This instructor's resource component contains a number of classroom demonstrations and laboratory experiments as a resource for instructors of introductory (as well as more advanced) materials science and engineering courses. The laboratory experiments and the classroom demonstrations are listed separately and within each list they are arranged by appropriate book chapter(s) and, on occasion, an experiment/demonstration is listed more than once. There is also a "General and Design of Experiments" category for experiments and a “General” category for demonstrations that contain demonstrations/experiments that address topics of a more general nature that are not directly coupled with the content of any specific book chapter.

Most demonstrations/experiments were presented as papers at the annual National Educators' Workshop--Standard Experiments in Engineering Materials, Science, and Technology, and appear in the proceedings of same; reference to one of these proceedings is abbreviated as "NEWU" (for National Educators' Workshop Update) and includes the workshop year (as two digits). We have included demonstrations/experiments that were presented at the 1988 through 1999 Workshops; this list will be updated periodically.

Those demonstrations/experiments presented at Workshops between 1988 and 2000 are available on a CD-ROM: EMSET CD-ROM version 2.0 by James A. Jacobs, which may be purchased from Prentice-Hall, Inc. (ISBN 0-13-030534-0); it is compatible with both Windows and Macintosh systems. In the list of demonstrations/experiments, reference to the CD-ROM is "EMSET." A number of these demonstrations/experiments also appear as papers in The Journal of Materials Education (J. Mater. Educ.) and are so referenced. We have included a brief description of each demonstration/experiment.
LABORATORY EXPERIMENTS

GENERAL AND DESIGN OF EXPERIMENTS

"The Use of Computers in a Materials Science Laboratory," J. P. Neville, NEWU 88, pp. 31-33 and EMSET. This paper discusses a technique that may be used to capture and store photomicrographs using a computer.

"MST Online: the Design of an Internet Gateway for Educational Resources in Materials Science and Technology," S. Raj Chaudhury, Matthew Sanders, Curtiss Wall, and James A. Jacobs, NEWU 99, pp. 463-473. This paper describes a web site that has been established along with its design philosophy and methodology. Included on the site is a list of instructional resources as well as useful links to other sites.

http://mst-online.nsu.edu

"Experiments and Other Methods for Developing Expertise with Design of Experiments in a Classroom Setting," John W. Patterson, NEWU 89, pp. 119-131. This paper describes available techniques to teach students how statistical methods may be used to design experiments. These techniques include mechanical simulations, computer simulations, and hands-on, in class exercises using simulated data.

"Demonstration of a Simple Screening Strategy for Multifactor Experiments in Engineering," Larry Panchula and John W. Patterson, NEWU 90, pp. 233-251 and EMSET. This paper outlines one technique (linear screening) used in designing experiments which is able to distinguish between those controllable variables that are important and those that are of little consequence. The technique is then applied to the design of a paper helicopter.

"An Innovative Multimedia Approach to Laboratory Safety," M. B. Anderson and K. P. Constant, NEWU 95, pp. 19-22 and EMSET. This software is an interactive safety tutorial that instructs and then tests the user as to laboratory safety precautions and procedures.

"Process Capability Determination of New and Existing Equipment," H. T. McClelland and Penwen Su, NEWU 93, pp. 187-193 and EMSET. This paper discusses a technique that is used to determine the process capability of new equipment, existing equipment, and testing laboratories. It also illustrates a method of objectively determining wear and other changes in equipment that is used for small quantity runs over a period of time. One example of the application of this technique is provided.

"Computer Integrated Laboratory Testing," Charles C. Dahl, NEWU 91, pp. 363-365 and EMSET. This paper describes how the computer may be used to collect experimental data, which data may be imported to a spreadsheet and ultimately displayed in tabular or graphic form. Two examples were cited: determination of alloy composition by measuring its cooling curve and consultation of the appropriate phase diagram; and determination of elastic modulus and other tensile properties from stress-strain tests.

"Using Experimental Design Modules for Process Characterization in Manufacturing/Materials Processes Laboratories," Bruce Ankenman, Donald Ermer and James A. Clum, NEWU 93, pp. 171-183 and EMSET. This paper describes modules that have been developed and tested in
two laboratory courses that deal with statistical experimental design, process modeling and improvement, and response surface methods. Each module is used as an experiment with the intention that subsequent experiments will employ statistical experimental design methods to analyze and interpret the data.

"Structural Laboratory Manual," Jack Kayser, NEWU 97, pp. 541-601. This paper consists of a laboratory manual that serves as a guide for eleven experiments performed in a civil engineering structural design course. The experiments are as follows: (1) Properties of Metal in Tension; (2) Evaluation of Bolts and Bolted Connections; (3) Flexural Beam Test; (4) Compressive Strength of Columns; (5) Evaluation and Testing of Welded Connections; (6) Material Properties of Balsa Wood; (7) Selecting Proportions for Normal Weight Concrete; (8) Mixing, Testing and Casting of Fresh Concrete; (9) Mechanical Properties of Concrete; (10) Batching and Testing of Mortar Specimens; and (11) Testing and Evaluation of Coarse Aggregate.

"Five Experiments in Materials Science for Less Than $10.00," F. Xavier Spiegel, NEWU 91, pp. 263-266 and EMSET. (1) When an age hardened aluminum nail is heated in an oven at 600°F for one hour, it will become soft (i.e., overaged) and may be bent by hand. (2) Pennies minted in the US since 1982 are zinc that has been electroplated with copper. It is possible to reveal the zinc by scratching off the copper coating. (3) When any US penny other than those minted in 1943 is heated in an oven at temperatures between 350°F and 400°F for about an hour, the surface will take on a golden tint, that may be removed by polishing. (4) Heating a US penny that was minted since 1982 at 700°F for about an hour will cause the zinc grains to experience grain growth. Bending such a penny will cause twinning to occur, and an attendant crackling noise (i.e., acoustic emission) that may be heard. (5) The phenomenon of fatigue may be demonstrated by repeatedly bending a paper clip back and forth until it fails.

"Structure, Processing and Properties of Potatoes," Isabel K. Lloyd, Kimberly R. Kolos, Edmond C Menegaux, Huy Luo, Richard H. McCuen, and Thomas M Regan, NEWU 91, pp. 331-359, EMSET, and J. Mater. Educ., Vol. 14, p. 103 (1992). Thermodynamic and mechanical behaviors of potatoes are investigated as they are processed (i.e., cooked) in both boiling water and a microwave oven. Cellular structural changes that occur during cooking are monitored by staining the potato specimens with potassium iodide. Specific heat and compressive strength are measured on the raw potatoes and also during various stages of cooking; alterations of these property values are related to changes in cell structure. Microwave cooking and boiling techniques are compared relative to rate of cell structure alteration and energy consumption.

"Incorporating 'Intelligent' Materials into Science Education," Robert J. Scheer, NEWU 94, pp. 147-157 and EMSET. This paper describes several hands-on, discovery type experiments students perform themselves and that involve polymeric materials. These experiments are inexpensive, use "intelligent" materials, and detection devices are the students' senses of sight and touch. Examples of these experiments include: plasticizer gradients in polyvinyl chloride, a shape memory polymer--polynorborene, and surface wettability gradient of polystyrene.

"Teaching the Principles of Materials Science Using Our Natural Surroundings: Spider Silk," Robert J. Scheer, NEWU 99, pp. 515-518. This paper first compares the mechanical properties of spider dragline silk with kevlar, rubber, and tendon material. It then goes on to
discuss molecular structures that give rise to silk materials that have different mechanical characteristics. Students may sense mechanical behavior by pulling on a test frame onto which rubber bands are mounted. Differences in mechanical behavior may be demonstrated by altering the number of attached rubber bands.

"Dimensionless Fun With Foam," Edward L. Widener, NEWU 94, pp. 69-71 and EMSET. Each of several transparent containers (e.g., beakers, jars, bottles) that have a variety of diameters and heights is filled with a vertical stream of water; temperature and velocity are maintained constant. When water overflows the container top, flow of water is abruptly shut off. A head of foam forms which subsequently subsides such that the container is not completely full. The final height of water in the container and also the water's free-fall distance from the water facet to the bottom of the container are measured. Other tests are also conducted for which, in addition to jar shape, other experimental parameters (e.g., free-fall distance, fluid velocity, fluid type, temperature) are varied; for each test the water height is measured. A dimensional analysis is conducted using those variables that have a significant effect; consideration is to be give to fluid geometry, motion, forces, etc.

"An Inexpensive 2732°F Miniature Electric Furnace for Teaching Materials Science," Luke Ferguson and Thomas Stoebe, NEWU 98, pp. 43-63. This paper describes the design and construction of an inexpensive (~200 $US) furnace that has a relatively high temperature capability (1500°C maximum and 1400°C continuous operation). An SiC heating element is used in addition to three layers of different insulating materials; muffle dimensions are 2 in. x 2 in. x 2 in. Power input as well as inner and outer wall temperature computations are made, which are in relatively close agreement with measured values.

"Teaching Statistical Quality Control and Process Analysis in [a] Materials Laboratory," Neda S. Fabris, NEWU 98, pp. 67-72. The first portion of this paper defines and explains statistical quality control charts and parameters—viz. mean, \( \bar{x} \), \( R \), \( p \), and \( c \) charts, dimensional tolerance, standard deviation, natural tolerance limit, three-sigma, six-sigma, upper specification limit, lower specification limit, machine capability potential index, and machine performance index. Using a micrometer, students measure diameters of a number of specimens at three different positions. Using these data, mean and standard deviation values are computed, as well as the machine natural tolerance value. Maximum part tolerances corresponding to six-sigma and three-sigma quality production are then determined and compared.

"Simulating Optical Correlation on a PC," Bret F. Draayer, NEWU 98, pp. 297-310. In this paper is explained how to use inexpensive and commercially available equipment to simulate optical correlation on a computer. Also discussed is how to design and construct a specific composite filter known as the equal correlation peak synthetic discriminant function. Simulations are used to demonstrate characteristics of this filter, and its ability to provide rotationally invariant responses in a coherent optical correlator.

"Four Windows Programs for the Materials Science Laboratory," Mike L. Meier, NEWU 99, pp. 199-204. This paper discusses computer software that may be used to simplify data analysis for four materials laboratory experiments: Heyn's method (for estimating average grain size), point count (for estimating the phase volume fraction in a multiphase material), the Jominy
end-quench test (for determining the hardenability of steels), and the observation of magnetic $B$-$H$ curves (using Audio Scope).

"Design Project for the Materials Course: To Pick the Best Material for a Cooking Pot," Kopl Halperin, NEWU 90, pp. 21-29 and EMSET. In this exercise students are to select a material for a common saucepan. In two previous experiments the heat conduction and corrosion characteristics of a number of saucepan materials were determined. From a list of materials used for saucepans, each student team is to select his/her preferred material and conduct a library search on at least one other property. Justification of the decision is to be defended in an oral presentation.

"Density by Titration," Raymond Bruzan and Douglas Baker, NEWU 94, pp. 572-577 and EMSET. The density of a polyethylene barrel component of a ball-point pen is determined using two techniques: titration and displacement. The density of the polyethylene lies between the densities of water and ethanol. For the titration method, a section of pen barrel is placed in a bath of ethanol of known mass and volume. Water is titrated into the bath until the pen barrel just becomes buoyant. Density of the pen barrel is equal to the density of the ethanol-water solution which may be determined from the solution's mass and volume.

For the displacement technique, a pen barrel section is weighed (massed), which section is then placed in a bath of ethanol; barrel volume is equal to the volume increase of the ethanol bath. Barrel (polyethylene) density is computed from these measured mass and volume values, which is compared to the titration value as well as the manufacturer-reported density.

CHAPTER 1
INTRODUCTION

"Introductory Materials Lab," Sayyed M. Kazem, NEWU 90, pp. 305-308 and EMSET. This paper describes laboratory activities that may be used to acquaint the beginning engineering student with various materials, their important properties, and how these properties are measured. These activities include investigating the following phenomena and properties: fracture, hardness, specific gravity, thermal conductivity, heat capacity, melting temperature, and corrosion/oxidation.

CHAPTER 3
STRUCTURES OF METALS AND CERAMICS

"Exploring the Crystal Structure of Metals," Richard P. Krepski, NEWU 94, pp. 497-501 and EMSET. Students generate close-packed planes of atoms using magnetic marbles. Next, face-centered cubic and hexagonal close-packed crystal structures are generated using close packed planes of these marbles that are glued together using spray craft glaze. The difference in mechanical properties for metals having these two crystal structures is demonstrated using a simple impact test: rods of aluminum and zinc that are supported at their ends are impacted with a hammer, and the difference in response is noted and explained on the basis of crystal structure. Amorphous structures are also demonstrated using the magnetic balls.
"Crystal Models for the Beginning Student," F. Xavier Spiegel, *NEWU 90*, pp. 31-44, *EMSET*, and *J. Mater. Educ.*, Vol. 14, p. 375 (1992). In this exercise atomic arrays for a number of common crystal structures may be generated. Model kits consist of spherical balls into which have been drilled diametrical holes. Arrays of vertical rods are mounted in base plates; baseplate pattern layout will be different for the various crystal structures. Students construct crystal structure models by placing balls on the appropriate rods and within appropriate interstitial sites.

"Crystal Models for the Beginning Student: An Extension to Diamond Cubic," Harvey A. West and F. Xavier Spiegel, *NEWU 94*, pp. 441-449, *EMSET*, and *J. Mater. Educ.*, Vol. 16, p. 283 (1994). This paper describes how the diamond cubic crystal structure may be generated using the same template as for body-centered cubic. For diamond cubic, the insertion of spacers—small diameter rods (e.g., straws)—is necessary. Placement of holes in the base-plate layout and the location of spacers are also included.


"Crystal Growing," J. P Neville, *NEWU 88*, pp. 35-36 and *EMSET*. Crystals of Epson salts are grown from a water-salt solution; their structures are noted. Next, a copper-aluminum alloy is melted; the crystals that form both during cooling and after solidification is complete are observed.

"Crystal Growth," Merrill Rudes, *NEWU 98*, pp. 291-294. This paper explains how crystals of phenyl salicylate may be grown from a melt, and how crystals of silver nitrate are produced by a chemical reaction.

"Symmetry and Structure Through Optical Diffraction," Jennifer Gray and Gretchen Kalonji, *NEWU 93*, pp. 491-497 and *EMSET*. In this experiment students, using diffraction of light, make correlations between x-ray diffraction, symmetry, and atomic structure. The experimental apparatus consists of a light bench and an optical laser. Using various computational tools, students create two-dimensional patterns that are made into slides. Using the optical bench both the image and diffraction pattern are observed. In addition, two-dimensional slices of common crystallographic structures are studied in a like manner.

"The Characterization of Materials Using X-Ray Diffraction," A. F. Sprecher, Jr., H. A. West, and A. A. Fahmy, *NEWU 92*, pp. 339-349 and *EMSET*. Students are provided with Debye-Scherrer diffraction patterns for several unknown elements, which have simple cubic, body-centered cubic, face-centered cubic or hexagonal close-packed crystal structures. After appropriate analysis of these patterns, each material is to be identified and precise value(s) of lattice parameter(s) is (are) to be determined.

"PC Laser Printer-Generated Cubic Stereographic Projections with Accompanying Student Exercise," Paul J. Coyne, Jr., Glenn S. Kohne, and Wayne L. Elban, *NEWU 94*, pp. 81-100 and *EMSET*. This paper describes a technique used to generate stereographic projections that employ a laser printer, a PC, and appropriate software. The program necessary for this
construction is also provided. The student is required to enter the coordinates of the central pole, and the coordinates and orientations of two other poles.

"Stereographic Projection Analysis of Fracture Plane Traces In Polished Silicon Wafers for Integrated Circuits," Wayne L. Elban, NEWU 94, pp. 103-121 and EMSET. The crystallographic orientation of silicon wafers is determined by performing a back-reflection Laue test in order to substantiate the orientation specified by the manufacturer. On wafers that have been broken, stereographic projection analyses are conducted on fracture plane traces in order to identify the crystallographic planes along which fracture occurs.

CHAPTER 4
POLYMER STRUCTURES

"Microscale Synthesis and Characterization of Polystyrene," Karen S. Quaal and Chang-Ning Wu, NEWU 93, pp. 221-237 and EMSET. Styrene specimens are polymerized using conventional laboratory techniques at constant temperature and using varying amounts of inhibitor. Number- and weight-average molecular weights are measured using a selective precipitation by thin layer chromatography technique. Two film casting techniques are used to produce thin films, and film thickness is measured using an interference fringe technique. Correlations for polymer yield-initiator concentration, molecular weights-initiator concentration, and molecular weight-film quality are explored.

CHAPTER 5
IMPERFECTIONS IN SOLIDS

"Bubble Rafts, Crystal Structures, and Computer Animation," James V. Masi, NEWU 94, pp. 415-419 and EMSET. A soap solution is prepared from a list of chemicals that is provided. Using a eyedropper and an aspirator bottle, bubbles having a uniform diameter of approximately 1 to 3 mm are blown into a glass dish. The following defects/processes may be generated and observed within this array of bubbles: grain boundaries, dislocations, vacancies, impurity atoms, slip, recrystallization, and annealing. Also, using a computer modeling program, each student is required to generate a crystal structure of his/her choosing.

"Measuring the Surface Tension of Soap Bubbles," Carl D. Sorensen, NEWU 91, pp. 391-395 and EMSET. A manometer is constructed using clear vinyl tubing (bent into a U-shape) and finely divided graph paper that are both mounted onto a masonite board. Into one end of the tubing is inserted the large end of a basketball inflation needle; a soap bubble solution is placed on the small needle end. As colored water is poured into the other end of the tubing, a bubble begins to form. That the pressure inside the soap bubble is greater than outside is demonstrated. Furthermore, the surface tension of the soap bubble is measured.

"Contact Angle Determination Procedure and Detection of an Invisible Surface Film," G. Meyer and R Grat, NEWU 88, pp. 13-26 and EMSET. The student is exposed to one technique used to measure the contact angle for a drop of liquid that lies on a planar solid surface. Furthermore, using this technique, an experiment is conducted wherein an invisible surface contaminant is detected.
"Effect of Temperature on Wetting Angle," Richard Brindos and Guna Selvaduray, NEWU 96, pp. 139-151. In this experiment the student determines the effect of temperature on the contact (or wetting) angle of molten solder on a solid copper substrate.

"Elementary Metallography," Sayyed M. Kazem, NEWU 91, pp. 57-64 and EMSET. This paper describes procedures (i.e., polishing and etching) used to prepare metal specimens for metallographic examination. Also described are four techniques that may be employed for making grain size measurements—viz., planimeter (Jeffries), intercept (linear and circular), and comparison.

"Microstructure Analysis (University and Industry Partnership)," Donald H. Martin and Gary L. Dawson, NEWU 90, pp. 45-52 and EMSET. Students first take a tour of the Dana Corporation—World Axle Development Center in which they visit the axle design and development, fatigue testing, sample preparation, and microstructural analysis facilities. Back at the university, instructions as to the preparation, examination, and evaluation of metallographic specimens are given. Two specimens that have been mounted and coarse polished are supplied to the students. They are do the final polishing and etching, and then conduct examinations using a metallurgical microscope; hardness tests are also performed. Students are then to identify the microconstituents in each of the two specimens.

