole}}$
SiO_2	Si = 28.09 g/mole, O = 15.99 g/mole $SiO_2 = 28.09 + 2(15.99) = \underline{60.08 \text{ g/mole}}$

3. Determine the total molecular weight of the $Na_2O \cdot B_2O_3 \cdot 2SiO_2$ glass by summing the weights contributed by each glass component.

Na_2O	61.98 g
B_2O_3	69.62 g
2 SiO_2	$\underline{2(60.08) = 120.16 \text{ g}}$
Total	$\underline{251.76 \text{ g}}$

4. Normalize each molecular weight fraction to 100 to determine weight percent. See below.

Na_2O	$\frac{(61.98)}{(251.76)} \times (100) = \underline{24.62 \text{ weight percent}}$
B_2O_3	$\frac{(69.62)}{(251.76)} \times (100) = \underline{27.65 \text{ weight percent}}$
2 SiO_2	$\frac{(120.16)}{(251.76)} \times (100) = \underline{47.73 \text{ weight percent}}$

5. The sum of the weight percentages for all glass constituents must equal 100%. This is a good double check of the calculations.
6. Many raw materials are available as compounds that decompose to the desired oxide upon heating. Compounds such as Na_2O and B_2O_3 are unstable in air and so are almost impossible to obtain as pure compounds. Na_2O is purchased as Na_2CO_3 (sodium carbonate). In the glass-making process, the Na_2CO_3 decomposes to form the desired Na_2O . Because we will start with Na_2CO_3 , this

is called a "source chemical." Listed below are our glass components, their sources, and changes that occur:

<u>Source Chemical</u>	<u>Source Chemical Formula</u>	<u>Glass Component</u> + <u>Off Gas</u>
Sodium carbonate	Na_2CO_3	Na_2O + CO_2
Boric acid	$2 \text{H}_3\text{BO}_3$	B_2O_3 + $3 \text{H}_2\text{O}$
Silica	SiO_2	SiO_2

We need to determine what mass of the source chemical is needed to produce one gram of component. This is our "conversion factor." Formula masses are used to determine this for each component.

a)	<u>Na_2O</u>	<u>Compound</u>	<u>Element</u>	<u>Mass</u>	<u>Atoms</u>	<u>Total Mass</u>
		Na_2O	Na	22.99	2	45.98
			O	16.00	1	16.00
				Mass of 1 mole =		<u>61.98 g</u>
		Na_2CO_3	Na	22.99	2	45.98
			C	12.00	1	12.00
			O	16.00	3	48.00
				Mass of 1 mole =		<u>105.98 g</u>

Because 1 mole of Na_2CO_3 produces 1 mole of Na_2O , the ratio is:

$$\frac{\text{Source}}{\text{Component}} = \frac{1 \text{ Na}_2\text{CO}_3}{1 \text{ Na}_2\text{O}} = \frac{105.98}{61.98} = 1.710$$

Therefore, 1.710 g of Na_2CO_3 will produce 1.00 g of Na_2O . This is our conversion factor.

b)	<u>B_2O_3</u>	<u>Compound</u>	<u>Element</u>	<u>Mass</u>	<u>Atoms</u>	<u>Total Mass</u>
		B_2O_3	B	10.81	2	21.62
			O	16.00	3	48.00
				Mass of 1 mole =		<u>69.62 g</u>
		H_3BO_3	H	1.01	3	3.03
			B	10.81	1	10.81
			O	16.00	3	48.00
				Mass of 1 mole =		<u>61.84 g</u>

The B_2O_3 component contains two boron (B) atoms, and the source contains only one B atom. Therefore, we need twice as much source. The ratio is:

$$\frac{\text{Source}}{\text{Component}} = \frac{2 \text{ H}_3\text{BO}_3}{1 \text{ B}_2\text{O}_3} = \frac{2 (61.84)}{69.62} = \frac{123.68}{69.62} = 1.776$$

Therefore 1.776 g of H_3BO_3 is needed to produce 1 g of B_2O_3 . This is our conversion factor for this chemical.

c) SiO_2 Because we are using SiO_2 as our source, the ratio:

$$\frac{\text{Source}}{\text{Component}} = \frac{1}{1} = 1.000 \text{ g}$$

Therefore, 1.00 is the conversion factor in this case. Note: no decomposition takes place with SiO_2 .

7. We will now go through a procedure to summarize our previous steps.

a) Divide a sheet of paper into 5 vertical columns with the following headings:

<u>Glass Component</u>	<u>Weight %</u>	<u>Source Chemical</u>	<u>Conversion Factor</u>	<u>Amount Needed (for 100 g)</u>
------------------------	-----------------	------------------------	--------------------------	----------------------------------

b) Fill in the component column with the compounds from step 1.

c) Fill in the weight percent column with the values calculated in step 3.

d) In the "source" column, place the formula of the actual chemical to be used in batching as noted in step 6.

e) For each source chemical, place the conversion factor that was calculated in step 6.

f) Multiply the number in the weight percent column by the corresponding conversion factor to calculate the amount of source chemical needed to make 100 g of glass. Place this number in the "Amount Needed" column. A completed work-up sheet is provided below for batching 100 g of $Na_2O \cdot B_2O_3 \cdot 2 SiO_2$ glass:

<u>Glass Component</u>	<u>Weight %</u>	<u>Source Chemical</u>	<u>Conversion Factor</u>	<u>Amount Needed (for 100 g)</u>
Na_2O	24.62	Na_2CO_3	1.710	42.10 g
B_2O_3	27.65	H_3BO_3	1.776	49.11 g
SiO_2	47.73	SiO_2	1.000	<u>47.73 g</u>
			Total	138.94 g

Activity: Standard Glass Batching

Student Learning Objectives

At the end of the activity the student will be able to:

- measure, combine, and homogeneously mix dry chemicals (generally in the form of oxides and carbonates) to be melted to form a glass.

Materials

- Ice cream carton
- Plastic bags
- Permanent markers
- Spatula/spoon
- Crucible (DFC)
- Silica (SiO_2)
- Boric acid (H_3BO_3)
- Sodium carbonate (Na_2CO_3)

Equipment

- Top-loading electronic balance with accuracy of ± 0.1 g

Procedure

1. Prepare a glass recipe workup sheet listing your source chemicals and relative amounts (generally expressed in grams) of each component to be used in the glass.
2. Collect all source chemicals into a common area (usually somewhere near the balance); clean area to avoid contamination of source chemicals.
3. Using a permanent marker, record glass oxide composition, weight percent, and **your** initials on the plastic bag.
4. Inflate the plastic bag to check for defects or leaks. Place the plastic bag inside the ice cream container. Replace lid.
5. Tare* the balance, weigh the empty ice cream container, and record the weight on the container.
6. Place weigh boat onto balance. Tare balance.

*Tare means return balance to zero.

7. Carefully clean spatula or spoon with water or ethanol, then dry it. Be very careful not to contaminate chemical sources with other chemicals or laboratory grit.
8. Weigh out each of the source chemicals, one at a time. Transfer from weigh boat to the ice cream container, and check off the weighed chemical on the workup sheet. **Note:** Accuracy and cleanliness are important.

Caution: Avoid creating dust as the chemicals are being emptied into the collection container. Fine particles of any material are a health hazard.

9. When all constituents have been weighed out, a gross weight is then taken to ensure that no major constituent was omitted.
 - a. Obtain gross weight by 1) removing weigh boat from balance, 2) tare balance, and 3) weigh ice cream container with added chemicals.
 - b. Subtract tare weight of original empty ice cream container (step 3) from gross weight (step 6.) This weight should equal the total batch weight from the batch workup sheet. A deviation of ± 0.5 percent is acceptable.
10. The powder is now ready to be blended to obtain a homogenous mixture. Gently stir, avoiding making dust, to develop a fine uniform mixture free of lumps. The best method for mixing is to seal the open end of the plastic bag with air trapped inside the bag. Shake the chemicals for several minutes. With your fingers crush any lumps of chemicals, and reshake the batch. This process is known as “shake and bake.”

Extension Activities

1. Discuss why a mixture of carbonates and oxides is used. Look up the melting points and decomposition temperatures for the various chemicals used (i.e., *CRC Handbook*; the chemistry teacher will have reference books like this). To get high melting point compounds [i.e., silica (SiO_2) or alumina (Al_2O_3)] into solution at much lower temperatures, glass modifiers such as sodium oxide (Na_2O), lithium oxide (Li_2O), and calcium oxide (CaO) are used. These chemicals have a relatively low melting point and are very corrosive in solution—especially a molten solution. Boron oxide (B_2O_3) is a glass network former as are silica and alumina. These chemicals form the network in the glass and keep the modifiers “locked up” or chemically stable in the glass.
2. Note that mixtures melt at lower temperatures than the pure compounds. Compare your glasses to more common mixtures like adding salt to ice water to lower its freezing point (i.e., making ice cream and clearing icy sidewalks).

Glass Melting

Instructor Notes

Reliability

This experiment works well. The quality of glass produced, though, depends on the formula, furnace temperature, and time at melt temperature.

Estimated Time for Activity

Two class periods.

Teacher Tips

1. Preheat furnace to 1050°C. Do not exceed limit on furnace temperature.
2. Hot plate should be set on “high” and the annealing oven at 500°C. If the glass sticks to the hot plate or stainless steel, lower the hot plate temperature to “medium.” This usually alleviates the sticking problem.
3. A good source for crucibles is DFC Ceramics (see Vendor List in Appendix). When ordering, ask that the crucibles be shipped UPS; this is less expensive than freight.
4. If you do not have a ceramic crayon, you can mark the crucible using a small brush and an iron salt or an iron oxide solution. Write on the crucible with the solution, and allow it to dry.
5. Stress to students that overfilling the crucible (more than 1/2 full) is a problem. As the chemicals heat and release gases, foaming will occur. It is often wise to check the melt about 5 min after it is placed in the furnace to see if foaming is a problem. This is especially true if the students are trying different ratios or formulas of glass that they are not familiar with and do not know how much foaming to expect. Remove the crucible from the furnace if foaming is excessive. Start the melting over with a new crucible and even less of a chemical batch so the foam will be contained in the crucible. If foaming continues to be a problem, check the chemical formulation; one of the chemicals may have too much water in it and need to be pre-treated to dehydrate it before further use.
6. First pour powder into a glass beaker. If students pour powder directly from a plastic bag, heat from the crucible melts the bag.
7. Glass may soak at 1050°C overnight to get good mixing but **be sure** your furnace maintains a stable temperature.

8. Students pouring glass for the first time are nervous. They often lift the pouring glass stream upwards, and as a result, the viscous glass puddle is pulled off the pour plate.
9. Usually, glass will have some bubbles in it. These bubbles are usually small and are remains from the foaming stage (decomposition of chemicals). The glass industry uses many techniques to remove bubbles from the molten glass. The students' best technique will be time—lots of melting time if bubbles are not wanted.
10. Watch students as they cut the glass streamer. Sometimes they get burned, especially if scissors are too small. Cut the glass streamer close to the crucible to prevent hot “strings” from developing.
11. If spatula for transferring glass bars is not preheated on the hot plate, the bars will often crack. Keep the spatula hot until the moment the glass is to be transferred to the annealing furnace, then move the glass quickly, but safely.

Safety

1. Hot and cold glass are the same color, beware! Move hand slowly over glass to determine if it is hot.
2. Students must wear safety glasses.
3. Have students wear gloves when handling hot material.
4. Have students remove metal articles from their persons, especially rings. These materials transfer heat quickly.
5. Have students practice before they do the actual glass pour, using tongs and moving crucibles while they are cool.
6. Watch out for cracked crucibles, they may break if excessive force is used while moving or pouring.

Disposal

1. Follow school regulations for normal broken glass disposal.

Activity: Glass Melting

Student Learning Objectives

At the end of the activity the student will be able to:

- melt, pour, air quench, and/or anneal a glass
- practice safe procedures for glass making.

Equipment

- Safety glasses (to be worn at all times)
- Heat-resistant gloves
- Ceramic crayon
- Tongs and spatula
- Ceramic brick to place hot crucible on after pouring glass
- Furnace
- Hot plate and stainless-steel pour surface
- Annealing oven
- Beaker, 250 mL
- Stainless steel bar
- Stainless steel stirring rod
- Stainless steel beaker
- Polarizing film

Procedure

Warning: Wear safety glasses.

1. Pre-heat furnace to appropriate temperature (usually 1050°C).

Note: Schedule time to accommodate pre-heat. It takes approximately 1 hour to heat the furnace from room temperature to 1050°C.

If annealing, pre-heat hot plate, stainless-steel pour surface, spatula and annealing oven approximately 1 hour before pouring. Set up bar molds.

2. Use a ceramic crayon to label a crucible with your initials, class period, and common name of glass.

3. In the fume hood, fill the melting crucible 1/2 full with the blended glass powder. Place the remaining powder, if any, into a Pyrex beaker, and set it aside.
4. Carefully open furnace door. Using gloves and tongs, transfer the crucible plus powder to the melting furnace. If oven is too hot, have your partner shield door with a ceramic heat shield. Close the furnace door. Allow glass powder to soak heat at temperature for approximately 20 min.
5. Remove the crucible and observe the melt. Powder should be molten with a viscosity of approximately 100 poise (consistency of honey). If it is not molten, increase set point temperature by 50°C and repeat step 4. This step should be repeated as many times as necessary until the powder melts and resulting glass has viscosity near 100 poise or the furnace temperature capacity is reached.

Caution: Do not exceed furnace temperature limit.

6. Remove the crucible from the furnace and carefully pour the blended powder from the Pyrex beaker onto the top of the molten glass until the crucible is 2/3 full. Replace crucible in furnace. Several powder additions may be required before all glass is in the crucible.
7. Soak for 1/2 hour at 1050°C. The melt soak time begins after the **last** addition of dry chemicals to the melt.
8. At 30-min intervals, stir the melt to ensure homogeneity by removing the crucible containing the glass and, while holding the crucible with metal tongs, mechanically stir the melt using a clean, 1/4-in. stainless-steel rod. This step can be skipped if care was taken in diligently mixing the chemicals. **Note:** Bubbling and foaming during the initial part of the melt also aid the mixing of the batch.

Pour Procedure

10. Using gloves, safety glasses, and tongs, remove the crucible from the furnace and either 1) air quench or 2) pour glass bars for annealing, according to the following steps:
 - a. **Air quench** - pour the molten material quickly onto a stainless steel pour plate. You may need to cut the glass from the crucible using scissors. Allow the material to cool until the glass surface is no longer dented by a slight tap of a metal spatula. Slide glass off pour plate into a stainless-steel beaker to contain flying particles produced when glass fractures upon cooling.

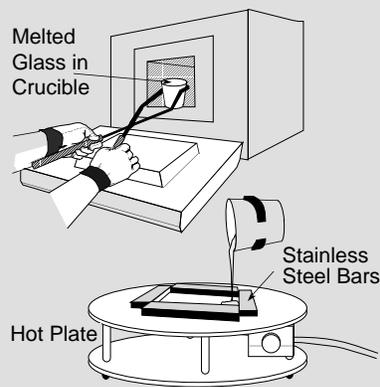


Figure 6.4. Glass Making

Caution: The stainless-steel beaker may become quite hot.

Note: Set hot plate on high (~300°C) and annealing oven at 500°C.

Safety Precaution: Heat-resistant gloves, reflective face shield, and safety glasses must be used when handling the molten glass!

- b. **Glass bars** - Remove molten glass from furnace, and pour into heated bar molds as quickly as possible (see Figure 6.4). Allow this material to cool until top surface of bar is no longer dented by a slight tap from metal spatula. Dismantle bar mold rapidly, and transfer the bar to the annealing oven using a heated spatula. Soak at annealing temperature for 2 hours, then turn the oven off and oven-cool to room temperature. Do not open furnace until it has completely cooled; otherwise, the annealing process is disrupted and the 2-hour annealing must begin again. Sometimes the glass will crack or shatter if the annealing process is disrupted.

Note: This experiment may be interrupted or stopped at many places, which allows students to do the work over several days. Use caution, however, when allowing the glass to soak for extended periods (i.e., 4 hours) in the furnace. This will cause the crucible to erode. Moreover, certain chemicals such as calcium oxide or large amounts of sodium oxide can cause the crucible to erode in less than 30 min.

Checking Annealed Glass

11. If the glass is clear and has been annealed, the glass can be checked for stresses by using two pieces of polaroid film. Sandwich the piece of glass between the two layers of polarized film, and hold the assembly so that direct light from an overhead projector or a fluorescent lamp passes through the materials. Rotate one of the polarized films 90° so the light waves passing through the assembly are altered. Stresses in the glass will appear as red-dish bands. In an unannealed or poorly annealed glass, the stress lines will be thin and numerous. In a glass partially annealed, and stress almost totally relieved, the bands will be broad and have almost no color. In a glass fully annealed, no lines or red bands will be observed.
12. For glass that did not anneal well, place the glass back into a cool furnace, turn it on, and allow it to heat 25°C higher than previously annealed. Let it anneal for 3 more hours, then let it cool down in the furnace over night. Check for stress lines using polarized film the following day.

Dragon Tears/Dragon Dribble

Instructor Notes

Reliability

Not every tear falling into the water will be whole. Many break upon cooling. Make many dragon tears, and a few will hold together.

Estimated Time for Activity

One class period.

Teacher Tips

1. Heat glass before class period begins.
2. When molten glass is poured into water, the rapid cooling of the glass exposed to the water and the slower cooling of the glass in the interior causes severe stress. This result is the glass surface is placed under compression. This compression may be demonstrated by taking a piece of the dragon dribble and breaking it. The stress is released by breaking the glass, which shatters into very small pieces. Use extreme caution, the flying glass can be dangerous. It's safest when done in a plastic bag.
3. The outside surface of the tear (drop) freezes as it hits the water.
4. The outside surface of the tear freezes in a low-density condition. The inside cools more slowly, resulting in a higher density.
5. The inside material is contracted relative to the outer skin. This results in a surface in compression (25,000 - 50,000 p.s.i. or much higher). Ceramics are strong in compression.
6. Cutting the "tail" off the dragon tear upsets the forces of equilibrium, which causes the dragon tear to break up into **dust!**
7. Examine a dragon tear, tempered glass, using polarized film. Follow step 11 on page 6.36.
8. Industrially tempered glass is air cooled by jets of air.
9. Students may also remove a tear from the water and anneal the tear to observe the change in the way the face fractures. Follow Step 12 on page 6.36.

10. With your students in a classroom setting, discuss tempered glass and why highly stressed glasses are made. (All automobile glass is tempered except for the windshield). Note the rainbow spots of the “temper shift” in the glass. Car windows and plate glass will often get oily looking “rainbow” spots on them. This is the “temper shift.” Tempered glass is very strong glass, designed to break into small pieces so people do not get severely cut in an accident. In the discussion of glass tempering be sure to include the terms compressive and tensile forces and their role in tempering.
11. Corelle dishes are a good example of a highly stressed material.

Safety

1. Students must wear safety glasses.
2. Cut tail in a plastic bag.

Disposal

1. Put crucible in normal trash.
2. Put glass in a science department glass disposal container.

Activity: Dragon Tears

Student Learning Objectives

At the end of the activity students will be able to:

- produce a “dragon tear”
- successfully cut the dragon tear in order to observe the effect of tempering and internal stresses.

Materials

- Plastic bag
- Glass from previous experiment
- Crucible

Equipment

- Melting furnace
- Metal tongs
- Stainless steel beaker
- Safety glasses
- Heat-resistant gloves
- Scissors or diagonal (dike) pliers
- Polarizing material
- Light source

Procedure

Warning: Wear safety glasses at all times.

1. Use the standard Na_2O , B_2O_3 , 2SiO_2 glass composition. Melt a small amount of glass (approximately 50 g) in the furnace at 1050°C for 1/2 to 1 hour. Fill stainless-steel beaker with cold water, and place it near oven.
2. Remove the molten glass from the furnace, and slowly pour the glass, drop by drop into the beaker containing water. Allow long fibers to trail from each droplet of glass. It will take some experimentation to produce whole droplets. Be patient.

3. When glass becomes too viscous to pour, return crucible to furnace for approximately 10-15 min. Step 2 can then be repeated. Set hot crucible on appropriate heat-resistant surface.

Caution: Step 4 is a dangerous step. Make sure all people in the laboratory are wearing their safety glasses.

4. After cooling, remove droplets with their long trailing fibers from the beaker. Place droplet in plastic bag with end of fiber exposed. Hold the droplet with one hand and begin cutting fiber, using diagonal-cut pliers, at the farthest point from the droplet. Continue cutting fiber, moving progressively closer and closer to droplet. At some distance (usually less than 3-4 cm) the dragon tear will explode into sand-sized particles in the bag.

Activity: Dragon Dribble

Student Learning Objectives

At the end of the activity students will be able to

- demonstrate the forces placed on glass when it is cooled rapidly.

Materials

- Batch of pre-melted glass [a ratio of 1:1:2 (Na_2O , B_2O_3 , 2SiO_2) works well] in crucible

Equipment

- Lindberg furnace
- Tongs
- Leather gloves
- Scissors
- Plastic bag
- Large Can (No. 10), bucket, or stainless steel-beaker
- Burner
- Safety glasses and/or face protection
- Polarized film

Procedure

Warning: Wear safety glasses and leather gloves for this experiment.

1. Use the gloves, tongs, and eye protection to remove the melted glass from the furnace.
2. Pour the glass in a small continuous stream into the can, bucket, or stainless-steel beaker containing water (see Figure 6.5). (The glass should form a continuous ribbon about the thickness of a dime or slightly thicker.)
3. After the glass has cooled, remove it from the water. (Any long pieces may be cut by melting with a Bunsen burner.)

Caution: Make sure everyone in the laboratory is wearing safety glasses. The tempered glass is dangerous if it shatters.

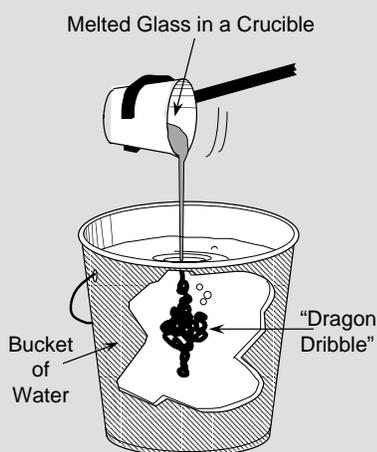


Figure 6.5. Dragon Dribble

4. Examine the glass with two pieces of polarized film. Orient the polarized film so little or no light is transmitted through it. Then place the glass between the polarized film and describe what you observe. Compare this to glass that was allowed to cool slowly. Check step 11 on page 6.36 for further details.
5. Place a piece of dragon dribble glass in a transparent plastic bag.
6. Break the glass in the bag. It should shatter into tiny pieces.
7. Record all observations in your journal.

Glass Coloring

Instructor Notes

Reliability

Students love this one! The biggest problem is using too much metal oxide; it makes the glass opaque.

Estimated Time for Activity

Two class periods.

Teacher Tips

1. This activity generates a lot of enthusiasm. It is a good example of the multicomponent conceptual learning process students encounter as they do the stained glass project (see Figure 6.6).
2. Varying the amount of the metal oxide varies the color intensity and sometimes the color. Color can also be affected by melting temperature.
3. Having ovens and furnace at operating temperature before class saves much time.

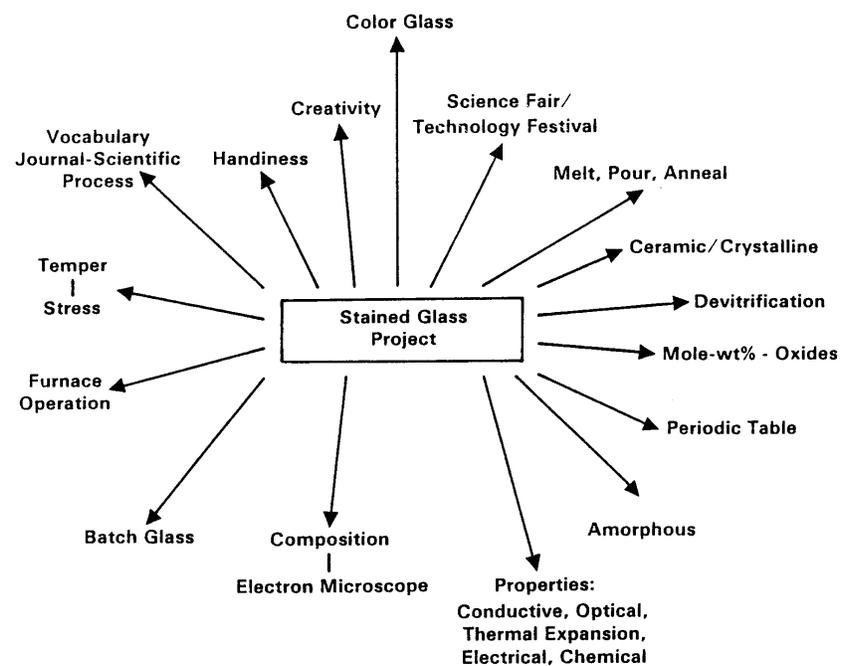


Figure 6.6. Diagram of the Multicomponent Conceptual Learning Students Encounter as they do a Stained Glass Project

4. Glass can be batched and colored one day—melted, poured, and annealed a second day.
5. You do not need to use oxides; carbonates work very well. They decompose to oxides during heating.
6. Art supply stores can give very good prices on carbonates as they are used in glazes.
7. Color is an excellent way to introduce students to spectroscopy and the electronic structure of atoms. Discuss what color is. Use a prism to generate simple spectra of your glasses.
8. Discuss color *control*. Can students make the same color twice?
9. Reference: Nassau, K. 1983. *The Physics and Chemistry of Color—The Fifteen Causes of Color*, Wiley, New York.

Safety

1. If crushing glass from previous lab, be careful. Students must wear goggles.
2. Use caution when pouring and annealing hot glass.

Disposal

1. Normal science department procedures.

Activity: Glass Coloring

Student Learning Objectives

At the end of the activity the student will be able to:

- describe the effect of adding a metal or metal oxide to a glass batch
- identify which metal oxides are responsible for which color changes.

Materials

- Glass from *Glass Melting* experiment or materials for melting glass from *Glass Melting* experiment
- Chromium (III) oxide, Cr_2O_3 (green)
- Neodymium oxide, Nd_2O_3 (light blue)
- Cobalt (II) oxide, CoO (dark blue)
- Copper (II) oxide, CuO (royal blue)
- Iron (III) oxide, Fe_2O_3 (brown)
- Crucible
- Plastic bag

Equipment

- Safety glasses
- Face shields
- Gloves
- Annealing oven
- Furnace
- Hot plate and stainless-steel pour surface
- Tongs
- Spatula
- Stirring rod
- Balance
- Weigh boat
- Stainless steel beaker
- Thick metal rod for breaking glass

Procedure

Safety Precaution: Safety glasses, face shield, and gloves should be worn when crushing glass or handling molten glass.

1. Prepare a batch workup sheet for a Na_2O , B_2O_3 , 2SiO_2 glass, or use previously melted borosilicate glass.
2. Batch the chemicals if you are going to prepare a new glass for this experiment. If you use glass prepared during a previous lab, crush the glass in the stainless steel beaker using a thick metal rod. Transfer your chemical batch or crushed glass to a crucible.
3. Weigh out 0.20 g of the desired metal or metal oxide in a small weigh boat.
4. Pour this into the crucible and stir.
5. Follow the melt and pour procedure in the Glass Melting lab. (Steps 5-10 using 10b for glass bars).