"Computer Vision in Microstructural Analysis," M. N. Srinivasan, W. Massarweh, and C. L. Hough, NEWU 91, pp. 131-139 and EMSET. An apparatus is described that may be used to examine, record, and characterize microstructures. Components include a microscope, a CCD camera, and a computer onto which has been loaded image acquisition and analysis software. Phase ratio, grain size, and morphological microstructural characterizations are possible. Students use this apparatus to examine, for an Al-7% Si alloy, the effect of section thickness (i.e., cooling or solidification rate) on microstructure.

"Microchemistry and the New Scanning Electron Microscopes," Matthew J. Kasdan and Stephen K. Kennedy, NEWU 98, pp. 167-172. This paper describes a procedure that may be used to determine the composition of volcanic materials and how composition varies with plate tectonic setting. Data are collected using a scanning electron microscope and an energy dispersive x-ray analysis apparatus; data analyses may be conducted using computer software routines.

"Artificial Microstructures," Mike L. Meier, NEWU 98, pp. 279-287. This paper describes simple techniques for generating artificial and idealized micrographs. These artificial micrographs are generated using Adobe Photoshop, and grain and phase boundaries are clearly resolved. Analytical techniques may be used by students to measure average grain size, grain aspect ratio, phase volume fractions, etc.

"Artifacts in X-ray Diffraction Experiments," Bruce J. Pletka, Ruth I. Schultz Kramer, and Edward A. Laitila, NEWU 99, pp. 531-542. This paper first describes how the formation of non-equilibrium structures in the Pb-Bi system for relatively slow cooling rates may be demonstrated. It then goes on to show that choice of etchant used in preparation for metallographic examination may influence microstructural characterization results. This is
accomplished using x-ray diffraction tests, and, in addition, optical and scanning electron microscopic examinations.

"Use of Websem (Remote Scanning Electron Microscope) to Characterize Automotive Wear Debris," Stephen K. Kennedy and Michael Gaston, *NEWU 99*, pp. 599-604. In this experiment groups of students remove debris particles from automobile oil filters. Each group then analyzes a number of these particles using an SEM (backscattering electron imaging mode). Particle sizes are measured and particle morphologies are noted. EDS spectral analyses are also performed. Analysis comparisons are made among the several groups relative to correlation with vehicle age of particle number and particle size. Students are then to speculate as to specific automobile components from which the debris particles originated.

CHAPTER 6
DIFFUSION

"Experiments in Diffusion: Gases, Liquids, and Solids for Under Five Dollars," James V. Masi, *NEWU 97*, pp. 451-457. This paper describes how the diffusion phenomenon may be vividly demonstrated in a gas, a liquid, and a solid. Approximate values of the diffusion coefficients may be calculated for each of the three cases, which values are then compared.

"Determination of Oxygen Diffusion in Ionic Solids," Shad Thomas, Erin Hasenkamp, and Guna Selvaduray, *NEWU 96*, pp. 469-483 and *J. Mater. Educ.*, Vol. 19, p. 213 (1997). Activation energy and pre-exponential values are determined for the diffusion coefficient of oxygen through a zirconia oxygen sensor. The diffusion coefficient is computed from measured oxygen partial pressures on both sides of the sensor, as well as the current and voltage measured across the sensor.

CHAPTER 7
MECHANICAL PROPERTIES

Metals

"Design and Construction of a Tensile Tester for the Testing of Simple Composites," Mark A. Borst and F. Xavier Spiegel, *NEWU 93*, pp. 53-99 and *EMSET*. The relatively inexpensive apparatus described in this paper is constructed of the following: (1) a threaded rod mounted on a hand wheel, which, when turned, applies the tensile force; (2) laminated maple support beams that make up part of the frame; (3) steel support rods that are attached to the maple support beams; (4) an oak drive beam; (5) a load cell; (6) a rail assembly; and (7) a set of grips that are machined from aluminum onto which faces sheets of rubber are attached. Calibration and verification of accuracy are necessary. Furthermore, the apparatus also allows measurement of lateral displacement of the specimen as it is elongated. Tests are performed on aluminum fiber-transparent plastic matrix and glass fiber-transparent plastic matrix composites, and fibers are embedded at several different orientations. Data are collected and presented as force versus elongation, and lateral displacement versus elongation. Moduli of elasticity are determined for the several orientations, and value comparisons are made.
"An Affordable Material Testing Device," Nikhil K. Kundu and Jerry L. Wickman, NEWU 94, pp. 201-209 and EMSET. This paper describes the design and construction of an apparatus that may be used to perform the following tests: tensile, punching shear, column buckling, beam bending, and spring rate. A metal frame is constructed from channel iron pieces and threaded rods; load is applied using a hand-operated hydraulic power pack. Other accessory equipment is also necessary and must be built. Also described is the manner in which the several tests are conducted; and actual test data are plotted.

"Table-top Experiments for Material Property Determinations," R. E. Smelser, E. M. Odom, and S. W. Beyerlein, NEWU 99, pp. 169-186. This paper describes how tensile, bending, and torsion tests are conducted using table-top apparatuses. The design and construction of this equipment were a component of senior design projects conducted by undergraduate students.

"Egg Bungee Cord Drop," Robert A. McCoy, NEWU 99, pp. 207-212. In this design exercise, groups of students design, construct, and test bungee cord apparatuses. The apparatus consists of an egg contained in a plastic bag that is attached to a bungee cord. Groups of students compete to see whose egg, when dropped from a height of approximately 20 feet, comes closest to the floor without hitting it. Full-scale practice drops are not allowed; rather, students decide on cord length by conducting and analyzing static and dynamic drop data on short pieces (of lengths between 0.25 and 0.5 m).

"Measurement of the Modulus of Elasticity Using a Three-Point Bend Test," Richard B. Griffin and L. Roy Cornwell, NEWU 97, pp. 75-80. This paper describes a simple technique that may be used to measure the modulus of elasticity of various materials (viz. stainless steel, brass, graphite fiber-epoxy matrix composite) in three-point loading. Equipment required includes a bending fixture, a dial indicator, a micrometer, and weights (20 g to 200 g).

"A Device for Measuring the Elastic Modulus of Spherical Solids," Mtrook Al Homidany and Brian L. Weick, NEWU 97, pp. 515-524. Measurement of elastic moduli of spherical specimens is possible by measuring the contact diameter that is produced by pressing the spherical surface against a glass plate. The load is applied using a simple lever arm apparatus. Data are presented for two rubber materials.

"Learning More From Tensile Test Experiment," Neda S. Fabris, NEWU 97, pp. 169-182. Using results from tensile tests for metals, students are asked to generate true stress-true strain plots, compute strength coefficient and strain hardening exponent values, and estimate true toughnesses.

"Properties of Metals in Tension," Jack Kayser, NEWU 99, pp. 629-630. In this experiment, students perform tension tests on steel, aluminum, and cast iron specimens. Stress-strain data are plotted and the following mechanical properties are determined for each metal: ductility (both reduction of area and elongation), tensile and yield strengths, modulus of elasticity, and moduli of resilience and toughness.

of bend radius. These values are compared to ratios that are predicted using a mathematical model.

"Composite Column of Common Materials," Richard J. Greet, NEWU 91, pp. 105-107 and EMSET. Several aluminum soda-pop cans are collected and their tops removed. Plaster of paris that has been mixed with water is poured into some of the cans and allowed to set up for one to two days. Top rims and dished can bottoms are removed; aluminum skins are then cut and peeled from about half of these cans. Compression tests are then performed on at least one empty can, at least one plaster of paris core material, and at least one plaster of paris core-aluminum skin composite. Students are to observe the mode of failure for each, and also the load at which failure occurs. These results are then discussed.

"Measurement of Strain Rate Sensitivity in Metals," Y. Y. Yang and R. G. Stang, NEWU 90, pp. 91-99 and EMSET. Wires of 60Sn-40Pb solder are deformed in tension and at room temperature using five different crosshead speeds. A true stress-strain curve is generated for each strain rate. Logarithm of true stress versus logarithm of strain rate data are plotted, from which the strain rate sensitivity coefficient of the solder may be computed.

"It's Hard to Test Hardness," Edward L. Widener, NEWU 90, pp. 161-167 and EMSET. This paper explores some unconventional hardness testing techniques, and how their hardnesses compare with values measured using traditional techniques.

"A Novel Approach to Hardness Testing," F. Xavier Spiegel and Harvey A. West, NEWU 95, pp. 325-328, EMSET, and J. Mater. Educ., Vol. 17, p. 91 (1995). In this experiment a simple rebound time-measuring device is used to determine the relative hardnesses of a number of common engineering materials, and to develop relationships between rebound times and hardnesses.

"Scleroscope Hardness Testing," Patricia J. Olesak and Edward L. Widener, NEWU 93, pp. 453-455 and EMSET. The "elastic" and "plastic" hardnesses of several common materials are measured using a scleroscope hardness testing apparatus. Elastic hardness is determined by measurement of rebound height of a steel ball bearing that is dropped from an elevated position—plastic hardness by measuring the diameter of the dent that results. For aluminum, rebound heights are compared to hardness measurements made using an Equotip hardness tester.

"Application of Hardness Testing in Foundry Processing Operations: A University and Industry Partnership," Donald H. Martin and Bruce Lash, NEWU 92, pp. 223-232 and EMSET. The first phase of this experiment is a plant tour, wherein students are shown facilities that are used to precipitation harden commercial alloys. In the second phase, the instructor demonstrates indentation and hardness (Brinell) computation procedures. Students perform their own hardness tests, and then covert Brinell hardnesses to values in other hardness scales, and also to tensile strength. Limitations on hardness testing procedures are also discussed.

"The Underlying Structure of Engineering Materials," Mike L. Meier and Karl Ewald, NEWU 98, pp. 209-215. This paper presents a technique that may be used to tensile test a metal specimen while simultaneously video taping changes in its microstructure. One face of a tensile specimen (of annealed C26000 brass) is polished. After mounting in a tensile-testing
apparatus, a stereo-zoom microscope is mounted and focused on the specimen surface. During the tensile test, load-elongation data are recorded and saved to disk. The microstructure is simultaneously monitored and recorded using a video camera that is directed through the microscope. Video capture and processing techniques using a PC are described.

"Mechanical Properties of Brittle Materials," L. R. Cornwell and H. R. Thornton, NEWU 91, pp. 369-373 and EMSET. Using a three-point bending test, elastic moduli and moduli of rupture are measured for four different wood types. The strengths of glass slides each of which has a single surface scratch are measured, also in three-point bending. Three scratch orientations are used: parallel to the longitudinal specimen direction, parallel to the transverse direction, and at an angle of 45° to the longitudinal direction. Influence of scratch direction on strength is determined.

"Ceramic Fibers," Bruce M. Link, NEWU 89, pp. 181-184, EMSET, and J. Mater. Educ., Vol. 12, p. 449 (1990). An aluminum wire is stressed in tension to fracture; the tensile-testing apparatus consists of C clamps, a bucket, and weights that are placed in the bucket. Breaking strength is then calculated from the load and measured diameter. The longest of the two wire pieces is then tested and its breaking strength determined in the same manner. This procedure is repeated until the longest remaining fiber is too short to continue. A glass fiber is prepared; it and its fractured segments are tested in a similar manner and their fracture strengths are computed. Strength increase with decreasing length for both materials are to be compared, and the mechanism for each explained.

"Use of a Four-Point Bend Apparatus to Determine the Modulus of Elasticity," Richard B. Griffin, L. Roy Cornwell, Carlos Yapura, Sivasubramaniam Krishnan, and John Hallford, NEWU 98, pp. 155-163. Moduli of elasticity for three metal alloys and a unidirectional graphite fiber-epoxy composite are measured in four-point bending. The inexpensive experimental apparatus consists of a stainless steel bend fixture, a dial indicator, and a series of weights. Moduli are determined from force-deflection curves, which are in reasonably good agreement with literature values.

"In-Class Experiments: Piano Wire and Polymers," David Stienstra, NEWU 94, pp. 422-428 and EMSET. For the first portion of this experiment, three 100-150 mm lengths of 20 gauge piano wire are provided to each group of students. One length is kept in its as-received state (i.e., cold drawn); the other two are austenitized at 870°C for one hour, and one is quenched in water while the other is furnace cooled to room temperature. Students are to bend each wire, note the relative force required, and also the relative degrees of ductility. On the basis of these tests, students in each group discuss and come to conclusions as to possible processing techniques and microstructures of the three wires.

The second portion involves investigating the influence of strain rate on the mechanical characteristics of several polymeric materials: silly putty, six-pack rings, nylon cable ties, and splat balls. These items are deformed at different strains rates, and differences in behavior are noted, which are explored in terms deformation mechanisms and polymer structures.

Ceramics
"Adapting Archimedes' Method for Determining Densities and Porosities of Small Ceramic Samples," Gail W. Jordan, NEWU 90, pp. 175-181 and EMSET. This paper describes a procedure for accurately measuring the densities and porosities of small ceramic specimens, having masses on the order of 1 g.

"Mechanical Properties of Brittle Materials," L. R. Cornwell and H. R. Thornton, NEWU 91, pp. 369-373 and EMSET. Using a three-point bending test, elastic moduli and moduli of rupture are measured for four different wood types. The strengths of glass slides each of which has a single surface scratch are measured, also in three-point bending. Three scratch orientations are used: parallel to the longitudinal specimen direction, parallel to the transverse direction, and at an angle of 45° to the longitudinal direction. Influence of scratch direction on strength is determined.

"Observing and Modeling Creep Behavior in Wood," Thomas M. Gorman, NEWU 94, pp. 345-349, EMSET, and J. Mater. Educ., Vol. 16, p. 231 (1994). A wood beam is loaded in three-point bending, and center-point deflection is measured as a function of time at constant load. Several models have been proposed as to creep mechanism; for each, creep deflection and time are related by a power-law expression. From a logarithm of creep deflection versus logarithm of time plot, power-law constants may be determined, which provide insight as to mechanism of creep.

Polymers

"A Simple Experiment for Determining Elastic Properties of Polymers," P. K. Mallick and Subrata Sengupta, NEWU 99, pp. 491-498. This paper describes an experiment that may be used to measure the modulus of elasticity and Poisson's ratio of the plastic of which a two-liter soft drink bottle is made. The bottle is strain gauged and internally pressurized using a bicycle pump. The pressure-strain data are used to determine values of E and v.

"Simple and Inexpensive Method for Testing Shear Strength of Adhesive Bonds," L. Roy Bunnell, NEWU 99, pp. 299-302. This paper describes a technique that may used to measure the shear strength of an adhesive (e.g. epoxy). The adhesive is applied to the surface of a coarse-threaded 7/16 x 1-1/2 inches machine screw onto which a nut is threaded; the epoxy is then allowed to cure. Shear strength is expressed in terms of the torque required to move the nut; the twisting force is applied and torque measured using a common torque wrench.

"Determining Significant Material Properties, a Discovery Approach," Alan K. Karplus, NEWU 91, pp. 223-231 and EMSET. Eight tensile specimens are cut from a two-liter plastic (PET or PETE) beverage container. The axes of four specimens are taken in a circumferential direction around bottle; for the others their axes are parallel to the bottle axis. Two specimen "throat" widths are used--6.25 mm (1/4 in.) and 12.5 mm (1/2 in.). Four specimens are then tensile tested at each of two different deformation rates, and loads at which the first maxima occur are measured. Failed specimens are then examined and the influences of throat width and deformation rate on the shape and ductility are noted. A three-factor, two-level factorial design of experiments procedure is used to identify which of (1) specimen orientation, (2) throat width, and (3) stretch rate significantly affect the maximum load.
"Effect of Strain Rate on Tensile Properties of Plastics," L. R. Cornwell, R. B. Griffin, and W. A. Massarweh, NEWU 90, pp. 279-289 and EMSET. Polypropylene specimens at room temperature are tensile tested to fracture using a variety of crosshead speeds. Using the resulting data, stress-strain plots are generated, from which yield strength and elongation values are determined and plotted versus rate of crosshead motion.

"Tensile Test Experiments with Plastics," Michael G. Thorogood, NEWU 96, pp. 331-336. Tensile tests are conducted on several plastic materials at room and elevated temperatures. Heating of specimens is accomplished using a lamp.

"The Effect of Surface Finish on Tensile Strength," Julie Chao, Selene Curotto, Cameron Anderson, and Guna Selvaduray, NEWU 96, pp. 309-324 and J. Mater. Educ., Vol. 19, p. 199 (1997). Surfaces of tensile specimens of high-density polyethylene and low-density polyethylene are roughened with grooves either parallel or perpendicular to the longitudinal axis; sandpapers having three grit sizes are used. Tensile strengths of the specimens are measured and then correlated with degree of surface roughness and direction of roughening.

"Solving a Product Safety Problem Using a Recycled High Density Polyethylene Container," P. Liu and T. L. Waskom, NEWU 92, pp. 283-290 and EMSET. Students are provided one-gallon high-density polyethylene milk jugs and asked to determine whether or not they can safely contain a gallon of water or a gallon of mercury under normal working conditions. Maximum stress levels are computed for the situation in which the container holding the liquids is lifted, and also in terms of pressures (stresses) exerted on its walls (i.e., the hoop stresses) for the static (non-lifting) situation. Dog-bone shaped specimens are fashioned from a milk jug, and then tensile tested. On the basis of these tests and safety factors, product safety conclusions are drawn for the containment of both water and mercury.

"Dynamic Mechanical Analysis of Polymeric Materials," Kristen T. Kern, Wynford L. Harries, and Sheila Ann T. Long, NEWU 89, pp. 13-18 and EMSET. This paper describes a dynamic mechanical technique that may be used to measure glass transition and onset temperatures for polymeric materials. The oscillation of an electromagnetic driving mechanism flexes the specimen at constant amplitude and over a range of frequencies. Resonant frequency and mechanical damping are measured as functions of specimen temperature. These data are then converted to and plotted as flexural storage and loss moduli versus temperature; glass transition and onset temperatures may be determined from these plots.

"Laboratory Experiments from the Toy Store," H. T. McClelland, NEWU 91, pp. 161-168 and EMSET. The first portion demonstrates, using a silicone polymer ("silly putty" or "nutty putty"), elasticity and plasticity phenomena, and how they are influenced by temperature. The silicone polymer is rolled into a ball and dropped onto a rigid surface both at room temperature and also after the ball has been cooled in ice. Levels of elasticity and relative rebound heights are noted and compared. After forming the putty into a cylinder, it is slowly pulled in the lengthwise direction at room temperature and also after cooling in ice water. Degrees of plasticity (ductility) and deformation forces are noted and compared. This procedure is repeated when the cylinder is rapidly deformed.