Extension Activities

1. Observe how color varies with thickness and concentration.
2. Try to identify the elements that color common glass (like 7-Up bottles, Coke bottles, beer bottles, etc.)
3. Not all the raw materials used to introduce color may be colored. How can this be possible?
4. Oxidation state will also affect color. (Note: Iron can be green or brown, depending on its oxidation state.)
5. Anneal the glasses until they crystallize, and examine them for changes in color and intensity.

Glass Fusing*

Instructor Notes

Reliability

This lab may take some experimentation. The actual temperature of your furnace, the type of glass used, and where the glass is placed in the furnace may affect how well the glass fuses. You may have to try it a few times to determine what gives the best results. Students appreciate this activity.

Estimated Time for Activity

One class period, but then the furnace should be monitored.

Teacher Tips

1. Fusing is the process of placing compatible glasses on a kiln shelf in a kiln. The temperature of the glass is slowly raised to around 800°C, and the glass is then cooled slowly through the annealing region.
2. Glasses from different manufacturers frequently have different ingredients, and this results in different coefficients of expansion. When this occurs, the glasses are said to be incompatible. Sometimes different glasses from the same manufacturer have different coefficients of expansion. When glasses have different expansion rates, they will fuse but then shrink at different rates. This will result in a high amount of stress, which usually leads to cracks eventually forming in the project. Some manufacturers sell a type of glass specifically designed for fusing. (Although it is fairly expensive, dichroic glass gives a nice effect when fused.)
3. Devitrification (forming of crystalline material) may occur as the fused glass is allowed to cool slowly in the annealing process. An unattractive change in the appearance of the glass may result from this. To prevent the formation of crystalline material, an overglaze is used. You may purchase "Spray A," or you may make your own from 20 Mule Team Borax. Mix 5 parts water with 1 part Borax by volume. Heat this mixture until the Borax dissolves. The Borax overglaze should be applied when it is hot, and it is most easily applied by spraying.

*This activity was developed by Spectrum Glass, Woodinville, Washington.

4. A kilnwash or shelf primer is recommended to be used on the surface upon which the glass is placed in the fusing process. If not used, the fused glass may stick to the surface. A mixture of 40% kaolin and 60% alumina hydrate by weight is a kilnwash recommended by Spectrum Glass.
5. Polarizing film may be used to check the fused glass project for stress that could exist due to the incompatibility of the glass.
6. Several good books are available on glass fusing, including: *The Fused Glass Handbook* (revised edition) by Gil Reynolds, (distributed by Fusion Headquarters, P.O. Box 69312, Portland, OR 97201 and *Glass Fusing, Book One* by Boyce Lundstrom and Daniel Schwoerer, published by Vitreous Group/Camp Colton, Colton, OR 97017.
7. Terms used in the lab:
Set point - The temperature the kiln is set for in this step.
Soak time - Length of time the temperature remains at the set point.
Flash vent - Turn off furnace. Open furnace door for 8 seconds. Close.
Drift - Allow the furnace temperature to decrease with power off and door closed.
8. Students may want to attach pins or clips to these to use as jewelry.

Safety

1. Students need to be careful of cutting themselves on the scrap glass, which is usually used for this activity. Students must wear goggles.
2. Use caution when heating glass in a furnace or opening furnace door when hot.

Disposal

1. Place waste glass in a glass disposal container.

Activity: Glass Fusing

Student Learning Objectives

At the end of the activity students will be able to:

- show a finished product that demonstrates creativity
- tell why an overglaze spray is used
- tell about the compatibility of different glasses
- explain the purpose of kilnwash
- explain the fusing process.

Materials

- Stained glass pieces
- Overglaze spray
- Kilnwash
- Ethyl alcohol (optional for cleaning)

Equipment

- Steel wheel glass cutter/tapper
- Self lubricating carbide wheel cutter
- Combination breaker grozier pliers
- Furnace
- Kiln shelf or other high temperature, flat, smooth surface
- Gloves
- Metal tongs
- Safety glasses

Procedure

Warning: Wear safety glasses at all times when working with glass.

- *1. Make a sketch of your planned fused glass project. (Your first trial should be with pieces no larger than about 10 cm [4 inches] square.)

*If your item is much larger than 10 cm on a side, check with your instructor for a good estimate on programming your furnace.

2. Either find pieces of scrap glass or cut out pieces using a glass cutter and some pliers. Use the glass suggested by your teacher.
3. Either place kilnwash on the surface you will be using or use a surface that already has been prepared.
4. Thoroughly clean all glass pieces you will be using with warm water. If they have oil on them, you may need to use ethyl alcohol.
5. Use overglaze spray to coat all exposed surfaces and edges.
6. Arrange the pieces of glass on the surface which has been kiln-washed and is ready for the oven. You may stack them 2 or 3 pieces deep, or you may want to place some crushed glass on other glass pieces.
7. Place the surface holding your project into the cool furnace; set the furnace for 788°C (1450°F) with a ramp time of 90 minutes, and turn on the furnace. Your instructor may need to okay this procedure.
8. When the temperature reaches the set point (788°C), let soak for about 10 minutes (or until it appears well fused). Then turn off the furnace, open the furnace door for 8 seconds, and then close the door and let the furnace cool. The opening and closing of the door is called flash venting.

Extension Activities

Recommended Firing and Annealing Charts for Fusing Glass

(These are suggested by Spectrum Glass for their glass. They are a good guide, but you may find through experimentation that other possibilities exist depending on the type and size of glass and the appearance of the product you are seeking.)

<u>Fusing project</u>	<u>Ramp time</u>	<u>Set pt.</u>	<u>Soak time</u>
Projects approximately 10 cm across and 2 layers deep	1. 90 min	788°C	10 min
	2. Flash vent		
	3. Drift	Room temp.	
Projects approximately 30 cm across and 2 layers deep	1. 2.5 hr	788°C	10 min
	2. Flash vent		
	3. Drift	510°	3 min
	4. 3 hr	371°C	
	5. Drift	Room temp.	
Projects approximately 50 cm across and 2 layers deep	1. 2.5 hr	788°C	10 min
	2. Flash vent		
	3. Drift	510°C	90 min
	4. 6 hr	465°C	30 min
	5. 3 hr	316°C	
	6. Drift	Room temp.	

Note: Drift means to allow the furnace to cool with power off and door closed until the next set temperature is achieved.

Project: Stained Glass - Sun Catcher or Window Panel

Student Learning Objectives

At the end of the activity students will be able to:

- show a finished product.

Materials

- Solder 50-50 lead tin alloy
- Flux
- Felt pen (non water soluble)
- Copper foil - copper wire
- Patina
- Finishing compound
- Stained glass
- Glass cleaner

Equipment

- Steel wheel cutter/tapper
- Self lubricating carbide wheel cutter
- 80-100 watt soldering iron - stand
- Sponge
- Combination breaker grozier pliers
- Breaking pliers
- Running pliers
- Glass grinder

Notes

1. Pattern shears reduce 1/32 in. of paper to allow for copper foil and solder.
2. Select colors and grain/pattern of glass, numbering each piece.
3. Keep iron **off** of foil to prevent cracking (thermal) and damage to adhesive backed foil.
4. Refer to text for difficult cuts.
5. Visit your local experts.
6. Reference: Wardell, Randy and Judy. 1983. *Introduction to Stained Glass: A Teaching Manual*. Wardell Publications, Belleville, Ontario.

Procedure

Warning: Wear safety glasses

1. Select a pattern (see Figure 6.7).
2. Trace pattern pieces onto glass with felt pen.
3. Score glass with self-lubricating wheel cutter
4. Tap bottom of score to promote crack growth. (Tap within 6 sec before molecules relax and dull the crack.)
5. Use grozier pliers or running pliers to snap pieces loose along score lines.

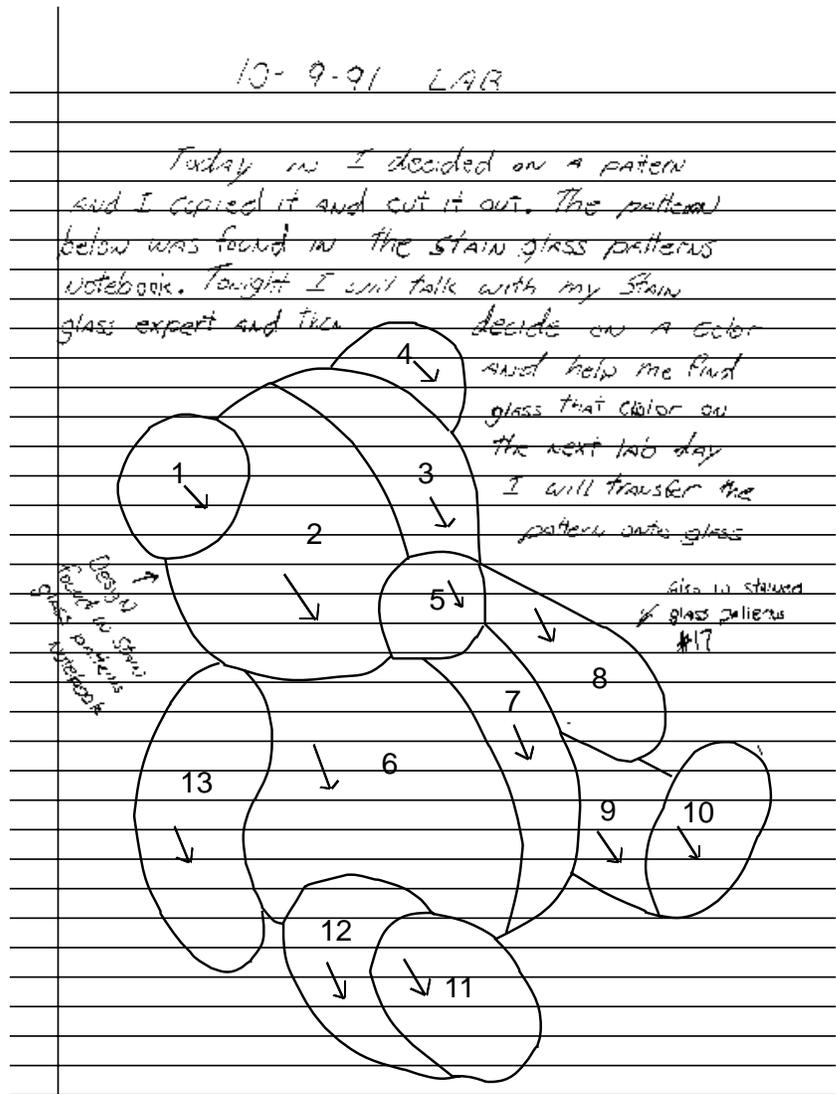


Figure 6.7. Pattern for a Project from Richland High School MST Student

6. Using the bench grinder, grind the edges of each piece to fit pattern.
7. Clean glass with glass cleaner.
8. Apply copper foil to each piece of glass with 1/4 in. overlap.
9. Fit pieces to form pattern shape.
10. Apply flux with small brush.
11. Tack with solder.
12. Solder both sides.
13. Clean glass.
14. Attach copper wire ring.
15. Apply patina to the solder to darken it.
16. Apply polishing compound.

Making Raku

Instructor Notes

Reliability

This experiment is very reliable. Students get excited about it. The only problem occurs when transferring project from charcoal to water. A piece may break.

Teacher Tips

1. This lab can be done over several days or weeks.
2. If you load the kiln with the pots to be raku fired and turn on the kiln about 3 hours before class starts, the pots will be ready for the students to do the exciting part. Once the pots have the characteristic red color and shiny appearance, they will stay at that state for quite some time in the hot kiln. Opening the kiln to remove a pot drops the temperature temporarily and should be done as quickly as possible to avoid damage to the ware and kiln.
3. An alternate to two separate firings is to use the raku firing to do both jobs. This is actually the way it was done originally. The problem is students tend to handle the green pots too roughly and they get broken before the firing.
4. The clay and glaze are readily available from pottery suppliers. Often the catalog will state that the clay or glaze is suitable for raku.
5. Have students try using clay from the banks of a river or stream.
6. Some students are very leery of reaching into the hot kiln to remove their pot because of the extreme heat they experience. It is best to quickly remove the pot as the lost heat cools the other pots, and they must reheat. Small kilns recover in about 5 min.
7. An art teacher can be an excellent resource person for this lab. Have the art teacher do the pinch pot technique teaching for your students. If that is not possible, try asking if one of your students knows the technique. Often, this is the case, and it gives that student a chance to be "special."
8. Give students a copy of the paper, using the Raku Glazing Process to show oxidation-reduction in chemistry. They enjoy the story of the potter. The recipes for other glazes is included for those that would like to go further. Other effects than copper and cobalt are very interesting. Try using those two metals as they are readily available and give good results.
9. Pottery is significant in many ancient cultures, and this lab can easily be tied into history and social studies.

10. When the pots come out of the water, they often are crazed. Because the glaze and ceramic pot cool at different rates the glaze gets a cracked appearance. This is normal and is considered part of the aesthetics of the pot. If the pot is not quenched, the reduction is reversed as oxygen recombines with the exposed metal. It is normal for the appearance of the pot to change over the first few days.

Safety

1. Take care when dropping the red hot pot in the sawdust to cover immediately; it will flare up. Be careful when removing the lid as the sawdust may burst into flame as oxygen re-enters the pail.
2. Use long tongs to handle all ware.
3. Work in teams where everyone has a job, i.e., 1) open kiln and close; 2) grab pot and move to sawdust; 3) bury pot.
4. Keep spectators far away.
5. When near an open kiln, remove **all** metal from your body. Coins, belts, eyeglasses, and earrings they can get hot enough to burn you.
6. You may want goggles that filter ultraviolet radiation and visible light for looking into the hot kiln.

Project: Making Raku

Student Learning Objectives

At the end of the activity students will be able to:

- make a clay pot using the pinch pot method
- describe the change in the pot after vitrification
- coat the pot with a raku-type glaze
- perform the raku technique upon the pot to observe the reduction and/or oxidation resulting from this technique.

Materials

- Clay, low-fire type
- Glaze, low-fire type
- Copper carbonate or other glaze metals as interest and budgets allow (see attachment)
- Paper cup or other container for glaze, 6 oz.
- Sawdust
- Nail for scratching initials
- Paint brush for applying glaze

Equipment

- Oven or kiln
- 5-gal metal bucket with lid
- Large pail for water
- Nylon string or wire
- Heat-resistant leather gloves
- Goggles
- Long-handled, 80 cm, tongs

Procedure

1. Cut a softball-sized piece of clay from the brick, and work it into a ball shape.
2. Work the clay into a cup (pot) shape as demonstrated by the instructor. Try to make it a uniform thickness (see Figure 6.8.).
3. Set the pot aside to dry over night (or longer).



Figure 6.8. Pinch Pot (Raku)

4. Turn the dry pot over, and scratch your initials into the bottom.
5. Turn the pot in to the instructor to be bisque fired, or bisque fire the pot at cone 4.
6. Observe and record the differences in the pot after it has been bisque fired.
7. Fill a 6-oz. paper cup 1/2 full of raku glaze. This is equal to about 100 g of dry glaze. To the glaze, add between 1 and 5 g of either of the two metal carbonates. Mix thoroughly. If the glaze becomes too thick, a little water may be added to maintain original consistency. It should be about as thick as heavy cream or cake batter.
8. Coat your pot with the glaze using a brush. Do not coat the bottom 0.5 cm of the pot. Use several thin coats. The glaze should be between 2 and 3 mm thick. Allow the glaze to dry completely.
9. Place the glazed pot into the kiln. Turn on the kiln, and allow it to heat until the pot is glowing cherry red and the outer surface is bright and shiny. The time will depend on the number of pots in the kiln. It will take about 3 hours. Once the pot is ready, you must have the pails with the sawdust and water close by and ready to use.
10. Put on the heat-protective leather gloves. Have a partner quickly open the kiln. Using the long-handled tongs, quickly grasp your pot, and immediately drop it into the pail of sawdust. You may push the pot into the sawdust if you wish. Place the lid on the pail, and leave it on for about 3 min. As soon as your pot has been removed, your partner should close the kiln.
11. After 3 min take the lid off of the pail. Watch out for a flare up! Using the long-handled tongs, remove your pot, and drop it immediately into the pail of water. Once the pot has stopped steaming, carefully remove it using a pair of tongs. Be careful, the water may be quite warm. Take the pot to a sink and clean it up. Be careful. Gentle scrubbing will remove black carbon deposits. On the cobalt pots the cobalt appears as a dark metallic coating. Don't scrub it off.
12. Observe and record the differences in the pot in your journal after the raku process.

Extension Activities

1. Compare raku pots to conventionally fired pots with the same glaze.
2. Discuss the terms "oxidized" and "reduced."
3. Measure pots for firing shrinkage, i.e., measure the diameter of the pot before firing and after firing. Record the results in your laboratory notebook. Theorize what is occurring. Discuss these results in your class or with your teachers.

Using the Raku Glazing Process to Show Oxidation-Reduction in Chemistry

(Whitaker, G. 1983. Prepared as a master's thesis, Western Washington University, Bellingham, Washington)

Introduction

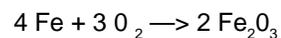
The art of raku was conceived and developed in Japan during the last quarter of the sixteenth century, specifically for the production of ceramic wares for use by the Zen Buddhists in the Tea Ceremony. The name "raku" meaning "pleasure or enjoyment," was given to the descendants of the famous sculpture-potters. Raku applies solely to the art and products of the raku family masters but it has also come to mean a ceramic technique that has been traditionally used by them. Raku is committed to the basic premise that the pot is the product of a process of mutual interaction and refinement between man and nature and that through this involvement man discovers his own significance. Raku places great reliance on maintaining a close and intimate relationship between the pot and its maker at all stages of production, and particularly so during the moments of truth when the pot is subjected to severe and sudden changes (Cooper).

The Making of Raku Ware

Raku wares are made by carving and refining forms down from larger leather-hard ones, which have been raised by a pinching technique. The Raku forms made by the joining techniques must have particular attention paid to welding the parts into a totally unified structure. Otherwise the wares will later split apart under the stresses of thermal shock. After drying the wares should be bisque fired, (bisque firing is the initial firing to vitrify (harden) the form) to a temperature of 850° to 900° Centigrade. It is important that raku bodies never approach their maturation temperature during firing. After the forms are removed from the kiln (see Figure 6.9), they are placed in a safe place to cool.

Oxidation and Reduction

Simply, oxidation is the addition of oxygen. Thus, when iron and steel are allowed to become wet and are exposed to the air, the subsequent process of rusting, in which the metallic iron acquires oxygen from the air, is known as oxidation. An example of this process is:



The metallic iron becomes an oxide and is said to have been oxidized. In ceramic firing, processes of oxidation are commonplace. Most ceramics and most metal enamels are fired in an oxidizing atmosphere with a copious air supply, so that all materials actively seeking oxygen can acquire it during the process (Shaw).

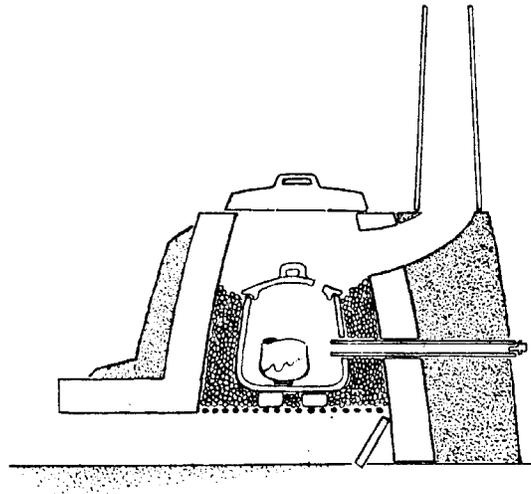


Figure 6.9. Small circular raku kiln burning coke or smokeless fuel. The saggar is the heart of the kiln and the main wall follows its profile. The walls may be made of common brick for a temporary kiln or of firebrick for a more permanent structure. The belly of the kiln is transversed by a number of fire-bars that both support the saggar and contain the fuel. The rectangular air intake tunnel may be used to direct fire from a flame gun to the center of the kiln if fast firing is desired. The kiln may be lit either with wood and the coke gradually added from above or by means of the flame gun. The chimney is a commercial chimney pot, and the whole kiln has an insulation of banked earth. The development of the glazes within the saggar may be observed at intervals through the viewing tube that may be made of metal or clay. The kiln will reach glazing temperature in 2 to 3 hours.

Reduction

There is an old Chinese legend that tells of a potter who lived many centuries ago. One day he was firing his kiln and was having a lot of trouble. It was one of those days when everything goes wrong. The fire wouldn't burn properly, the chimney wouldn't draw, the place was full of smoke, and the air was filled with a horrible odor. The potter was afraid that most of the ware, which he had glazed with a lovely green copper glaze, would be ruined.

When he opened the kiln he found his fears were justified, for piece after piece came out blistered, blackened, and dull. But in the very center of the kiln, there was one vase that was a beautiful blood red. Such a color had never been seen before on any piece of pottery. The potter's neighbors and co-workers marvelled at it. It was so beautiful that it was sent to the emperor as a gift. The emperor in turn admired the color so much that he had the vase broken and the fragments set in rings as though they were precious stones. Then he sent the potter an order for a dozen more red vases.

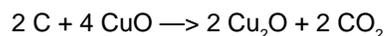
The potter's troubles began. He tried again and again but he could not reproduce that red color. He checked his glaze formulas carefully and used exactly the same ingredients that he used that day, but all the pots came out green. The emperor grew impatient. Messengers arrived from

the palace, saying *produce or else!* Finally our potter was in despair. He decided to fire one last kiln and loaded it with vases covered with glazes as before. But during the height of the fire, his courage failed him. He opened the door of his kiln and jumped in.

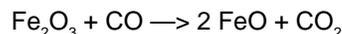
His assistant ran up quickly. The kiln fire was smokey and there was a bad smell in the air. They shut down the flames and allowed the kiln to cool, and when they opened it, what did they find? No trace of our poor potter, but yes, you've guessed it—the kiln was full of beautiful red pots.

And there, according to the legend, was discovered the secret of reduction. The potter's assistants reasoned that if a human body produced such results, maybe a dead pig would work and they tossed a pig into the next fire. Again they got beautiful red pieces. Then they tried substituting such things as wood and straw, and still the trick worked.

Reduction results when the fire is overloaded with carbon. When this happens, the green oxide of copper loses some of its oxygen and becomes a red oxide.



Likewise, a red oxide of iron loses some of its oxygen and becomes a black oxide. This reduction process is shown by the chemical equation:



Iron oxide exists in several different combinations, and each proportion of iron to oxygen has a characteristic color as follows:

Fe_2O_3	Ferric iron	red
Fe_3O_4	Ferrous-ferric	yellow
FeO	Ferrous iron	black
Fe	Metallic iron	no color

Red oxide of copper produces the *sang-de-boeuf* or ox blood color, while the black oxide of iron produces the gray-green color known as celadon (see Table 6.2).

Reduction is obtained in the down draft type of kiln by closing the damper and adjusting the burners so that the flame does not get enough air and burns yellow (see Figure 6.9). This sends free carbon into the kiln. There is loss of heat during this process, so in high fire work the potter has to alternate periods of oxidation and reduction. With the muffle type of kiln, it is not so easy to produce controlled reduction, for the flames do not touch the ware, and, if the muffle is tight, even though the flame releases free carbon it will not get a chance to act on the pieces. Reduction can be produced, however, by putting some organic material such as sawdust, straw, or dry leaves, which will ignite instantaneously inside the muffle. In the case of low fire luster glazes, organic material is actually mixed with the glaze itself (Kenney).

An American version of the classic Japanese raku technique also involves a reduction process. A specially prepared glazed pot is fired to a deep red color, then while still glowing red hot, it is quickly plunged into a container filled with organic matter such as straw, sawdust, or oil. The pot will acquire a smoked appearance, and a copper glaze will give a red color due to the now present copper or a luster glaze due to metallic copper forming.

Table 6.2. Coloring Action of Oxides In Glazes*

Oxide	Percent	Color in Lead Glaze	Color in Alkaline Glaze	Color When Reduced
Chromium oxide	2%	Vermilion at cone 012 Brown at cone 06 Green at cone 06		
Cobalt carbonate	0.5%	Medium blue	Medium blue	Medium blue
	1%	Strong blue	Strong blue	Strong blue
Copper carbonate	0.5%			Copper red
	1%	Green	Turquoise	Deep red
	2-3	Deep green	Turquoise	Red and black
	8%	Green with metallic areas	Blue-green with metallic areas	
Ilmenite	3%	Tan specks	Gray-black specks	Spotty brown
Iron chromate	2%	Gray-brown	Gray	
Iron oxide	1%			Celadon
	2%	Pale amber	Pale tan	Olive green celadon
	4%	Red-brown	Brown	Mottled green
	10%	Dark red	Black-brown	Saturated iron red
Manganese carbonate	4%	Purple-brown	Purple-violet	Brown
Nickel oxide	2%	Gray-brown	Gray	Gray-blue
Rutile	5%	Tan	Gray-brown	
Vanadium stain	6%	Yellow	Yellow	
Cobalt carbonate	0.5%	Gray-blue	Gray-blue	
Iron oxide	2%			
Cobalt carbonate	0.5%	Blue-purple	Aubergine	
Manganese carbonate	4%			
Cobalt carbonate	0.5%	Gray-blue	Gray-blue	Textured blue
Rutile	3%			
Copper carbonate	3%	Textured green	Textured	
Rutile	3%	blue-green		
Ilmenite	27%	Textured brown	Textured	Spotty brown
Rutile	2%		gray-brown	
Iron oxide	8%			
Cobalt carbonate	1%			Black
Manganese carbonate	3%			
Cobalt carbonate	3%			
Iron oxide	2%	Mirror black		
Manganese carbonate	2%			
Manganese carbonate	6%			
Iron oxide	3%	Luster brown		

*Source: Nelson, G.C. 1957. *Ceramics Reference Manual*, Burgess Publishing Co.

Raku Glazes

Raku glazes are usually better applied thickly, and the relationship to glazed and unglazed areas carefully considered as the blackened reduced body can be very attractive. The pots are put into the kiln when it is estimated to have reached a sufficiently high temperature that can be judged by color—a rich red orange—or measured by a pyrometer. During the firing, the glazes will begin to bubble as they melt and when they have settled evenly and have a shiny reflective surface, the glazes have matured. Depending on the efficiency of the kiln, this will take about 20-40 min. When the pots are taken from the kiln, they will oxidize as they are brought into the air, and, if reduction is required, it should take place now. Burying the pot inside a metal dustbin full of sawdust or other material and then covering the bin with a reasonably well fitted lid will ensure a well-reduced glaze. Dark gray acrid smoke will be given off indicating a good reducing atmosphere. If copper is present in a glaze or in painted decoration, a rich lustrous surface will result from this heavy reduction. The body will be turned black by carbon.

After about 15 to 20 min, remove the pot and quench it immediately by placing it quickly into water to prevent reoxidation in the atmosphere. If the glaze is still molten when placed into water it will froth to give an unpleasant surface.

(A frit is a glaze that has been fired in a crucible and once cooled has been ground into a powder form for use. This process is used to seal in toxic glazes such as lead because of the high toxicity of this substance.) Alkali frit, lead frit, and borate frit, can be combined with about 10% whitening and 10% ball clay to give glazes that will work well. Additions of 5-10% tin oxide will give a rich white glaze that will usually crackle to give a large network of black lines. This contrasts well with the black matte body. Additions of coloring oxides will give the following results:

Copper	2-3%	turquoise
Cobalt	0.5%	blue
Manganese	1-2%	purple-brown
Iron	2-6%	creams-ambers

(Also see Table 6.3 for other coloring metals.)