For the second portion of the experiment, clay materials are extruded through extrusion presses that may be purchased at toy stores. The influence of extrusion speed is investigated; material movement during extrusion is also examined using two colors of clays.
"In-Class Experiments: Piano Wire and Polymers," David Stienstra, *NEWU 94*, pp. 422-428 and *EMSET*. For the first portion of this experiment, three 100-150 mm lengths of 20 gauge piano wire are provided to each group of students. One length is kept in its as-received state (i.e., cold drawn); the other two are austenitized at 870°C for one hour, and one is quenched in water while the other is furnace cooled to room temperature. Students are to bend each wire, note the relative force required, and also the relative degrees of ductility. On the basis of these tests, students in each group discuss and come to conclusions as to possible processing techniques and microstructures of the three wires.

The second portion involves investigating the influence of strain rate on the mechanical characteristics of several polymeric materials: silly putty, six-pack rings, nylon cable ties, and splat balls. These items are deformed at different strains rates, and differences in behavior are noted, which are explored in terms deformation mechanisms and polymer structures.

"Study of Rheological Behavior of Polymers," Ping Liu and Tom L. Waskom, *NEWU 97*, pp. 47-50. Influences of shear rate and temperature on the viscosity of recycled high density polyethylene containing 5% recycled tire particles are determined in this experiment.

"Inexpensive Experiments in Creep and Relaxation of Polymers," Kopl Halperin, *NEWU 94*, pp. 369-377 and *EMSET*. For both creep and relaxation tests, dog-bone specimens of various plastic materials are either procured or fabricated from available products (e.g., food containers, shower curtains, etc.). With creep tests, C-clamps support the specimens and weights from specimens. Length measurements are made as functions of time for the various plastics, from which strain-versus-time plots are constructed.

Relaxation tests are conducted using a tensile testing apparatus. For each specimen, a force is gradually applied to a predetermined level, at which time crosshead motion ceases; load is measured as a function of time, and data are plotted as stress versus time.

"Stress-Strain Characteristics of Rubber-Like Materials: Experiment and Analysis," David J. Allen, *NEWU 91*, pp. 301-305 and *EMSET*. A neoprene rubber band suspended by one end is stressed in tension to failure by suspending incrementally calibrated weights from its other end. Stress and strain values are determined and then graphed on a log-log plot. A linear relationship is observed which means stress is related to strain through power law expression. Power law constants are determined from this log-log plot.

"Rubberlike Elasticity Experiment," Richard Greet and Robert Cobaugh, *NEWU 89*, pp. 89-91 and *EMSET*. Load-deflection curves are generated for both green and white erasers (commercially available) that are stressed in compression for both loading and unloading cycles; students observe mechanical hysteresis for both curves. Engineering stress-strain curves are next generated from these data. Elastic moduli values are calculated using data taken along the center of the hysteresis loop. These values are then compared to those observed for metallic materials. Areas within the hysteresis loops are measured, which correspond to energy absorbed per unit volume of material for each load-unload cycle.

"Stretchy 'Elastic' Bands," Alan K. Karplus, *NEWU 97*, pp. 383-388. Rubber bands 3-1/2 in. long and having widths of 1/8 in. 1/4 in. and 1/2 in. are attached to a scale and then stretched to a total length of approximately 24 in. by hand and at a constant rate; load is measured at one inch intervals. The same procedure is following as the bands are unstretched. Load-
displacement and stress-strain curves are generated. Areas under both load and unload curves for each rubber band are approximated, the difference of which equals the energy absorbed per unit volume. Students are to explain differences in energy values for the three band widths.

"Stretchy 'Elastic' Bands II," Alan K. Karplus, *NEWU 98*, pp. 431-443. Four-, six-, twelve-, and eighteen-inch rubber band loops are made by cutting and then tying together (using square knots) number 33 rubber bands: two rubber bands are required for each of the four- and six-inch loops, four rubber bands for the twelve-inch loop, and six rubber bands for the eighteen-inch loop. Each of these loops is attached to a scale and stretched at a constant rate to a strain of 500%. The same procedure is following as the loops are unstretched. Load-displacement and stress-strain curves are generated. Areas under both load and unload stress-strain curves for each loop are approximated, the difference of which equals the energy absorbed per unit volume. Energy differences for the four loops are then compared.

"Stretchy 'Elastic' Bands III--Contaminant Effects," Alan K. Karplus, *NEWU 99*, pp. 315-328. Rubber bands in an "as received" state as well as rubber bands which have been coated with various substances (i.e., machine oil, castor oil, water, liquid hand soap, and talcum powder) are tensile tested: approximately constant loading and unloading rates are employed; furthermore, load and deflection values are measured during each test. Load-deflection plots are constructed, and the influences of the several surface coatings are ascertained by comparing the shapes of and the areas under these plots.

"Tensile and Shear Strength of Adhesives," Kenneth A. Stibolt, *NEWU 89*, pp. 115-117 and *EMSET*. This paper describes how a tensile-testing apparatus may be used to measure the tensile and shear strengths of adhesive materials.

"Mechanical Properties of Crosslinked Polymer Coatings," Jeffrey Csernica, *NEWU 93*, pp. 325-338, *EMSET*, and *J. Mater. Educ.*, Vol. 15, p. 249 (1993). In this experiment the influences of the crosslinking agent-primary resin ratio and curing temperature on the mechanical properties (and, thus, degree of crosslinking) of a polymer coating are investigated. Three different primary resin-crosslinking formulations are prepared; a hydroxyl-functional polyester and hexamethoxymethyl melamine are, respectively, the primary resin and crosslinking agent. Thin films of these three formulations are applied to steel panels and subsequently cured at temperatures ranging between 70°C and 190°C. Room-temperature hardnesses of these films are then measured by scratching with pencil leads having different hardnesses; film hardnesses are plotted as a function of curing temperature. (Knoop hardnesses may also by measured.) In addition, impact resistances of the films are measured using a drop-weight test; these are also plotted versus curing temperature.

"Knotty Knots," Alan K. Karplus, *NEWU 93*, pp. 369-372 and *EMSET*. Twenty three-foot long specimens of some type of string (e.g., fishline, thread, etc.) are prepared. Four are pulled (by hand) in tension to failure using a tubular scale (which measures the applied load); failure loads are recorded and averaged. This same procedure is repeated for situations in which four different types of knots are tied in the string centers. From these values, stress concentration factors may be determined for the various knot types.

experiment involves evaluating the cure state (i.e., degree of crosslinking) of an epoxy resin during a manufacturer-suggested cure cycle by monitoring the epoxy's dielectric properties. The appropriately prepared liquid resin is positioned within the sensor, which is situated within a curing oven. The dielectric response (i.e., product of dielectric loss and frequency) is measured during the curing cycle, and, when plotted versus temperature, completeness of cure may be ascertained.

CHAPTER 8

DISLOCATIONS AND STRENGTHENING MECHANISMS

"Bubble Rafts, Crystal Structures, and Computer Animation," James V. Masi, NEWU 94, pp. 415-419 and EMSET. A soap solution is prepared from a list of chemicals that is provided. Using a eyedropper and an aspirator bottle, bubbles having a uniform diameter of approximately 1 to 3 mm are blown into a glass dish. The following defects/processes may be generated and observed within this array of bubbles: grain boundaries, dislocations, vacancies, impurity atoms, slip, recrystallization, and annealing. Also, using a computer modeling program, each student is required to generate a crystal structure of his/her choosing.

"Mechanism of Slip and Twinning," Mansur Rastani, NEWU 91, pp. 235-243 and EMSET. Several features that result from slip and twinning phenomena are observed using a microscope. These include: (1) slip lines that appear on the surface of a copper specimen after it has been plastically deformed; (2) dislocation etch pits that are revealed on the surface of a sodium chloride crystal; (3) slip bands that appear on a polished surface of a polycrystalline mild steel that has been loaded in tension; (4) twin boundaries that are revealed on a brass specimen that has been polished and etched; and (5) twin bands on the surface of a deformed hexagonal close-packed metal specimen.

"Work-Hardening and Annealing in Metals," L. Roy Bunnell and Stephen W. Piippo, NEWU 89, pp. 179-180. Each student is given two pieces of bare copper wire. One is work hardened by bending and twisting; the phenomenon of work hardening is noted and discussed. The other is bent in the same manner, and one of the wires is heat treated (i.e., annealed). At this time both wires are twisted again, the relative required forces are noted, and the phenomenon of recrystallization is discussed.

"Testing Rigidity, Yield Point, and Hardenability by Torque Wrench," Edward L. Widener, NEWU 93, pp. 501-502 and EMSET. This paper describes demonstrations of rigidity, yield point, and strain hardening. For the first demonstration, a large-loop paper clip is gripped in a vise; using a fish scale the clip is twisted 90° in one direction and then 90° in the opposite direction. Strain hardening is represented by the difference in pull forces for the two deformations. Quantitative measurements are conducted in a similar manner on a rod of a ductile metal alloy that is twisted using a torque wrench. Elastic return after twisting through a small angle is noted. Next, torque values are measured at various angles of twist in one direction (as the rod is plastically deformed), and then in the opposite direction; torque values are now plotted versus twist angle.
"Some Experimental Results in the Rolling of Ni$_3$Al Alloy," Hui-Ru Shih and Vinod K. Sikka, *NEWU 95*, pp. 309-315 and *EMSET*. The rolling properties of a Ni$_3$Al are investigated, as well as the influence of heat treatment and grain structure on the ductility, hardness, and tensile properties.

"Improved Measurement of Thermal Effects on Microstructure," Mansur Rastani, *NEWU 92*, pp. 199-207 and *EMSET*. Incandescent light bulbs are lit for various times up to about 8 s, during which time the tungsten filaments experience recrystallization. After each thermal treatment, the coiled filament is stretched to a predetermined length and then allowed to elastically recoil; recoiled length is measured from which an elastic recovery factor is computed. Filament specimens are mounted, polished, etched, and from metallographic examination, degrees of recrystallization are determined. Correlations are drawn between elastic recovery factor and fraction of uncrystallized material.

CHAPTER 9
FAILURE

"Instrumented Materials Testing," Thomas J. Mackin, *NEWU 95*, pp. 199-216 and *EMSET*. This paper consists of a series of illustrations, tables, and lists relating to fracture, principles of fracture mechanics, and simple tests that may be used to study the fracture behavior of materials.

"Holy Holes" or "Holes Can Make Tensile Struts Stronger," Alan K. Karplus, *NEWU 96*, pp. 447-451. This experiment demonstrates that the load carrying capacity of a tensile strut for some materials (at constant cross-sectional area) will depend on the number of holes that pass through the strut, and, also, hole diameter.

"Studying Macroscopic Yielding in Welded Aluminum Joints Using Photostress," Kishen Kavikondala and S. C. Gambrell, Jr., *NEWU 94*, pp. 404-411 and *EMSET*. A dog-bone specimen is machined from a welded aluminum plate. The region surrounding the weld is abraded, cleaned, and both an adhesive and a photoelastic coating are applied. This specimen is mounted into a tensile testing apparatus that has been programmed to load in a predetermined sequence. During loading and at each sequence step, a color photograph of the weld junction is taken using a telemicroscope that is attached to a reflection polariscope. Strains may be measured at preselected regions near the weld from fringe patterns that have been photographed; these strains may also be converted into stress values. From these data, stress-strain curves may be generated at the several chosen locations.

"Fluorescent Penetrant Inspection," Sankar Sastri, *NEWU 88*, pg. 7 and *EMSET*. This experiment familiarizes the student with the fluorescent penetration technique for detecting surface cracks and defects.

"Magnetic Particle Inspection," Sankar Sastri, *NEWU 88*, pg. 9 and *EMSET*. This is an experiment that familiarizes the student with the magnetic particle inspection technique for detecting surface cracks, defects, and other discontinuities in ferromagnetic materials.
"Radiographic Inspection," Sankar Sastri, *NEWU 88*, pg. 11 and *EMSET*. This experiment familiarizes the student with the radiographic inspection technique for detecting cracks, porosity, hot tears, etc.

"Introduction to Nondestructive Testing," David E. Werstler, *NEWU 94*, pp. 75-78 and *EMSET*. This paper describes an experiment which uses ultrasonic testing, magnetic particle testing, and eddy current testing techniques to detect internal flaws in materials. Results of the ultrasonic technique are compared with a radiograph provided by the instructor. The acquisition of equipment at minimal costs is also addressed.

"Crater Cracking in Aluminum Welds," R. Carlisle Smith, *NEWU 93*, pp. 241-244 and *EMSET*. In this experiment, the student first performs a side weld in 6061-T6 aluminum. A second side weld is made in such a way as to fail. A dye penetrant is now applied, and any cracks that have formed may be observed with a black light.

"Isotropic Thin-Walled Pressure Vessel Experiment," Nancy L. Denton and Vernon S. Hillsman, *NEWU 91*, pp. 291-298 and *EMSET*. A thin-walled brass tube is mounted in an electromechanical test apparatus; internal pressure within the tube may be applied using a hydraulic system, and a strain rosette is installed on the tube outer surface. Strain is measured a function of pressure, and also as a function of tensile load (with and without the application of internal pressure). Principal strain values are calculated from measured strains; principal stress values may then be determined. From these data an empirical Poisson's ratio for the brass is computed and compared to the theoretical value. An empirical wall thickness is also determined which is compared to the actual wall thickness.

"An Automated Data Collection System for a Charpy Impact Tester," Bernard J. Weigman and F. Xavier Spiegel, *NEWU 92*, pp. 379-384 and *EMSET*. The heart of the automated data collection system described in this paper consists of a potentiometer that is connected to the pivotal point of the rotating hammer on the Charpy impact testing apparatus. Angular displacement of the hammer (the difference between initial and final pendulum positions) is measured by the potentiometer. Data are collected by a computer and energy absorption is determined. Apparatus calibration is necessary.

"An Automated Digital Data Collection and Analysis System for the Charpy Impact Tester," Glenn S. Kohne and F. Xavier Spiegel, *NEWU 93*, pp. 471-480 and *EMSET*. The accuracy and consistency of measurements made with the standard Charpy impact tester are improved by the incorporation of an automated data collection and analysis system. Pendulum position is monitored using an optical disc, a light source, and a detector. Signals from this system are fed to a computer that determines pendulum velocity and kinetic energy as functions of its position.

"Charpy V-Notch Impact Testing of Hot Rolled 1020 Steel to Explore Temperature-Impact Strength Relationships," Seth P. Bates, *NEWU 90*, pp. 129-135 and *EMSET*. Charpy V-notch measurements are made on hot rolled 1020 steel standard specimens at temperatures ranging between -193°C and 100°C. Subambient temperatures are achieved using liquid nitrogen, dry ice immersed in ethanol, ice, and ice-brine solutions. Water baths heated with a Bunsen burner are used for producing temperatures above the ambient. Data are plotted as impact strength versus temperature, which demonstrate the ductile-to-brittle transition for this alloy.
"The Anisotropy of Toughness in Hot-Rolled Mild Steel," Philip J. Guichelaar, NEWU 93, pp. 287-290 and EMSET. Modified Charpy V-notch impact test specimens are machined from hot rolled 1018 steel bar stock both parallel and perpendicular to the rolling direction. Specimens are tests for impact strength using a Charpy impact testing apparatus or an equivalent. Student reports discuss reasons for the anisotropic nature of the test results.

"Impact Testing of Welded Samples," Calvin D. Lundeen, NEWU 91, pp. 99-102 and EMSET. Students are to prepare and arc weld together bars of 1020 steel. Square, single-bevel, and double-bevel welds are to be made using a clamping fixture. Welded specimens are now inspected visually and classified as to quality—poor through excellent. Each sample (unnotched) is then tested for impact strength using a Charpy apparatus. The effects of single- and double-beveling on impact energy are observed, as is also the influence of weld quality.

"A Miniature Fatigue Test Machine," Steven M. Tipton, NEWU 92, pp. 139-146 and EMSET. This paper describes a relatively simple fatigue-testing apparatus in which wire specimens are deformed in bending. Stress state is difficult to quantify, which requires the use of simplifying assumptions. The author suggests that fatigue tests be conducted on various metal alloys, on steels that have been subjected to a variety of heat treatments, and using more than one stress amplitude in order to investigate the validity of Miner's rule.

"Paper Clip Fatigue Bend Test," Alan K. Karplus, NEWU 94, pp. 125-131 and EMSET. Fatigue tests are conducted on regular size paper clips. Three paper clips are each repeatedly bent through an angle of 45° and the numbers of cycles to failure are counted; an average of the three values is computed. This procedure is repeated for bend angles of 90°, 135°, and 180°. Data is plotted as bend angle versus number of cycles.

A jumbo paper clip is fatigue tested in the same manner and its data are plotted and compared to those of the standard size clip. Furthermore, tests may also be conducted on other materials (e.g., brass paper fasteners and aluminum welding rods).

"Accelerated Fatigue Test," Yulian Kin and Dennis Holler, NEWU 99, pp. 189-195. This paper describes a procedure that has been used to measure the fatigue behavior in a relatively short time period. Tests are performed on between 16 and 20 low-carbon steel specimens. A family for S-N curves are plotted for 5%, 50%, and 95% probabilities of failure. On the basis of these results, an accelerated test is designed and performed; these results are interpreted in terms of the cumulative fatigue damage concept.

"Case Hardening: An Activity to Demonstrate Brinell Hardness," C. Ray Diez, NEWU 97, pp. 347-350. The phenomenon of case hardening is demonstrated by measuring and comparing the surface hardness (Brinell) of both carburized and uncarburized mild steel specimens.

"An Automated System for Creep Testing," F. Xavier Spiegel and Bernard J. Weigman, NEWU 91, pp. 253-262 and EMSET. An automated data collection system is described that may be used to measure, analyze, and plot creep deformation versus time. This system consists of a PC, a 16 channel multiplexed A-D converter, and low-friction potentiometers. Creep tests are conducted at room temperature on 60 Sn-40 Pb solder.
"Case Studies in Metal Failure and Selection," David Werstler, *NEWU 97*, pp. 53-55. Teams of students are required to determine the causes of product failures, and then recommend failure prevention measures to include changes in materials that are used. Failure case studies presented in this paper are mountain bike frames, a tug driveshaft, and hammers for a glass pulverizer.

"Room Temperature Creep of Solder," Robert G. Stang, *NEWU 98*, pp. 367-377. This paper describes an experimental technique that may be used to perform room-temperature creep tests. The materials tested are solid core solder (Bi-Sn or Pb-Sn) wires. Specimen elongation is measured using a ruler or cathetometer. Insight as to mechanism may be ascertained by making tests at several stress levels.

**Ceramics**

"Ceramic Fibers," Bruce M. Link, *NEWU 89*, pp. 181-184, *EMSET*, and *J. Mater. Educ.*, Vol. 12, p. 449 (1990). An aluminum wire is stressed in tension to fracture; the tensile-testing apparatus consists of C clamps, a bucket, and weights that are placed in the bucket. Breaking strength is then calculated from the load and measured diameter. The longest of the two wire pieces is then tested and its breaking strength determined in the same manner. This procedure is repeated until the longest remaining fiber is too short to continue. A glass fiber is prepared; it and its fractured segments are tested in a similar manner and their fracture strengths are computed. Strength increase with decreasing length for both materials are to be compared, and the mechanism for each explained.

"Fracture of Brittle Solids," R. D. Doherty and S. K. Nash, *NEWU 88*, pp. 41-45 and *EMSET*. A tensile-testing apparatus is used to load glass microscope slides to fracture in a three-point bending jig. Tests are made on slides in the as-received state, and also slides that had been subjected to the following treatments: scored lengthwise and widthwise using 400 grit silicon carbide abrasive paper; etched in a 5% HF solution; and both scored and etched. For each group of slides, arithmetic mean, standard deviation, and standard error of the mean modulus of rupture values are calculated and compared.

"Fracture of Glass," John M. Henshaw, *NEWU 92*, pp. 353-358 and *EMSET*. Students examine the fracture behavior of glass and factors that affect the fracture strength using three-point bending tests. Two testing apparatus designs are described. Glass laboratory slide specimens in the following conditions are tested: as-received, annealed, acid-etched (using hydrofluoric acid), scratched on the top (compression) face, and scratched on the bottom (tension face). Average and standard deviation fracture strength values are determined; students are to explain any value differences among the several specimen types. The modulus of elasticity of glass may also be measured, and the phenomenon of static fatigue observed.

"Measuring the Weibull Modulus of Microscope Slides," Carl D. Sorensen, *NEWU 91*, pp. 397-406 and *EMSET*. Three-point bending tests are conducted on twenty five glass microscope slides; fracture loads are recorded from which fracture strengths (i.e., σ's) are determined. Fracture strengths are then ordered on the basis of magnitude, from which probabilities of survival (i.e.,
$P_s$'s) are computed. When $\ln(\ln(1/P_s))$ is plotted versus $\ln\sigma$, the slope of a straight line drawn through the data points yields the Weibull modulus value for these glass slides.

"Glass Fracture Experiment for Failure Analysis," Charles V. White and Kathryn Forland, NEWU 94, pp. 389-394 and EMSET. Each student group is provided a drinking glass with smooth sides. The glass is placed in one plastic bag which is sealed after the air has been removed. This parcel is then placed in a second plastic bag, and the students in the group are instructed to break the glass. After very carefully opening the bags the glass pieces are placed on a paper on a work table. After consulting reference material, students note the nature of fracture for each fracture surface and determine areas of fast and slow fracture. The glass is then reassembled using clear tape, after which each piece is examined with the naked eye and at low-power magnification. Each side of each piece is marked with an arrow that points in the fracture path direction, and also an "f" or an "s" to indicate whether the fracture mode was fast or slow.

"Tempered Glass," L. Roy Bunnell, NEWU 91, pp. 47-50 and EMSET. The procedure and theory of glass tempering are first discussed. A piece of car side window glass is obtained from a wrecking yard. A strong light is shined through a polarizing filter, then through the glass, and another polarizing filter situated on the far side. As one of the polarizing filters is rotated, a stress pattern that was created by air jets during tempering may be observed. The strength of this tempered glass sheet is demonstrated by supporting its ends on two pieces of wood and then standing on it. Time permitting, the students may be required to temper glass; molten droplets of Pyrex glass are quenched in water.

"The Effect of Surface Treatment on the Strength of Glass," Robert G. Stang, NEWU 96, pp. 201-210. Three-point bending tests are used to measure the modulus of rupture of glass rods that have been thermally tempered, annealed, annealed and surface damaged, and exposed to molten potassium nitrate. Influences of the various surface treatments may be ascertained by comparison of moduli of rupture.

"Evaluation of Chemically Tempered Soda-Lime-Silica Glass by Bend Testing," L. Roy Bunnell and Steve W. Piippo, NEWU 96, pp. 57-63. This experiment demonstrates that the bend strengths of common glasses may be improved by a cation exchange process conducted at an elevated temperature.

"Thermal Shock of Ceramic Materials," L. Roy Bunnell, NEWU 91, pp. 51-53 and EMSET. Several 3-mm diameter aluminum oxide rods are given to the students, who bend them until fracture. Another set of rods is heated to 500°C, and then quenched in water and dried. The next day, these rods are immersed in ink, which penetrates and reveals any surface cracks after any excess ink is removed. Students bend these rods to fracture, and note that their strengths are lower than the untreated set. Finally, the thermal shock index is discussed, and values for a variety of common ceramic materials are cited.

"Impact of Flaws on Strength," JoDee Daufenbach and Alair Griffin, NEWU 94, pp. 397-401 and EMSET. Test specimens are thin ceramic sheets (unfired) consisting of alumina powder and a polymer that have been fabricated by tape-casting. Two sets of specimens contain flaws having two different lengths; flaws are cut into the tapes using a laser. Control flaws are not
introduced into the third specimen set. Each specimen is clamped into a table-top test apparatus and then pulled in tension with a gradually increasing load until failure occurs. The regions of failure are examined, and average and standard deviation failure load values are compared for the three specimen sets; students are to explain value differences.

"How a Heat Pack Works," Robert A. McCoy, NEWU 97, pp. 159-166. Students explore the operation of a heat pack--i.e., heat is generated from the exothermic crystallization of supercooled sodium acetate trihydrate. Teams of students measure cooling curves for several activation temperature and surrounding temperature combinations.

**Polymers**

"Stress Concentration: Computer Finite Element Analysis vs. Photoelasticity." Vernon S. Hillsman, NEWU 94, pp. 173-176 and EMSET. Stress concentration analyses are performed on a transparent and birefringent plastic bar with a circular hole drilled through the center of its large faces and when a tensile load of 50 lb is applied. Three types of analyses are conducted and the results compared: finite element analysis, photoelasticity, and reference tables.

"Plastic Part Design Analysis Using Polarized Filters and Birefringence," J. L. Wickman, NEWU 93, pp. 355-360 and EMSET. A commercially available injection molded transparent/translucent plastic part, while being rotated, is examined using a polariscope. The presence of photoelastic fringe patterns indicates the presence and location of residual stresses. A tensile or compressive load is applied using a loading fixture, at which time stressed regions begin to take on color. Analysis of these fringes during loading can be used to locate various features of the molding apparatus (e.g., gates, parting lines, etc.) from which an isometric drawing of the part may be made. Whether or not the plastic part meets the design criteria specified by the manufacturer may be determined.

"Life Estimate Based on Fatigue Crack Propagation," Yulian Kin, Harvey Abramowitz, Toma Hentea, and Ying Xu, NEWU 97, pp. 371-380. Four-point bending fatigue tests are performed on polycarbonate sheets using three different stress intensity ranges. Fatigue crack propagation is monitored using a video camera. Plots of logarithm of crack growth rate versus logarithm of stress intensity range are subsequently generated, from which values of the $C$ and $m$ constants are determined for each stress intensity range. Approximate fatigue lifetimes are computed using these $C$ and $m$ values; lifetimes provide some indication as to the frequency with which inspections for cracks should be conducted.

"Laboratory Measurement of J-Integral," Yulian Kin, Harvey Abramowitz, Toma Hentea, Jim Higley, and Jason Richards, NEWU 98, pp. 145-152. This paper describes J-integral measurements that are made on notched specimens of polycarbonate using four-point flexural loading. Crack initiation and growth are monitored using a video camera; crack images are captured and stored by an image grabber. Values of the J-integral and critical J-integral are determined, from which a critical stress intensity factor is computed.

"Failure Analysis of Injection Molded Plastic Engineered Parts," Jerry L. Wickman and Nikhil K. Kundu, NEWU 94, pp. 179-185 and EMSET. This paper describes a senior-level project as part of a capstone course that is to last for six to eight weeks. Six duplicate pieces of an
injection molded engineering plastic part are obtained. All available information relative to the part are collected and documented (i.e., where used, what properties are expected, consumer abuse, etc.) which will be used in a failure analysis. Part failure(s) of a particular type is (are) assumed to occur, which are to be justified. A plan is formulated using design of experiment procedures to induce laboratory failure, which plan is carried out.

"Effect of Temperature on the Impact Behavior and Dimensional Stability of Thermoplastic Polymers," Wayne L. Elban and Matthew J. Elban, NEWU 99, pp. 123-143. This paper describes a procedure for evaluating the ductile-to-brittle transition characteristics of and ABS copolymer and recycled HDPE. Tests are conducted using a bench-top Charpy apparatus, and at temperatures between -196°C and 135°C. Notch sensitivity is also ascertained by comparing impact strengths of V-notched and notch-free specimens. Fracture surfaces are also observed.

"Dielectric Determination of the Glass Transition Temperature ($T_g$)," Heidi R. Ries, NEWU 89, pp. 7-11 and EMSET, and J. Mater. Educ., Vol. 12, p. 325 (1990). This paper describes a technique that may be used to determine the glass transition temperature of a noncrystalline polymer by measuring the temperature dependence of its dielectric dissipation factor.

"Dynamic Mechanical Analysis of Polymeric Materials," Kristen T. Kern, Wynford L. Harries, and Sheila Ann T. Long, NEWU 89, pp. 13-18 and EMSET. This paper describes a dynamic mechanical technique that may be used to measure glass transition and onset temperatures for polymeric materials. The oscillation of an electromagnetic driving mechanism flexes the specimen at constant amplitude and over a range of frequencies. Resonant frequency and mechanical damping are measured as functions of specimen temperature. These data are then converted to and plotted as flexural storage and loss moduli versus temperature; glass transition and onset temperatures may be determined from these plots.

"Optimizing Wing Design by Using a Piezoelectric Polymer," Mukul Kundu and Nikhil K. Kundu, NEWU 94, pp. 194-199 and EMSET. Four wings having different configurations are constructed from a sturdy and flexible plastic sheet. Onto the underside of each wing is mounted a strip of the piezoelectric polymer polyvinylidene fluoride (PVDF) to which are attached electrical leads. The wings are situated in a wind tunnel and exposed to laminar air flow at a maximum velocity of 20 m/s. Stability and lift data for the four wings are collected and analyzed using an amplifier circuit and a computer system.

CHAPTER 10
PHASE DIAGRAMS

"Integration of Laboratory Experiences into an Interactive Chemistry/Materials Course," John B. Hudson, Linda S. Schadler, Mark A. Palmer, and James A. Moore, NEWU 97, pp. 359-368. This paper describes laboratory experiments that are performed in a freshman chemistry of materials course. These experiments are as follows: (1) for benzene, determination of its pressure-temperature phase diagram and computation of its heat of vaporization; and, (2) for the photoelectric effect, observation of the relationships between photoelectron current and both wavelength and intensity of a light source.
"Making a Phase Diagram," William K. Dalton and Patricia J. Olesak, *NEWU 97*, pp. 83-85. Phase boundaries for the lead-tin phase diagram are determined from cooling curves. Lead-tin alloys having several compositions are melted by heating to 400°C. The alloys are then allowed to cool; temperature is measured as a function of time for each alloy using a thermocouple, a microcomputer thermometer, and a stop watch.

"Experiments with the Low Melting Indium-Bismuth Alloy System," Richard P. Krepski, *NEWU 91*, pp. 143-147 and *EMSET*. Alloys of 60 wt% Bi-40 wt% In and 34 wt% Bi-66 wt% In are prepared. The fracture behavior for these alloys as well as for pure bismuth and pure indium and explored and then discussed. The melting points of these two alloys (viz., approximately 105°C and 72°C) are then measured and compared to the melting temperatures of the pure metals; these values may be explained in terms of the In-Bi phase diagram. The unusual expansion-upon-solidification phenomenon may be observed, as well as the formation of a oxide film on surfaces of the molten materials. Simple casting experiments may easily be conducted.


"Cu-Zn Binary Phase Diagram and Diffusion Couples," Robert A. McCoy, *NEWU 91*, pp. 111-118, *EMSET*, and *J. Mater. Educ.*, Vol. 15, p. 345 (1993). Three high-purity copper rod pieces are immersed in molten zinc and each is then equilibrated at 400°C for a time period of 1, 4, or 9 days. After quenching to room temperature, the specimens are sectioned transversely, and the newly exposed surfaces are polished and etched. From photomicrographs taken at 50X, the β, γ, and ε phase layers are identified. A horizontal line is constructed on the Cu-Zn phase diagram at 400°C, from which the composition of each phase is determined at its two interfacial boundaries. A concentration profile is constructed for each specimen, assuming that composition varies linearly with position within each phase region. Using these profiles, students are to explain the abrupt changes in composition at phase layer interfaces, and why no regions are observed wherein there is a mixture of two phases. On the basis of relative diffusion rates of copper and zinc, students are also to explain the formation of voids in the γ and ε phase regions. Finally, photomicrographs are also taken of the three specimens at a higher magnification (i.e., 500X), from which phase region widths are measured. Computation of 4 day-to-1 day and 9 day-to-1 day layer width ratios for the β and γ phases should validate the square root of time dependence of layer thickness as predicted by the solution to Fick's second law.

"Materials Processing Laboratory Instruction: Structure-Property-Processing Relationships," James A. Clum, *NEWU 90*, pp. 1-9, *EMSET*, and *J. Mater. Educ.*, Vol. 13, p. 151 (1991). Four or five lead-tin or lead-indium alloys having different compositions are prepared. Specimens of these alloys are melted, and each is solidified in two ways—relatively fast and slow cooling. All of these specimens, as well as specimens of the as-received materials, are polished, etched, and the microstructure of each is photographed and analyzed with respect to grain size, phase fraction, and phase distribution. Hardness and microhardness tests are next performed on each sample. As-received and as-cast specimens of all alloy compositions are now heat treated;
after which microstructural examination and hardness tests are performed as above. Now, as-received and as-cast specimens of each alloy are compression deformed to two different percents of height reduction (e.g. 25% and 50%). Microstructural examinations and hardness tests are then performed on all of these specimens. And, finally, all deformed samples are then subjected to a recrystallization heat treatment, after which microstructural examinations and hardness tests are again conducted. A summary report that contains all data and photomicrographs along with explanations of the results is submitted to the instructor.

CHAPTER 10
PHASE TRANSFORMATIONS

"How a Heat Pack Works," Robert A. McCoy, NEWU 97, pp. 159-166. Students explore the operation of a heat pack—i.e., heat is generated from the exothermic crystallization of supercooled sodium acetate trihydrate. Teams of students measure cooling curves for several activation temperature and surrounding temperature combinations.

"Low Carbon Steel: Metallurgical Structure vs. Mechanical Properties," Robert D. Shull, NEWU 88, pp. 47-50 and EMSET. A hairpin (made of a low carbon steel) in the as-received condition is bent to indicate its ductility. A second hairpin is heated with a propane torch until it is red hot, and then quickly quenched in a bucket of water. This hairpin is tested as to its ductility also by bending. A third hairpin is heated with a torch, quenched in a bucket of water, then placed over a candle for a couple of minutes, followed by quenching in water. It is also bent to show its ductility. The student is to compare and explain the ductilities of these three hairpins. If metallurgical polishing facilities are available, a section of each of the three specimens should polished, etched, and photographed using a microscope so that their microstructures may be observed.

"In-Class Experiments: Piano Wire and Polymers," David Stienstra, NEWU 94, pp. 422-428 and EMSET. For the first portion of this experiment, three 100-150 mm lengths of 20 gauge piano wire are provided to each group of students. One length is kept in its as-received state (i.e., cold drawn); the other two are austenitized at 870°C for one hour, and one is quenched in water while the other is furnace cooled to room temperature. Students are to bend each wire, note the relative force required, and also the relative degrees of ductility. On the basis of these tests, students in each group discuss and come to conclusions as to possible processing techniques and microstructures of the three wires.

The second portion involves investigating the influence of strain rate on the mechanical characteristics of several polymeric materials: silly putty, six-pack rings, nylon cable ties, and splat balls. These items are deformed at different strains rates, and differences in behavior are noted, which are explored in terms deformation mechanisms and polymer structures.

"Austempering," James P. Nagy, NEWU 89, pp. 171-175 and EMSET. This experiment consists of austenitizing several specimens of a 4140 steel and then immersing them in a lead bath a 400°C for various lengths of time, followed by water quenching to room temperature. Hardness tests are then performed. Specimens are mounted, polished, etched, and subjected to microscopic observation. For each specimen, students are required to determine percents of bainite and martensite, and, in addition, to draw the cooling cycle on an isothermal...
transformation diagram for this alloy. Correlations between hardness and time in lead bath, as well as hardness and bainite content are also made.

"Steel Heat Treatment Lab: Austempering," Patricia J. Olesak, NEWU 96, pp. 257-259. Specimens of 4140 steel are austenitized and then quickly immersed in a molten lead-tin solder bath that is maintained at a temperature of 375°C for times ranging from 10 s to 1000 s. Hardness is measured, which decreases with increasing immersion time: bainite content increases with an attendant decrease in martensite content.

"Microstructure Analysis (University and Industry Partnership)," Donald H. Martin and Gary L. Dawson, NEWU 90, pp. 45-52 and EMSET. Students first take a tour of the Dana Corporation--World Axle Development Center in which they visit the axle design and development, fatigue testing, sample preparation, and microstructural analysis facilities. Back at the university, instructions as to the preparation, examination, and evaluation of metallographic specimens are given. Two specimens that have been mounted and coarse polished are supplied to the students. They are to do the final polishing and etching, and then conduct examinations using a metallurgical microscope; hardness tests are also performed. Students are then to identify the microconstituents in each of the two specimens.

CHAPTER 12
ELECTRICAL PROPERTIES

"Visual Quantum Mechanics--A Materials Approach," S. Raj Chaudhury, N. Sanjay Rebello, Larry Escalada, and Dean Zollman, NEWU 96, pp. 155-162. This paper describes computer simulations in the Visual Quantum Mechanics (VQM) software package (e.g., wave functions, energy bands, atomic spectroscopy, semiconductor device simulator). It also mentions that quantum phenomena may be demonstrated using light-emitting diodes (LEDs).

"How Does Change in Temperature Affect Resistance?" Jenifer A. T. Taylor, NEWU 90, pp. 261-263 and EMSET. In this experiment the influence of temperature on the electrical resistance of silicon and copper are investigated. Resistance measurements on a silicon boule are conducted at room temperature, and also at a slightly elevated temperature which is achieved using a hot plate. For a copper coil, resistance is measured at room temperature, in ice water (0°C), and in liquid nitrogen (-196°C). The temperature-resistance characteristics of the two materials are compared, differences of which the student is to explain.

"Laboratory Experiments in Integrated Circuit Fabrication," Thomas J. Jenkins and Edward S. Kolesar, NEWU 92, pp. 235-270 and EMSET. Over a ten-week period, students fabricate and test integrated circuits. They are supplied with one copy of a photomask set and ten silicon wafers during the second meeting period. Six individual exercises are performed, as follows: (1) initial oxidation; (2) photolithography; (3) diffusion; (4) gate oxidation; (5) metallization; and (6) final testing and analysis.

"Bulk Etching of Silicon for Micromachining," Thomas J. Jenkins, John H. Comtois, and Victor M. Bright, NEWU 94, pp. 41-51. In this experiment students explore the characteristics of anisotropic etching of silicon which is important in micromachining of microelectromechanical systems. Students are provided with silicon substrates the surfaces of which have been masked.
with a collection of features; suggested features are square and rectangular patterns having a variety of dimensions. Etches are performed using two different etchants, and etching times are noted. The etched silicon substrates are now examined with an optical microscope. Characteristics of the resulting etch pits (e.g., depth and profile) are analyzed, from which etch rates of several crystallographic planes may be determined for both of the etchants used.