After the pots have cooled, the glaze surface needs to be cleaned to remove soot and dirt with a stiff brush, wire wool, or an abrasive cleaning powder. Care should be taken not to remove the reduce metal if you have strived to get that appearance.

Now we come to an area where almost anything goes and daring experimentation is half of the fun! Because of the low temperature of raku firing, potters can use such things as lead all alone to make a glaze, but because of the hazards of raw lead, it seems wiser to use colemanite, (a natural mineral containing both calcium and borate) and various frits as fluxes (a substance that promotes melting).

Borax mixed into a paste with water and brushed thickly on a piece will form a glaze; so will Boraxo.

Interesting lusters often develop during reduction in glazes containing copper. Metallic lusters can be achieved by adding 1-3% silver nitrate or 2-5% tin chloride (see Table 6.3).

Table 6.3. Suggested Additions of Coloring Oxides to Reduction Glazes*

Cobalt carbonate	1/2%	medium blue
Cobalt carbonate	1/2%	light blue
Cobalt carbonate	1/2%	} turquoise
Chrome oxide	1%	
Cobalt carbonate	1/2%	} warm textured blue
Rutile	3%	
Cobalt carbonate	1/2%	} grey-blue
Nickel oxide	1%	
Nickel oxide	1%	grey or grey-brown
Manganese carbonate	4%	brown
Manganese carbonate	4%	} Textured brown
Rutile	2%	
Ilmenite	3%	spotty brown
Ilmenite	2%	} textured yellow-brown
Rutile	2%	
Iron	1%	celedon
Iron	2%	dark olive celedon
Iron	4%	mottled green or brown
Iron	10%	saturated iron red
Copper	1/2%	copper red
Copper	1%	deep copper red
Copper	3%	red to black
Cobalt	1%	} black
Iron	8%	
Manganese	3%	

*Source: Nelson, G.C. 1957. *Ceramics Reference Manual*, Burgess Publishing Co.

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Ceramic Slip Casting

Instructor Notes

Reliability

This lab takes some experimentation. You may have to try it a few times for experience and best results, but it is worth it.

Teacher Tips

1. The chemical composition of plaster of paris (which the slip casting molds are made from) is calcium sulfate ($\text{CaSO}_4 \cdot 0.5 \text{H}_2\text{O}$). When the plaster of paris is mixed with water, it hydrates and cures into a solid, hard structure with the chemical composition $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$. If slip casting molds are heated above 56°C (135°F), the waters of hydration can be driven off, and the mold will begin to crumble. Be cautious when drying the mold; $38\text{-}47^\circ\text{C}$ ($100\text{-}120^\circ\text{F}$) is hot enough to dry them.
2. Clay used for slip casting is a mixture of components that helps reduce the firing temperature (see Table 6.5). Compositions vary slightly, so it's a good idea to check and see if you have the proper pyrometric cones for the clay slip you have acquired. More than likely you will, because most clay slip sold at local ceramic shops is nearly the same composition.

Table 6.5. Typical Casting Slip Composition*

Whiteware Slip		Refractory Slurry	
Material	Concentration (Vol%)	Material	Concentration (Vol%)
Nonplastics	25-30	Alumina (<45 μm)	40-50
Clay	15-25	Ball clay	0-10
Water	45-60	Water	50-60
Additives** (wt%)			
Na_2SiO_3 , Na polyacrylate, Na lignosulfonate	<0.5	Deflocculant	NH_4 polyacrylate 0.5-2
CaCO_3	<0.1	Coagulant	MgSO_4 0-0.1
BaCO_3	<0.1		
Clay < 1 μm	Variable amount	Binder	NH_4 alginate, carboxymethyl cellulose, methyl cellulose, hydroxyethyl cellulose 0-0.5

*Source: Reed, J. S. 1988. *Introduction to the Principles of Ceramic Processing*, Wiley

**Percentage by weight of solids in slurry.

3. Most slips (slip casting slurry) are sold by local ceramic supply outlets as a slurry ready for casting. If you need to buy the ceramic slip as a powder, then follow the manufacturer-recommended mixing instructions by measuring the appropriate amount of water into a bucket or pitcher then adding the powder while stirring the water. Continue to stir the slurry until all lumps are gone.
4. Instead of using rubber bands to hold the slip casting mold together, old inner tubes from automobiles can be cut into bands and used to tightly secure the mold.

Safety

1. The kiln or furnace, and its contents, can be hot. Place a sign (Caution - Hot) to warn students the furnace is being used. Wear leather gloves and safety glasses when working with a hot furnace or kiln.

Activity: Ceramic Slip Casting

Student Learning Objectives

At the end of the activity students will be able to:

- handle molds and materials while making a useful article with clay slip
- use pyrometric cones to measure temperature
- make and fire an object following the slip casting procedure.

Materials

- X-acto knife
- Clay slip [clay, water, and sodium silicate or sodium polyphosphate (calgon)]
- Cone stand
- Rubber bands
- Small bucket or pitcher
- Small sponge

Equipment

- Furnace or kiln
- Kiln furniture (shelves and setters)
- Plaster of paris mold

Procedure

1. Separate slip cast mold and clean any dirt; the mold should be dry. (Your tongue will stick to a dry mold). Molds may be stored at $\sim 38^{\circ}\text{C}$ (100°F) to keep them dry. Put the mold together by matching holes. Carefully secure mold with rubber bands.
2. Pour ceramic slip into mold slowly and evenly. Fill mold slightly above the pouring hole to form a sprue.
3. Let the ceramic slip sit for approximately 15 min or until desired thickness is reached (about 1/8 in.) If you are doing several castings, monitor the thickness as a function of time.
4. Pour the excess slip out of the mold back into the pouring container. Leave the mold inverted to drain.
5. Turn the mold over, and let it sit for at least 1 hour or until firm.

6. Carefully remove the casting from the mold by removing the rubber bands and lifting it out. Try not to twist or deform the casting as this may cause it to warp as it dries. (Make note of any pieces that get deformed, so you can observe if they dry or fire differently.) Put the mold away where it can dry out and stay clean. [Do not dry or store plaster molds at temperatures above 57°C (135°F.)]
7. Using an X-acto knife, remove the sprue. Be careful not to damage the ware.
8. Let the casting set for 24 hours before continuing.
9. After the casting is hard and dry to the touch it is still very fragile, but can be handled.
10. Using an X-acto knife and a damp (NOT WET) sponge, fettle the casting. Fettle is trimming off any excess clay and removing the "seam" marks made by the mold. Pay special attention to the rim and bottom. Rub any chips down with the sponge. Generally, "patching" does not work, so be careful. (Put your initials and date on the bottom of the casting.) On test pieces, score registration lines 1 in. apart in various locations on the ware. Measure the distance between the lines as accurately as you can.

If the piece is complex it may need some assembly. Attach handles etc. by making a paste of clay and water (thickened slip works well), scoring both surfaces to be joined, and covering it with the paste. Firmly press the pieces together, and wipe away any excess clay with a damp sponge. Allow the piece to dry overnight before firing.

Caution: Furnace may be hot. Use leather gloves and safety glasses when working with hot materials or equipment.

11. Set the casting on a clay stilt or other suitable piece of kiln furniture. Place it in the furnace.
12. Place the cone appropriate for the clay composition (#5) on the cone stand, and place it in the furnace so you can see it without opening the door. If the furnace is large and there are a lot of castings, you will want to place several sets of cones throughout the furnace even if you can't see them all. This way you can get an idea of how uniform the temperature is throughout the furnace and note its effect on the ware.
13. When filled, close the furnace and set the temperature to 750°C. (This is called the "set point." It is the temperature you want; it is not necessarily the temperature the furnace is currently at.) This is not the firing temperature of the clay. You want to heat the clay slowly to the firing temperature to allow the water and any organic material plenty of time to get out of the clay. If you don't, the castings will break from the pressure of steam and other gases trying to escape.

14. Let the furnace sit undisturbed for 45 min. Then check to see if it has reached 750°C. Wait for the furnace to reach the set point before continuing. If the furnace is not allowed to reach the set point it can draw too much power and overshoot the set point by a large amount, and then you will never really know what temperature the furnace is.
15. Turn the temperature up to 915°C.
16. Wait another 45 minutes to check to see if the furnace has reached 915°C. Wait for the furnace to reach 915°C before continuing.
17. Increase the set point to 1075°C and leave for 1-1/2 hours.
18. Once the furnace has reached the set point, check the cones every 15 min or so by looking through the peep hole. If the furnace does not have a peep hole, you will have to estimate the firing time from the set points used. When the cones have slumped to the proper position turn the furnace off. **DO NOT OPEN THE FURNACE.** Let the furnace cool down for 24 hours before opening. If you open the furnace when it is hot, it and the ware inside will cool so fast it can break (thermal shock).
19. After the cool down period, “crack” the furnace by opening it slightly. Use a wedge if necessary to keep the door open only an inch or so.
20. When the ware is cool enough to touch, remove it. Make note of the location and condition of the cones in the furnace.

Suggested Questions

21. How does the slip flow and handle? Does it respond to stirring, standing?
22. How long did you leave the slip in the mold, and how thick did the casting become? Compare your results with other groups. Plot thickness as a function of time in minutes.
23. Describe the appearance of the casting during the stages of drying. Did the color change? Hardness? Did any cracks appear? How much did it shrink? Remeasure the distance between the registration lines you made on the unfired ware.
24. Did the castings fired in different parts of the furnace look different after firing? What about the cones? Did any of the castings deform during firing?
25. Why do you think we used plaster molds? What do you think the plaster does to the slip? (Hint: Stick your tongue on a clean plaster mold.)
26. What is the relationship between the set point and the actual temperature of the furnace?

27. Why do we use pyrometric cones in addition to the set point and firing schedule?
28. When does the casting shrink? Why does the casting shrink?
29. Explain why any castings deformed during firing.
30. What are the limitations on the shapes of slip cast pieces?
31. Why doesn't the clay settle out of the slip?

Extension Activities

1. Glazing (see the glazing section in "Making Raku").
2. Make your own plaster molds and discuss some of the unique properties of plaster.
3. You may want to heat the cones in the furnace to record the effects of various time and temperature schedules. Can you find different schedules that result in the cones having the same appearance?
4. Identify as many slip cast objects as you can at home. (Don't forget the toilet!)

Making Glass from Soil

Instructor Notes

Reliability

This activity is an experimental study to develop glass from the soil in your geographic area. Most soils can be melted into glass.

Estimated Time for Activity

Two class periods.

Teacher Tips

1. Most soils are high in silica (SiO_2), the main ingredient in the network of most common glasses. It would be a good experience to try to make glass from soil.
2. This experiment is designed to let students use a scientific method to make the best material from given conditions. For example, the melt temperature will not exceed 1050°C , and the chemical ingredients will be soil and anhydrous borax ($\text{Na}_2\text{B}_4\text{O}_7$).
3. Students initially will need to try a number of samples. A suggested range would be 30 weight percent (wt%) soil/70 wt% borax, a 50/50 wt% ratio, and a 30 wt% borax/70 wt% soil ratio. Depending on how these samples melt, you can narrow the compositional range. First you can eliminate samples that do not fully melt. Likewise, if the glass is very fluid, you can observe some of the soil settled at the bottom that did not dissolve. You can also eliminate these samples because they have too much borax and the crucible may be attacked by the glass and leak before the settled soil is dissolved. Additional glass compositions (i.e., 45 wt% borax/55 wt% soil) can be made.
4. When the compositional range of acceptable glass samples (i.e., 50/50 wt% and a 45/55 wt% of soil to borax ratio) is determined, test these samples for durability. Break or cut these samples, and place an approximately 5-g sample in a clean plastic container with 40 to 50 mL of water. Measure the pH of the solution 24 hours later. If the pH has changed significantly (i.e., <8.5), students may want to narrow the compositional range even further to make a better glass. These glasses will need to be tested for durability to check if they have improved.
5. You can make soil glass by following the procedures for glass batching and melting found in the Ceramics Section of your MST handbook, or by experimentally trying it as if it were a new material never researched before. In all cases, use caution, knowledge, and safe practices to perform experimentation.

Safety

Note: Because students are working under experimental conditions, they need to use extreme caution when initially melting the glass. Excessive foaming can occur in some chemical reactions.

1. When loading the melting crucible, students should fill it only about 1/4 full, and then melt it. Watch the initial reaction by checking the melt after 7 to 10 min. If excessive foaming occurs or has occurred, proceed with extreme caution while melting the remaining glass batch. If foaming is "normal," follow usual melting procedure.
2. Use borax anhydrous ($\text{Na}_2\text{B}_4\text{O}_7$) as a borax chemical additive. Anhydrous means "without water." Twenty Mule Team Borax, which is available at most grocery stores, contains the maximum amount of water allowed to chemically bond with borax ($\text{Na}_2\text{B}_4\text{O}_7 \cdot 10 \text{H}_2\text{O}$). If the borax has water, this increases melt foaming and can lead to crucible spillover. If you use borax with water, drive off most of the water by pretreating the borax to about 200°C . Borax has a melting point of 741°C .
3. Follow notes found in the glass batching and melting section of the MST handbook.

Extension Activities

Students can learn a lot about phase behavior, melting, and phase diagrams by doing a series of melts that includes the entire composition range for borax and soil. This activity is very similar to the Alloying Tin and Lead experiment in the Metals section of this handbook except some of the borax/soil compositions will not melt. Table 6.6 provides 11 compositions with a suggested amount of batch size for this experiment.

Table 6.6. Display of Borax/Soil Compositions

	$\text{Na}_2\text{B}_4\text{O}_7$ (Borax)		SiO_2 (Soil)	
	g	wt%	g	wt%
1.	50	100	0	0
2.	45	90	5	10
3.	40	80	10	20
4.	35	70	15	30
5.	30	60	20	40
6.	25	50	25	50
7.	20	40	30	60
8.	15	30	35	70
9.	10	20	40	80
10.	5	10	45	90
11.	0	0	50	100

Students will batch each composition (see Standard Glass Batching for proper batch instructions). They will begin melting the compositions at 725°C. Wait until the furnace temperature has reached equilibrium, then check the crucibles. Follow safety procedures found in the Glass Melting instructions. If one of the compositions is melting or has melted, record the temperature, and remove that crucible. Raise the temperature of the furnace 25°C, and wait until temperature equilibrium has been reached (10-15 minutes should do). Check the crucibles. If any of these compositions has melted, remove them. Continue raising the temperatures and checking the crucibles until all the compositions are melted or a maximum of 1150°C is reached.

Note: *Temperatures above 1150°C are very difficult to work at because of the intensity of the heat. Do not try melting activities above this temperature.*

This activity may take a week or more depending on how carefully the students melt the glass and how long they wait for the furnace temperature to increase. When students are finished, they can do several activities with the results:

1. Plot the data to determine the effects of composition on melt behavior (see Figure 6.10). Does your composition have a eutectic? Which composition looks like it makes the best glass?
2. Make a display using the crucibles. Label each crucible clearly with glass composition and melt temperature. The display will visually show changes in melt characteristics and glass behavior. It can be a great learning tool.

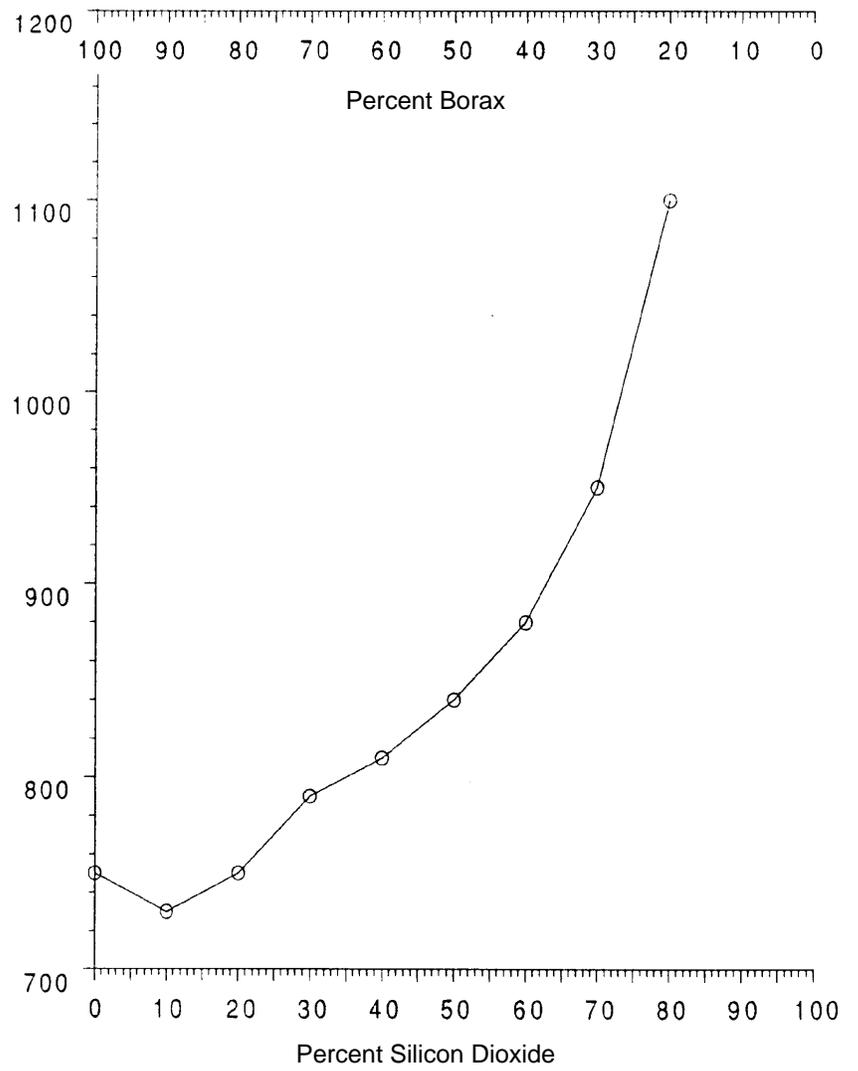


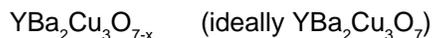
Figure 6.10. Melt Behavior of Borax/Soil Compositions

Making and Testing Superconductors

Instructor Notes

Teacher Tips

1. Superconductors are conductive materials that have an extremely low resistance to the flow of an electric current. That is, they have a theoretical resistance (R) equal to zero ohms. Most materials that exhibit superconductivity possess this property only at very low temperatures. Until 1986, these temperatures were close to absolute zero (0°K). Superconductivity has been achieved at temperatures above that of liquid nitrogen (77°K). The race is on in the scientific community to create a superconductor that can conduct electricity without resistance at increasingly higher temperatures. Although the new "high temperature" superconductors are in the developmental stage, some day they may be used in superfast computers, magnetically levitated trains, high-powered electric cars, and energy transmission lines that transmit electricity with virtually no power loss.
2. Follow the procedure described in this section to make a ceramic superconductor from three metal oxides: yttrium oxide (Y_2O_3), barium peroxide (BaO_2), and copper (II) oxide (CuO). BaCO_3 can be used in place of BaO_2 . The molar ratio of the three metals in the complex is 1:2:3, yttrium to barium to copper. The following is one way of expressing a molecular formula for this particular superconductor:



Caution: Some chemicals used in making superconductors are toxic. Please check the content of these materials in a chemical safety book. When students process chemicals when weighing or open-container grinding, the work should be done in a ventilating (fume) hood. Disposable plastic gloves should be worn, and it is advisable to wear a good-quality particulate mask for added safety.

3. Superconductivity, was first discovered in 1911 by Heike Kamerlingh Onnes while observing mercury at liquid helium temperatures (4°K , -452°F). The critical temperature (T_c) at which a material is superconductive has remained very low since that first discovery, rising only about 4°K per decade with research. By 1973, the best of the superconductors possessed a T_c of 23°K (-418°F). The discovery in 1986 of a superconductor with a T_c greater than the temperature of liquid nitrogen (77°K , -321°F) was a giant step toward making the process more practical. Cooling with liquid helium is expensive, whereas the cost of a gallon of liquid nitrogen is comparable to the cost of a gallon of milk!

4. The greenish material mentioned in step 8 of the experiment has been seen in several experiments with this superconductor. The greenish material is a non-superconductive phase, which has the composition of Y_2BaCuO_5 . The black phase is the desirable superconducting material, approaching the ideal composition of $YBa_2Cu_3O_7$.
5. The Meissner effect is a phenomenon that all true superconductors exhibit while in their superconductive state. When cooled to its proper temperature (the critical temperature, T_c), the superconductor repels all magnetism regardless of polarity. The classic picture of a magnet suspended in mid-air above a superconductor is a result of the Meissner effect.

4. The mixing and grinding of these chemicals is very important. The smaller the particle size, the better the chance superconductivity will occur. Any number of grinding methods can be used, preferably automated. If hand grinding is necessary, be certain to grind as long as possible. One way to do this would be for a group of students to share the work, each taking a 10-minute turn at grinding. If a rock tumbler is used, operate overnight, and check the consistency of the material the next day to see if it is finely powdered.

The grinding/mixing process allows for the dispersion of atoms to form the $YBa_2Cu_3O_7$ crystalline structure. The compounds used to make this type of superconductor are hard, refractory, but brittle, materials. They do not diffuse readily during the heating process, which allows the crystal structure to form. So the material must be ground again and again to allow these hard—and on the molecular level—large compounds to be broken and moved around so they can be close to the $YBa_2Cu_3O_7$ crystals that are forming. The finer the powder of the original material and the finer the powder from grinding, the easier it will be to form the superconducting crystalline matrix.

5. Samarium cobalt magnets have an extremely strong magnetic field for their size. This is important because common magnets are generally bulky and have weak magnetic fields. The weight of the magnet can overcome the force of the electric field and the levitating (Meissner) effect will not be seen. Samarium Cobalt magnets can be purchased commercially; these same magnets are commonly used in light-weight head phones, in case you have an old pair to take apart.

Activity: Making and Testing Superconductors

Student Learning Objectives

At the end of the activity students will be able to:

- make a superconductor using chemical batching, mixing and grinding (pulverizing), heating, pressing, and tempering
- test for superconductivity using the principal of the Meissner effect or testing for resistance using a micro-ohmmeter
- describe what mechanism makes a material superconductive.

Materials

- Yttrium oxide, Y_2O_3
- Barium peroxide, BaO_2 , (or barium carbonate)
- Copper (II) oxide, CuO
- Solvent: toluene or trifluorotrichloroethane
- Disposable protective gloves (such as PVC gloves)
- Safety glasses
- Zinc stearate
- Alcohol, (C_2H_5OH)
- Liquid nitrogen, $N_2(l)$
- Samarium cobalt magnet
- * Tweezers (non magnetic)
- Oxygen gas (optional)
- Particulate mask
- Polystyrene cup

Equipment

- Balance
- Furnace capable of achieving $950^{\circ}C$
- Furnace controller to ramp temperature at controlled rates
- Hydraulic press
- Grinding chamber (disc mill), rock tumbler, or automated mortar and pestle (standard, hand-operated mortar and pestle may be used)
- Die to form superconductor
- Micro-ohmmeter (four-point type) (optional)
- Annealing oven capable of achieving $475^{\circ}C$
- Fume hood



Procedure

Making Superconductors

1. Make calculations for the batch using the 1:2:3 ratio. Table 6.7 shows an example for a 0.1 mole batch, which is enough to make several superconductors. To achieve a ratio of 1:2:3 (Y, Ba, Cu), use a molar ratio of 1:4:6 for (Y₂, Ba, Cu).

Table 6.7.

Ratio	Compound	Molecular Weight (g/m)	Multiplier (for 0.1 mole)	Mass (g)
1	Y ₂ O ₃	225.81	0.1	22.58
4	BaO ₂	169.33	0.4	67.73
6	CuO	79.54	0.6	47.72

2. Weigh the chemicals, and place them in a container to go into a grinding chamber or mortar and pestle. If a grinding chamber is not available, use a rock tumbler with a very hard object such as a chunk of stainless steel or a piece of quartz added to help the grinding process.
3. Add 30 g of toluene to aid in mixing.

Caution: Vapors from toluene are not healthy. Work in a fume hood.

4. Grind for 1 hour. The smaller the resulting particles, the better. Grinding the material to the smallest possible size is **very** important in producing this type of superconductor material.
5. Let the toluene evaporate in a fume hood.
6. Place the powdered mixture in the furnace at 900-925°C for 18 hours.
7. Remove from furnace, cool, and repeat steps 3 – 7.
8. After you remove the mixture from the furnace for the second time, examine the mixture to see if any greenish-colored material is evident. If so, repeat steps 3 – 7. More than 25% greenish material indicates an incorrect mixture of chemicals, poor chemical quality, or improper oxidation. If this occurs, mix a new chemical batch.
9. Grind again to a fine powder—once again, the smaller the particles, the better.
10. Weigh out quantities of the material to make pellets. The quantities are determined by the size of the mold to be used. (12-g and 15-g quantities have been used to form pellets about 9 x 17 x 42 mm).
11. Clean the die with alcohol. Lubricate with a very light dusting of zinc stearate used as a mold release agent.
12. Place the superconducting material in the die, and distribute evenly.
13. Press with a hydraulic press.
 - a. Gradually increase the pressure to 5000 lb (pressure of 5000 to 6000 lb for a 1.0 in² surface area).
 - b. Hold the pressure for a couple of minutes.
 - c. Let the press gradually release the pressure itself.
14. Remove the top part of the die, and extract the pellet.
15. Place the pellets in the oven for sintering.
 - a. Heat the oven at 300°C/hour.
 - b. Heat pellets at least 8 hours at 950°C.
 - c. Cool at 50°C/hour to bring furnace back to room temperature.
16. Place the pellets in the annealing oven at 450°C for 18 hours. If oxygen gas is available, bubble O₂ over the pellets while they are being annealed. After the allotted time, let the oven cool to room temperature with the pellets inside.
17. Remove the pellets from the annealing oven. They are now ready to be tested for superconductivity.

Testing the Superconductors

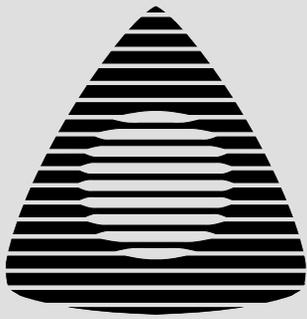


1. Attach the micro-ohmmeter (four-point type) to a pellet and take a resistance reading at room temperature. Now submerge the pellet in liquid nitrogen, and take a second reading. In its cooled state, the resistance measurement should read zero ohms. (Readings from this measurement can be erratic due to poor contact or high-contact resistance).
2. Test for the Meissner effect using a Samarium cobalt magnet and liquid nitrogen.
 - a. Place the superconductor in a pool of liquid nitrogen. A polystyrene cup cut down to 1 in. high works well in containing the liquid N_2 when testing the superconductor. The pellet can be placed on a small metal block (brass or aluminum works well) acting as a pedestal while in the liquid N_2 .
 - b. Allow the superconductor to cool for a few minutes. Continue replenishing the liquid nitrogen supply around the pellet as the N_2 dissipates.
 - c. With the tweezers, carefully place the magnet so that it is just above the superconductor. The height at which the magnet will remain suspended in air varies depending on the strength and size of the magnet—the smaller and stronger the magnet, the better. Once the magnet is balanced above the pellet, it can be set into a spinning motion with the flick of a finger or tweezers.