"Micromachining of Suspended Structures in Silicon," John H. Comtois, Thomas J. Jenkins, and Victor M. Bright, NEWU 94, pp. 53-65. After having completed the experiment "Bulk Etching of Silicon for Micromachining," students perform a laboratory exercise in which suspended structures in silicon (e.g., cantilevers and trampolines) are fabricated using etching processes.

"Water Drop Test for Silver Migration," Ted Gabrykewicz, NEWU 94, pp. 363-366 and EMSET. This experiment studies the migration of silver in water when a DC voltage gradient is present. (Silver migration is a serious problem in thick film microelectronic circuitry.) The test consists of placing a drop of water on two silver or silver-palladium alloy conductors that are positioned less than 0.2 mm apart. Electrical contact is made between both conductors and either a 1.5 V or 9 V battery, and the length of silver dendrites that form between the two conductors is measured as a function of time using a microscope. The influences of voltage and alloy content on silver migration rate are determined.

"Experiments in Diamond Film Fabrication in Table-Top Plasma Apparatus," James V. Masi, NEWU 93, pp. 341-352 and EMSET. A procedure for heteroepitaxially depositing polycrystalline diamond thin films onto silicon and sapphire wafers in a microwave assisted plasma is described. The substrates are placed in a polycarbonate bell jar that is evacuated; an argon-ethyl alcohol gas mixture is then leaked back into the jar. When the microwave source is turned on the diamond thin film is deposited as a result of decomposition of the ethyl alcohol. The film may also be doped n- or p-type by additions of boron trichloride or phosphorus trichloride. The electrooptical properties of these heterojunctions may also be measured.

"Temperature-Dependent Electrical Conductivity of Soda-Lime Glass," L. Roy Bunnell and T. H. Vertrees, NEWU 92, pp. 443-448 and EMSET. Wire electrical contacts are attached to a strip of window glass; these are connected in series with a 75- or 100-watt light bulb. When the ends of this testing unit are plugged into a 110 V outlet, the intensity with which this bulb glows is a visual indicator of the electrical resistivity of the glass. At room temperature the bulb does not glow since the resistivity of the glass is very low. When heated with a propane torch, the bulb begins to glow, which shows that the electrical resistivity of the glass diminishes with increasing temperature.

If the same experiment is conducted on a steel nail, at room temperature the bulb will glow brightly; furthermore, the bulb will not dim perceptibly when the nail is heated.

"Learning About Electric Dipoles from a Kitchen Microwave Oven," H. Jain, NEWU 96, pp. 271-276. This paper demonstrates that the heating of substances in a microwave oven is by dipole relaxation of polar molecules. This is accomplished by measuring the variation in temperature of specimens of water, alcohol, and ice as a function of initial specimen temperature.
"Phase Transition Studies in Barium and Strontium Titanates at Microwave Frequencies," Jai N. Dahiya, NEWU 92, pp. 361-370 and EMSET. Phase transitions, transition temperatures, and the dielectric behavior for barium titanate and a barium titanate-strontium titanate alloy are investigated using a microwave resonant cavity and at a microwave frequency of 9.12 GHz; tests are made as temperature is varied. When frequency shifts and Q-changes are plotted versus temperature, temperatures at which phase transitions occur may be discerned. At the Curie temperature (120°C for barium titanate and 34°C for the alloy), upon cooling, the cubic phase transforms to a tetragonal phase, and, correspondingly, the dielectric behavior changes from paraelectric to ferroelectric.

"Piezoelectric and Pyroelectric Effects of a Crystalline Polymer," Nikhil K. Kundu and Malay Kundu, NEWU 89, pp. 71-76, EMSET, and J. Mater. Educ., Vol. 12, p. 135 (1990). This demonstration of piezoelectric and pyroelectric effects is accomplished using a specially treated poly(vinylidene fluoride) (PVDF) film specimen to which copper electrodes are attached. For demonstration of the piezoelectric effect, a steel ball is attached to the center of the specimen. Weights having various masses are dropped from a specific height, and electrical signals generated are recorded on a strip chart recorder. The pyroelectric effect is demonstrated by thermally cycling the specimen, which produces fluctuations in measured electrical output.

"Optimizing Wing Design by Using a Piezoelectric Polymer," Mukul Kundu and Nikhil K. Kundu, NEWU 94, pp. 194-199 and EMSET. Four wings having different configurations are constructed from a sturdy and flexible plastic sheet. Onto the underside of each wing is mounted a strip of the piezoelectric polymer poly(vinylidene fluoride) (PVDF) to which are attached electrical leads. The wings are situated in a wind tunnel and exposed to laminar air flow at a maximum velocity of 20 m/s. Stability and lift data for the four wings are collected and analyzed using an amplifier circuit and a computer system.

"Use of Piezoelectric Crystals for Voice Recognition," Harvey Abramowitz, NEWU 98, pp. 381-392. A piezoelectric crystal is connected to an oscilloscope and then placed on the larynx of a student. The student voices a specific sound for several seconds, and the resulting pattern is noted on the oscilloscope (as sweep rate versus time). When this procedure is repeated for other students, it is noted that the pattern is distinctive for each student; different pattern types are obtained for men and women, and when other sounds are voiced.

Time domain plots are generated simultaneously for the piezoelectric crystal and a microphone using a PC and appropriate software; comparisons are made between the two plots. From these data, vocal tract spectra plots are then generated with the aid of a PC.

"Optimizing Wing Design by Using a Piezoelectric Polymer," Mukul Kundu and Nikhil K. Kundu, NEWU 94, pp. 194-199 and EMSET. Four wings having different configurations are constructed from a sturdy and flexible plastic sheet. Onto the underside of each wing is mounted a strip of the piezoelectric polymer poly(vinylidene fluoride) (PVDF) to which are attached electrical leads. The wings are situated in a wind tunnel and exposed to laminar air flow at a maximum velocity of 20 m/s. Stability and lift data for the four wings are collected and analyzed using an amplifier circuit and a computer system.
TYPES AND APPLICATIONS OF MATERIALS

"Tool Grinding and Spark Testing," Edward L. Widener, *NEWU* 92, pp. 123-126 and *EMSET*. When metal alloys are brought into contact with a grinding wheel sparks are generated; and, alloy identification is often possible on the basis of sparking characteristics. Students are instructed, for various alloys, whether or not sparks are generated, and, if so, their characteristic natures and colors. They then have the opportunity to conduct their own spark tests.

"Cast Iron, Wrought Iron and Steel (Historical Perspective and Properties of Ferrous Material)," Archie M. Cooke, *NEWU* 98, pp. 457-465. This paper first describes how, qualitatively, the mechanical strength of wrought iron, cast iron, and steel may be assessed and compared using bend tests on bar specimens. The phenomenon of strain hardening is demonstrated on wrought iron by repeatedly bending a bar specimen. The author then discusses from an historical perspective the development of technologies to produce various ferrous alloys.

"Identification of an Unknown Steel Specimen," William D. Callister, Jr., *NEWU* 96, pp. 67-74 and *J. Mater. Educ.*, Vol. 17, p. 79 (1995). Students are required to plan out and execute an experimental strategy to determine the alloy designation and heat treatment for an unknown steel specimen given a list of possible alloy designations and a list of four possible heat treatments.

"Metallurgical Evaluation of Historic Wrought Iron to Provide Insights into Metal-Forming Operations and Resultant Microstructure," Wayne L. Elban and Mark A. Elban, *NEWU* 96, pp. 29-51. This paper describes how microstructural characterization and hardness tests were used to date and identify the processing of a wrought iron that was produced sometime in the 1800s.

CHAPTER 14
SYNTHESIS, FABRICATIONS, AND PROCESSING OF MATERIALS

*Metals*

"Austempering," James P. Nagy, *NEWU* 89, pp. 171-175 and *EMSET*. This experiment consists of austenitizing several specimens of a 4140 steel and then immersing them in a lead bath at 400°C for various lengths of time, followed by water quenching to room temperature. Hardness tests are then performed. Specimens are mounted, polished, etched, and subjected to microscopic observation. For each specimen, students are required to determine percents of bainite and martensite, and, in addition, to draw the cooling cycle on an isothermal transformation diagram for this alloy. Correlations between hardness and time in lead bath, as well as hardness and bainite content are also made.

"Steel Heat Treatment Lab: Austempering," Patricia J. Olesak, *NEWU* 96, pp. 257-259. Specimens of 4140 steel are austenitized and then quickly immersed in a molten lead-tin solder bath that is maintained at a temperature of 375°C for times ranging from 10 s to 1000 s. Hardness is
measured, which decreases with increasing immersion time: bainite content increases with an attendant decrease in martensite content.

"Demonstration of Kinetic Relationships by Precipitation-Hardening Experiments," Philip J. Guichelaar and Molly W. Williams, NEWU 90, pp. 265-272 and EMSET. Specimens of 2024 aluminum bar stock are solution heat treated and then quenched in water at room temperature. One specimen is naturally aged (at room temperature) for one week, at which time hardness measurements are made. Six specimens are precipitation heat treated at each of 220°C and 175°C for various times; after cooling to room temperature they are also hardness tested. Two other sets of specimens are solution heat treated, cold rolled (about 5%), and then precipitation heat treated and hardness tested as previously. The kinetics of precipitation hardening for this alloy are presented as hardness versus the logarithm of aging time, and the influence of cold working is noted.

"Be-Cu Precipitation Hardening Experiment," Richard L. Cowan, NEWU 91, pp. 189-193, EMSET, and J. Mater. Educ., Vol. 14, p. 133 (1992). Specimens of Cu-1.8 Be or Cu-2.0 Be are solution heat treated and then quenched in agitated water at room temperature. Hardness measurements (Rockwell B scale) are then made. Precipitation heat treatments are conducted on these specimens for a variety of times ranging from 1 h to 45 h. Hardness tests are then conducted after cooling to room temperature, from which a plot of hardness versus logarithm of heating time is generated. This procedure may be repeated at various aging temperatures by other groups of students. Microstructural changes that occur during the heat treatments are discussed, as well as the shape of the plots and how these plots are affected by aging temperature.

"Heat Treating of Materials," Edward L. Widener, NEWU 91, pp. 383-387 and EMSET. After austenitizing, steel specimens are annealed, normalized, water quenched, and tempered. Hardness measurements are conducted in order to ascertain the influence of each heat treatment on the mechanical properties. Specimens of an aluminum alloy are fully annealed and normalized, and in addition, solution heat treated, naturally aged, and artificially aged; hardness tests are also conducted on these specimens.

"Identification of an Unknown Steel Specimen," William D. Callister, Jr., NEWU 96, pp. 67-74 and J. Mater. Educ., Vol. 17, p. 79 (1995). Students are required to plan out and execute an experimental strategy to determine the alloy designation and heat treatment for an unknown steel specimen given a list of possible alloy designations and a list of four possible heat treatments.

"Metallurgical Evaluation of Historic Wrought Iron to Provide Insights into Metal-Forming Operations and Resultant Microstructure," Wayne L. Elban and Mark A. Elban, NEWU 96, pp. 29-51. This paper describes how microstructural characterization and hardness tests were used to date and identify the processing of a wrought iron that was produced sometime in the 1800s.

"Effect of Risers on Cast Aluminum Plates," H. T. McClelland, NEWU 94, pp. 527-534 and EMSET. In this experiment eight different configurations are chosen for a sand mold into which molten aluminum is to be cast. Configuration variables include: the location of a gating system (without risers) at three different mold positions; and the use of risers having
two different diameters and heights that are incorporated into these same gating systems. Castings made in the several different molds are analyzed as to quality and degree of shrinkage. In addition, the percent yield is determined for each mold configuration.

"Application of Hardness Testing in Foundry Processing Operations: A University and Industry Partnership," Donald H. Martin and Bruce Lash, NEWU 92, pp. 223-232 and EMSET. The first phase of this experiment is a plant tour, wherein students are shown facilities that are used to precipitation harden commercial alloys. In the second phase, the instructor demonstrates indentation and hardness (Brinell) computation procedures. Students perform their own hardness tests, and then covert Brinell hardnnesses to values in other hardness scales, and also to tensile strength. Limitations on hardness testing procedures are also discussed.

"From Sand Casting to Finished Product," Donald H. Martin and Keith Sinram, NEWU 93, pp. 269-283 and EMSET. In phase I, the instructor demonstrates the construction of a sand mold by hand-ramming, with the inclusion of both a sprue and a gating system; this is followed by the pouring of an aluminum casting. The students, during phase II, are taken on a tour of a foundry and shown the casting of flywheel rings. And, during phase III, also a plant tour, machining operations that are performed on these flywheel ring castings are demonstrated.

"Testing Sand Quality in the Foundry," Donald H. Martin, Hermann Schwan, and Michael Diehm, NEWU 94, pp. 331-342 and EMSET. Some type of bonding agent (i.e., clay) and water must be added to sand in order for it to hold its shape when formed into casting molds in foundries. Water content is critical relative to quality of the cast part. Students perform tests that are used to determine the moisture percent in molding sands by making weight measurements. A plant tour is also conducted so the students may observe the procedure in an actual foundry operation.

"Lost Foam Casting," David E. Werstler, NEWU 96, pp. 221-226. This experiment demonstrates a technique for producing some aluminum castings. An expandable polystyrene foam pattern is immersed in loose sand, which pattern is burned out and subsequently replaced by the molten metal.

"Powder Metallurgy: Solid and Liquid Phase Sintering of Copper," Rex Sheldon and Martin W. Weiser, NEWU 92, pp. 417-430 and EMSET. In this experiment, basic powder metallurgy principles are illustrated using copper powder (to demonstrate solid-state sintering), and copper powder to which is added a small quantity of a low-melting metal (e.g., tin, zinc, lead) (to demonstrate liquid-phase sintering). The influences of particle size, pressing force, sintering temperature, and sintering time are investigated using the Taguchi method of experimental design. The experiment is typically conducted over a three-week period.

"Visualizing Weld Metal Solidification Using Organic Analogs," Daniel W. Walsh and Gary R. Rogers, NEWU 92, pp. 387-392 and EMSET. This paper describes how the solidification of metal alloys may be simulated in-situ using a low-melting temperature and transparent organic material: succinonitrile. Several processes/phenomena may be observed, including epitaxial nucleation, competitive growth, morphological changes, and defect formation; these processes/phenomena ultimately affect the microstructure, and consequently, the properties, of a weld.
"Studying Macroscopic Yielding in Welded Aluminum Joints Using Photostress," Kishen Kavikondala and S. C. Gambrell, Jr., NEWU 94, pp. 404-411 and EMSET. A dog-bone specimen is machined from a welded aluminum plate. The region surrounding the weld is abraded, cleaned, and both an adhesive and a photoelastic coating are applied. This specimen is mounted into a tensile testing apparatus that has been programmed to load in a predetermined sequence. During loading and at each sequence step, a color photograph of the weld junction is taken using a telemicroscope that is attached to a reflection polariscope. Strains may be measured at preselected regions near the weld from fringe patterns that have been photographed; these strains may also be converted into stress values. From these data, stress-strain curves may be generated at the several chosen locations.

"Impact Testing of Welded Samples," Calvin D. Lundeen, NEWU 91, pp. 99-102 and EMSET. Students are to prepare and arc weld together bars of 1020 steel. Square, single-bevel, and double-bevel welds are to be made using a clamping fixture. Welded specimens are now inspected visually and classified as to quality—poor through excellent. Each sample (unnotched) is then tested for impact strength using a Charpy apparatus. The effects of single- and double-beveling on impact energy are observed, as is also the influence of weld quality.

"Crater Cracking in Aluminum Welds," R. Carlisle Smith, NEWU 93, pp. 241-244 and EMSET. In this experiment, the student first performs a side weld in 6061-T6 aluminum. A second side weld is made in such a way as to fail. A dye penetrant is now applied, and any cracks that have formed may be observed with a black light.


"Some Experimental Results in the Rolling of Ni₃Al Alloy," Hui-Ru Shih and Vinod K. Sikka, NEWU 95, pp. 309-315 and EMSET. The rolling properties of a Ni₃Al are investigated, as well as the influence of heat treatment and grain structure on the ductility, hardness, and tensile properties.

Ceramics

"Experiments in Diamond Film Fabrication in Table-Top Plasma Apparatus," James V. Masi, NEWU 93, pp. 341-352 and EMSET. A procedure for heteroepitaxially depositing polycrystalline diamond thin films onto silicon and sapphire wafers in a microwave assisted plasma is described. The substrates are placed in a polycarbonate bell jar that is evacuated; an argon-ethyl alcohol gas mixture is then leaked back into the jar. When the microwave source is turned on the diamond thin film is deposited as a result of decomposition of the ethyl alcohol. The film may also be doped n- or p-type by additions of boron trichloride or phosphorus trichloride. The electrooptical properties of these heterojunctions may also be measured.
"Preparation of Simple Plaster Mold for Slip Casting," T. G. Davidson and L. A. Ketron, NEWU 93, pp. 255-258 and EMSET. This paper explains the procedure for producing a porous gypsum mold that may be used to slip cast a ceramic piece.

"Slip Casting," T. G. Davidson and L. A. Ketron, NEWU 93, pp. 261-265 and EMSET. In this experiment the students prepare slips consisting of ball clay, kaolin, feldspar, flint, water, and a deflocculant. Drain and solid castings are made using plaster molds. The influences of water and deflocculant contents, as well as mold density on the character and quality of the slip piece may also be investigated.

"Properties of Magnetic Ferrites with a Simple Fabrication Method," Luke Ferguson and Thomas Stoebe, NEWU 97, pp. 185-195. Toroidal ferrite cores are slip cast from water-based ceramic slips, which cores are subsequently dried and fired. The magnitude of the magnetic properties of these cores may be ascertained using several techniques, including the generation of magnetic flux density-field strength hysteresis loops.

"Microwave Sintering of Machining Inserts," David E. Werstler, NEWU 93, pp. 363-365 and EMSET. This experiment allows the student to explore process control variables relative to the microwave sintering of a ceramic part (i.e., a cemented tungsten carbide cutting tool insert). Students decide which process variables they want to study and then design a two-factor, three-level experiment with the sintered bulk density as the response. Powdered material is pressure compacted into the desired insert shape. Using a microwave oven, the piece is heated in three stages to dewax, degas, and finally isothermally sinter the piece. Bulk density is then measured.

"Ceramic Processing: Experimental Design and Optimization," Martin W. Weiser, David N. Lauben, and Philip Madrid, NEWU 91, pp. 67-95 and EMSET. Students have the opportunity to slip cast and fire clay-based ceramic bars, and then measure their properties. Processing and firing parameters are variable within certain limits, the levels of which are to be selected by the several student teams. Processing parameters include clay composition, inclusion content, dispersant type, and dispersant concentration; firing variables are peak firing temperature, peak firing time, and ramp rate. The influences of these parameters on several properties (e.g., four-point bending strength, density) are to be ascertained. Experimental design is part of the exercise, wherein students, using the method of orthogonal arrays, are able to study the effect of each parameter with a minimum number of experiments. After the tests have been conducted, a data reduction process in conjunction with the Taguchi method is used to determine the effect of each parameter on the properties, and also, the optimal combination of processing/firing parameter values. A confirming experiment is then carried out if this combination was not one of the chosen experiments. This experiment is designed for three three-hour laboratory sessions conducted over a three-week period.