Vocabulary—Ceramics*

Alumina
Amorphous
Annealing
Blowing
Brittle
Casting
Crystal
Crystalline
Drawing
Fiber optics
Fire
Glassy
Inorganic
Meissner effect
Optical
Phase change
Pores
Pressing
Refractory
Resistance
Silica
Sinter
Superconductor
Tempering
Thermal shock
Viscosity

*Instructor may vary vocabulary to suit particular content presented.



Experiments/ Demonstrations

Polymers

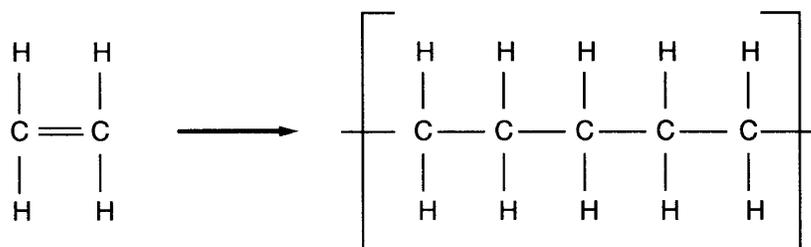
Polymers

Introduction

As you look around, you will find plastic materials almost everywhere. Plastics are part of a chemical family called polymers, which also includes elastomers (rubber) and adhesives. Some polymers, such as cellulose are naturally occurring, but most are chemically synthesized using chemicals derived from petroleum, which are called petrochemicals. The main petrochemical used for making polymers is natural gas.

Petroleum is a widely used product in our world, consuming billions of gallons daily for powering everything from automobiles to motorbikes and producing other forms of power (i.e., electricity through power generation). Petrochemicals use only 5% of this available petroleum, and only about half of the petrochemicals go into making polymeric materials.

Polymers (poly-mers), meaning many units, are created by joining together monomers (single units, usually a chemical compound such as ethylene gas as demonstrated in the example), using various combinations of heat, pressure, and catalysts. For instance, polyethylene is created by polymerizing ethylene gas as shown in the following chemical equation. A combination of heat, pressure, and a catalyst cause the double bond between the two carbon atoms in the ethylene gas to break and attach to other ethylene molecules. A polyethylene molecule is thus formed.



The brackets in the above equation indicate that the polyethylene molecule continues out to very long lengths relative to the size of the carbon and hydrogen atoms.

Polymers have become such an integral part of our lives that most of the time they are not recognized. Of course, we all recognize plastic bags, pens, telephones, fast food containers, and other common things as plastic, but we often fail to recognize other important polymer applications such as contact lenses, clothing fabrics (Dacron, Orlon, Nylon, Spandex, and Rayon), carpet fibers, automobile tires, foam cushions in furniture and mattresses, shoe soles, paints, pipes,

computer chips, and masks to produce electronic “chips,” automobile bumpers, and innumerable other objects. Plastics influence our lifestyle more than we could ever imagine. If we ever were to use just natural fibers (cotton and wool) instead of polymeric fibers for clothing, carpets, etc., all the available land in the United States would have to be used to raise sheep or cotton to maintain our present lifestyle.

Classification of Plastics

Thermoplastic

Basically, two types of plastics exist, thermoplastics and thermosets. Thermoplastics can be melted and reformed or reused. Typical thermal plastics include polyethylene, polypropylene, PVC, and nylon. Thermoplastics are converted to usable products by melt processing, (injection molding, extrusion, blow molding, and thermofoaming) which are explained below.

Injection molding forces melted polymer into a cold mold under pressure. When the polymer cools, it produces a part such as a pen barrel, a comb, a Tupperware container, a garbage can, or a refrigerator liner. Extrusion forces the melted polymer through a die to form continuous shapes such as pipe, tubing, sheet, or decorative molding. Blow molding uses air pressure to blow up the melted plastic like a balloon inside of a mold. When the plastic cools, it forms a bottle or other hollow shape. Thermoforming takes heated sheets of plastic and draws them into a mold with a vacuum to form such things as butter tubs, drinking glasses, small boats, and pick-up-truck bed liners.

Thermoset

Thermoset polymers “cure” or crosslink by a chemical process to become a stable material that cannot be melted. Typical thermosets include epoxy, polyester, phenolic, polyurethane, and silicone.

Thermoset materials are often used with reinforcements such as glass, Kevlar, and carbon fibers to make strong, lightweight parts such as fiberglass boats, airplane wing panels, Corvette car bodies, skis, gasoline storage tanks, septic tanks, chemically resistant pipe, and many other things. They are also used as adhesives that can be formulated to bond almost anything.

Some thermosets are very hard and tough (bowling balls), while others are soft and pliable (rubber tires, balloons, baby squeeze toys). Some are used for paints and some for bonding thin sheets of wood to make plywood.

Slime

Instructor Notes

Reliability

This lab works very well. It does take time for the polyvinyl alcohol to dissolve. Make sure the solution is clear.

Estimated Time for Activity

One class period.*

Teacher Tips

1. Polyvinyl alcohol can be purchased as a solid or as a 4% solution from supply houses. If it is purchased as a solid, you need to get a 99% hydrated, 170,000 + molecular weight variety.
2. Adding the 4% sodium borate causes the establishment of cross links making the "slime." To make 100 mL of a 4% solution, add 8 g of $\text{Na}_2\text{B}_3\text{O}_7 \cdot 10\text{H}_2\text{O}$.
3. To speed the process of making slime, the polyvinyl alcohol can be dissolved ahead of time. A very quick method with very little mess is to place the solid polyvinyl alcohol and water in a capped, appropriately sized jar or bottle and place it in a microwave. **Be sure the cap is not on tight.** Heat in the microwave for about 2 min. This should make the water very warm but not hot. Tighten cap and, shake for a minute or two. If it has not all dissolved, heat for an additional minute (**loosen cap again**) and shake. This method eliminates the sticky gooey mess of stirring and heating for a pro-longed period on a hot plate. The solution dissolves very readily this way and gives a nice clear solution.
4. Adding food coloring is not necessary. It gives color only.
5. If students take the product home, they should realize it does not keep well. If left uncovered, it dries out. If left sealed, after handling, mold will begin growing on it in a few days.
6. Solutions of polyvinyl alcohol and sodium borate are stable and can be stored indefinitely.
7. References: Casassa, et al. 1986. "The Gelation of Polyvinyl Alcohol with Borax." *Journal of Chemical Education*, vol. 63, 70.1 pp. 57-60.

*One class period is approximately 1 hour.

Suggested Questions

8. Describe the polyvinyl alcohol solution before the borate (cross-link) is added.
9. Write a paragraph describing the product.
10. Is it a solid or a liquid?
11. What does “poly” mean?
12. What does “polymer” mean?
13. What does the cross-link do when it is added to the polymer? How is the viscosity of the solution affected and why?

Safety

1. The polyvinyl alcohol is FDA-approved for indirect food use (food packaging) and ophthalmologic (eye treatment) solutions, i.e., contact lens solutions. A 1959 study determined polyvinyl alcohol was an animal carcinogen (Flynn Scientific Chemical Catalog, 1992).

Activity: Slime

Student Learning Objectives

At the end of the activity students will be able to:

- observe and describe the properties of a prepared substance
- describe the nature of a polymer
- describe how crosslinking affects a polymer using models, drawings, discussion, and writing.

Materials

- Water, 96 mL
- Food coloring, a few drops
- Polyvinyl alcohol, 4.0 g
- Sodium borate, 4% solution (6 mL)
- Paper cup, 6 oz

Equipment

- Beaker, 250 mL
- Stirring rod
- Thermometer
- Graduated cylinder, 100 mL
- Graduated cylinder, 10 mL
- Plastic sandwich bag
- Hot plate

Procedure

1. Measure out 96 mL of water into a 100-mL graduated cylinder.
2. Carefully pour the water into a 250-mL beaker, and place it on a hot plate.
3. Heat the water to near boiling (95°C, approximately).
4. Add a few drops of food coloring to the warm water, if desired.
5. Accurately weigh out 4.0 g of polyvinyl alcohol into a 6-oz. paper cup.
6. Remove the water from the hot plate. Slowly, while stirring, add the polyvinyl alcohol to the warm water.

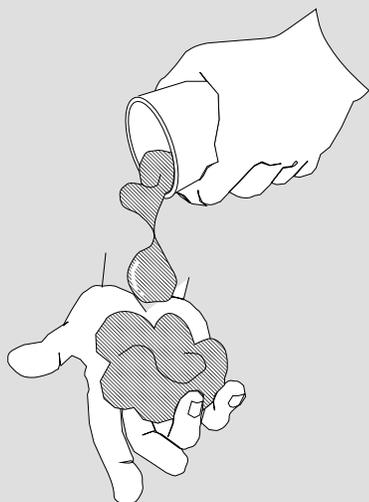


Figure 7.1. Slime

7. Place the beaker back on the hot plate until the temperature reaches about 90°C. Keep stirring until the polyvinyl alcohol is completely dissolved. Be patient.
8. Add 6 mL of 4% sodium borate, stirring constantly as you add the solution.
9. Pour the product into your plastic sandwich bag to cool before studying its properties.
10. Clean your equipment. (Hint: Roll product around in beaker to clean out most of the product, then wash.)
11. As students study the material they enjoy handling it. Have students try pouring it into their hands (Figure 7.1).

Extension Activity

1. Try adding more polyvinyl alcohol or a stronger or weaker concentration of sodium borate to the slime. Observe how these chemical changes affect the properties of the materials. Be sure and record this information in your journal.
2. Use a funnel or cheap paint “viscosity cup” to note the effect of changing variables on the viscosity of a product.

Note: *Viscosity is an indirect indication of the amount of cross-linking that has taken place.*

Polymer Foam Creations

Instructor Notes

Reliability

This lab works every time unless resins are too cold or too old.

Estimated Time for Activity

One class period.

Teacher Tips

1. Several different types of foams can be made. When purchasing the polyurethane foam, obtain two kits at the minimum: a rigid foam kit and a flexible foam kit. The procedure for each of these kits is the same as the procedure described for this lab. After the different foams are made, students can compare the similarities and differences of the materials.
2. When the two liquids are mixed together, they cause a chemical reaction that generates heat and carbon dioxide (CO₂). The CO₂ forms bubbles in the polymer matrix to create a foam.
3. This experiment would be a good group activity, with each group making one type of foam. This could save time and material and allow for student interaction as each group compares their polymeric foam with others.
4. It is best to refrigerate the liquids if they will not be used for an extended period of time. Be sure that when they are used that they have reached room temperature before the experiment begins; otherwise, the reaction may not occur.
5. One vendor of polyurethane kits is IASCO, 5724 West 36th St., Minneapolis, MN 55416-2594 (see Vendor list in Appendix).

Activity: Polymer Foam Creations

Student Learning Objectives

At the end of the activity students will be able to:

- mix two organic compounds together to observe the reaction and resulting polymeric material that is produced
- compare this material to other materials made using this procedure
- evaluate the similarities and differences between this material and other materials made following this procedure.

Materials

- Polyurethane foam (rigid and flexible types)
- Paper cups, 6 oz.
- Stir stick
- Plastic bag or newspaper to catch spill
- Mold (if desired)

Equipment

- Balance

Procedure

1. Weigh liquids for either rigid or flexible foam into separate cups, following the directions found on back of polyurethane containers.
2. Pour both liquids into a third, preferably larger, cup when you are ready to observe the experiment. The liquids will not degrade or react when kept in separate cups, but once they are combined they need to be stirred vigorously to mix the liquids as thoroughly as possible. Stir for 30 sec \pm 5 sec (see Figure 7.2.) Be sure to stir the contents at the walls and bottom of the cup too.

Note: *Stirring too long will collapse the foam as it reacts. Not stirring thoroughly will leave areas of stickiness; this is unreacted liquid.*

3. Place stir stick and stirred liquid on the plastic bag or newsprint, and observe the chemical reaction.
4. The reaction begins quite slowly at first, generating only a few bubbles. If your hand is wrapped around the cup you will feel heat being generated from the exothermic reaction that is occurring.

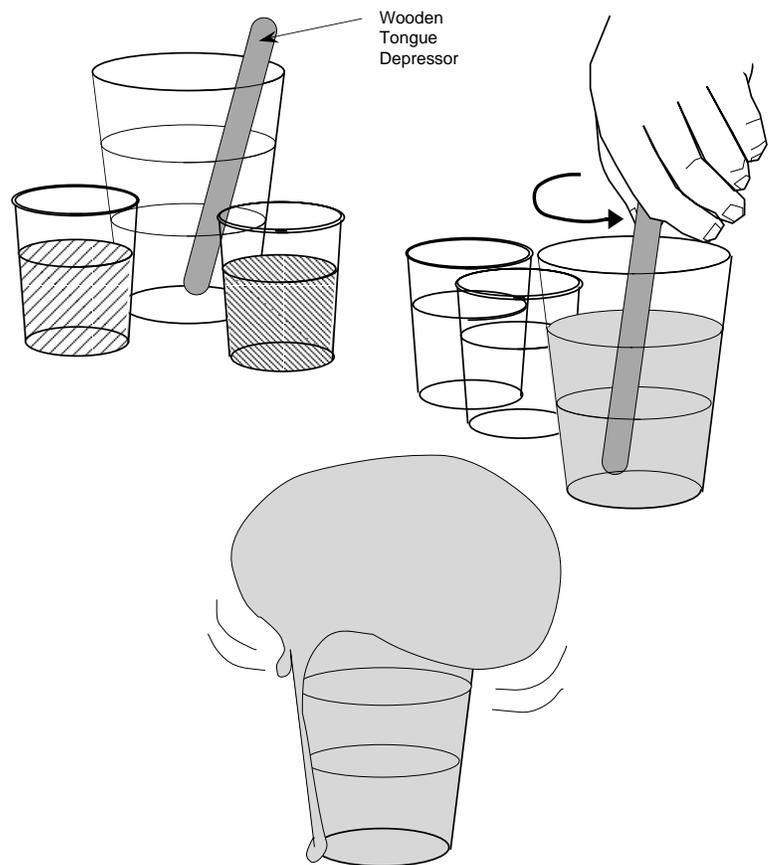


Figure 7.2. Polymer Foam

This exothermic reaction generates gas within the liquid that will form the few bubbles you will see at first. The reaction will evolve into a rapid eruption as heat, gas, and some odor are increasingly generated.

5. The polymeric foam that has been created will be sticky until it cures. It can then be handled.
6. Be sure to discard the cups, stick, and spilled material as they tend to be very sticky. Fantastic works well for cleaning up sticky messes.
7. Repeat with the other type of foam(s).

Nylon 6-10

Instructor Notes

Reliability

You always get nylon, but its strength is poor.

Estimated Time for Activity

One class period.

Teacher Tips

- The name "nylon" is used to represent a particular type of synthetic polymer. Different nylons can be made, and they are identified by a numbering system that indicates the number of carbon atoms in the monomer chain. Nylons made from diamines (1,6 hexanediamine) and dibasic acids (sebacoyl chloride) are designated by two numbers. As Table 7.1 shows, the number 6 represents the number of carbon atoms in the diamine (1,6 hexanediamine), and the number 10 represents the number of carbon atoms in the acid (sebacoyl chloride contains 10 carbons). The nylon formed from these is called 6-10 nylon.

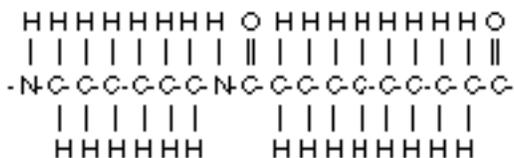
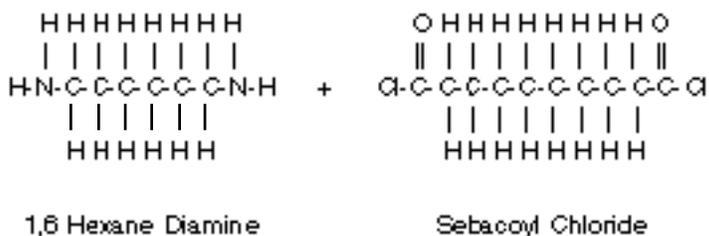


Table 7.1. A Dimer of 6-10 Nylon

- Many diamines and diacids (or diacid chlorides) can be reacted to make other condensation polymers that are described by the generic name "nylon." One such product is the commercial polymer nylon 6-6, which can be prepared by substituting the 6 carbon adipyl chloride for sebacoyl chloride in the procedure above.

3. Sebacoyl chloride is quite expensive. To reduce cost, this experiment can be done as a demonstration.
4. If ventilation is a problem, do this experiment as a demonstration.

Safety

1. 1,6 hexanediamine irritates skin, eyes, and respiratory tract.
2. Sodium hydroxide is very caustic and can cause severe burns. The solid will absorb moisture from the air and make puddles that could cause burns. Be sure to clean up any sodium hydroxide that is spilled.
3. Sebacoyl chloride irritates skin, eyes, and respiratory tract.
4. Hexane is very flammable. The vapor may irritate the respiratory tract.
5. Do not allow chemicals to touch skin. Wear plastic or rubber gloves during this experiment.
6. Wear chemical goggles for eye protection.

Disposal

1. Mix any remaining reactants thoroughly to produce nylon. The nylon should be washed thoroughly in running tap water before being discarded in a solid waste container.
2. Any remaining liquid should be neutralized with either sodium bisulfate (if basic) or sodium bicarbonate (if acidic) and washed down the drain with water.

Activity: Nylon 6-10

Student Learning Objectives

At the end of the activity students will be able to:

- make a type of polymer called nylon
- create a thermoplastic resin synthesized through step polymerization (condensation).

Materials

- 1,6 hexanediamine. Be aware that this chemical can also be found as hexamethyldiamine or 1,6 diaminehexane.
- Hexane or cyclohexane
- Sebacoyl chloride
- Plastic or rubber gloves
- Phenolphthalein or food color (optional)
- Sodium hydroxide

Equipment

- Beaker, 250 mL
- Graduated cylinder, 100 mL
- Stirring rods
- Graduated cylinder (2), 10 mL
- Balance
- Forceps or tweezers
- Safety glasses/chemical goggles

Procedure

Safety Precautions: Use a well-ventilated room or an exhaust hood or canopy for the experiment. Wear plastic or rubber gloves and chemical goggles. The instructor needs to inform you of all hazards associated with this experiment before you begin.

1. Use a balance to weigh (mass) 3.0 gm of 1,6 hexanediamine plus 1.0 gm sodium hydroxide (NaOH).
2. Dissolve these chemicals in 50 mL of distilled water in a 250-mL beaker. This is solution "A."

3. Use a 10-mL graduate cylinder to measure 2.0 mL of sebacoyl chloride. Add this to 48 mL of hexane, which has been measured with the 100-mL graduate cylinder. This is solution "B."
4. Phenolphthalein or food coloring may be added to solution "A."
5. Slowly pour solution B down the inside of the beaker containing solution A in such a way that two distinct layers are formed.
6. With forceps or tweezers grasp the polymer film that forms at the interface of the two solutions, and pull it carefully from the center of the beaker (see Figure 7.3).
7. Wind the polymer thread (nylon) onto a stirring rod.
8. Wash the polymer thoroughly with water before handling.

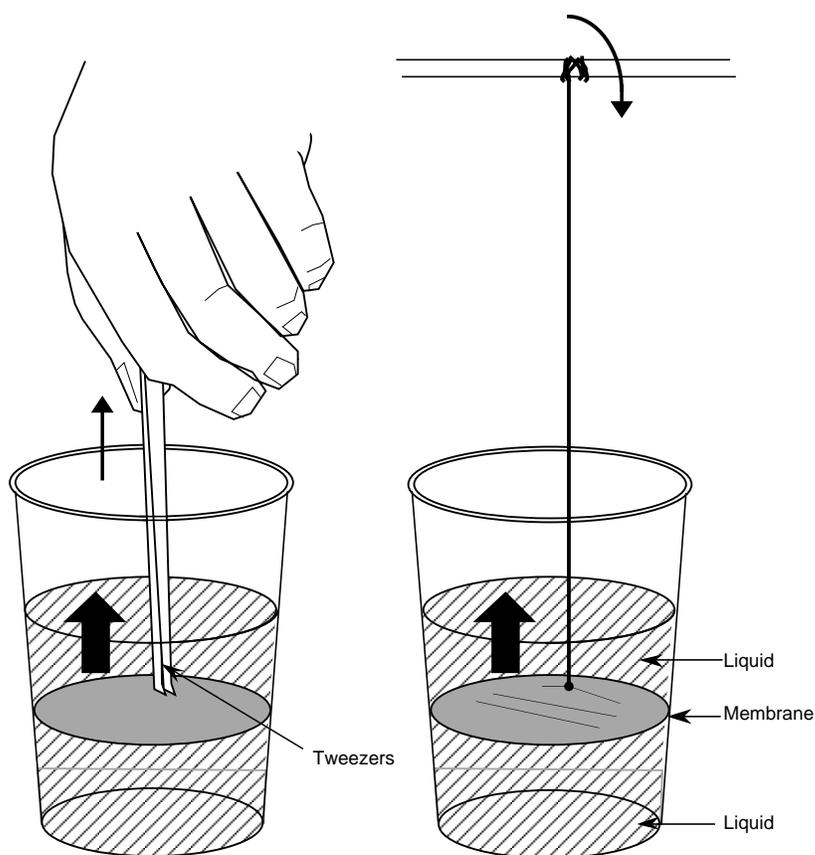


Figure 7.3. Nylon 6-10

Casting a Rubber Mold from RTV

Instructor Notes

Reliability

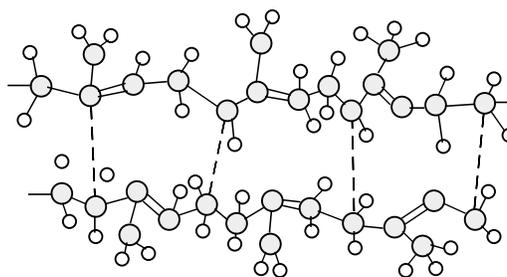
This experiment works very well. Make sure the surfaces that will be contacted by the rubber are *clean*. Curing of silicone rubber is inhibited by oil, pressure sensitive tape adhesive, and many other things.

Estimated Time for Activity

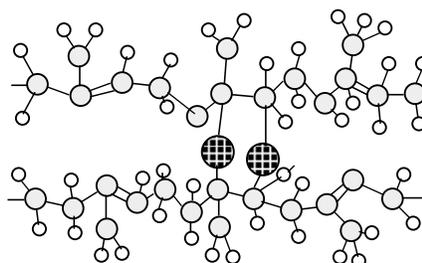
Two class periods.

Teacher Tips

1. Room temperature vulcanization (RTV) silicone rubber is a versatile molding material. It is a white pourable liquid that cures at room temperature without exothermic heat. Figure 7.4 shows the chemical process that occurs when rubber vulcanizes.



(a) Natural rubber - thermoplastic



(b) Vulcanized (cross-linked) rubber - thermoset

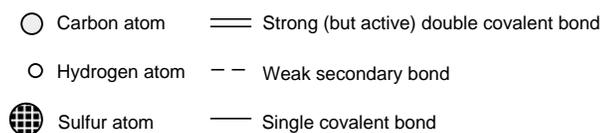


Figure 7.4. Vulcanized Rubber

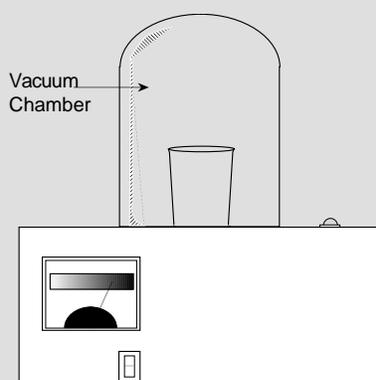


Figure 7.5. Vacuum Chamber for De-Airing RTV

2. Patterns from which a mold will be made can be of stone, glass, wood, plastic, ceramic, wax, even soap. **Note:** If the part to be molded is glass or has a glazed surface, a mold release must be used to keep the silicone rubber from adhering to the part. Silicone rubber bonds tightly to some glassy materials. All other materials, such as paint, plastic, metal, and wood, easily separate from silicone rubber.
3. Castings can be made of urethane resins, polyester, plaster, wax, low-melt metals, epoxies or other silicones.
4. It is important to use the correct RTV for the casting material you are using.
5. The IASCO catalog lists six different RTVs according to casting materials used. They include the mold-making material Silastic “E” RTV by Dow Corning. This is an excellent mold material. Silastic “E” can be used for polyurethane and polyester castings. It is not recommended for vinyls. Other resins, and low-melt metals, can be used in different types of RTV. The IASCO catalog has a good description of these RTVs.
6. The vacuum chamber (see Figure 7.5) can be as simple as a vacuum pump and a bell jar. If a vacuum is not available for outgassing, most of the bubbles will rise to the surface in about 10 min and can be popped by gently blowing on them. Jarring the table or bench with the repeated hammering of your fist helps the bubbles rise.
7. In step 7 a 3-in. or 4-in.-diameter PVC pipe about 3-in. high works well for a dam to pour RTV into rather than a paper cup.
8. In the next activity, Epoxy Resin Casting, the molds will be used to mass produce objects.
9. Remind your students that:
 - If they spill the RTV while performing the lab, allow the spills to cure and they will easily peel from the contact surface. Trying to clean up wet silicone is very messy; it smears.
 - They shouldn't mix more than 1/4 the volume of the cup because overflow may occur at the time the vacuum is applied. The silicone tends to expand rapidly as it releases bubbles.
 - The part they are reproducing should have a flat surface that can be put flat against the bottom of the paper cup used in step 7.

Safety

1. Materials used in this experiment can irritate the eyes. Use ventilation.

Activity: Casting a Rubber Mold from RTV

Student Learning Objectives

At the end of the activity students will be able to:

- follow the instruction to make a silicone rubber mold for casting a polymeric part
- explain and complete the necessary steps needed to make a rubber mold using RTV (room temperature vulcanizing).

Materials

- Silastic "E" RTV silicone rubber, 15 g
- Silastic "E" curing agent, 1.5 g
- Paper cups (3), 6 oz
- Stir stick
- Mold release

Equipment

- Balance/scale
- Part (object to be reproduced in mold)
- Vacuum chamber

Notes

1. If you spill while conducting this lab, just allow the spills to cure, then they will easily peel off. Trying to clean up wet silicone is very messy; it smears.
2. Do not mix more than one-fourth of the volume of the cup because overflow may occur at the time the vacuum is applied. The silicone tends to expand rapidly as it releases bubbles.
3. The part you reproduce should have a surface that can be put flat against the bottom of the paper cup (or dam) used in step 7.

Procedure

1. Measure out 15 g of silicone rubber into a 6-oz paper cup.
2. Measure out 1.5 g of curing agent into a 6-oz paper cup.
3. Pour the 1.5 g of curing agent into the 15 g of silicone rubber. Scrape the curing agent container clean with the stir stick.

4. Thoroughly stir the silicone mixture a minimum of 5 min. Be sure to scrape the sides and bottom of the cup with the stirring stick to ensure the curing agent has been stirred thoroughly into the silicone rubber.
5. Place cup into vacuum chamber.
6. Apply vacuum. As silicone releases its bubbles it expands. It will reach a maximum height and then rapidly subside. Continue to hold the vacuum until all bubbles have burst, then release the vacuum and remove cup from vacuum chamber.
7. Carefully place part to be molded on the bottom in the center of a clean 6-oz paper cup (or other prepared dam).
8. Carefully pour mixture into cup on top of part. **Do not move the part!** Do not move liquid stream around mold area, but continue to pour entire batch onto single point where the pour was begun. This will help prevent bubbles from entering into pour.
9. Let cure 24 hours ("E" RTV can be cured in 1 hour at 150°F if desired) or as directions state.
10. Remove RTV mold from container.
11. Remove the part used to shape the mold. Now the mold is ready for casting a part.
12. Record the procedure you used and findings in your journal.

Epoxy Resin Casting

Instructor Notes

Reliability

If resin instructions are followed, no problems occur with this lab. It is very straightforward.

Estimated Time for Activity

One class period.

Teacher Tips

1. This activity can be done after the RTV activity or as a stand-alone activity.
2. The resin dye is not necessary. It is used to add color to the object.
3. The resin will shrink as it cures. It usually adheres to the sides of the mold so that shrinkage is only in one direction, from the top.
4. When debubbling, do not allow the resin to spill over into the vacuum chamber. The cup used for mixing should be about one-third full so when the vacuum is applied, and the bubbling resin rises, it will not overflow. The vacuum should be kept running even after the resin subsides, until all the bubbles have burst or about 5 min has elapsed. It may continue to "boil" or bubble after 5 min, but this is long enough.
5. A safety cup or pan larger than the mixing cup can be used to catch overflow in the vacuum chamber.
6. Have acetone available to clean up spills. It has been found that Fantastic household cleaner does as well as acetone and is much safer.
7. Other resins and low-melt metals can also be used for casting materials *provided* the correct type of RTV is used. The IASCO catalog lists different types of RTV with suggested casting materials.

Safety

1. Wear safety glasses. Plastic gloves can be helpful in keeping the sticky epoxy off the skin.
2. Do not use polyester resin. Its fumes are repulsive and irritating. The catalyst, methyl ethyl ketone peroxide (MEKP), can cause blindness if it comes in contact with the eyes.

Activity: Epoxy Resin Casting

Student Learning Objectives

At the end of the activity students will be able to:

- demonstrate the ability to follow directions to make an epoxy resin casting
- describe the effect of adding a catalyst to initiate a chemical reaction thereby changing the characteristics of the material.

Materials

- Epoxy Resin (Two-part kit)
- Color dye, 4 drops (optional)
- Paper towels, 20 cm x 20 cm (8 in. x 8 in.) and 30 cm x 30 cm (12 in. x 12 in.)

Equipment

- Safety glasses
- Plastic gloves
- Silicone rubber mold
- Paper cup (3), 6 oz.
- Stirring stick
- Vacuum chamber
- Balance/scale

Note: *Wear safety glasses. Plastic gloves can be helpful in keeping the sticky epoxy off the skin.*

Do not allow the resin to spill over into the vacuum chamber. When mixing the resin, only fill the cup 1/3 full so when a vacuum is applied, and the bubbling resin rises, it will not overflow. Keep the vacuum going even after the resin subsides until all bubbles have burst or 5 min has passed.

Procedure

1. Place silicone rubber mold on a piece of folded paper towel. (Be sure mold is laying flat.)
2. Cut a 20 cm x 20 cm (8 in. x 8 in.) piece of paper towel, and place it on balance to protect it from spills.

3. Measure liquids from the epoxy kit into separate cups, following the directions found on the back of resin containers. Use only the amount needed for your mold. Be careful not to fill each cup more than 1/6 full (see foaming notes in this procedure).
4. Add 1 to 4 drops of resin dye if you desire, your choice of color.
5. Pour one cup into the other, scraping as much of the liquid out with the stirring stick as the cup is draining. The liquids will not degrade or react when kept in separate cups, but once they are combined, they need to be stirred vigorously to mix the liquids as thoroughly as possible. Be sure to stir the contents at the walls and bottom of the cup too.
6. Mix the resin for a minimum of 3 min.
7. Place blended resin into the vacuum chamber to remove bubbles.

Caution: Do not let resin foam over the top of the cup; it can damage the vacuum apparatus.

8. Follow the laboratory procedure for operating vacuum chamber.
9. Pour the outgassed resin carefully into the mold, and avoid trapping air in the resin.
10. Let the resin cure. The cure rate can be accelerated if the resin is heated (50°C is the maximum temperature suggested).

Project: Nightlight

Student Learning Objectives

At the end of the activity students will be able to:

- make a nightlight using epoxy resin.

Estimated Time for Activity

Two class periods.

Materials

- Neon lamps, Radio Shack, Part No. 272-1100B (includes two lamps with resistors per package)
- Copper strip, 16 ga x 1/4 in. x 3 in.
- Plastic cup #6 or paper cup (6 oz)
- Epoxy resin
- Solder
- Flux

Equipment

- Safety glasses
- Drill press
- Drill bit, 1/8 in. diameter
- Welding rod, 1/8 in. x 2 in.
- Tin snips
- Soldering iron

Procedure

1. Using 1/8-in. drill bit, drill a hole 1/4 in. from the end of each copper strip.

Caution: Be sure to secure the copper strips in a vice or with pliers so the copper will not cause injury if it freezes to the drill bit while it is being drilled.

2. Cut copper strip in half using tin snips making two 1-1/2 in. pieces.
3. Poke welding rod horizontally through sides of plastic cup 1 in. above the top of the planned resin pour (see Fig. 7.6).

4. Solder the neon lamp with resistor to the two copper strips.
5. Suspend copper strips, centered 1/2 in. between strips, inside cup on welding rod. Be sure no part touches sides or bottom of cup.
6. Weigh out the necessary amount of resin needed to cover the nightlight as shown in Figure 7.6.
7. Add drops of color as desired to the resin.
8. Add appropriate drops of catalyst to the resin as recommended by manufacturer, and stir for 3 min.
9. Pour resin carefully into the cup. (Do not get any resin on the welding rod).
10. Allow resin to cure for 24 hours. Remove welding rod, then peel cup from resin and you have a nightlight.
11. Clean off any flashing of resin, and plug the light into a wall socket to check that it works correctly.
12. Before plugging in, check for short circuits. (Ask Ed, one of last year's summer institute teachers. His nightlight was very intense, but did not last very long.)

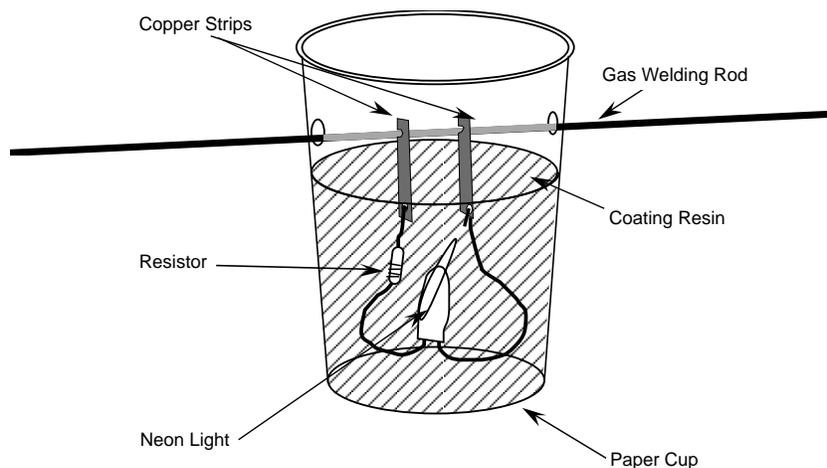


Figure 7.6. Night Light

Polymer ID

Instructor Notes

Reliability

Students will get results with common plastics.

Estimated Time for Activity

One class period.

Teacher Tips

1. The term plastics is used to describe a variety of substances that, although may feel and look different, all share the fundamental characteristic of moldability. Some plastics are molded by the action of heat and/or force while other plastics are fluid enough to flow into a desired shape. Substances shaped by heat and/or force behave partly as solids, flowing and changing shape like a liquid under the action of the molding force, but having enough rigidity of a solid to remain in the new form once the force and heat are removed. Other plastics are much more fluid and require time for the action of cross-linking between molecules to hold the plastic in the desired shape as a solid.
2. Plastics come from materials that are found in nature—petroleum, natural gas, coal, resins, air, and salt—but require less energy to manufacture than equivalent products made from alternative materials (currently, the manufacturer of plastic resins uses less than 5% of U.S. petrochemicals). To make plastic, compounds containing basic elements such as carbon, hydrogen, oxygen, chlorine, and nitrogen are first extracted from the natural source material in a refining process. The compounds (called feedstock) are then converted into small molecules called monomers. The monomers are then linked together using heat, pressure, and the addition of various chemicals to form longer, larger molecules called polymers. Polymers have the property of moldability; they are plastic in its most basic form.
3. Polymers (plastic materials) are sold to manufacturers in the form of granules, powder, pellets, flakes, or liquids for eventual processing/manufacturing. Approximately 45 different “families” of plastics exist, and some 30 different techniques are used to manufacture plastic objects. Some of the most widely used production techniques include blow molding (used for solid objects such as toys, cd's, and appliances) and casting (used for objects made from liquid resins, such as jewelry and sink bowls).

4. Plastics can undergo the setting or hardening process in two different ways. On this basis they are classified into two groups: thermoplastic plastics and thermosetting plastics. Thermoplastic materials are those that are hard and rigid at normal temperatures, but become soft and pliable when heated. A thermoplastic, such as high-density polyethylene, polystyrene, or nylon, can be softened and hardened repeatedly simply by heating and cooling. Thermosetting plastics, such as epoxy, polyurethane foam, and unsaturated polyester, however, are "set" irrevocably in their final shape by either heat, catalysts, or other chemical means. During molding, a chemical change occurs in this type of plastic that essentially eliminates the property of moldability. The material becomes rigid and will not again have flexibility.
5. With so many different plastics you might think it would be difficult—if not impossible—to tell one type of plastic from another. But, by applying simple principles, it can be done. The plastics industry has devised an experiment to determine the type of plastic used in numerous plastic products. Recyclers apply the principles of some of these tests to separate types of plastics so they may be used again (recycling).
6. Five broad identification methods exist for plastics:
 1. trade name
 2. appearance
 3. effects of heat
 4. effects of solvents
 5. relative density.

A good reference is Richardson, Terry. 1983. *Industrial Plastics: Theory and Applications*. South Western Publishing Company, 1983, Second Edition, Delmar Publishers, 1989, pp. 60-65.

7. Recycling plastics has made polymer identification much easier because many plastic container companies now code the plastic with a number that can be referenced (see list below).
 - 1 = PETE (polyethylene terephthalate, or PET)
 - 2 = HDPE (high density polyethylene)
 - 3 = V (vinyl/polyvinyl chloride, or PVC)
 - 4 = LDPE = (low density polyethylene)
 - 5 = PP (polypropylene)
 - 6 = PS (polystyrene)
 - 7 = Other (all other resin types)

Activity: Polymer ID

Student Learning Objectives

At the end of the activity students will be able to:

- tentatively identify a plastic using simple test procedures of odor and flammability
- place selected plastics into their appropriate group using suitable techniques.

Materials

- Samples of plastic from home, work, or environment
- Aluminum foil

Equipment

- Bunsen burner
- Safety glasses

Procedure

1. Select as many samples of plastics as you can find.
2. Observe and record in your journal their color, feel, flexibility, and odor, if any.
3. Identify the materials as thermosetting or thermoplastic by heating a stirring rod in a Bunsen burner flame for 3-5 sec. Do not get the stirring rod red hot! Press it against the plastic sample being tested. If it softens, it is a thermoplastic. If not, it is probably a thermosetting plastic.
4. Perform flame test using identification chart in Table 7.2. Record results.

Table 7.2. How to Identify Plastics

Here is a preliminary guide that will help you to identify many of the basic types of plastics using simple techniques and readily available tools. Naturally, these tests should be used only for tentative identification because some complex plastic compounds require a rigorous analysis for identification.

To initially determine whether a material is thermoset or thermoplastic, heat a stirring rod (to about 500°F) and press it against the sample. If the sample softens, the material is thermoplastic; if not, it is probably thermosetting.

Next, hold the sample to the edge of a flame until it ignites. (Hold in the flame for about 10 sec if no flame is produced immediately.) If the material burns, note the color of the flame, the nature of the smoke, the presence of soot in the air and if in burning the sample drips. Next, extinguish the flame and cautiously smell the fumes. (In identifying odor, a known sample is most helpful for comparison.) Finally, check your observations against the known characteristics of each plastic given below. Once you have made a tentative identification it usually is desirable to make one additional test to confirm the results of the original identification.

Materials	No Flame	Burns, But Extinguishes on Removal of Flame Source			Continues to Burn After Removal of Flame Source				Remarks
	Odor	Odor	Color of Flame	Drips	Odor	Color of Flame	Drips	Speed of Burning	
THERMOPLASTICS									
ABS	—	Acrid ^a	Yellow, blue edges ^a ,	No ^a	Acrid	Yellow, blue edges	Yes	Slow	Black smoke with soot in air
Acetals	—	—	—	—	Formaldehyde	Blue, no smoke	Yes	Slow	—
Acrylics	—	—	—	—	Fruity	Blue, yellow tip	No (cast) Yes (molded)	Slow	Flame, may spurt if rubber modified
Cellulosics									
Acetate	—	Vinegar ^c	Yellow with sparks ^a	No ^a	Vinegar	Yellow	Yes	Slow	Flame may spark
Acetate Butyrate	—	—	—	—	Rancid butter	Blue, yellow tip	Yes	Slow	Flame may spark
Ethyl Cellulose	—	—	—	—	Burnt sugar	Yellow, blue edges	Yes	Rapid	—
Nitrate	—	—	—	—	Camphor	White	No	Rapid	—
Propionate	—	—	—	—	Burnt sugar	Blue, yellow tip	Yes	Rapid	—
Chlorinated Polyether	—	^b	Green, yellow tip	No	—	—	—	—	Black smoke with soot in air
Fluorocarbons									
FEP	Faint odor of burnt hair	—	—	—	—	—	—	—	Deforms; no combustion, but drips
PTFE	Faint odor of burnt hair	—	—	—	—	—	—	—	Deforms; does not drip
CTFE	Faint odor of acetic acid	—	—	—	—	—	—	—	Deforms; no combustion, but drips
PVF, Nylons	Acidic	—	—	—	—	—	—	—	Deforms
Type 6	—	Burnt wool	Blue, yellow	Yes tip	—	—	—	—	—
Type 6/6	—	Burnt wool or hair	Blue, yellow tip	Yes	—	—	—	—	More rigid than type 6 nylon
Phenoxies	—	Acrid ^c	Yellow ^c	No ^c	Acrid ^d	Yellow ^d	Yes ^d	Slow ^d	Black smoke with soot in air

Table 7.2. How to Identify Plastics (contd.)

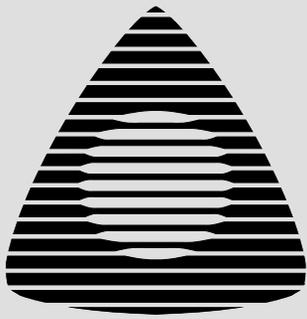
Materials	No Flame	Burns, But Extinguishes on Removal of Flame Source			Continues to Burn After Removal of Flame Source				Remarks
	Odor	Odor	Color of Flame	Drips	Odor	Color of Flame	Drips	Speed of Burning	
THERMOPLASTICS									
Polycarbonates	—	Faint, sweet aromatic ester	Orange	Yes	—	—	—	—	Black smoke with soot in air
Polyethylenes	—	—	—	—	Paraffin	Blue, yellow	Yes	Slow	Floats in water
Polyphenylene Oxides (PPO)	—	Phenol	Yellow-orange	No	—	—	—	—	Flame spurts; very difficult to ignite
Modified Grade	—	Phenol	Yellow-orange	No	—	—	—	—	Flame spurts; difficult to ignite; soot in air
Polyimides	^b	—	—	—	—	—	—	—	Chars; mat'i very rigid
Polypropylenes	—	Acrid ^a	Yellow ^a	No ^a	Sweet	Blue, yellow tip	Yes	Slow	Floats in water; more difficult to scratch than polyethylene
Polystyrenes	—	—	—	—	Illuminating gas	Yellow	Yes	Rapid	Dense black smoke with soot in air
Polysulfones	—	^b	Orange	Yes	—	—	—	—	Black smoke
Polyurethanes	—	—	—	—	^b	Yellow	No	Slow	Black smoke
Vinyls									
Flexible	—	Hydrochloric acid	Yellow with green spurts	No	—	—	—	—	Chars, melts
Rigid	—	Hydrochloric acid	Yellow with green spurts	No	—	—	—	—	Chars, melts
Polyblends									
ABS/Polycarbonate	—	—	—	—	^b	Yellow, blue edges	No	—	Black smoke with soot in air
ABS/PVC	—	Acrid	Yellow, blue edges	No	—	—	—	—	Black smoke with soot in air
PVC/Acrylic	—	Fruity	Blue, yellow tip	No	—	—	—	—	—
THERMOSETS									
Alkyds	—	—	—	—	—	—	—	—	—
Diallyl Phthalates	—	—	—	—	Phenolic	Yellow	No	Slow	Black smoke, cracks
Diglycol Carbonate	—	—	—	—	Acrid	Yellow	No	Slow	Black smoke with soot
Epoxies	—	—	—	—	Phenol	Black smoke	No	Slow	Black smoke with soot in air
Melamines	Formaldehyde and fish	—	—	—	—	—	—	—	—
Phenolics	Formaldehyde and phenol ^c	Phenol and wood or paper ^d	Yellow ^d	No	—	—	—	—	May crack
Polyesters	—	Hydrochloric acid ^a	Yellow ^a	No ^a	^b	Yellow, blue edges	No	Slow	Cracks and breaks
Silicones	^b	—	—	—	—	—	—	—	Deforms
Ureas	Formaldehyde	—	—	—	—	—	—	—	—

^a Flame retardant grade. ^b Nondescript. ^c Inorganic filler. ^d Organic filler.

Vocabulary—Polymers*

Amorphism
Blowing agent
Cellular foam plastic
Cross linking
Crystallinity
Elastomer
Elastomers
Exothermic
Inorganic polymer
Natural polymer
Organic polymer
Plasticity
Polyamide (nylon)
Polychloroethene
Polyester resin
Polyethylene
Polymer
Polymerization
Polyphenylethene
Silicone rubber
Thermoplastic
Thermosets
Vulcanization

*Instructor may vary vocabulary to suit particular content presented.



Experiments/ Demonstrations Composites

Composites

Introduction

A composite material is a combination of two or more separate materials that has characteristics not shown by either of the materials separately. An automobile tire, for instance—an example of a composite material—is made of rubber reinforced by one or more types of fibers, such as nylon, rayon, steel, glass, or Kevlar. The rubber does a fine job of keeping the pressurized air inside, but would not survive the stresses imposed on it by the car as it is driven. The fibers are strong and tough, but it would be impossible for a structure made only from the fibers to hold air. Together, the materials form a composite structure that both holds air and resists stresses.

Looking more closely at the composition and structure of the tire tread, we can see that it too is a composite. The rubber provides a high friction force, very handy to have in the case of a car. A pure rubber tire wouldn't last very long, because the material is not very strong and becomes gummy when heated. Tiny balls of carbon known as carbon black reinforce the rubber and give it resistance to wear. Tire rubber compounds represent a trade-off between friction and durability, these factors being adjusted by the relative amounts of rubber and carbon black.

Composite materials have been around for a long time. Wood, a natural composite, is composed of cells made from cellulose fibers and bound together with a natural glue called lignin. If dried wood is examined under a microscope, the cellular arrangement becomes obvious. Although wood can be split parallel to these long cells, it is strong with the grain. The air spaces provided inside the cells of dried wood make it light in weight. This arrangement contributes to high strength at low weight and to toughness.

In the thirteenth century, the Mongols made composite bows from combinations of wood, animal tendons, silk, and adhesives. Even before that time, the Hebrew people added straw to their clay bricks to increase their durability.

Concrete is another example of a composite, and it has been made since Roman times. The rocks and sand are the reinforcement part of this composite, and the cement provides the cohesion that binds the structure/material together.

In addition to these "old" composites, the drive for stronger, stiffer, and lighter materials has produced many more modern composites of even higher performance such as tennis racquets, fishing poles, aircraft, space and automobile parts, and hulls of boats.

At the heart of any composite, a strong fibrous material bears the load. The fiber is constrained by the second material in the composite (the matrix) such that it takes the desired shape. Modern fishing rods are almost universally made from composites, whether the reinforcing fibers are glass, graphite, boron, or a mixture of these materials. The fibers, although strong, are not very stiff because they are very small in diameter, less than one-thousandth of an inch. By adding a matrix material, which is usually some type of epoxy in the case of the fishing rod, the fibers are tied together so that stress can be transferred from one fiber to another and so the fibers share the load. To further lighten the rod, it is made with a hollow core and is tapered so that the handle is thicker than the tip.

Most composites are used to make “things” that require high values of mechanical properties such as strength (resistance to breakage) or stiffness (resistance to bending) at a minimum weight. In these roles, composites can be made superior to structures made from any single material.

Modern composites use started with fiberglass in 1930, which is made from fine glass fibers bonded in most cases by polyester resin. The glass fibers are very strong in tension, and the resin helps to define the shape, bonds well to the fibers, and prevents the fibers from damaging each other by rubbing against their neighbors. Currently, many different types of fibers are available; the fibers are often quite expensive but are worth the price when the alternatives are considered. As more and more composite materials are used, the price will drop or become more compatible. Example: Some racquets, when they first came out, were \$280 and now sell for \$35.

A few years ago, composites were used only in parts of airplanes where their complete failure would have caused no serious problems. As confidence and reliability continues to increase, composites are being used in increasingly critical applications. Currently, several critical parts of passenger airliners are made from composites; some military airplanes are made largely from composites. Building the Voyager, the airplane that flew around the world without refueling in 1986, would have been impossible without modern composite materials.

Making Concrete

Instructor Notes

Reliability

This lab is designed to be experimental with lots of room for making mistakes and changes and testing the effects these cause. The success rate is determined by the care used in measuring and mixing ingredients.

Teacher Tips

1. Concrete is a composite material made from sand, rocks (aggregate), and cement. Students are familiar with this material but many have never made concrete and may not know how it cements itself together. Thousands of different kinds of concrete are used for many different applications. It would take much study to understand the many different compositions, reactions, and applications of this material.
2. Portland cement forms hydration bonds as it is setting in the concrete matrix. This means that the water added to the cement takes part in a reaction with the cement particles. The water forms a strong bond with the cement, and the cement particles are locked together in an intertwining matrix. Cement does not dry, it cures. Another way to put it is that the water does not evaporate, it becomes part of the concrete composite. Once concrete is formed it is very difficult to break and impossible to reverse the process back to the original materials. Hydration in concrete forms very strong bonds.
3. This lab is divided into two parts: First, have all students make cement so they become familiar with the material. Second, allow students to vary compositions to determine how these changes affect the concrete. Students can begin by making a common concrete from Portland cement. The composition of concrete made from Portland cement can vary also, so first try a common composition of 40/60 weight percent sand to rock ratio and a 45/55 weight percent water to cement ratio.
4. Once students have learned how to work with concrete, they can do some scientific exploration. By altering the composition of concrete, the properties of the material will also be altered. Testing and evaluating these changes is part of the work of a scientist. Encouraging students to follow the scientific process will help them learn, explore, evaluate, and be creative as they work with materials.

5. Test the samples following a test procedure, such as the one described on the following page (see Testing Materials) and record both the procedure used and the test results.

Suggested Questions

6. What strengthens this material?
7. Are there other materials which could be added to concrete to strengthen it? Try your theory by making and testing it.
8. Is there a better way to test concrete?
9. What is the best use for concrete materials?

Activity: Making Concrete

Student Learning Objectives

At the end of the activity students will be able to:

- describe a composite material
- explain why a composite might be chosen to replace more conventional materials
- participate in making concrete materials
- describe the process used in the experiment
- identify several composite materials used commonly in our lives.

Materials

- Portland cement
- Water
- Sand
- Gravel or small rock

Equipment

- 1- to 2-gallon plastic container
- Mold or dam (see #1 of procedure in Making Concrete or #1 under Testing Materials)
- Scale
- Stirring stick (strong wooden dowel would work)
- Clamp for securing concrete for testing
- Weights for testing strength of concrete

Procedure

1. Make a mold or dam into which the concrete can be poured. A dam could be as simple as placing 2- x 4-in. pieces of wood together to create a 4- x 4-in. square. A rectangle of larger dimensions also could be made. An appropriate mold could be a plastic glove or a silicone mold for shaping a part.
2. In a 1- to 2-gallon plastic container, thoroughly mix 258 g of sand, 404 g of rock, 93 g of water, and 118 g Portland cement.
3. Pour the mixture into the mold or dam.
4. Let the concrete cure over night before handling it.

Project: Varying Concrete Components and Testing New Materials

In this project you get to experiment with different compositions of materials to make concrete and then test the concrete samples you create.

Procedure

Other concrete components—like sand or cement—can be varied, tested and the results compared. More sophisticated tests can be made by adding two component variables such as water and sand to the matrix.

1. Using the composition from step 2 in Making Concrete, change a single component in the composition, and test and evaluate how this variable will affect the material. An example would be to add 5% more water to a concrete batch. Try another sample with an additional 5% water, and analyze the material. A suggested test for your samples is found below (see Testing Materials).
2. Now reverse the process, and see how less water (5% and 10% less) affects the concrete. Test and record these results in your journal. Can the strength of these materials be evaluated from the results of these tests?
3. Another variation to the composition would be to replace rock with other materials, and investigate the results. Our garbage landfills are rapidly filling up. Are there some materials that could take the place of rock? Try ground-up milk jug parts or pieces of metal or ground automobile tires, and test the results of these concretes.

Testing Materials

1. To establish consistency in the data, you must establish a standard method to test each concrete sample. An example would be to make a standard size mold (i.e., a wood mold 1 x 1 x 10 in.). Each concrete sample could then be poured into the mold and cured for the same length of time (i.e., 3 days or maybe 7 days—just be consistent). A simple procedure for testing the strength of concrete could be applied as follows. The set up is shown in Figure 8.1.
2. Secure each sample with a “C” clamp 2 in. in from the edge of a table. On the end of the sample suspended over the edge of the table, add a device (basket or hanger) from which weights can be added.
3. Obtain weights of approximately the same mass. Weights could be small blocks of concrete you can make and weigh or blocks of metal weighing approximately the same.

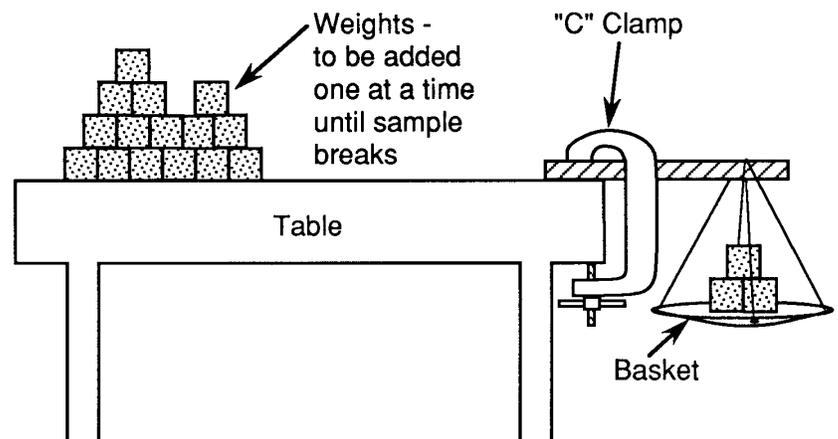


Figure 8.1. Testing Materials

4. Add weights one at a time to the basket until the sample breaks.
5. In your journal, record the weight necessary for failure to occur.