"Development of Mechanical Strength in a Ceramic Material Fired at Several Different Temperatures," L. Roy Bunnell and Steven W. Piippo, NEWU 94, pp. 353-359 and EMSET. Clay-based bars of circular cross section (having approximately 20 mm diameters) are extruded and cut into lengths of approximately 0.5 m. Five specimens are fired at each of five temperatures ranging between 650°C and 1050°C for 1.5 h. After cooling to room temperature three-point bend tests are conducted using an inexpensive test apparatus; fracture
strengths are computed, as are also average and standard deviation values. Data are plotted as average strength versus firing temperature.

"Use of Bells to Illustrate Ceramic Firing Effects," Steven W. Piippo and L. Roy Bunnell, NEWU 93, pp. 517-520, EMSET, and J. Mater. Educ., Vol. 15, p. 179 (1993). In this experiment, six slip cast and unfired bells are purchased from a hobby shop; if necessary, holes are drilled to permit the bells to be hung. All but one bell is bisque fired, and each of these is then fired at a different temperature between the specified bisque and fully fired temperature for one hour; they are now slowly cooled to room temperature. A density or relative density measurement is made on each bell. All bells including the unfired one are hung on strings, and then gently tapped. Ring duration and pitch (frequency) will vary from bell to bell, which may then be correlated with density and degree of bonding.

Polymers

"Making Products Using Post Consumer Recycled High Density Polyethylene: A Series of Recycling Experiments," Ping Liu and Tommy S. Waskom, NEWU 96, pp. 285-289. A variety of types of post-consumer thermoplastic products are collected, sorted, and cleaned. These materials are cut into small flakes using a granulator, and subsequently extruded into 1/4 in. strands; the strands are subsequently cut to form pellets. Finally, the pellets are injection molded in preparation for mechanical testing in order to determine the properties of these recycled plastics.

"Compression Molding of Composite from Recycled HDPE and Recycled Tire Particles," Ping Liu, Tommy L. Waskom, Zhengyu Chen, Yanze Li, and Linda Peng, NEWU 95, pp. 159-163 and EMSET. The effects of several processing variables (e.g. temperature, holding time, and pressure) on the characteristics of these compression molded composite materials are determined. Experimental design is also an important component of this exercise.

"Correlation of Birefringent Patterns to Retained Orientation in Injection Molded Polystyrene Tensile Bars," Laura L. Sullivan, NEWU 97, pp. 41-44. Birefringent patterns (using polarized light) produced in injection molded polystyrene are used to determine the effects of various molding parameters on residual stress and tensile strength.

"Peel Properties of a Pressure Sensitive Adhesive," Elizabeth C. Edblom, NEWU 93, pp. 483-488, EMSET, and J. Mater. Educ., Vol. 17, p. 339 (1995). Rubber/resin pressure sensitive adhesives are compounded having three different rubber-resin ratios. These adhesives are spread (with uniform thickness) onto films and then dried by heating to a temperature of 150°C. Coating weights are measured. Peel properties are determined by attaching the adhesive to a clean steel panel and measuring the peel rate at a 180° angle under a load of approximately 200 g. This test is now performed on tapes having this same formulation but with different coating rates; this procedure is now repeated on the other formulations. Correlations are deduced between peel rates and percentage of tackifier and also coating weight. Finally, the influence of peel force on peel rate is determined using Magic Tape.

"Ultrasonic Welding of Recycled High Density Polyethylene (HDPE)," Ping Liu and Tommy L. Waskom, NEWU 94, pp. 221-225 and EMSET. Flat sheets approximately 125 mm x 125 mm
are cut from HDPE milk containers. Two such sheets are ultrasonically welded together using specified welding parameters. Standard dog-bone shaped specimens are prepared so as to include the weld; these specimens are tensile tested and peak load is recorded. Influences of the various welding parameters (e.g. weld time, trigger force, etc.) on peak load may also be investigated.

CHAPTER 15
COMPOSITES

"Use of a Four-Point Bend Apparatus to Determine the Modulus of Elasticity," Richard B. Griffin, L. Roy Cornwell, Carlos Yapura, Sivasubramaniam Krishnan, and John Hallford, NEWU 98, pp. 155-163. Moduli of elasticity for three metal alloys and a unidirectional graphite fiber-epoxy composite are measured in four-point bending. The inexpensive experimental apparatus consists of a stainless steel bend fixture, a dial indicator, and a series of weights. Moduli are determined from force-deflection curves, which are in reasonably good agreement with literature values.

"Fiber Reinforced Composite Materials," H. A. West and A. F. Sprecher, NEWU 90, pp. 137-144, EMSET, and J. Mater. Educ., Vol. 13, p. 161 (1991). This paper describes procedures that may be used to measure various characteristics of unidirectional fiber-reinforced composite materials. Fiber content may be determined from a photomicrograph and using a point count technique. The several elastic properties may be measured by applying tensile stresses at various orientations relative to the fiber direction.

"Mechanical Properties of Composite Materials," H. Richard Thornton and L. R. Cornwell, NEWU 92, pp. 45-48 and EMSET. Test coupons of an oriented graphite fiber-epoxy matrix laminate composite are loaded in tension to failure. Tests are made for two laminate orientations—viz., 0° (i.e., fibers oriented parallel to the load direction) and 90° (fibers oriented perpendicular to the load direction). Stress-versus-strain plots are generated from which modulus of elasticity and ultimate tensile strength values are noted. These data, as well as other tensile data provided by the instructor, are input into a computer program that calculates the modulus for a laminate composed of off-angle plies. Such an off-ply laminate is tensile tested, and its modulus is compared to the analytical value.

"A Method for Measuring the Shear Strength of Polymers and Composites," Luis Gardea and Brian L. Weick, NEWU 97, pp. 281-291. Shear tests to failure are performed on unfilled and glass-fiber filled polymeric materials using a shear test jig that is loaded in a tensile testing apparatus. For each material, multiple experiments are conducted which allows for determination of confidence intervals; also, the influence of glass fibers is noted. Fracture surfaces are examined for insights as to fracture mechanisms.

"Continuous Unidirectional Fiber Reinforced Composites: Fabrication and Testing," M. D. Weber, F. Xavier Spiegel, and Harvey A. West, NEWU 93, pp. 45-50, EMSET, and J. Mater. Educ., Vol. 14, p. 293 (1992). This paper first of all describes the fabrication of inexpensive continuous and unidirectional fiber-reinforced composite specimens consisting of aluminum wires having various orientations that are embedded in a transparent polymer matrix. Also,
when stressed in tension it is possible to observe/demonstrate the following: elastic anisotropy, rule of mixture relationships, Poisson's ratio, and the ability to determine fiber volume content.

"Composite Column of Common Materials," Richard J. Greet, NEWU 91, pp. 105-107 and EMSET. Several aluminum soda-pop cans are collected and their tops removed. Plaster of paris that has been mixed with water is poured into some of the cans and allowed to set up for one to two days. Top rims and dished can bottoms are removed; aluminum skins are then cut and peeled from about half of these cans. Compression tests are then performed on at least one empty can, at least one plaster of paris core material, and at least one plaster of paris core-aluminum skin composite. Students are to observe the mode of failure for each, and also the load at which failure occurs. These results are then discussed.

"Design and Construction of a Tensile Tester for the Testing of Simple Composites," Mark A. Borst and F. Xavier Spiegel, NEWU 93, pp. 53-99 and EMSET. The relatively inexpensive apparatus described in this paper is constructed of the following: (1) a threaded rod mounted on a hand wheel, which, when turned, applies the tensile force; (2) laminated maple support beams that make up part of the frame; (3) steel support rods that are attached to the maple support beams; (4) an oak drive beam; (5) a load cell; (6) a rail assembly; and (7) a set of grips that are machined from aluminum onto which faces sheets of rubber are attached. Calibration and verification of accuracy are necessary. Furthermore, the apparatus also allows measurement of lateral displacement of the specimen as it is elongated. Tests are performed on aluminum fiber-transparent plastic matrix and glass fiber-transparent plastic matrix composites, and fibers are embedded at several different orientations. Data are collected and presented as force versus elongation, and lateral displacement versus elongation. Moduli of elasticity are determined for the several orientations, and value comparisons are made.

"Microstructural Preparation and Examination of Polymer-Matrix Composites," Wayne L. Elban, Maddy M. Rutzebeck, Ryan A. Small, and Adam M. Walsh, NEWU 95, pp. 57-68 and EMSET. Students prepare polymer-matrix composites for microscopic examination using modified metallographic techniques. These specimens are subsequently examined using reflected light microscopy, and their microstructures are characterized.

"Laminated Thermoplastic Composite Materials from Recycled High Density Polyethylene," Ping Liu and Tommy L. Waskom, NEWU 93, pp. 113-118 and EMSET. Square and flat sheets are cut from HDPE milk containers. Between two pairs of HDPE sheets is inserted a square piece of glass fiber fabric. This combination of sheets is then compressed under a normal load of 2/9 tons and at a temperature in the vicinity of 135°C for several minutes, which results in the production of a composite laminate. Dog-bone shaped laminate specimens are prepared which are tensile tested. Tensile strength and laminate thickness are correlated with pressing temperature.

"Composite of Glass Fiber with Epoxy Matrix," Ping Liu and Tommy L. Waskom, NEWU 99, pp. 623-625. Student groups prepare fiber glass laminates by impregnating fiber glass strips with an epoxy resin. After curing the cantilever beam strength of each laminate is tested and specific loading capacity (i.e., specific strength) is determined. Group grades are based on specific loading capacity values.

"Composite of Glass Fiber with Epoxy Matrix," Ping Liu and Tommy L. Waskom, NEWU 96, pp. 279-281. Student teams fabricate by hand lay-up, glass fiber-epoxy matrix laminate specimens. Specific strengths are determined from cantilever bend tests. Grades are awarded to teams on the basis of specific strength ranking.

"Effects of Core Thickness and Fiber Orientation on Composite Beam Stiffness," Vernon S. Hillsman and Patricia J. Olesak, NEWU 95, pp. 81-84 and EMSET. With this experiment students participate in the hand lay-up process by constructing glass/epoxy composite panels. In addition, the effects of core thickness and fiber orientation on composite beam stiffness are demonstrated.

"Fabrication and Evaluation of a Simple Composite Structural Beam," Myron J. Schmenk, NEWU 90, pp. 77-89 and EMSET. Each student team is to design a composite structural material that consists of organic fibers or particulates bonded by an adhesive. A fabrication technique to produce the beam is to be formulated and used. After fabrication, beams are tested for tensile strength and stiffness; and finally composite beam performance is compared to that of a wood beam.

"Construction and Testing of Simple Airfoils to Demonstrate Structural Design, Materials Choice, and Composite Concepts," L. Roy Bunnell and Steven W. Piippo, NEWU 92, pp. 451-459 and EMSET. Model airfoils (i.e., wings) are constructed using balsa and spruce woods that are fastened together using a cyanoacrylate adhesive; these foils are then covered. Several structural versions of the airfoils are possible; in addition, wood type may be varied for the several components. The airfoils are weighed, and then clamped to a workbench such that a specified airfoil length is cantilevered over the workbench edge. Weights are applied to the cantilevered ends, and loads required to cause a 1-cm deflection are noted; from these values stiffness parameters are computed by taking load-airfoil mass ratios. Loads are then increased until the airfoils fail. Strength parameters for the several airfoils are taken as the failure load-airfoil mass ratios. Values of these stiffness and strength parameters for the several designs are compared; students are then asked to propose design changes and/or substitution of other wood types to improve stiffness and strength parameter values.

"Simple Stressed-Skin Composites Using Paper Reinforcement," L. Roy Bunnell, NEWU 90, pp. 273-277 and EMSET. In this experiment, using polyurethane foam rubber beams, the following are demonstrated: (1) regions of compressive and tensile forces when the beam is bent; (2) the influence on stiffness of a stress skin (i.e., construction paper sheet) applied to one beam face; and (3) how stiffness is affected by stress skins applied to two opposing beam faces.

"Computerized Testing of Woven Composite Fibers," Amy Laurie Wilkerson, NEWU 95, pp. 339-349 and EMSET. Students use a computerized testing apparatus to perform tensile tests on various woven fibers that are utilized in composite materials. Test results yield tensile property data.
"Relationship Between Moisture Changes and Dimensional Change in Wood," Thomas M. Gorman, NEWU 97, pp. 89-95. Shrinkage coefficients of a wood are determined for longitudinal, radial, and tangential orientations by fully saturating oven-dried specimens with water using a vacuum pump and a vacuum chamber.

"An Experiment on the Use of Disposable Plastics as a Reinforcement in Concrete Beams," Mostafiz R. Chowdhury, NEWU 91, pp. 315-327 and EMSET. The influence on compressive and tensile strengths of various types of disposable plastics as reinforcements in concrete is investigated. Reinforcement materials include: (1) disposable plastic molds that are shredded and cut into strips having a variety of sizes and shapes; (2) plastic soda pop bottles cut into strips that are subsequently punctured; and (3) automobile tires that are cut into strips. Also tested is a concrete beam that is prestressed using a rubber tendon.

"Concrete Repair Applications," Leonard W. Fine, NEWU 94, pp. 381-385 and EMSET. A high molecular weight methacrylate monomer is thoroughly mixed with a catalyzer as well as sand, silica flour, and titanium dioxide. This mixture is then cast in miniature concrete molds or filled into cracks of previously prepared concrete specimens. Sufficient time is allowed for curing, after which strength and modulus tests may be conducted. The strength of this material may be visually demonstrated in the classroom by striking it with a hammer.

CHAPTER 16
CORROSION AND DEGRADATION OF MATERIALS

"A Simple Demonstration of Corrosion Cells," Philip J. Guichelaar and Molly W. Williams, NEWU 89, pp. 29-36, EMSET, and J. Mater. Educ., Vol. 12, p. 331 (1990). For this demonstration, two days prior to the laboratory/demonstration session, the instructor prepares several different corrosion cells wherein relatively large steel nails (in some instances also wrapped with wires of other metals) are immersed in various types of water solutions contained in test tubes. After observing these cells, students are to indicate whether a corrosion cell exists, identify anodic and cathodic regions, and indicate the most likely chemical reactions that occur at each anode and cathode.

"The Application of Computers to the Determination of Corrosion Rates for Metals in Aqueous Solutions," R. B. Griffin, L. R. Cornwell, and Holly E. Ridings, NEWU 96, pp. 185-197. This experiment illustrates how the corrosion rates of metals immersed in aqueous solutions may be measured using electrochemical techniques and a computer.

"Understanding Galvanic Corrosion Tricks to Prevent Some Expensive Failures," Gautam Banerjee and Albert E. Miller, NEWU 97, pp. 65-72. This is a demonstration/experiment in which strips of several metals (e.g., Al, Zn, Fe, and Pt) as well as pairs of these strips in contact with one another are immersed in a hydrochloric acid solution. Relative corrosion rates (i.e., rates of gas evolution) are observed which the students are asked to explain.

"Corrosion Demonstration Utilizing Low Cost Materials," John R. Williams, NEWU 97, pp. 399-405. Small strips of a variety of metal alloys are immersed in ammonia and a dilute bleach
solution. Students are to observe (for periods of up to two weeks), record, and explain any corrosion reactions that occur.

"Experiments in Corrosion for Younger Students by and for Older Students," James V. Masi, NEWU 92, pp. 129-135 and EMSET. For college students, several hours in advance of the class/laboratory session, into each of three Petri dishes is poured a water-sodium chloride-agar solution. An ordinary iron nail is placed in one dish; a nail that has half of its shank coated with a thin layer of copper is placed in a second dish; while in the third dish is placed a nail that has a zinc coating along a portion of its shank. Students are to observe and record their observations. Next, into a 3% NaCl-water electrolyte solution are immersed pairs of electrodes: iron nail-deformed iron nail, iron nail-copper wire, iron nail-copper sheet, and iron nail-zinc coated iron nail. Leads are clipped to the pairs of electrodes, voltage and current readings are taken, and electrode polarities are noted. Students are to report their observations and answer several questions. Also, indicators (viz., phenolphthalein and potassium ferricyanaide) may be used to locate anode and cathode regions.

College students then mentor junior high school students in conducting corrosion experiments. One of these involves measuring the voltage between a copper nail and a steel nail that have been inserted into either a potato or a lemon.

"Anode Materials for Electrochemical Waste Destruction," Peter M. Molton and Clayton Clarke, NEWU 89, pp. 19-28 and EMSET. Students measure the corrosion resistance of various materials (e.g., stainless steel, graphite, and titanium) relative to their suitability for anodes to be used in the electrochemical oxidation of hazardous organic chemical wastes.

"Sensitization of Stainless Steel," James P. Nagy, NEWU 88, pp. 27-30 and EMSET. Each of several specimens of 304 stainless steel is heat treated at a temperature that lies between 550°C and 1050°C. After cooling to room temperature, the specimens are immersed in an HF-HNO₃-water solution for between 24 and 48 h. Weight loss measurements are made, which values represent the degree of intergranular corrosion as a result of sensitization; thus, the temperature range over which sensitization occurs may be determined.

"Experiments in Natural and Synthetic Dental Materials: A Mouthful of Experiments," James V. Masi, NEWU 95, pp. 227-238 and EMSET. This experiment is designed to do the following: (1) show that elements of both good and poor design are found in the area of biomaterials; (2) demonstrate the process of designing materials to withstand the complex interactions found in the oral cavity; (3) conduct analyses (i.e., corrosion, microstructural) on those materials currently used; and (4) suggest possible solutions to problems that exist with the present technology.

"The Effect of Thermal Damage on the Mechanical Properties of Polymer Regrinds," Nikhil K. Kundu, NEWU 89, pp. 93-99, EMSET, and J. Mater. Educ., Vol. 12, p. 143 (1990). Three hundred bar specimens of a commercially available polycarbonate material are formed by injection molding. All specimens are then ground up and remolded; ten specimens are tested for flexural strength, twenty for impact energy, and five for melt flow index; average values are determined. The remaining specimens are reground and remolded, and tests are conducted as previously. This procedure is repeated three more times. Average values for these three measured properties are then plotted versus number of processing times; these plots show how this polycarbonate material experiences thermal degradation.
"Environmental Stress Cracking of Recycled Thermoplastics," Nikhil K. Kundu, NEWU 90, pp. 253-260, EMSET, and J. Mater. Educ., Vol. 14, p. 283 (1992). This paper describes an experimental technique that may be used to investigate how the presence of a stress affects the flexural strength of unreinforced polycarbonate and 30% glass fiber-reinforced polycarbonate materials that are exposed to a toluol propanol (1:10) solution; in addition, the influence of recycle iterations on strength is investigated. Bar specimens are injection molded and stresses are induced by forcing an oversized steel ball into a 3 mm-diameter hole that had been drilled through the specimen. A three-point bending test is used to measure the flexural strength.

"Biodegradable Plastics: An Informative Laboratory Approach," Jeffery S. Humble, NEWU 90, pp. 291-296 and EMSET. This experiment is designed to refute or substantiate plastics manufacturers' claims that their products are made biodegradable by additions of small quantities of corn starch. Test specimens in the form of strips are cut from "biodegradable" plastic trash bags. These specimens are mounted on a test stand that is situated out of doors and that permits exposure to the elements (sunlight, heat, moisture, etc.); alternatively, the degradation process may be speeded up by using an accelerated testing apparatus. Degradation rate may be determined my making weight-loss measurements, and/or by periodically removing specimens and testing their tensile strengths.

"Evaluating the Strength and Biodegradation of a Gelatin-Based Material," Kyumin Whang and Matthew Hsu, NEWU 97, pp. 99-108. Thin film and gel polymer specimens are produced from gelatin solutions. The strengths of these specimens are measured using a ball-on-ring apparatus; students are to explain differences in these strength values. The various specimen types are immersed in solutions having different pHs and at several temperatures. Degradation rate is determined from weight loss-versus-time data. Differences in degradation rate are to be discussed and explained by the students.

"Weakening of Latex Rubber by Environmental Effects," L. Roy Bunnell, NEWU 97, pp. 315-318. Two sets of rubber bands are stretched varying amounts across nails that had been drive into wooden boards. One set is kept in darkness; the other exposed to sunlight. No failures are noted after 600 h for the unexposed set. The influences of sunlight exposure (i.e., UV radiation) and strain on time to failure are determined for the exposed set.

"Study of Molecular Degradation of Polymers by Intrinsic Viscosity," Ping Liu and Danuta Ciesielska, NEWU 99, pp. 29-36. This paper describes a technique whereby the level of degradation of polymeric materials (as a consequence of recycling) may be determined by making viscosity measurements. Polymer degradation occurs by molecular chain scission, which results in a decrease in molecular weight. Furthermore, molecular weight (and thus degradation level) may be ascertained from viscosity measurements of the polymer. The viscosity measurement technique is outlined.

"Accelerated Aging Study of ABS Copolymer," Wayne L. Elban, Scott N. Hornung, and Matthew C. Reinhardt, NEWU 99, pp. 77-100. Room-temperature tensile tests are conducted on ABS copolymer specimens that have been aged at 50°C, 75°C, 90°C, and 105°C. Affects of these aging treatments are determined by comparing mechanical properties (as measured from the tests) with literature values; in addition, fracture surfaces are examined with the naked eye as
well as using reflected light microscopy. Dimensional stability is also ascertained by measuring changes in specimen dimensions.

"Galvanostatic Polarization Curves for Teaching Purposes," Carlos E. Umaña, NEWU 98, pp. 189-205. This paper describes how polarization curves may be determined using a galvanostatic technique that doesn't require sophisticated equipment. Experimental curves are determined for mild steel in a deareated sodium chloride solution. Auxiliary and work electrodes are graphite and saturated calomel, respectively.

"Galvanic Polarization Curves for Teaching Purposes--Part II," Carlos E. Umaña, NEWU 99, pp. 331-340. This experiment is a continuation of part I. Polarization curves for mild steel are measured in the same manner as described in part I, and within the current density range of 1 to 10 μA/cm². In this lower current density range, data is collected using a polarization resistance method, and corrosion current density may be estimated without a knowledge of actual Tafel slope values.

"Experiments in Natural and Synthetic Dental Materials: A Mouthful of Experiments," James V. Masi, NEWU 95, pp. 227-238 and EMSET. This experiment is designed to do the following: (1) show that elements of both good and poor design are found in the area of biomaterials; (2) demonstrate the process of designing materials to withstand the complex interactions found in the oral cavity; (3) conduct analyses (i.e., corrosion, microstructural) on those materials currently used; and (4) suggest possible solutions to problems that exist with the present technology.

CHAPTER 17
THERMAL PROPERTIES

"Improved Technique for Measuring Coefficients of Thermal Expansion for Polymer Films," Stephanie L. Gray, Kristen T. Kern, Sheila Ann T. Long, and Wynford L. Harries, NEWU 90, pp. 119-127 and EMSET. The linear coefficient of thermal expansion of the copolymer FEP Teflon is measured using a thermomechanical analysis apparatus in conjunction with an LVDT in the temperature range -150°F to 150°F. This value is compared to the literature value. Thermal cycling tests are also conducted for one thousand cycles; the influence of thermal cycling on expansion coefficient is ascertained.

"Thermal Conductivity of Metals," Sayyed M. Kazem, NEWU 89, pp. 37-43 and EMSET. Into cylindrical bar specimens of each of an aluminum alloy, brass, and steel are embedded five thermocouples at various positions along the lengths. Each specimen is surrounded by insulation, and one end is placed on a hot plate. Temperature is measured as a function of time for each thermocouple, which data are plotted; times at which steady state heat conduction may be determined from these plots. From steady state temperature profiles of the three alloys, thermal conductivity ratios for pairs of alloys may be computed, and compared to reference values.

"High Thermal Conductivity of Diamond: Demonstration and Comparative Analysis," Patrick M. Stephan, NEWU 92, pp. 433-439 and EMSET. Thermocouples are attached to one end each
of thin copper and CVD (chemical vapor deposited) diamond coupons using silver epoxy. The other end of each is immersed in a bath of ice water, and thermocouple output (in millivolts) is measured as a function of time for times up to 40 s using a voltmeter. Plots of thermocouple output (or, equivalently, temperature) versus time reveal the relative rates of heat flow through these two materials.

"How a Heat Pack Works," Robert A. McCoy, NEWU 97, pp. 159-166. Students explore the operation of a heat pack—i.e., heat is generated from the exothermic crystallization of supercooled sodium acetate trihydrate. Teams of students measure cooling curves for several activation temperature and surrounding temperature combinations.

"Cooling Fin Materials and Convective Cooling," Richard J. Greet, NEWU 90, pp. 67-75 and EMSET. Rods of several common engineering metal alloys are mounted vertically in a baseplate by pressing them into drilled holes. A thermocouple is affixed to each of the free rod ends, and three thermocouples are attached to the baseplate. For the free convention situation, the baseplate is placed on a hot plate and temperatures are measured and recorded until thermal equilibrium is achieved. This procedure is repeated for forced convection by blowing air onto the rods using a fan. Rod-end temperatures for free the free convection case are compared to values computed from the thermal conductivities of the various alloys. Total powers dissipated for all materials and for both free and forced convection are determined and compared.

"Thermal Shock of Ceramic Materials," L. Roy Bunnell, NEWU 91, pp. 51-53 and EMSET. Several 3-mm diameter aluminum oxide rods are given to the students, who bend them until fracture. Another set of rods is heated to 500°C, and then quenched in water and dried. The next day, these rods are immersed in ink, which penetrates and reveals any surface cracks after any excess ink is removed. Students bend these rods to fracture, and note that their strengths are lower than the untreated set. Finally, the thermal shock index is discussed, and values for a variety of common ceramic materials are cited.

CHAPTER 18
MAGNETIC PROPERTIES

"How to Compute the Atomic Magnetic Dipole Moment of an Element: An Engineering Approach," Carlos E. Umaña, NEWU 97, pp. 139-145. This paper describes a technique whereby the theoretical atomic magnetic dipole moment for an element may be determined.

"The Magnetization Process--Hysteresis," Richard Balsamel, NEWU 89, pp. 105-113 and EMSET. This paper describes how one may construct an apparatus that may be used to demonstrate the magnetic characteristics of both ferromagnetic and nonferromagnetic materials.

"Hysteresis Loops and Barkhausen Effects in Magnetic Materials," Luke Ferguson and Thomas Stoebe, NEWU 96, pp. 241-254 and J. Mater. Educ., Vol. 18, p. 311 (1996). This is an experiment in which the student observes the Barkhausen effect--i.e., hears popping and crackling noises produced as magnetization directions change at domain walls. In addition, magnetization-magnetic field strength curves for ferromagnetic materials are generated.
"Demonstration of Magnetic Domain Boundary Movement Using an Easily Assembled Videocam-Microscope System," John W. Patterson, *NEWU 91*, pp. 309-312 and *EMSET*. Observation of domain motion within a ferrimagnetic garnet crystal is possible using an apparatus composed of a home video camera, a ten-power microscope objective lens, and a small adjustable-beam flashlight. The light source is mounted on one side of and shines through the crystal; the video camera focuses on the other side of the crystal through the objective lens. A magnet brought into close proximity of the crystal causes the domains to move which may monitored and recorded by the video camera.

"Effect of Heat Treatment on Magnetic Properties of a Metal Alloy," Wenchiang R. Chung and Margery L. Morse, *NEWU 90*, pp. 183-186 and *EMSET*. Specimens of Alloy 48 (48% Ni, 52% Fe) are heat treated for four hours at 927°C, and subsequently removed one by one at ten-minute intervals and air-cooled to room temperature. Neodymium-iron hard magnets are placed on the Alloy 48 specimens for one hour in order to magnetize them. Magnetic measurements are made on the Alloy 48 samples using a gaussmeter. Magnetic induction-magnetic field strength plots are constructed so as to ascertain the influence of heat treatment on the magnetic characteristics of this alloy.

"Properties of Magnetic Ferrites with a Simple Fabrication Method," Luke Ferguson and Thomas Stoebe, *NEWU 97*, pp. 185-195. Toroidal ferrite cores are slip cast from water-based ceramic slips, which cores are subsequently dried and fired. The magnitude of the magnetic properties of these cores may be ascertained using several techniques, including the generation of magnetic flux density-field strength hysteresis loops.

"Making and Testing Superconductors," James A. Nelson, *NEWU 88*, pp. 63-83 and *EMSET*. This paper describes the procedure for synthesizing and processing the high critical temperature superconductor YBa$_2$Cu$_3$O$_7$ by batching, mixing, grinding, powder pressing, and heat treating. Procedures are described for (1) verifying that this material exhibits superconductive behavior; (2) demonstrating the Meissner effect; (3) measuring the critical magnetic field; (4) measuring the critical current density; and (5) demonstrating the reverse ac Josephson effect.

"High $T_c$ Superconductors: Are They Magnetic?" Robert D. Shull, *NEWU 88*, pp. 1-5 and *EMSET*. This paper describes several demonstrations involving phenomena experienced by superconducting materials—in this case YBa$_2$Cu$_3$O$_7-x$. This first is to determine whether YBa$_2$Cu$_3$O$_7-x$ is diamagnetic or either paramagnetic or ferromagnetic below its critical temperature. The second phenomenon is the Meissner effect. And the third phenomenon involves a difference in magnetic behavior depending on whether a magnetic field is present or absent when the superconductor is cooled to below its $T_c$.

"Determination of the Curie Temperature in Ferro- and Ferrimagnets," R. Valenzuela and E. Amano, *NEWU 98*, pp. 175-181. Toroidally shaped specimens of ferromagnetic and/or ferrimagnetic materials are used. Each specimen is magnetized by a primary coil, whereas the relative permeability of the material is measured using a secondary coil. Specimens are heated in a furnace, and relative permeability is measured as a function of temperature; at the Curie temperature, the permeability diminishes abruptly to a very small value.
"Experiments in Magnetics for Telecommunications: Organic and Sol-Gel," James V. Masi, NEWU 99, pp. 111-120. This paper describes how magnetic polymers may be produced using a sol-gel technique, how the magnetic characteristics of these materials are measured, and, finally, the manner in which the structures of these materials are characterized.

"A Method for the Measurement of Magnetostriction in Ferromagnetic Alloys," O. García-Hernández, R. Galindo, K. L. García, and R. Valenzuela, NEWU 99, pp. 635-646. This paper describes a procedure that may be used to determine the magnetostriction constant of a ferromagnetic material. A continually increasing stress is applied to a ferromagnetic material that is subjected to a magnetic field. Magnetic field-magnetic induction hysteresis plots at several stress levels are displayed on an oscilloscope. Hysteresis loop areas are measured from photographs taken of these plots, from which the magnetostriction constant may be determined.

CHAPTER 19
OPTICAL PROPERTIES

"X-Ray Radiographic Exercises for an Undergraduate Materials Lab," John M. Winter, Jr. and Kirsten G. Lipetzky, NEWU 97, pp. 605-608. Three exercises are described in this paper. The first is one in which compare the absorption of x-rays by three types of glass: a thin-walled glass vase, a thicker glass vase (i.e., leaded crystal), and magnifying glass (the thickest). Students are asked to explain differences in degrees of absorption. For the second exercise, students measure the linear mass absorption coefficient for x-rays passing through an aluminum alloy. Whereas, for the final exercise, several ball bearings are situated in a block of foam packing material. Students are to determine bearing locations in three-dimensions using radiographs taken from three orthogonal directions.

"Integration of Laboratory Experiences into an Interactive Chemistry/Materials Course," John B. Hudson, Linda S. Schadler, Mark A. Palmer, and James A. Moore, NEWU 97, pp. 359-368. This paper describes laboratory experiments that are performed in a freshman chemistry of materials course. These experiments are as follows: (1) for benzene, determination of its pressure-temperature phase diagram and computation of its heat of vaporization; and, (2) for the photoelectric effect, observation of the relationships between photoelectron current and both wavelength and intensity of a light source.

"Correlation of Birefringent Patterns to Retained Orientation in Injection Molded Polystyrene Tensile Bars," Laura L. Sullivan, NEWU 97, pp. 41-44. Birefringent patterns (using polarized light) produced in injection molded polystyrene are used to determine the effects of various molding parameters on residual stress and tensile strength.

"Plastic Part Design Analysis Using Polarized Filters and Birefringence," J. L. Wickman, NEWU 93, pp. 355-360 and EMSET. A commercially available injection molded transparent/translucent plastic part, while being rotated, is examined using a polariscope. The presence of photoelastic fringe patterns indicates the presence and location of residual stresses. A tensile or compressive load is applied using a loading fixture, at which time stressed regions begin to take on color. Analysis of these fringes during loading can be used to locate various features of the molding apparatus (e.g., gates, parting lines, etc.) from which an isometric
drawing of the part may be made. Whether or not the plastic part meets the design criteria specified by the manufacturer may be determined.

"The Colorful Character of Materials," Edward L. Widener, NEWU 98, pp. 139-141. A number of different metal alloys, ceramics, and polymers are collected and their optical characteristics (e.g., degree of translucency, color) are examined and noted. The three characteristics of color (viz. chroma, intensity, and radiance) are modeled using a color tower--i.e., a cylinder in which brightness is represented by longitudinal position, the direction of a radial vector represents chroma, and vector length corresponds to intensity. A number of situations in which iridescence (i.e., rainbows) are present is noted. Finally, several practical applications for which the observed color is important are cited.

CHAPTER 20
ECONOMIC, ENVIRONMENTAL, AND SOCIETAL ISSUES IN MATERIALS SCIENCE AND ENGINEERING

"Industrial Plastics Waste: Identification and Segregation," Edward L. Widener, NEWU 89, pp. 1-5 and EMSET. This paper presents several techniques that may be used to identify various plastic types. These include kits that cite tests (both destructive and nondestructive), by which identification is made on the basis of measured properties. The author also describes a "burn test" wherein a plastic specimen is exposed to an open flame; identification may be made by observation of combustibility, smell, and the nature of the smoke that is produced when the flame is extinguished.

"Biodegradable Plastics: An Informative Laboratory Approach," Jeffery S. Humble, NEWU 90, pp. 291-296 and EMSET. This experiment is designed to refute or substantiate plastics manufacturers' claims that their products are made biodegradable by additions of small quantities of corn starch. Test specimens in the form of strips are cut from "biodegradable" plastic trash bags. These specimens are mounted on a test stand that is situated out of doors and that permits exposure to the elements (sunlight, heat, moisture, etc.); alternatively, the degradation process may be speeded up by using an accelerated testing apparatus. Degradation rate may be determined my making weight-loss measurements, and/or by periodically removing specimens and testing their tensile strengths.

"Plastic Recycling Experiments in Materials Education," Ping Liu and Tommy L. Waskom, NEWU 95, pp. 151-155 and EMSET. Students collect post-consumer plastic products, granulate these recycled products into flakes, which are extruded into plastic rods. The properties and quality of these rods are then determined using tensile and/or hardness tests.

"Making Products Using Post Consumer Recycled High Density Polyethylene: A Series of Recycling Experiments," Ping Liu and Tommy S. Waskom, NEWU 96, pp. 285-289. A variety of types of post-consumer thermoplastic products are collected, sorted, and cleaned. These materials are cut into small flakes using a granulator, and subsequently extruded into 1/4 in. strands; the strands are subsequently cut to form pellets. Finally, the pellets are injection molded in preparation for mechanical testing in order to determine the properties of these recycled plastics.
"Simple Classroom Demonstrations in Chemistry and Materials Science," John B. Hudson, *NEWU 99*, pp. 521-527. This paper describes six demonstrations that are used to illustrate relevant materials science principles and concepts. These demonstrations include the following: conservation of energy (using a ball of glazier's putty); the dependence of atomic vibration frequency on mass and bond strength (using styrofoam balls, hexagonal nuts, and piece of molybdenum wire); a model of a high molecular weight linear polymer (using a string of wooden or plastic beads that are held together with a strong string); solid-state diffusion by a random walk process [using a grid of squares drawn on an overhead transparency sheet, a number of pennies and washers, and some means of generating random numbers (e.g. a calculator)]; the glass transition temperature of an elastomer (using a racquet ball, a flask of liquid nitrogen, and a pair of tongs); and age hardening in an aluminum alloy [using two pieces of precipitation hardenable alloys (one that has been annealed, the other that has been treated for maximum hardness), and a 2x4 piece of lumber].

"Experiments in Materials Science from Household Items," F. Xavier Spiegel, *NEWU 92*, pp. 373-375 and *EMSET*. This paper describes four illustrative demonstrations of material properties using common household items. In the first, using a coat hanger and two pieces of string, it is shown that sound is transmitted more efficiently in a solid (i.e., the string) than through air.

An interesting thermoelastic phenomenon--rise in temperature that an elastomer experiences when it is stretched--is demonstrated by stretching a rubber band and then touching to one's upper lip.

A balloon is used to demonstrate that there is a difference in behavior between stretched and unstretched polymers. When the outside surface of an inflated balloon is touched with a sharp object (such as a skewer) it will burst. However, if the skewer is carefully inserted through the inflation hole and then brought in contact with the inside of the balloon, it (the balloon) will remain inflated for some time.

Corn starch is mixed with water to give a consistency similar to pancake batter. If this mixture is stirred slowly, it will behave as a fluid. On the other hand, when stirred rapidly, the behavior will be more like a solid.

"Inexpensive Materials Science Demonstrations," F. Xavier Spiegel, *NEWU 93*, pp. 121-123 and *EMSET*. (1) Anisotropy may be demonstrated using filament tape (i.e., parallel and aligned threads embedded in a polymer tape, one side of which is coated with an adhesive). It is relatively easy to tear the tape in the direction of the threads, but nearly impossible parallel to the threads.