Composite Experiments

Instructor Notes

Reliability

All these experiments work well. Some experiments may require several trials if they have never been tried before.

Teacher Tips

1. These experiments help familiarize students with the processes and materials used to make common composites.
2. The experiments demonstrate the relationship among materials, weight, design of structure, and cost by taking students through building and testing different materials, doing a simple and crude strength-to-weight comparison, or a cost analysis of material types.
3. The experiments can also be highly detailed exercises in building and testing several identically sized test samples exposed to identical test conditions (See Young's Modulus Testing of Beams). Students can observe vastly differing results because of different material characteristics, even though objects are built to the same design. To accurately test materials this way, it is important that dimensions of each sample be identical.
4. Good examples exist of cross-linkage, types of fiber orientation, matrix formation, and stress/strain matrix curves in the Jacobs' textbook.
5. Epoxy curing time can be decreased by heating the epoxy in a furnace. Do not overheat the epoxy; it will burn. A suggested temperature of 50°C will dramatically decrease the curing time.
6. Fantastic household cleaner is an excellent substitute for cleaning sticky epoxy messes. We recommend this product (over acetone) because acetone has some health hazards associated with it.
7. Honeycomb is a difficult product to obtain. Boeing Surplus in Seattle, Washington, has been the main supply source. Contact a mentor teacher or PNL staff if additional material is needed.
8. Kevlar is made from fibers that are strong and thin. Special ceramic scissors from Jensen Tools, Inc. (See Vendor List in Appendix) are needed to effectively cut the fabric. These scissors are quite spendy. Use only as directed by manufacturer.
9. Tacky tape (zinc chromate) for the honeycomb composite project (#4) is supplied by Schnee-Morehead, Inc. (See Vendor List in Appendix). Some teachers have used molding clay with success.

Suggestions for Conducting Introduction to Composite Experiments: Projects 1-4

The following four experiments are identical except that a material or process has been changed in each project.

As a manageable means to conduct the experiments and allow the students maximum exposure to a variety of composite materials without doing all the experiments, small work groups with separate composite activities may work best. A suggested way would be to divide the class into four groups. One group could hand laminate the epoxy resin items while another group works with the epoxy resin items on the hydraulic press (see Table 8.1 for sample group assignments).

When the groups complete the activity, each group reports their observations, which have been written in their journals, to the entire class. Strength tests can then be conducted on the materials to further study properties of these composites.

Table 8.1. Sample Groupings for Composite Experiments

Group A		
1a	Fiberglass cloth with epoxy resin	hand laminated
1b	Fiberglass mat with epoxy resin	hand laminated
1c	Fiberglass cloth with epoxy resin	vacuum bagged
1d	Fiberglass mat with epoxy resin	vacuum bagged
1e	Fiberglass cloth with epoxy resin	hydraulic press
1f	Fiberglass mat with epoxy resin	hydraulic press
Group B		
2b	Kevlar with epoxy resin	hand laminated
2b	Kevlar with epoxy resin	vacuum bagged
2c	Kevlar with epoxy resin	hydraulic press
Group C		
3a	Honeycombed composite with glass cloth	hand laminated
3b	Honeycombed composite with glass cloth	vacuum bagged
3c	Honeycombed composite with glass cloth	hydraulic press
Group D		
4a	Honeycombed composite with Kevlar cloth	hand laminated
4b	Honeycombed composite with Kevlar cloth	vacuum bagged
4c	Honeycombed composite with Kevlar cloth	hydraulic press

Project 1: Fiberglass Hand Laminating Process

Student Learning Objectives

At the end of the activity students will be able to:

- make a composite to apply and test the concept of combining two or more different materials to obtain a new material. The new material will exhibit new and improved properties than the original materials.

Materials

- Fiberglass
- Epoxy resin (two-part kit)
- Paper measuring cup, 4-6 oz
- Brush (1 in.)
- Polyethylene, 8 x 36 in. (clear plastic bags)
- Acetone or Fantastic
- Tongue depressor or disposable stirring sticks
- Eye dropper
- Plastic gloves
- Wax paper or plastic for table cover

Procedure

1. Cut five to six 3- to 4-cm x 30- to 40-cm fiberglass strips (mats) with scissors. Weigh the batch of strips to be used in the composite.
2. Approximately 2 oz of epoxy resin is needed for this experiment. Follow the directions on the back of the resin can, measuring the ingredients into a paper cup. Thoroughly mix contents with tongue depressor for 3-5 min.
3. Place polyethylene sheet on table top to protect the table.
4. Pour a small amount of resin onto the polyethylene surface.
Note: resin does not stick to polyethylene. Spread to 4- x 40-cm area with brush.
5. Place one fiberglass 3 to 4-cm x 30 to 40-cm mat onto the resin.

6. Dip brush into resin. Paint the resin into the fiberglass mat by gently stroking the brush over the fiberglass. Begin brushing in the middle, and stroke toward the outer edges. The fiberglass will absorb the previously poured resin. Apply only enough resin with the brush to saturate the fiberglass.
7. Place second fiberglass mat (dull side up) onto the first layer. Apply resin with brush, working from the center out to prevent air bubbles. Add only enough resin with the brush to wet or saturate the fiberglass.
8. Repeat process with each additional fiberglass laminate.
9. Upon completion, place brush into empty cup.
10. Cover the fiberglass laminate with a polyethylene sheet. Apply a flat weight (i.e., books, wood, or metal slab).
11. Observe the contents of the cup and brush to verify that the resin is curing. The cup will feel warm from an exothermic reaction that is taking place. An odor will be increasingly noticeable as a chemical reaction occurs.
12. Clean the brush with acetone or Fantastic. Discard the cup and clean the table top if necessary.
13. Let the composite cure until rigid.
14. Take a final weight of the composite.

Extension Activities

1. Test the sample by breaking it. Determine the force necessary for the composite to break.
2. Make additional samples of this same composite using more epoxy. Be sure to weigh the fiberglass before and after making the sample. Test the sample as in 1 above. Record observations and test results in your journal. Also be sure to record any differences in processing the materials (i.e., change in size of fiberglass mats, seepage of epoxy from mat, etc.). Does additional epoxy strengthen the composite?

Project 2: Kevlar Hand Laminating Process

Materials

- Kevlar
- Epoxy resin (two-part kit)
- Paper measuring cup, 4-6 oz
- Brush, 1 in.
- Ceramic blade scissors
- Polyethylene 8 x 36 in. (clear plastic bags)
- Acetone or Fantastic
- Tongue depressor or disposable stirring stick
- Eye dropper
- Plastic gloves
- Wax paper or plastic for table top cover

Procedure

1. Follow the same procedure used in Project 1, but use Kevlar instead of fiberglass.
2. Kevlar is very difficult to cut with conventional scissors. Ask your teacher for ceramic scissors to cut the Kevlar fabric.

Project 3: Press Laminating Process Using Fiberglass

Materials

- Fiberglass
- Epoxy resin (two-part kit)
- Hydraulic press with a minimum 3-in. x 12-in. pressure loading surface area
- Paper measuring cup, 4-6 oz
- Brush, 1 in.
- Polyethylene, 8 x 36 in. (clear plastic bags)
- Acetone or Fantastic
- Tongue depressor or disposable stir stick
- Eye dropper
- Plastic gloves
- Wax paper or plastic for table cover

Procedure

1. Prepare mats as in Project 1, using fiberglass and epoxy resin. Be sure to weigh the batch of mats before applying the epoxy.
2. Cover the laminate (your composite matrix) with a polyethylene sheet. Place the laminate on a 3-in. x 12-in. metal plate and cover with a matching metal plate.
3. Place the plates in the hydraulic press and apply enough pressure to force the excess resin from the composite. It would be wise to have a catch basin of aluminum foil or plastic to catch any resin that might run over the edge of the pressure plates as the resin is extruded by the pressure.
4. Let the composite cure.
5. Clean the brush with acetone or Fantastic. Discard the cup and clean the table top if necessary.
6. Trim excess resin from the edges of the composite.
7. Weigh the composite after it has been peeled from the polyethylene cover.
8. A comparison can be made at this point of the amount of resin it takes to make a hand-laminated composite versus a pressure-compressed composite.

Project 4: Honeycomb Composite Using Vacuum Bag Process

Student Learning Objectives

At the end of the activity students will be able to:

- construct, apply a vacuum, and observe curing a hand lay-up honeycomb core composite.

Materials

- 3-5 mil polyethylene sheet (20 x 20 in.)
- Zinc chromate tape (tacky tape) or clay
- Honeycomb
- Fiberglass cloth
- Epoxy resin (two-part kit)
- Osnamburg-bleeder cloth (throw-away fabric to absorb excess resin)
- Paper cup
- Stir stick
- Paint brush, 1 in. wide
- Perforated Teflon or perforated polyethylene
- Silicone mold release

Equipment

- Aluminum vacuum plate
- Vacuum pump

Note

1. Use a minimum of the epoxy resin on the fiberglass as the resin will bleed out as a vacuum is applied.
2. Cover vacuum hole in aluminum plate with a gauze pad or folded bleeder cloth to prevent resin from plugging vacuum pump/line.

Procedure

1. Apply silicone mold release to an aluminum plate (see Figure 8.2). Rub or spray on silicone, and gently wipe off excess. Silicone prevents the composite from sticking to the plate.
2. Cut polyethylene sheet at least 2 in. larger than the honeycomb piece to be made or processed.

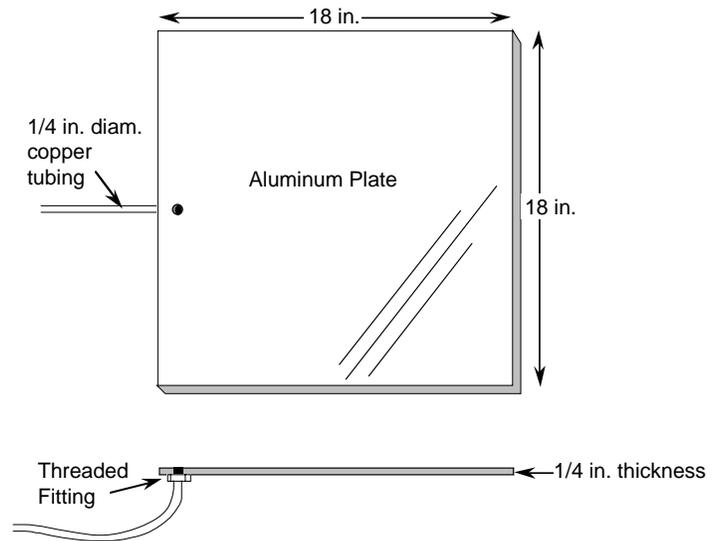


Figure 8.2. Aluminum Vacuum Plate Used in Vacuum Bag Process

3. Cut four pieces of fiberglass 1 in. larger than the honeycomb piece.
4. Mix resin and catalyst at appropriate ratio, as instructions direct.
5. Place fiberglass cloth onto polyethylene sheet, and carefully work resin into cloth with a 1-in. brush, from the center to outer edges.
6. Repeat for second layer of fiberglass, working resin in with brush.
7. Place honeycomb onto fiberglass.
8. Place next layer of fiberglass cloth on top of the honeycomb.
9. Repeat steps 5 and 6, working resin into fiberglass.
10. Lay perforated plastic or Teflon on top of final fiberglass layer.
11. Place bleeder cloth over the composite laminate.
12. Apply zinc chromate tape (tacky tape) around outer edge of aluminum vacuum plate. This creates an air-tight barrier.
13. Cover with polyethylene sheet being careful that a seal is formed as the polyethylene contacts the tacky tape.
14. Pull a vacuum of 20 in. of mercury on the vacuum plate until laminate has cured.
15. Shut off the vacuum, and unwrap composite from vacuum apparatus. You now have a honeycomb composite material.
16. Discard materials that cannot be reused.
17. Check for defects where epoxy did not laminate the honeycomb and fiberglass skin. It may take several tries to obtain a well-laminated composite.

Simple Stressed-Skin Composite

Instructor Notes

Reliability

These demonstrations work well.

Teacher Tips

1. The experiment outlined is designed for minimal expense per concept learned. If students are interested in exploring the capabilities of different reinforcement fibers, such materials as Fiberglass cloth, woven Kevlar, or woven graphite fibers can all be used to make additional beams that can be evaluated by the cantilever beam test (see Young's Modulus Testing of Beams). Additionally, other fabrication techniques such as vacuum bagging may be used to achieve better bonding while using even less epoxy. To save on supplies and time, the instructor may wish to prepare demonstration beams using the more exotic materials rather than having each student make all the beams. These demo beams may then be measured nondestructively for stiffness using the cantilever beam apparatus.

Prerequisite: The student should understand the concept of Young's modulus of elasticity, a measure of a material's stiffness. The *Jacob's* textbook is a reference for this information.

Demonstration

The following two demonstrations are a lead-in to the next activity.

Procedure

Demonstration 1:

1. With a dark ink marker, draw on one face of a foam-rubber beam evenly spaced (i.e., 1 cm) lines (Figure 8.3).
2. Demonstrate by bending the foam rubber beam that the initially parallel lines get farther apart on one side (the tensile side) and closer together on the other side (the compressive side, see Figure 1).
3. Introduce the concept of stressed-skin composites by stating that a strong and stiff material, if attached to these faces, will provide substantial reinforcement to the structure by resisting such tensile or compressive forces.

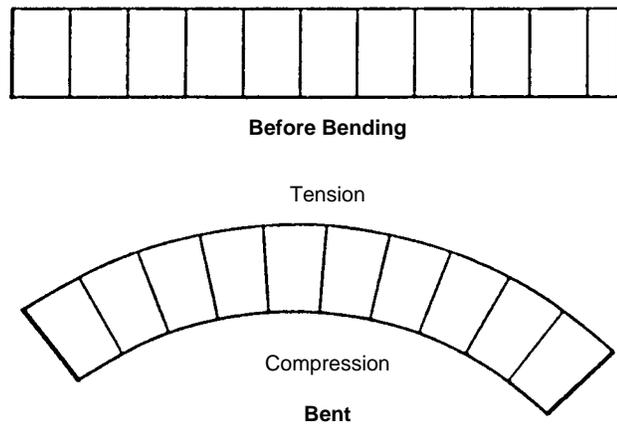


Figure 8.3. Foam-Rubber Beam Used to Illustrate Tensile and Compressive Forces Resulting From Bending

Demonstration 2:

Bend precut pieces of polyurethane foam insulation (8 cm x 8 cm x 30-40 cm) with vertical lines 1-cm apart on all 8-cm faces. Students will soon note that the beam is not very stiff and will not bend very far before breaking.

Activity: Simple Stressed-Skin Composites Using Paper Reinforcement

Student Learning Objectives

At the end of the activity students will be able to:

- demonstrate the composite reinforcement concept using readily available materials
- demonstrate the consequences of certain defects in these structures.
- quantify the gains made by engineered composite construction, using a simple measurement of Young's modulus of elasticity.

Materials

- Foam rubber beam about 8 cm x 8 cm x 30 cm, with vertical lines on all of the 8-cm faces
- Polystyrene or polyurethane insulating foam, cut into 3 x 3 x 18 cm strips
- Heavy paper such as construction paper
- Waxed paper or polyethylene
- Slow-setting (>3 h) non-allergenic epoxy resin, curable at room temperature

Equipment

- Cantilever beam-loading device (See Young's Modulus Testing of Beams in this section)
- Known weights of about 100 g
- Dial-gauge indicator capable of measuring to 0.025 mm (although most will measure in thousandths of an inch)
- Calculator

Procedure

1. Prepare stressed-skin composites as follows: leave one beam as is; bond one 3 x 18 cm face of a second beam with construction paper; bond both 3 x 18 cm faces of a third beam with construction paper; make the fourth beam the same as the third, but make an intentional disbond by placing a piece of waxed paper or polyethylene 3 cm x 6 cm at the midpoint of one of its paper-reinforced faces. To achieve the best possible bond, use minimal epoxy, but be certain of complete coverage. Weight the beams

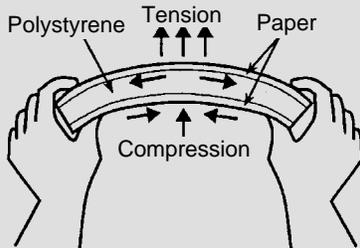


Figure 8.4. Two-Faced Reinforced Beam

with books, wood, or bricks to push materials together or to compress them during the curing process. Use waxed paper or polyethylene to separate the composites from surfaces such as tabletops where bonding is not desired.

- To test the beams, weigh them after any necessary trimming, then record the weight gains (relative to a nonreinforced beam) for reference. Bend the non-reinforced beams again for calibration purposes. Then bend the single-sided beam with the non-reinforced face first on the tensile side; the beam should be bent only slightly, *taking care not to break it*. Note that this one-sided reinforcement does not have much effect on the stiffness. Finally, bend the beam, so that the nonreinforced face is on the compressive side until it breaks. Note that the foam collapses on the compressive side. This is because the reinforcement has made the beam much stronger on the tensile side.
- Now bend the two-faced reinforced beam without the intentional debond; it is noticeably stiffer than either of the two preceding beams (See Figure 8.4). You may want to break some of these beams to observe whether failure occurs on the tensile or compressive face. Next, bend the defected beam, but not to the breaking point, with the defect on the tensile side. Note that the defect has essentially no effect. Finally, bend the defected beam with the defect on the compressive side until it fails. Note that the nonbonded paper pops away from the foam in what is known as buckling. Buckling is a fairly common failure mode for this kind of composite and can be avoided by close attention to complete epoxy coverage as the composite is being constructed.
- See Young's Modulus Testing of Beams activity in this section.
- Follow the same procedure with the one-sided and two-sided reinforced beams. The deflection should be at least 0.25 mm; if not, apply more weight until it is. You will note that the beam reinforced on one side is not much stiffer than the one without reinforcement, just as was learned by hand bending. Similarly, the two-sided reinforcement produces impressive gains in stiffness. Some students may want to relate the stiffness gains to the weight gains involved in the various reinforcements. Although the stiffness of the foam beams has been increased greatly by using only paper reinforcement, the resulting composites are not very stiff when compared with other materials. However, the density of the foam beams is very low compared with other solid materials. The following values of Young's modulus for some common materials may be useful for comparison:

<u>Material</u>	<u>E, GPa</u>
Aluminum	69
Steel	207
Many solid polymers	3
Glass	69

Note: 1 GPa = 10^9 Pa.

Activity: Young's Modulus Testing of Beams

Student Learning Objectives

At the end of the activity students will be able to:

- set up a sample beam of material for testing
- test the sample beam or material
- calculate Young's Modulus.

Materials

- Prepared sample or beam

Equipment

- Apparatus for testing Young's Modulus (Figure 8.5)
- Dial indicator
- Support for dial indicator
- Weights
- Calculator

Procedure

1. Clamp material (test specimen or sample) to be tested to the upright 2 x 4 in. wood beam.
2. Adjust the dial indicator so it just touches the bottom of the specimen or sample.
3. Zero the dial indicator.
4. Place 50-g weight into paper cup placed on top of the specimen (see Figure 8.5).
5. Record deflection of dial indicator.
6. Continue adding weights if desired to get measurable deflection.
7. Calculate Young's Modulus using the following equation:

$$\text{Young's Modulus (in Pascals, Pa)} = 4(98) WL^3/DBH^3$$

where W = weight in g; L = unsupported length of sample in cm; D = deflection of unsupported sample in cm; B = width of sample in cm; H = height of sample in cm; and 98 = conversion factor to change g/cm^2 to Pascals, the international unit for elastic modulus.

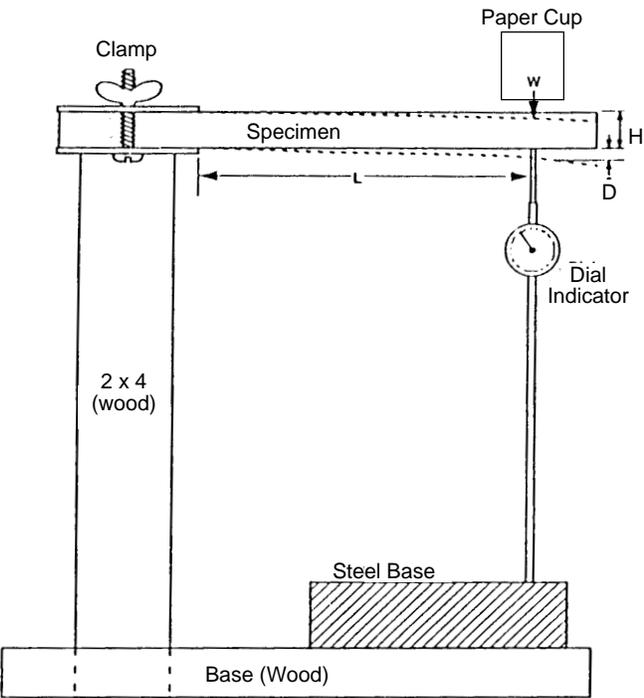


Figure 8.5. Apparatus Used to Evaluate Stiffness of Composite Beams by Measuring Deflection of a Cantilever Beam in Bending

Airfoils

Instructor Notes

Reliability

This experiment will work well. The airfoils produced will have measurable lift and give measurable differences in weight to strength ratios for the various airfoil designs.

Teacher Tips

1. Balsa sheets are available from hobby supply stores and some scientific supply catalogs. Total cost for this activity is approximately \$200.00 for a class of 25 students.
2. Transparent polyester (monokote) is available from model airplane hobby shops.
3. The glue to bond the balsa is cyanoacrylate (Superglue). Common brands used in model airplane building are Zap and Hot Stuff.

Caution: Avoid breathing the fumes of reacting cyanoacrylate. Be careful not to bond fingers together as cyanoacrylate adheres quickly and tenaciously to skin. If this should happen, use the debonding chemical available at hobby shops, or wait 10 min before slowly rolling the bonded surfaces apart. Do not pull fingers directly apart or use sharp blades to cut the skin surfaces apart. Take extra care to avoid getting glue in your eyes.

4. The special iron designed for use in model construction and the high-temperature heat gun used in model construction are available from hobby stores.
5. The various parts of the wing are illustrated and labeled for orientation in Figure 8.6. Figure 8.7 gives the actual size for the airfoil used in the project. If you wish to do a larger or smaller version of the airfoil, it can be enlarged or reduced on a photocopier.
6. In testing the airfoil, the free-end length needs to be carefully measured as load deflection is a cube function. Figure 8.8 shows a possible test system.
7. When students are testing airfoils for failure, it is wise to check the approximate distance they have placed their weighing container from the floor: If the container is placed more than 5 cm from the supporting surface, the airfoil will be totally destroyed when it fails.

8. In discussing cause(s) for failure, students should speculate on what could have been done differently during construction. All the wings tested so far have failed at the point of attachment to the clamp and the test apparatus. Failure occurs under compression at the interface between the wing and the clamp.
9. Students could now build a second modified wing that remedies the problem, or they could build an identical wing with different materials (say a wing made from polystyrene insulating foam covered with balsa—which makes impressive gains in mechanical strength). They should stay within the weight limits; keep weight to a minimum.
10. Keep these results to build a data base as other classes conduct this project.

Project: Constructing and Testing a Composite Airfoil

Student Learning Objectives

At the end of the activity students will be able to:

- test a constructed airfoil to determine its relative stiffness and point of destruction
- graph results of different designs to determine the best construction.

Materials

- Balsa wood, sheet 1/16 in. x 3 in. x 36 in. (36)
- Balsa wood leading edge 3/8 in. x 5/16 in. x 36 in. (18)
- Balsa trailing edge 1/8 in. x 3/4 in. x 36 in. (16)
- Balsa 1/8 in. x 1/4 in. x 36 in. (12)
- Spruce 1/8 in. x 1/4 in. x 36 in. (9)
- Bicarbonate of soda, Na_2HCO_3 (baking soda)
- Transparent polyester covering material, Monokote or equivalent (2 sq yd)
- Glue, cyanoacrylate (Zap or Hot Stuff)
- Wax paper
- Sand paper, 150 grit
- Strong string or duct tape

Equipment

- T head pins (1 box)
- Heat gun (high temperature) used in model construction
- Electric iron, designed for model construction
- Plastic or cloth bag (or plastic pail)
- Meter stick
- Steel templates, cut to Clark Y airfoil shape, with notches for spars
- X-Acto knives or equivalent hobby knives with straight point blades
- 60 x 120 cm fibrous ceiling tile, flat finish (building board)
- Trays (6), approximately 5 x 15 cm long for sodium carbonate
- Vacuum cleaner with brush

Procedure

1. Use Table 8.2 to select the balsa and/or spruce your group will use to construct the airfoil. Cut the pieces slightly larger than the templates from the 1.6 mm (1/16 in.) sheets of balsa. Drill holes in the balsa to accommodate the posts of the template.

Table 8.2.

Variation	Description
BW	Ribs 6 cm apart, balsa spars
BN	Ribs 3 cm apart, balsa spars
BWS	Ribs 6 cm apart, balsa spars, shear webs
SW	Ribs 6 cm apart, spruce spars
SN	Ribs 3 cm apart, spruce spars
SWS	Ribs 6 cm apart, spruce spars, shear webs

BW = balsa with wide spars; BN = balsa with narrow spars; BWS = balsa with shear webs; SW = spruce with wide spars; SN = spruce with narrow spars; SWS = spruce with shear webs

2. Make a template-balsa sandwich using all rib pieces.
3. Carve and sand the balsa to match the templates; be careful not to sand the templates themselves.
4. To make notches for the spars, (see Figures 8.6 and 8.7) glue a 10-cm strip of 150-grit sandpaper to the 1/4 in. face of some scrap spruce spar wood. Sand the spar notches in the ribs, avoiding enlarging the notches in the templates.
5. Take a piece of wax paper large enough to cover the building board, and mark reference lines on it to guide the placement of the spar and ribs. Be sure the reference lines are spaced correctly for your airfoil ribs and are at right angles to the spar reference line.
6. Cover the building board with the wax paper. This will prevent the wing from becoming glued to the board as well as giving you a placement guide for the spar and ribs.
7. Pin the bottom spar in place on the building board.
8. Pour sodium bicarbonate (Na_2HCO_3) into a long narrow tray.
9. Dip the rib pieces into the sodium bicarbonate. The tiny amount of soda that sticks to the rib will accelerate the reaction of the cyanoacrylate and strengthen the bond.
10. Hold each rib perpendicular to the building board, making sure each closely follows the reference lines.

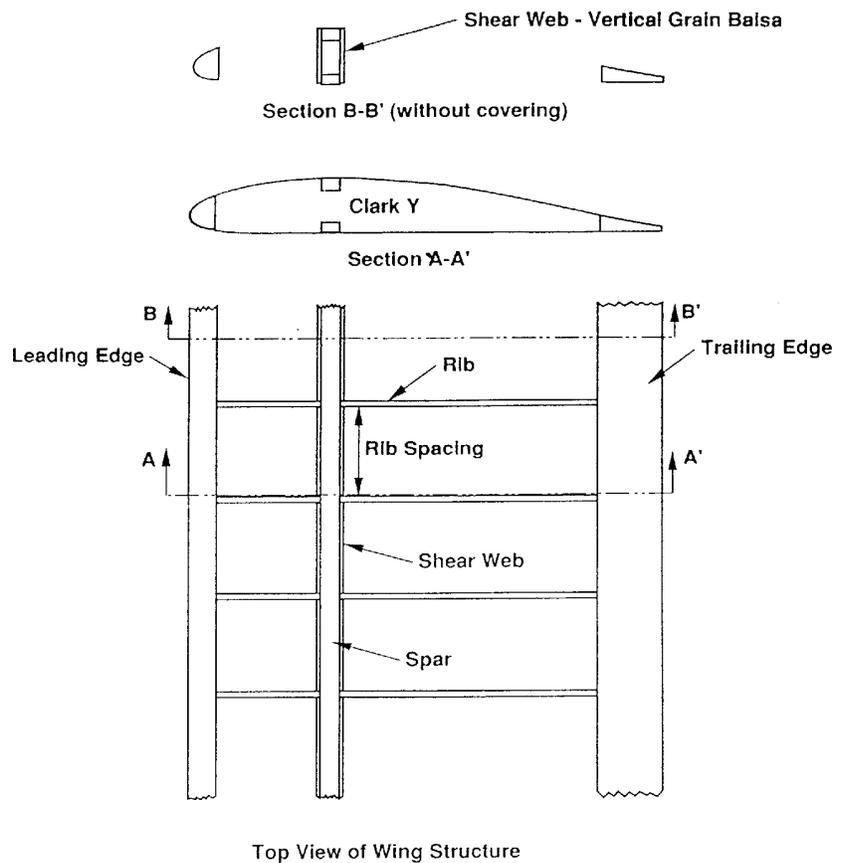


Figure 8.6. Construction Details of a Model Airplane Wing

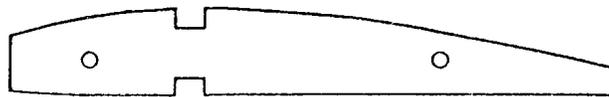


Figure 8.7. Clark Y Airfoil (pattern for template—enlarge as necessary)

11. Apply the cyanoacrylate to the junction of the spar and rib. The bond will secure this junction in 2 to 3 seconds.

Caution: Avoid breathing the fumes of reacting cyanoacrylate. Be careful not to bond fingers together as cyanoacrylate adheres quickly and tenaciously to skin. If this should happen, use the debonding chemical available at hobby shops, or wait 10 min before slowly rolling the bonded surfaces apart. Do not pull fingers directly apart or use sharp blades to cut the skin surfaces apart. Take extra care to avoid getting glue into eyes.

12. Set the top spar securely in place, and apply cyanoacrylate to the joints.
13. Pin leading edge and trailing edge in place. Under the leading edge, use a 3-mm (1/8-in.) shim to hold it up, since the airfoil is not quite flat.
14. Bond with cyanoacrylate.
15. If shear webs are to be attached to the spars, cut the webs so the grain of the wood is perpendicular to the building board, then bond to the front and back surfaces of the top spar with cyanoacrylate.
16. Remove the wing, turn it over, and then bond the bottom spar and shear webs together with cyanoacrylate.
17. The outer ribs on each end of the wing need to be strengthened to prevent warpage as the wing-covering material shrinks. To strengthen each end rib, glue a piece of scrap spar material onto the outer ribs.
18. Carefully sand the wing as necessary. Use a vacuum cleaner with brush to remove dust. Set aside wing while you prepare the transparent polyester covering material.
19. Cut a piece of covering approximately 1 cm larger on all sides than the wing. Follow manufacture's instructions for applying the covering, first tacking it in place using an iron, then use a heat gun to shrink the film.

Testing

1. Record the weight of each wing to be tested for strength and stiffness.
2. Using a clamp that fits the shape of the airfoil's top profile, fasten the wing to the edge of the workbench, allowing approximately 35 cm of the airfoil to hang free like a cantilever (see Figure 8.8). Because the deflection under load is a cube function, the free length should be carefully controlled.
3. Suspend a container (plastic or cloth bag or small plastic pail) from the top spar using a strong string or duct tape. Weight will be added to the container that will cause deflection. This container should be about 5 cm from the floor. Can you think of a reason why?
4. Using a meter stick fixed to the base, measure the distance to the nearest millimeter from the lower wing surface to the floor.
5. Place weights in the suspended container until a deflection of 1 cm is attained.
6. Weigh the container and weights, and record the value in your journal.

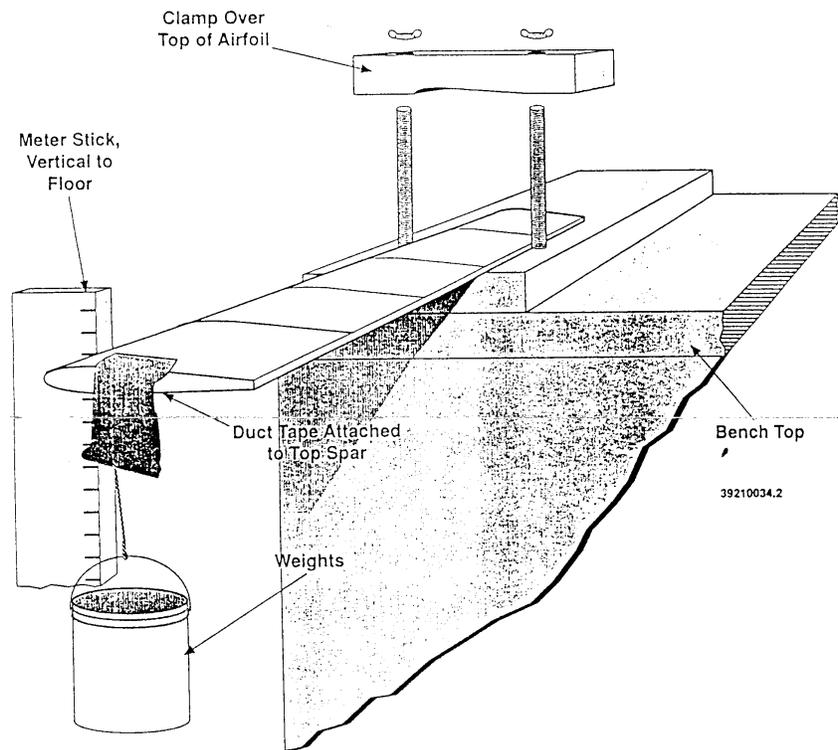


Figure 8.8. Arrangements to Test Stiffness and Strength of Airfoil Sections

7. Continue adding weight until failure occurs. Record the failure weight and the approximate deflection at failure in your journal.
8. Observe and describe the failure point and any characteristics that you saw during the loading process in your journal.
9. Plot class test results with the x-axis as the structure type and the y-axis as the weight to cause the 1 cm deflection (graph I) and the weight to cause failure (graph II).
10. Observe the graphs for any pattern or trends. Are the two graphs similar?

Making Paper

Instructor Notes

Reliability

This lab works very well with any plant material. However, it is not recommended that students use wood as it takes too long and can be hard on the blender. Leaves, straw, rice, and grasses work well. You may want to experiment and use cardboard, used paper, construction paper, or blue jeans in making paper.

Teacher Tips

1. Using the borates for pulping is much safer than using sodium hydroxide. All work well however. Care should be taken when heating so the solution does not boil over. The solution is hot and caustic. If students get splashed, rinse off immediately.
2. Screen door screen works well for the deckle (screen). Do not use fiberglass screen as it is too flexible.
3. The size of the screen is not important. Use a size that will fit in the tray you will use to hold the pulp mixture.
4. Often the pulp sticks to screen a little, a gentle pry at a corner will release the pulp from the screen.
5. When ironing the paper, turn the cloth over to speed drying. The cloth will come off easier if the paper is not dried to a crisp.
6. Stopping at any point where indicated will not change the end results. This lab can be done over several weeks, if the need arises.
7. For students who want to go farther, they can add potassium alum to make the paper waterproof or add a piece of thin wire or thread to the screen before pressing to make water-marked paper.
8. To get a whiter paper, the pulp can be bleached with ordinary household bleach. Simply add about 50 mL of bleach to the mixture after boiling and before blending. Allow to set overnight. Rinse bleach out the next day, and then continue with the pulping operation.
9. Paper is made from cellulose fibers. Although many different types of plants are used to produce paper in the United States, most paper is made from trees.
10. The Egyptians used papyrus to create the first paper-like writing surface. Paper as we know it today was probably invented in China. Papermaking was for centuries a slow and difficult process. In the early 1800s, the continuous roll method of making paper was developed so paper could be mass produced.

11. Recycled paper is now being used to create “new” paper. Waste paper is dumped into a large mixing machine called a pulper pit. Here the paper is mixed with water, heated, and becomes “pulp.” The pulp is forced through screens of smaller and smaller mesh to remove foreign objects. To remove the ink the pulp goes through several tanks where it is bleached to form a white pulp. Paper that is not “de-inked” is considered “minimum impact paper”. The bleached, cleaned pulp is spread on large rolls of screen and is pressed and dried to form paper.
12. References: Burdette, Conway and Ernst. 1988. *The Manufacture of Pulp and Paper: Science and Engineering Concepts*, Tappi Press; American Paper Institute. 1972. *The Statistics of Paper*, New York.

Project: Making Paper

Student Learning Objectives

At the end of the activity students will understand how to:

- make a cellulose pulp from plant material
- make paper from pulp.

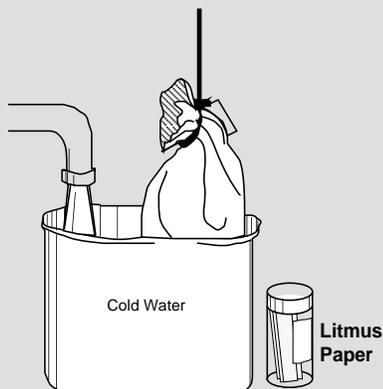
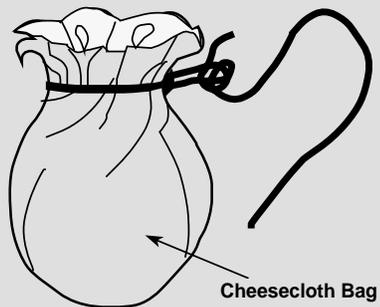
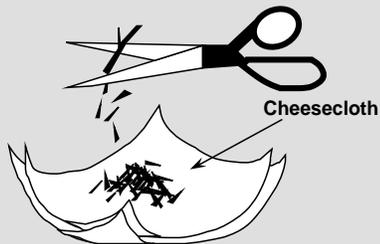
Materials

For making pulp:

- Dried plant material
- Cheese cloth
- String
- Pulping chemical (borax or sodium borate, sodium pyroborate, sodium tetraborate, or sodium hydroxide)
- Red litmus

For making paper:

- Pulp
- Wire screen (screen door screen 10 cm x 10 cm or to fit tray)
- Masking tape or plastic tape
- Plastic tray (for wire screen to fit into)
- Cookie sheet
- Sponges
- Pieces of cloth (cotton is best)
- Blocks of wood to fit wire screen
- Micropipette
- Spatula
- Stirring rod
- Electric iron - to be shared
- Chemical goggles



Equipment

- Balance
- Scissors
- Hot plate or other source of heat
- 600 mL beaker or suitable container
- Blender

Procedure

1. *Preparing the plant material:* Cut two pieces of cheesecloth into 25-cm x 25-cm squares. Lay one piece of cheesecloth on the other. Cut the dried plant material into the center of the cheesecloth. Make the pieces less than 1 cm in length. Gather the cheesecloth to make a large “tea bag” with the cut plant material inside. Write your name on a tag and attach to a string to identify your tea bag.
(You may stop at this point if time runs out)
2. *Boiling:* Place your tea bag in the 600-mL beaker. Add enough warm water in 100-mL increments to cover your “tea bag.” Add 10 g of pulping chemical for each 100 mL of water you used. (Note if you are using sodium hydroxide use 5 g for each 100 mL of water used.) Place the beaker on the hot plate. Adjust heat to gently boil the contents for 45 min to 1 hour. Add hot water as the water in the beaker boils away. If time allows, boiling can continue for several hours. (Note: Boiling plant material in pulping chemical creates a smell some people find unpleasant. Do this activity in a well-ventilated area.)

Caution: Use chemical goggles.

(You may stop at this point if time runs out. Just leave the tea bag in the beaker with the pulping chemical. Turn off the heat!)

3. *Washing:* Carry the beaker carefully to a sink. Turn on the cold water, and empty the beaker into the sink. Note the color of the liquid. Fill the beaker with cold water and dip your “tea bag” in and out of the water several times. Empty the pot. Refill the beaker with water and repeat dipping process. Continue to wash your “tea bag” in this manner until the water rinse is uncolored. Test a few drops of this water with red litmus paper. Wash your “tea bag” until the rinse water will not turn red litmus blue. When the litmus stays red you have removed all the pulping chemical.

(You can stop at this point. You can store your rinsed tea bag in a tightly sealed container at room temperature for a day or two. Refrigerate if storage is for a longer period.)

4. *Pulping*: Squeeze your “tea bag” to press out most of the water. Cut open the bag. Put a handful of your plant material into a food blender (save the rest in a covered container). Add 20 to 30 mL of water, and place the cover on the blender. Turn on the blender for about 10 sec. If the blender does not mix the material smoothly, turn it off. Add another 20 mL of water and try again. Continue adding water until the mixture blends smoothly. Blend for 1 min at medium speed. Stop the blender and look carefully at the pulp. Blend for another minute and look at the pulp again. Continue until the pulp stops changing in appearance. You now have pulp to make paper. Pour your pulp into a storage container; put a lid on it.

(You may stop here. Pulp can be stored at room temperature for a day or two or in the refrigerator for several weeks.)

5. *Making paper*:

A. Making a screen

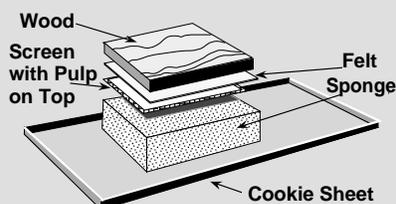
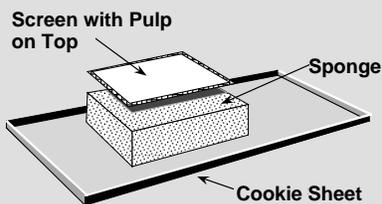
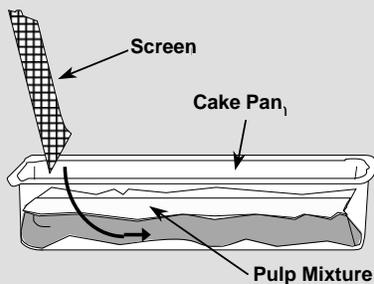
There are several ways to add an edge to the screen. These edges make it easier to remove the paper from the screen later. Your screen can be used over and over again. The easiest way is to place masking tape all the way around the four edges of your screen.

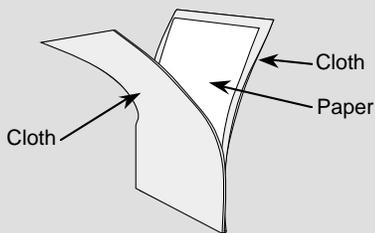
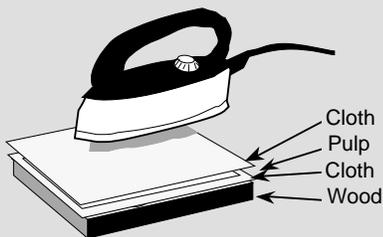
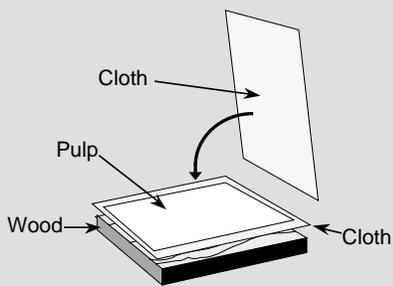
B. Loading the screen

Soak the sponge and the pieces of cloth in water. Squeeze out as much water as you can, then place the sponge on the cookie sheet. Just before you begin, plug in the iron and turn it on medium heat. Pour 1 to 2 cm of water into the plastic tray. Add some of your pulp to the water. Stir the mixture well to separate the fibers of the pulp. Add pulp until the mixture is a little too thick to see through. Slide the wire screen into the pulp mixture from one end, and let it rest on the bottom. Do not drop the screen in the mixture as it will trap the fiber below the screen. Move the screen around and stir up the mixture to get an even layer of pulp above the screen. Lift the screen out of the pan, and place it on the damp sponge. The pulp side should be up. Use your finger to push any tufts of pulp that hang over the border of the screen onto the open meshwork. This will make it easier to pull the paper off the screen later. Check the pulp visually for bare spots. Use a micropipette to add a few drops of undiluted pulp to fill in any bare spots.

C. Pressing the pulp

Place a piece of damp cloth over the pulp on the screen. Place a block of wood over the cloth. Press down on the wood as hard as you can to squeeze most of the water out of the pulp. Lift off the block of wood, and set it aside. Lift the sandwich of cloth, pulp, and screen off the sponge. Turn the sandwich over so the screen is on top. Lift one corner of the screen so you can see the pulp. Use a thin spatula (or the blade of a knife) to peel the sheet of





pulp off the screen. Work slowly and carefully. Don't worry if you tear the sheet of pulp. To repair tears, use a micropipette to put a few drops of pulp mixture over any tears.

D. Drying the paper

Cover the sheet of pulp with another sheet of damp cloth. Iron this sandwich (cloth, pulp, cloth) until it is completely dry. You may turn the sandwich over once or twice as you are ironing to speed drying. When the sandwich is completely dry, carefully peel the two pieces of cloth away from the paper. Examine the paper that you have made.

(You can make as many sheets of paper as time permits now. Just remember to add undiluted pulp as you remove more sheets of pulp.)

Extension Activities

1. Compare different types of paper (look at fibers under a microscope).
2. Research the current technology being used to recycle paper and produce "new" paper.
3. What is dioxin? Why is/could it be a problem? How is it used in papermaking?
4. What do wasps have to do with the topic of paper?
5. What is a watermark? Create your own paper that has your own watermark.
6. Investigate the history of rice paper.
7. Create masks using paper.
8. Use various materials to create paper, or add flowers or fabric to your pressed pulp to make designs.

Peanut Brittle

Instructor Notes

Reliability

This activity works well if directions are followed, but success will vary. It is an excellent activity before winter break.

Estimated Time for Activity

One class period.

Teacher Tips

1. This lab's origin is unknown, but it is a well-known and much appreciated (delicious) experience.
2. It is important that you protect the students and yourself from harmful chemicals by
 - making sure the equipment is clean (beakers, thermometer, stirring rod). Purchase and dedicate the equipment for only this lab. You don't want contamination. Washing and sterilizing equipment at the end of the lab and storing it for next year will help ensure cleanliness.
 - making sure the materials are new and fresh
 - sucrose is table sugar
 - glucose is corn syrup
 - mixed esters are margarine
 - protein pellets are peanuts
 - sodium bicarbonate is baking soda
 - 4-hydroxy-3-methoxybenzaldehyde is vanilla (artificial OK, real is better)
3. Students may over heat the sugar solution and burn it (Yuk!).
4. When adding vanilla and baking soda, the beaker should be held with a hot pad.
5. It is recommended that raw spanish peanuts be used, but this is definitely not necessary. They cook as the brittle is formed.

Safety

1. Be careful of flames and hot surfaces, burns are possible.
2. If glass rods or thermometers break, discard the batch.
3. Do not use mercury thermometers.

Activity: Peanut Brittle

Student Learning Objectives

At the end of the activity students will be able to:

- investigate the formation of a delicious composite material by the infusion of CO₂ into a mixture of protein inclusions and foamed saccharides
- Cooperate with other students in performing this activity in a small group because of time limitation
- understand this experiment is edible, cleanliness is absolutely necessary.

Materials

- Sucrose, 75 g
- Glucose, 3M, 60 g
- Water, 20 mL
- Mixed esters, 19 g
- Protein pellets, Spanish, 50 g
- Sodium bicarbonate, 4 g
- 4-hydroxy-3-methoxybenzaldehyde, 1.0 mL
- Paper towels, 30 cm x 30 cm
- Plastic cup (5), 3 oz.
- Aluminum foil, 30 cm x 30 cm

Equipment

- Safety glasses
- Beaker, 400 mL
- Beaker tongs
- Stirring rod
- Bunsen burner/hot plate
- Ring stand and ring
- Wire gauze (ceramic centered)
- Graduated cylinder, 25 mL
- Thermometer (candy)
- Scale/balance

Procedure

1. Clean laboratory. Wipe down balance/scale and areas surrounding it with a damp cloth. Wash any other surfaces that will be used for this experiment. Wash your hands too!
2. Keep an accurate record of the process you followed in your laboratory journal.
3. Weigh out 75 g of sucrose into a plastic cup.
4. Weigh out 60 g of 3M glucose solution into a plastic cup.
5. Measure out 20 mL of water into a plastic cup, using graduated cylinder.
6. To a 400-mL beaker add steps 1-3.
7. Heat this mixture of saccharides slowly. Stir constantly. Bring to a boil. Use as cool a flame or heat that will maintain boiling. Avoid burning the saccharides.

Note: *Never stir solution with your thermometer; always use a stirring rod.*

8. Weigh out 7 g of solidified mixed esters in a plastic cup. Add 6 g of the solidified mixed esters to the boiling glucose-sucrose solution. Take the remaining 1 g of solidified mixed esters, and lightly coat a 30-cm square of aluminum foil.
9. Continue to heat and stir. Use beaker tongs to stabilize the beaker while stirring.
10. Weigh out 50 g of Spanish protein pellets on a piece of 30-cm-square paper towel.
11. When the temperature reaches 138°C, add the Spanish protein pellets (containing arachin, conarchin, and oleic-linoleic glycerides.)
12. Continue to stir.
13. Weigh out 4 g of NaHCO_3 into a plastic cup.
14. In a 25 mL graduated cylinder, put 1.0 mL of 4-hydroxy-3-methoxybenzaldehyde.
15. Prepare a pad by folding a paper towel into fourths.
16. When the temperature reaches 154°C, remove the beaker from the heat source. Place the beaker on the paper pad near the aluminum foil. Remove the thermometer.
17. While one partner holds the beaker and is prepared to stir, the other adds the 4-hydroxy-3-methoxybenzaldehyde and NaHCO_3 .
18. Stir vigorously. When the rising mixture slows, pour the mixture on to the aluminum foil.

19. When the mixture has cooled, break up the new product, submit a small sample for judging, and consume the rest at will.
20. Thoroughly clean all equipment and the laboratory; remember, this experiment is edible, so make sure to clean all equipment so the next group can use it. Dispose of paper towel and plastic cups.
21. Finish writing observations in your journal. Write a summary report of this lab to include generic terms for ingredients and the product you made.

Vocabulary—Composites*

Advanced composites

Cermets

Composites

Curing

E-glass

Fatigue

Fiber

Filament

Carbon black

Epoxy

Laminated composites

Sandwich composites

Glass fibers

Kevlar

Laminate

Matrix

Nondestructive evaluation

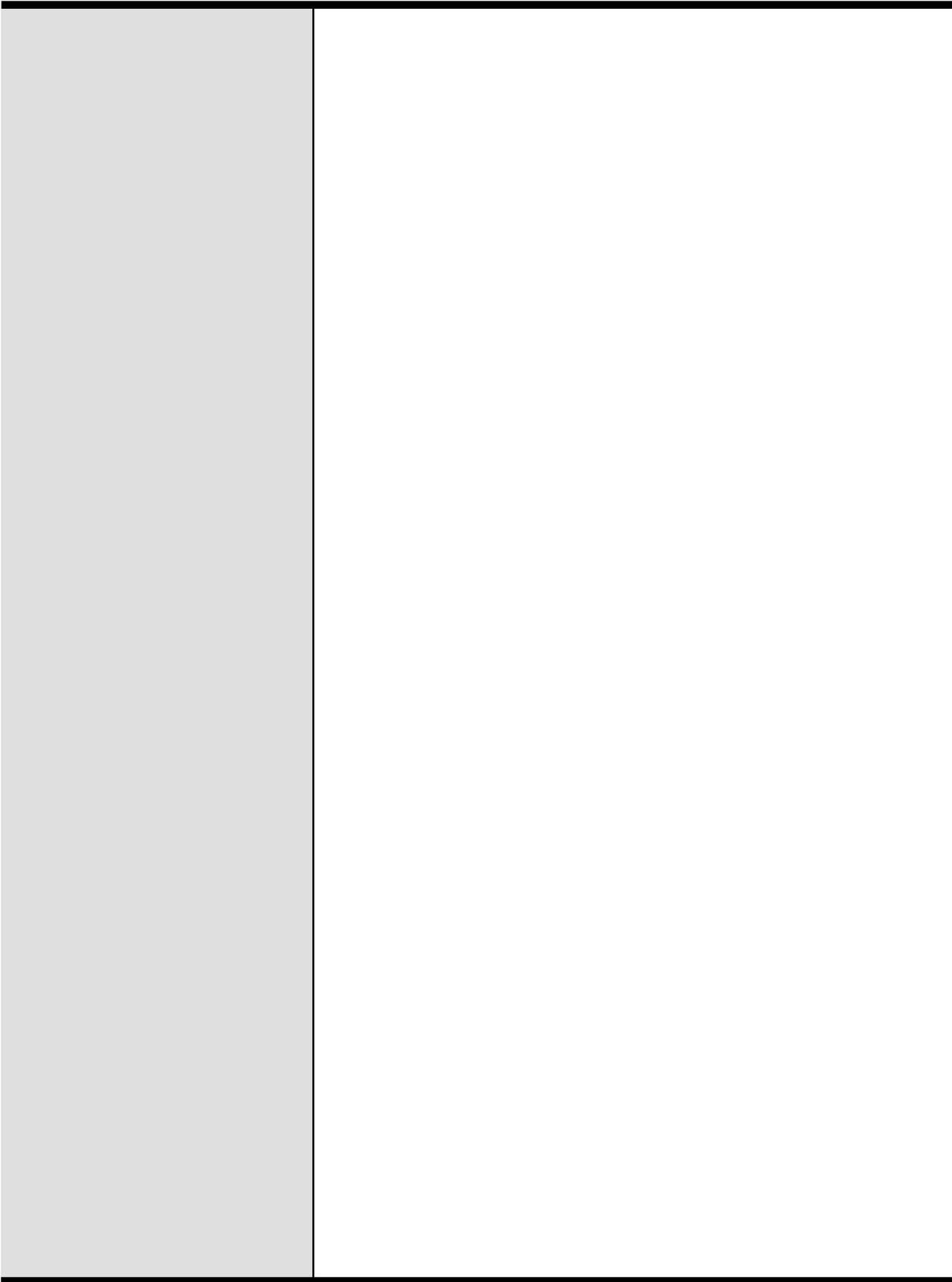
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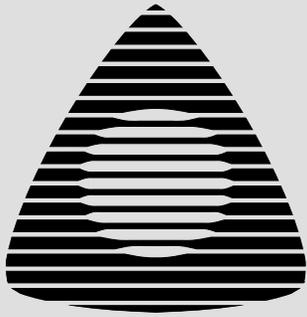
S-glass

Whisker

Specific stiffness

*Instructor may vary vocabulary to suit particular content presented.





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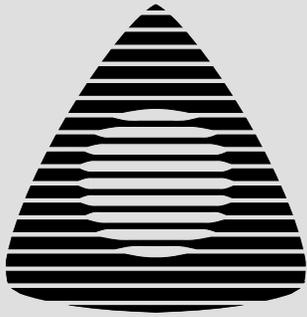
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Resource Appendix

Resource Appendix

Vendors

Arbor Scientific
P.O. Box 2750
Ann Arbor, MI 48106-2750
1-800-367-6695
Fax (313) 913-6201

Cline Glass
1135 S.W. Grand Ave.
Portland, OR 97214
1-800-547-8417
(Catalog is \$5)

DFC Ceramic
P.O. Box 110
Cannon City, CO 81212
1-800-284-9498

Edmund Scientific Co.
101 East Gloucester Pike
Barrington, NJ 08007-1380
(609) 573-6295
Fax (609) 573-6295

Fisher - EMD
Educational Materials Division
485 Frontage
Burr Ridge, IL 60521
1-800-955-1177

Flinn Scientific Inc.
P.O. Box 219
131 Flinn Street
Batavia, IL 60510
1-800-452-1261

Frei and Borel
126 2nd St.
Oakland, CA 91607
1-800-772-3456

Contents

- **Vendors**
- **Printed Materials**
- **Business Resources**
- **Videos**
- **Ordering the Space Shuttle Tile**
- **Innovative Materials, Processes, and Products Developed by Battelle Memorial Institute**

Frey Scientific
905 Hickory Lane
P.O. Box 8101
Mansfield, OH 44901-8101
1-800-225-3739

Gesswein
1540 West Glen Oaks Blvd.
Suite 104
Glendale, CA 91201
1-800-232-2311

IASCO
5724 West 36th Street
Minneapolis, MN 55416-2594
1-800-328-4827
Fax (612) 920-2947

Jensen Tools Inc.
7815 South 46th Street
Phoenix, Arizona 85044-5399
(602) 968-6231
(Source for scissors for cutting Kevlar)

Lab Safety Supply Co.
P.O. Box 1368
Janesville, WI 53547-1368
1-800-356-0783
(Suppliers of safety equipment and laboratory supplies)

Lindberg
275 Aikens Road
Asheville, NC 28804
1-800-438-4851
(Replacement furnace parts only)

Rex-Roto
5600 East Grand River
Fowlerville, Michigan 48836
(517) 223-3787
(Source of GH board for furnace—minimum order \$100)

Rio Grande
6901 Washington N.E.
Albuquerque, NM 87109
1-800-545-6566

Sargent-Welch
911 Commerce Court
Buffalo Grove, IL 60089
1-800-727-4368
Fax 1-800-676-2540

Schnee-Morehead, Inc.
111 N. Nursery
Irving, Texas 75060
(214) 438-9111
(Supplier of Tacky tape – minimum order \$250)

Science Kit & Boreal Labs
P.O. Box 5059
San Luis Obispo, CA 93403-5059
1-800-828-777

Spectrum Glass Co., Inc.
P.O. Box 646
Woodinville, WA 98072-0646
(206) 483-6699
1-800-426-3120 (out of state only)

Swest
26017 Huntington Lane #F
Olencia, CA 91355
1-800-527-5057

Vesuvius-McDaniel Company
P.O. Box 560
Beaver Falls, PA 15010
(412) 843-8300
(Source of alumina rod—minimum order \$150)

Vigor
Habsons Jewelry Supply
1424 Fourth Ave., Suite 303, Fourth & Pike Bldg.
Seattle, WA 98101
1-800-678-7759

Western Industrial Ceramics
10725 S.W. Tualatin-Sherwood Rd.
Tualatin, OR 97062
1-800-727-9424
(Suppliers of ceramic board – trade name Fiber Frax—minimum order \$100)

Supplies from Hardware Stores

Propane torch kit (\$15)
Leather gloves
Hammers
Tin snips
Triangular file
Glass cutters
Pliers
Steel wool
Tongs
Plaster of paris
Epoxy resin - in small amounts
Wire cutters
Screw drivers
Wire - copper and iron

Supplies from Grocery Stores

Ammonium alum
Twenty Mule Team Borax ($\text{Na}_2\text{B}_4\text{O}_7 \cdot 10 \text{H}_2\text{O}$), sodium borate
Cornstarch
Vinegar
Cups (paper and plastic)
Plastic bags
Paper bags
Marbles
Silly putty
Washing soda (Na_2CO_3), sodium carbonate

Supplies from Lumber Yards

Wood
Portland cement
Gravel (rock aggregate)
Sand

Note:

- A. Silica may be picked up cheaply at local art supply stores
- B. Materials for vacuum bagging are not readily available. One possible source is Molen Co., Inc., 22651 83rd Ave. S. Kent, WA, (206) 872-6877
- C. Stainless steel molds are not very common, but local metal working shops are possible. A source is Alaskan Copper & Brass, 3223 6th Ave. S, Seattle, WA 98134 (206) 623-5800. They have
 - 1 in. square stainless bar in 12 ft sections (41 lb) at \$3.06/lb
 - 1/4 in. round rod in 12 ft sections (2 lbs) at \$3.28/lb
 - 1/2 in. stainless plate at 22 lb/ft² for \$1.70/lb plus cutting (minimum cutting charge is \$18)

Materials/Equipment Price List

This list is only a sample, and PNL does not recommend or endorse the vendors listed. Note that prices are not guaranteed by the vendors; make sure you get a quote first. Several vendors are West Coast companies, and shipping could be expensive. It would be better to use the items list and research local vendors for prices. One-time-expense items are noted in the last column with an "A." Those items that will have to be replaced are noted by "B." Some items will need to be replaced annually, others less frequently.

Qty	Unit	Description	Order #	Vendor	Cost	Extension	Code
12	ea	100-gm "Weights"	05592	Frey	\$3.95	\$47.40	A
12	ea	110V Lamp socket with plug	02644 & FGA	Frey	\$4.45	\$53.40	A
4	ea	400° Thermometer	S-80005-10G	Sargent-Welch	\$5.04	\$20.16	A
1	4 liter	Acetone	A0010	Flinn	\$20.61	\$20.61	B
6	ea	Alcohol burner	700-008	Rio Grande	\$4.62	\$27.72	A
1	500 g	Aluminum	A0023	Flinn	\$10.35	\$10.35	B
2	sets	Aluminum pieces	02896	Frey	\$6.65	\$13.30	A
24		Aprons, lab	60175	Science Kit Boreal	\$7.70	\$184.80	A
1	ea	Balance, .01	S40104-2	Fisher	\$695.00	\$695.00	A
2	ea	Balance, .1	S40085	Fisher	\$99.50	\$199.00	A
1	ea	Ball & ring device	01164	Frey	\$10.95	\$10.95	A
1	btl	Barium peroxide	B0058	Flinn	\$18.55	\$18.55	B
1	pk	Beaker, 100 mL	S-4678-H	Sargent-Welch	\$20.25	\$20.25	A
1	pk	Beaker, 250 mL	S-4678-K	Sargent-Welch	\$21.05	\$21.05	A
1	pk	Beaker, 400 mL	S-4678-L	Sargent-Welch	\$24.50	\$24.50	A
2	pk	Beaker, 600 mL	S-4678-M	Sargent-Welch	\$16.07	\$32.14	A
2		Bench vise	113-134	Rio Grande	\$19.23	\$38.46	A
1	100 g	Benzoic acid	B0197	Flinn	\$9.25	\$9.25	B
1	500 g	Boric acid	B0081	Flinn	\$8.60	\$8.60	B
4	sets	Brass cylinder	02154	Frey	\$5.95	\$23.80	A
3	ea	Breaker grozier pliers	2111	Cline	\$16.70	\$50.10	A
3	doz	Brush, 1 in.	1420370KX78	Iasco	\$6.90	\$20.70	B
1	ea	Buffing rouge	331-072	Rio Grande	\$13.36	\$13.36	B
12	ea	Bunsen burner	S-11705	Sargent-Welch	\$9.76	\$117.12	A
12		Bunsen burner hose	S-12121-A	Sargent-Welch	\$8.32	\$99.84	A
1	lb	Copper wire, 18 ga	05190	Frey	\$6.70	\$6.70	B
2		Carbide wheel cutter	1960	Cline	\$30.70	\$61.40	A
1	pk	Carbon stirring rod	705-121	Rio Grande	\$9.53	\$9.53	A
1		Centrifugal or vacuum cast	705-190	Rio Grande	\$724.30	\$724.30	A
1	ea	Ceramic blade scissors	195B140	Jenson Tools	\$39.00	\$39.00	A
1	100 g	Chromium (III) oxide	C0224	Flinn	\$8.80	\$8.80	B
1	100 g	Cobalt (II) oxide	C0220	Flinn	\$34.95	\$34.95	B

Resource Appendix

Qty	Unit	Description	Order #	Vendor	Cost	Extension	Code
6	ea	Continuity device		Radio Shack	\$18.00	\$108.00	A
1	500 g	Copper (II) carbonate	C0095	Flinn	\$17.30	\$17.30	B
1	500 g	Copper (II) oxide	C0101	Flinn	\$23.70	\$23.70	B
1	roll	Copper bell wire (#18)	05184	Frey	\$10.75	\$10.75	B
4	roll	Copper foil	1104	Cline	\$7.15	\$28.60	B
1	sheet	Copper strip	C0079	Flinn	\$20.20	\$20.20	B
1		Copper tweezers	501-107	Rio Grande	\$7.28	\$7.28	A
1		Crucible, with handle	704-119	Rio Grande	\$15.06	\$15.06	A
1	case-72	DFC crucible	990-21-06	DFC Ceramics	\$75.90	\$75.90	B
2	box-10	Disposable gloves	10704060RV5	lasco	\$5.95	\$11.90	B
1	box-50	Disposable mask	144057YRV23	lasco	\$16.95	\$16.95	B
4		Draw plate	113-055	Rio Grande	\$46.09	\$184.36	A
2		Draw tongs	111-002	Rio Grande	\$18.38	\$36.76	A
2	gal	Epoxy resin	101051BRX83	lasco	\$47.50	\$95.00	B
1	4 liter	Ethyl alcohol	E0013	Flinn	\$21.31	\$21.31	B
12	ea	Evaporating dish	15227	Frey	\$2.50	\$30.00	A
2	yd	Fiberglass	106014RRW33	lasco	\$3.95	\$7.90	B
1	pk-12	File	14715	Frey	\$32.35	\$32.35	A
1		Flask tongs	704-026	Rio Grande	\$8.85	\$8.85	A
1		Flux	1283	Cline	\$4.35	\$4.35	B
1		Furnace	30711-063	Sargent-Welch	\$1,858.00	\$1,858.00	A
1		Furnace controller	30783-021	Sargent-Welch	\$1,586.00	\$1,586.00	A
1		Glass cleaner	1224	Cline	\$4.20	\$4.20	B
3		Glass grinder	2210	Cline	\$95.40	\$286.20	A
1	lb	Glass rod (6 mm)	01046	Frey	\$4.75	\$4.75	B
5	lb	Glass tubing (6 mm) (flint)	01081	Frey	\$4.95	\$24.75	B
1	pr	Gloves, high temp.	32885-451	Sargent-Welch	\$52.50	\$52.50	A
1	pk	Graduated cylinder, 10 mL	S-24469-B	Sargent-Welch	\$20.20	\$20.20	A
2	pk	Graduated cylinder, 100 mL	S-24669-E	Sargent-Welch	\$32.10	\$64.20	A
2	pk	Graduated cylinder, 250 mL	S-24673-G	Sargent-Welch	\$29.00	\$58.00	A
2		Hand buffing tool	205-042	Rio Grande	\$83.69	\$167.38	A
1	25 g	Hexamethylenediamine	H0045	Flinn	\$8.90	\$8.90	B
1	500 ml	Hexane	H0002	Flinn	\$10.71	\$10.71	B
6	ea	Hot plate	33927-502	Sargent-Welch	\$260.00	\$1,560.00	A
1	50# box	Investment	702-084	Rio Grande	\$39.47	\$39.47	B
1	500 g	Iron (III) oxide	F0010	Flinn	\$12.10	\$12.10	B
2		Jeweler saw	1101-122	Rio Grande	\$24.61	\$49.22	A
1	yd	Kevlar	106028RRW33	lasco	\$30.95	\$30.95	B
2	lb	Lead	L0064	Flinn	\$6.55	\$13.10	B
6	ea	Magnets	18458	Frey	\$6.70	\$40.20	A
12	ea	Magnifying lens	FGA02490	Frey	\$4.15	\$49.80	A

Qty	Unit	Description	Order #	Vendor	Cost	Extension	Code
1	box	Microscope slides	12361	Frey	\$6.05	\$6.05	B
12	ea	Mirror	18469	Frey	\$0.75	\$9.00	A
1	can	Mold release	104038ORY22	lasco	\$11.50	\$11.50	B
4		Mortar & pestle	S62250-60D	Sargent-Welch	\$8.75	\$35.00	A
1	250 g	Naphthalene	N0065	Flinn	\$7.25	\$7.25	B
1	250 g	Naphol	N0033	Flinn	\$16.05	\$16.05	B
1		Neodymium magnet	P8-9701-02	Arbor	\$5.00	\$5.00	A
12	pk	Neon lamp with resistor	272-1100B	Radio Shack	\$1.25	\$15.00	B
1	4 oz	Nichrome wire, #24	02249	Frey	\$13.40	\$13.40	B
1	4 oz	Nichrome wire, 30 ga	05186	Frey	\$19.40	\$19.40	B
2		No bubble solution	702-151	Rio Grande	\$10.29	\$20.58	B
1		Oven	703-014	Rio Grande	\$1,075.70	\$1,075.70	A
1		Overglaze spray	3125	Cline	\$17.50	\$17.50	B
1	box-10	Paper cup, 3 oz	142014GRV58	lasco	\$4.00	\$4.00	B
1	box-10	Paper cup, 6 oz	142019GRV58	lasco	\$39.50	\$39.50	B
1		Patina	1220	Cline	\$2.55	\$2.55	B
2		Pattern shears	621	Cline	\$32.45	\$64.90	A
4		Permanent marker, fine	2001	Cline	\$1.95	\$7.80	B
1	100 g	Phenyl salicylate	P0021	Flinn	\$10.85	\$10.85	B
1	box	Pickling solution	501-023	Rio Grande	\$8.64	\$8.64	B
1		Plastic tweezers	111-119	Rio Grande	\$18.86	\$18.86	A
1	box	Polarizing film	990226	Frey	\$18.50	\$18.50	A
2		Polarizing film	990228	Frey	\$11.95	\$23.90	A
1		Polisher/buffer	336-255	Rio Grande	\$349.76	\$349.76	A
3	qt	Polyurethane foam, flexible	102183YRW70	lasco	\$22.50	\$67.50	B
3	qt	Polyurethane foam, rigid	102186YRW70	lasco	\$19.95	\$59.85	B
1	500 g	Polyvinyl alcohol	P0154	Flinn	\$22.15	\$22.15	B
1	pk	Pyrex glass	GP9010	Flinn	\$6.85	\$6.85	A
1	pk	Resin dye	107091ORV34	lasco	\$4.95	\$4.95	B
2	sets	Ring stand with rings	S-78370	Sargent-Welch	\$25.50	\$51.00	A
2		Rubber mixing bowl, 4 qt	702-132	Rio Grande	\$17.35	\$34.70	A
12		Rubber sprue base	702-315	Rio Grande	\$5.19	\$62.28	A
2		Running pliers	2127	Cline	\$21.60	\$43.20	A
24	ea	Safety glasses	FGC07096	Frey	\$4.95	\$118.80	A
1		Sal amoniac	2560	Cline	\$4.70	\$4.70	B
1	pk	Scoop	12782	Frey	\$12.95	\$12.95	A
1	25 ml	Sebacoyl chloride	S0284	Flinn	\$33.55	\$33.55	B
1	set	Sieve	66030-01	Science Kit Boreal	\$56.00	\$56.00	A
2	qt	Silastic "E" RTV silicone rub	102027ORX84	lasco	\$24.50	\$49.00	B
1	can	Silicone mold release	104019YRX04	lasco	\$3.95	\$3.95	B
2		Sinker mold	1820500RY27	lasco	\$22.95	\$45.90	A

Resource Appendix

Qty	Unit	Description	Order #	Vendor	Cost	Extension	Code
1	12 kg	Sodium carbonate	S0309	Flinn	\$41.10	\$41.10	B
1	500 g	Sodium hydroxide	S0075	Flinn	\$11.50	\$11.50	B
1	20 g	Sodium polyacrylate	W0013	Flinn	\$8.90	\$8.90	B
2	lb	Solder	1000	Cline	\$6.60	\$13.20	B
4		Soldering iron with stand	2514	Cline	\$31.20	\$124.80	A
2		Spatula, large	57940-141	Sargent-Welch	\$15.00	\$30.00	A
25	sq ft	Stained glass		Cline	\$6.00	\$150.00	B
18		Stainless flask	702-360	Rio Grande	\$3.58	\$64.44	A
2	ea	Stainless spatula	702-141	Rio Grande	\$10.83	\$21.66	A
2		Stainless steel beaker	13973-047	Sargent-Welch	\$21.30	\$42.60	A
2	pk-6	Steel ball, 6 mm	02636	Frey	\$1.55	\$3.10	A
12		Steel wheel cutter	1901	Cline	\$3.85	\$46.20	A
2	box	Stir stick	142031GRX3	Iasco	\$3.75	\$7.50	B
1	pk	Stirring rod	20078	Frey	\$2.75	\$2.75	A
12	ea	Striker	S-13095	Sargent-Welch	\$2.00	\$24.00	A
12		Thermometer, 110°C	S80035-10B	Sargent-Welch	\$3.10	\$37.20	A
1	100 g	Thymol	T0030	Flinn	\$14.90	\$14.90	B
2	500 g	Tin	T0015	Flinn	\$74.80	\$149.60	B
1	btl	Toluene	T0019	Flinn	\$7.31	\$7.31	B
12	ea	Tongs	S-82125	Sargent-Welch	\$3.40	\$40.80	A
1		Tongs, long	62453-004	Sargent-Welch	\$42.00	\$42.00	A
12	ea	Tweezers	00571	Frey	\$1.45	\$17.40	A
1	500 g	Urea	U0003	Flinn	\$6.75	\$6.75	B
1	ea	Variac	62546-261	Sargent-Welch	\$162.00	\$162.00	A
2		Wax-forming tools	700-810	Rio Grande	\$33.55	\$67.10	A
1		Wax, modeling	700-124	Rio Grande	\$31.94	\$31.94	B
1	box	Wax, sprue	700-741	Rio Grande	\$11.59	\$11.59	B
1	100 g	Yttrium oxide	Y0007	Flinn	\$133.00	\$133.00	B
2		Zam	331-124	Rio Grande	\$10.75	\$21.50	B
2	500 g	Zinc	Z0003	Flinn	\$10.80	\$21.60	B
1	500 g	Zinc stearate	Z0018	Flinn	\$33.85	\$33.85	B
1	100 g	Zinc, granular	Z0028	Flinn	\$6.90	\$6.90	B

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Journals

Advanced Composites. 7500 Old Oak Blvd., Cleveland, Ohio.

Aerospace America. 370 L'Enfant Promenade, S.W., Washington D.C.

Aviation Week. P.O. Box 503 Hightstown, New Jersey.

Compressed Air. 253 E. Washington Avenue, Washington, New Jersey.

Discover. Newsstand Publication.

Engineering Design. DuPont Co., External Affairs, Attn: Engineering Design, Room N-2400, Wilmington, Delaware.

Heat Treating. 191 S. Gary Ave., Carol Stream, Illinois.

High Technology. P.O. Box 2808, Boulder, Colorado.

Materials News. Dow Corning, Midland, Michigan.

"NASA SPINOFF" Technology Utilization Division, Office of Commercial Programs, P.O. Box 8757, Baltimore-Washington International Airport, Baltimore, Maryland.

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National Geographic. P.O. Box 2895, Washington, D.C.

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Note: Numerous books exist on all levels of stained glass expertise, too many to list. Your local stained glass supply outlet will have a good selection or resources. Select patterns and/or project books your students will enjoy working with.

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Business Resources

The following businesses have supported the MST program with free information.

ALCOA

Spokane, Washington
(509) 663-9278
Publication: Company Brochures

Bethlehem Steel

(215) 694-5906
Publication: Company Brochures

Cab-o-Sil

Cabot Corporation
Tuscola, Illinois
(800) 222-6745
Publication: Company Brochure
Product: Cab-o-sil

Corning Incorporated

Corning, New York
(607) 974-8271
Publication: Glass Brochures

Compressed Air

A Division of Ingersoll-Rand Co.
Washington, New Jersey 07882
(908) 850-7817
Publication: Compressed Air Magazine

Dow-Corning

Midland, Michigan
1-800-248-2481
Publication: Materials News

Battelle, Pacific Northwest Laboratories

Richland, Washington
(509) 375-2584
Publication: Profile

Schott Glass Technologies, Inc.

Duryea, Pennsylvania
(717) 457-7485
Publication: Company Brochures

Videos

This brief list of videos have been used in the MST classroom. Many other excellent videos may be available from your school media center, local libraries, and local industries.

Bureau of Mines, Audiovisual Library, Cochrans Mill Road P.O. Box 18070, Pittsburgh, Pennsylvania 15236, (412) 892-6400

Celebration of Light, The Making of Waterford Glass, Waterford Crystal, Inc., Waterford Wedgewood, USA, Belmar, New Jersey, (201) 938-5900

Steuben Glass, Corning Glass, Corning New York, 1-800-235-2357.

Superconductors, Public Broadcasting Network, New York.

Copper, Boron, Platinum, Silver, Gold in Modern Technology, Out of Rock - Minerals Extraction -Uses-Loss-Recycling, National Bureau of Mines Films.

Materials - Engineering the Future, American Society of Materials (ASM) International, Materials Park, Ohio, 44073, (216) 338-5151.

Miracle by Design, Dubs Inc., 1220 N. Highland Ave., Hollywood, California 90038, Facsimile (213) 466-7406.

Spectrum Glass, Spectrum Glass Company, Woodinville, Washington.

Potpourri Video #1, Race Against Time, The Challenge of Manufacturing, The New Engineers, The Junior Engineering Technical Society (JETS), 1420 King St, Suite 405, Alexandria, Virginia 22314-2715.

Potpourri Video #4, The Observatories, Search for Tomorrow, What About Tomorrow, Superconducting Super Collider, Applying Aerospace Technology, Satellites and the Space Shuttle: What Keeps them Up?, The Junior Engineering Technical Society (JETS), 1420 King St, Suite 405, Alexandria, Virginia 22314-27.

Meet the Engineers, Vol 3, The Junior Engineering Technical Society (JETS), 1420 King St, Suite 405, Alexandria, Virginia 22314-2715.

Not Your Usual Field Trips (Plastics), Society of Plastic Engineers, 14 Fairfield Dr. Brookfield, CT 06805-0403, Phone: (203) 775-0471; Fax (203) 775-8490.

Engineering a Brighter Future for Yourself, American Society of Materials (ASM) International, Materials Park, Ohio 44073, 1-800-336-5152

Owens Corning Fiberglass, Corporate Production, Inc., 4516 Mariota Avenue, Toluca Lake, California 91602.

Manufactured Fibers, American Manufacturers Association Inc., 1150 17th St NW, Washington D.C., 20036.

Lost Wax Casting with Kerr, order no. 260-3210 (\$57.25), Gesswein, 10031 South Pioneer, Santa Fe Springs, California 90670, 1-800-949-5480, Facsimile (310) 942-7308.

Ordering the Space Shuttle Tile

The ceramic space shuttle tile used by NASA to shield the space shuttle from the atmosphere's fierce re-entry heat is available to schools for the cost of shipping the tile (about \$10.00, cash on delivery). The tile must be used for educational purposes only.

To order the space shuttle tile send a letter, like the sample below

Lyndon B. Johnson Space Center
Attn: Eileen Bellmyer
Mail Code JF34
Houston, TX 77058

Dear Ms. Bellmyer:

I understand that our school can receive space shuttle tiles from your office for educational purposes. I am sure these items would instill an interest in science and the space program in our students. If these are available please send them to the address below.

Lincoln Community High School
Attn: Mary Allen
320 South Lane
Learned, IL ZIP007
(509) 555-1212

Thank You,

Lynn B. Jones
Principal
Lincoln Community High School

The tile will be shipped Federal Express collect unless otherwise notified; therefore, make sure the correct street address of the school where someone (school office perhaps) will be present during the working day to pay for the shipping costs.

Before NASA will ship the space shuttle tile, they will call your school principal to ensure the request is legitimate. The tile will become school property and be used for school functions only. It generally takes 6 to 8 weeks for the entire process to be completed. If you encounter problems or need some questions answered call Eileen Bellmyer at (713) 483-7965.

Innovative Materials, Processes, and Products Developed by Battelle Memorial Institute*

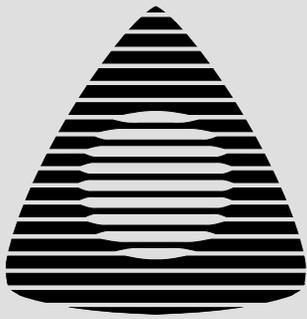
Advanced materials and innovative chemical processes are often required to help solve environmental, energy, and industrial problems. First known for its materials research and development, Battelle has been involved in developing innovative new products, processes, and technologies for more than 60 years. Battelle scientists, engineers, and technologists have worked with metals and their alloys, polymers, ceramics, and composites to create new and improved materials and develop cost efficient processes for forming and fabricating materials. Battelle continues to be a leader in this field. A sampling of Battelle's materials-related project achievements are highlighted below.

- an antimagnetic and rustproof alloy for watch springs, later found to be of value in a mechanical heart valve (1935)
- production of zirconium, titanium, and other reactive metals in pure form through an iodide method (1940)
- a study leading to U.S. Mint production of sandwich coins—coins from a copper core with copper-nickel cladding (1965)
- preparation of ceramic teeth to be implanted in human jaws (1970)
- coating for Titleist golf ball that keeps it from splitting (1976)
- a concrete joint that can withstand the stress of a severe earthquake (1978)
- a device to measure and evaluate the impact resistance of laminated glass (1978)
- an instrument that uses laser-produced X-rays to determine quickly the chemical structures of a variety of metals and other materials, some that could not be easily determined by other methods (1980)
- a general purpose, fire-retardant paint for submarines that doesn't emit harmful vapors while drying (1981)
- hot-corrosion and erosion-resistant coatings that reduce corrosion problems in gas turbines and diesel engines caused by alternative fuels (1984)
- a clear scratch- and abrasion-resistant coating to protect automobile surfaces (1985)

*Battelle Memorial Institute operates Pacific Northwest National Laboratory for the U.S. Department of Energy.

- a hydrothermal processing technique that produces paint pigments with greatly improved properties (1987)
- biodegradable packages that are clear, strong , and inexpensive (1988)
- materials for magnets to power a superconducting supercollider (1989)
- ceramic space fabrics comparable in strength to steel and aluminum that weigh only one-tenth as much (1990)
- anti-static packaging materials for shipping computers (1991)
- optical digital recording (1991)
- biodegradable plastic made from chemically modified natural products such as wood cellulose or cotton fibers (1991)
- aerogel, a lightweight insulator that looks like frozen smoke and doesn't produce CFCs that will be used in refrigerators (1992)
- coating technology for Dow Chemical Company's "smart" windows, which control solar radiation coming into buildings (1993).

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Sample Experiments/ Demonstrations