(2) When one tries to continually fold a piece of paper, a point is reached at which it cannot be folded any more. This exercise demonstrates that mechanical strength is affected by the number of composite folds.

(3) Into a 3" x 5" index card are cut two one-inch long slits from one of the 5" edges; each slit is positioned about one inch from and parallel to one of the 3" sides. A hole is now punched at the bottom of one of the slits. When the card is pulled in tension on the 3" sides, it will fail not where the hole was punched, but rather, where the slit alone was made. This is an example of crack deflection around the hole.
(4) This demonstration involves a bimetallic disk—that is a flat disk one side of which is a stainless steel that is joined to Invar. In the as-received state, it is bent such that one side is convex, the other concave. Using one's thumb, the disk is bent such the convex side becomes concave and vice versa, and then it is placed on a flat surface, concave side down. After a short time, the disk will suddenly jump off this surface as it springs back to the original convex-concave configuration. The spontaneous reversal is caused by a difference in coefficients of thermal expansion for the two alloys.

"Everyday Objects and Class Demonstrations in Materials Science Class Designed to Help Students Learn," Neda S. Fabris, NEWU 99, pp. 425-429. This paper presents a number of classroom demonstrations that facilitate the learning of principles of materials and employ common objects that are familiar to most students. Concepts and principles that are illustrated include the following: introduction to different materials, atomic structure, atomic arrangement, imperfections in atomic arrangements, atomic movements in materials, and mechanical testing/properties.

"Demonstrations in Materials Science from the Candy Shop," F. Xavier Spiegel, NEWU 94, pp. 189-191 and EMSET. The ductile-to-brittle transition is may be demonstrated using chewing gum. Ductile failure is demonstrated by pulling a stick of gum from both ends at room temperature. Gum may be made to fracture in a brittle manner if it is cooled in a refrigerator or allowed to dry out before being pulled in tension.

Brittle fracture may be demonstrated by fracturing a piece of hard candy. Nuts are added to peanut brittle, not only to make it more tasty, but also to improve the mechanical strength; this same principle is used in designing engineering composites. Elastic, anelastic, and plastic deformations may be demonstrated by pulling a licorice stick from both its ends.

When a wintergreen mint is chewed (broken) in a dark room, flashes of light are generated; this phenomenon is termed triboluminescence.

"Corking an Open-Ended Tank," Edward L. Widener, NEWU 99, pp. 649-653. This paper presents a problem for which there are multiple solution approaches. The problem statement is as follows: "Assume your boss needs a quick, cheap answer to an EPA mandate for only 10% uncovered area. You must find the open-area of any solvent-tank, subject to evaporation, after covering the surface with small corks in a close-packed pattern. The tank diameters are unknown. All corks are the same, but much smaller than any of the tanks. You try several experiments with specific tanks and floats. Then try a general geometric approach, select a simple 'unit cell,' and find the minimal open area is under 10%." Containers (cans, pans, etc.), water, and floats (corks, puffed cereals, etc.) may be used. The author outlines several approaches that may be used to solve the problem.

"There are Good Vibrations and Not So Good Vibrations," F. Xavier Spiegel, NEWU 95, pp. 319-321 and EMSET. This demonstration illustrates some interesting responses of materials to vibrations.

"Tutorials for Introduction to Materials Engineering," Charles J. McMahon, Jr., NEWU 98, pp. 353-364. This paper presents a number of figures that accompany computer animations and that illustrate fundamental principles and concepts of materials science and engineering.
CHAPTER 1
INTRODUCTION

"Materials All Around Us," James A. Jacobs, NEWU 95, pp. 87-91 and EMSET. This exercise is designed to motivate students to learn about materials and their properties. This is accomplished by having them keep journals, and collect and bring to class mounted samples of a variety of materials that are found in common products.

CHAPTER 2
ATOMIC STRUCTURE AND INTERATOMIC BONDING

"Ionic Bonding, An Introduction to Materials and to Spreadsheets," Mike L. Meier, NEWU 99, pp. 153-166. This paper describes how, using spreadsheets, interatomic forces and energies, as well as several physical properties (i.e., Young's, shear, and bulk moduli; melting temperature) may be computed for inorganic compounds.

CHAPTER 5
IMPERFECTIONS IN SOLIDS

"Artificial Microstructures," Mike L. Meier, NEWU 98, pp. 279-287. This paper describes simple techniques for generating artificial and idealized micrographs. These artificial micrographs are generated using Adobe Photoshop, and grain and phase boundaries are clearly resolved. Analytical techniques may be used by students to measure average grain size, grain aspect ratio, phase volume fractions, etc.

CHAPTER 7
MECHANICAL PROPERTIES

"An Introduction to Strength of Materials for Middle School and Beyond," Nancy L. Denton and Vernon S. Hillsman, NEWU 93, pp. 147-151 and EMSET. This paper describes demonstrations that illustrate several basic mechanics principles using common equipment and supplies—viz., fishing line, plastic straws, a foam bar, hex head bolts, etc. These principles include axial force and deflection, buckling, torsion, and bending. Students may also be provided an opportunity to build and strength test structures using craft sticks and glue.

"Craft Stick Beams," Alan K. Karplus, NEWU 95, pp. 95-101 and EMSET. This experiment is designed, using craft sticks or popsicle sticks, to: (1) provide a phenomenological "hands-on" experience that shows how geometry influences the load carrying capacity of a material used in construction; (2) demonstrate that different materials have different failure characteristics; and (3) demonstrate how the performance of a composite material is affected by its construction.

"Elasticity, Plasticity, and Anelasticity: Demonstrations," F. Xavier Spiegel, NEWU 96, pp. 293-295. Various combinations of the three phenomena—elasticity, plasticity, and anelasticity—are
demonstrated using a coat hanger, a rubber band, a spring, modeling clay, and a plastic beverage container.

"Egg Bungee Cord Drop," Robert A. McCoy, NEWU 99, pp. 207-212. In this design exercise, groups of students design, construct, and test bungee cord apparatuses. The apparatus consists of an egg contained in a plastic bag that are attached to a bungee cord. Groups of students compete to see whose egg, when dropped from a height of approximately 20 feet, comes closest to the floor without hitting it. Full-scale practice drops are not allowed; rather, students decide on cord length by conducting and analyzing static and dynamic drop data on short pieces (of lengths between 0.25 and 0.5 m).

"From Rugs to Demonstrations in Engineering Materials Class," Neda S. Fabris, NEWU 96, pp. 229-237. This paper describes several simple classroom demonstrations that illustrate the following concepts: modulus of elasticity, Poisson's ratio, shear stresses introduced by tensile loading, normal stresses in shear deformation, grain size strengthening, and dislocation movements.

"Testing Rigidity, Yield Point, and Hardenability by Torque Wrench," Edward L. Widener, NEWU 93, pp. 501-502 and EMSET. This paper describes demonstrations of rigidity, yield point, and strain hardening. For the first demonstration, a large-loop paper clip is gripped in a vise; using a fish scale the clip is twisted 90° in one direction and then 90° in the opposite direction. Strain hardening is represented by the difference in pull forces for the two deformations. Quantitative measurements are conducted in a similar manner on a rod of a ductile metal alloy that is twisted using a torque wrench. Elastic return after twisting through a small angle is noted. Next, torque values are measured at various angles of twist in one direction (as the rod is plastically deformed), and then in the opposite direction; torque values are now plotted versus twist angle.

"It's Hard to Test Hardness," Edward L Widener, NEWU 90, pp. 161-167 and EMSET. This paper explores some unconventional hardness testing techniques, and how their hardnesses compare with values measured using traditional techniques.

"In-Class Experiments: Piano Wire and Polymers," David Stienstra, NEWU 94, pp. 422-428 and EMSET. For the first portion of this experiment, three 100-150 mm lengths of 20 gauge piano wire are provided to each group of students. One length is kept in its as-received state (i.e., cold drawn); the other two are austenitized at 870°C for one hour, and one is quenched in water while the other is furnace cooled to room temperature. Students are to bend each wire, note the relative force required, and also the relative degrees of ductility. On the basis of these tests, students in each group discuss and come to conclusions as to possible processing techniques and microstructures of the three wires.

The second portion involves investigating the influence of strain rate on the mechanical characteristics of several polymeric materials: silly putty, six-pack rings, nylon cable ties, and splat balls. These items are deformed at different strains rates, and differences in behavior are noted, which are explored in terms deformation mechanisms and polymer structures.

"Measurement of Viscosity: Classroom Demonstration," Richard B. Griffin and Lance Terrill, NEWU 99, pp. 657-663. This paper describes a procedure that may be used to measure the
viscosity of glycerin at several temperatures in the vicinity of the ambient; measurements are made using a rotational viscometer. From resulting data an activation energy is calculated.

"Knotty Knots," Alan K. Karplus, NEWU 93, pp. 369-372 and EMSET. Twenty three-foot long specimens of some type of string (e.g., fishline, thread, etc.) are prepared. Four are pulled (by hand) in tension to failure using a tubular scale (which measures the applied load); failure loads are recorded and averaged. This same procedure is repeated for situations in which four different types of knots are tied in the string centers. From these values, stress concentration factors may be determined for the various knot types.

"A 69 Cent Look at Thermoplastic Softening," Linda S. Vanasupa, NEWU 92, pp. 275-277 and EMSET. The effect on the mechanical behavior of a polymer as a consequence of heating above its glass transition temperature is demonstrated. A plastic tooth brush is bent at room temperature and also after it has been heated in boiling water for a couple of minutes; differences in its mechanical characteristics are noted.

CHAPTER 7
DISLOCATIONS AND STRENGTHENING MECHANISMS

"From Rugs to Demonstrations in Engineering Materials Class," Neda S. Fabris, NEWU 96, pp. 229-237. This paper describes several simple classroom demonstrations that illustrate the following concepts: modulus of elasticity, Poisson's ratio, shear stresses introduced by tensile loading, normal stresses in shear deformation, grain size strengthening, and dislocation movements.

"Work-Hardening and Annealing in Metals," L. Roy Bunnell and Stephen W. Piippo, NEWU 89, pp. 179-180. Each student is given two pieces of bare copper wire. One is work hardened by bending and twisting; the phenomenon of work hardening is noted and discussed. The other is bent in the same manner, and one of the wires is heat treated (i.e., annealed). At this time both wires are twisted again, the relative required forces are noted, and the phenomenon of recrystallization is discussed.

"Testing Rigidity, Yield Point, and Hardenability by Torque Wrench," Edward L. Widener, NEWU 93, pp. 501-502 and EMSET. This paper describes demonstrations of rigidity, yield point, and strain hardening. For the first demonstration, a large-loop paper clip is gripped in a vise; using a fish scale the clip is twisted 90° in one direction and then 90° in the opposite direction. Strain hardening is represented by the difference in pull forces for the two deformations. Quantitative measurements are conducted in a similar manner on a rod of a ductile metal alloy that is twisted using a torque wrench. Elastic return after twisting through a small angle is noted. Next, torque values are measured at various angles of twist in one direction (as the rod is plastically deformed), and then in the opposite direction; torque values are now plotted versus twist angle.

CHAPTER 9
FAILURE
"Paper Clip Fatigue Bend Test," Alan K. Karplus, NEWU 94, pp. 125-131 and EMSET. Fatigue tests are conducted on regular size paper clips. Three paper clips are each repeatedly bent through an angle of 45° and the numbers of cycles to failure are counted; an average of the three values is computed. This procedure is repeated for bend angles of 90°, 135°, and 180°. Data is plotted as bend angle versus number of cycles.

A jumbo paper clip is fatigue tested in the same manner and its data are plotted and compared to those of the standard size clip. Furthermore, tests may also be conducted on other materials (e.g., brass paper fasteners and aluminum welding rods).

CHAPTER 10
PHASE DIAGRAMS

"Demonstrating the Critical Properties of Carbon Dioxide," Leonard W. Fine, NEWU 97, pp. 443-448. Several pieces of dry ice are inserted into a piece of Tygon tubing 1/2 in. in diameter and about 6 in. long. The tube ends are clamped with jumbohosecocks. As the dry ice sublimes, pressure within the tubing increases, which causes the carbon dioxide to transform first to a slush and then to a liquid. The pressure ultimately reaches a level that causes tube failure.

CHAPTER 11
PHASE TRANSFORMATIONS

"In-Class Experiments: Piano Wire and Polymers," David Stienstra, NEWU 94, pp. 422-428 and EMSET. For the first portion of this experiment, three 100-150 mm lengths of 20 gauge piano wire are provided to each group of students. One length is kept in its as-received state (i.e., cold drawn); the other two are austenitized at 870°C for one hour, and one is quenched in water while the other is furnace cooled to room temperature. Students are to bend each wire, note the relative force required, and also the relative degrees of ductility. On the basis of these tests, students in each group discuss and come to conclusions as to possible processing techniques and microstructures of the three wires.

The second portion involves investigating the influence of strain rate on the mechanical characteristics of several polymeric materials: silly putty, six-pack rings, nylon cable ties, and splat balls. These items are deformed at different strains rates, and differences in behavior are noted, which are explored in terms deformation mechanisms and polymer structures.

CHAPTER 12
ELECTRICAL PROPERTIES

"Visual Quantum Mechanics--A Materials Approach," S. Raj Chaudhury, N. Sanjay Rebello, Larry Escalada, and Dean Zollman, NEWU 96, pp. 155-162. This paper describes computer simulations in the Visual Quantum Mechanics (VQM) software package (e.g., wave functions, energy bands, atomic spectroscopy, semiconductor device simulator). It also mentions that quantum phenomena may be demonstrated use light-emitting diodes (LEDs).

"The Human Half-Adder: Understanding the Big Picture of Digital Logic," Linda Vanasupa and David Braun, NEWU 97, pp. 269-277. This is an exercise designed to show students how
transistors operate in an integrated circuit. Each student is assigned to and then functions as either a logic element or a half logic element.

"Temperature-Dependent Electrical Conductivity of Soda-Lime Glass," L. Roy Bunnell and T. H. Vertrees, *NEWU* 92, pp. 443-448 and *EMSET*. Wire electrical contacts are attached to a strip of window glass; these are connected in series with a 75- or 100-watt light bulb. When the ends of this testing unit are plugged into a 110 V outlet, the intensity with which this bulb glows is a visual indicator of the electrical resistivity of the glass. At room temperature the bulb does not glow since the resistivity of the glass is very low. When heated with a propane torch, the bulb begins to glow, which shows that the electrical resistivity of the glass diminishes with increasing temperature.

If the same experiment is conducted on a steel nail, at room temperature the bulb will glow brightly; furthermore, the bulb will not dim perceptibly when the nail is heated.

"Liquids That Take Only Milliseconds to Turn into Solids" (or "Application Advancements Using Electrorheological Fluids"), John A. Marshall, *NEWU* 93, pp. 317-322 and *EMSET*. An energizing probe (unenergized) is inserted into an electrorheological fluid and then removed; students observe the fluid behavior (i.e., the fluid flows freely back into the container). The probe is again inserted, energized, and removed; the students observe a gelling of the fluid around the probe rods. At this time the probe is de-energized, and the gelled electrorheological fluid liquefies and drips back into the container.

**CHAPTER 14**

**SYNTHESIS, FABRICATION, AND PROCESSING OF MATERIALS**

"The Incandescent Light Bulb," Leonard W. Fine, *NEWU* 96, pp. 263-268 and *J. Mater. Educ.*, Vol. 18, p. 345 (1996). In this demonstration the several materials used in the various components of the incandescent light bulb and their properties are noted. Oxidation of the tungsten filament is also demonstrated.

"Newmismatic Metallurgy," Edward L. Widener, *NEWU* 97, pp. 493-495. This paper discusses the compositions and characteristics of metals and metal alloys that are used for various coins. The histories of several types of coins are also presented.

"Shape Memory Alloys," John A. Marshall, *NEWU* 99, pp. 71-73. This paper describes a technique whereby motion is created using a shape memory alloy. The demonstration device consists of a plastic strip (cut from a milk carton), two push pins, an elastic band, and a shape memory (nitinol) alloy wire that is heated using two AA batteries.

"Visio-Plastic Modeling of Metal Forging and Extrusion," Ghassan T. Kridli, *NEWU* 99, pp. 477-480. This paper describes a modeling technique that uses a soft material (such as plasticine) to demonstrate material flow and study strain distributions that are produced in forgings and extrusions. Plasticine strips of equal thickness and of two different colors are stacked in such a manner that colors alternate from layer to layer. This layered strip assembly is then forced through a die. Strain distributions and material flow may be noted by observing configurational alterations of the original layered structure.
"Polybutadiene (Jumping Rubber)," Leonard W. Fine, *NEWU 95*, pp. 75-78 and *EMSET*. This is a dramatic demonstration of a polymerization reaction wherein the product polymer erupts from the bottle in which reactant solutions are mixed.

"Laboratory Experiments from the Toy Store," H. T. McClelland, *NEWU 91*, pp. 161-168 and *EMSET*. The first portion demonstrates, using a silicone polymer ("silly putty" or "nutty putty"), elasticity and plasticity phenomena, and how they are influenced by temperature. The silicone polymer is rolled into a ball and dropped onto a rigid surface both at room temperature and also after the ball has been cooled in ice. Levels of elasticity and relative rebound heights are noted and compared. After forming the putty into a cylinder, it is slowly pulled in the lengthwise direction at room temperature and also after cooling in ice water. Degrees of plasticity (ductility) and deformation forces are noted and compared. This procedure is repeated when the cylinder is rapidly deformed.

For the second portion of the experiment, clay materials are extruded through extrusion presses that may be purchased at toy stores. The influence of extrusion speed is investigated; material movement during extrusion is also examined using two colors of clays.

CHAPTER 15
COMPOSITES

"Designing with Brittle Matrix Composites," Ken Reifsnider, *NEWU 95*, pp. 247-270 and *EMSET*. This paper consists of a series of illustrations, tables, and lists that cite properties and applications of this group of materials.

"Simple Stressed-Skin Composites Using Paper Reinforcement," L. Roy Bunnell, *NEWU 90*, pp. 273-277 and *EMSET*. In this experiment, using polyurethane foam rubber beams, the following are demonstrated: (1) regions of compressive and tensile forces when the beam is bent; (2) the influence on stiffness of a stress skin (i.e., construction paper sheet) applied to one beam face; and (3) how stiffness is affected by stress skins applied to two opposing beam faces.

CHAPTER 17
THERMAL PROPERTIES

"The Combined Effect of Thermal Conductivity and Thermal Expansion in a PMMA Plastic Heated by Thermal Radiation," Carlos E. Umaña, *NEWU 97*, pp. 111-118. The upward deflection of the end of a cantilever beam of PMMA that is situated above a hot plate is explained by its lack of heat radiation transmissibility for infrared radiation, its low thermal conductivity, and its high coefficient of thermal expansion.

"Introductory Heat Transfer," Edward L. Widener, *NEWU 91*, pp. 377-382 and *EMSET*. Using common and readily available equipment and supplies, seven demonstrations dramatically illustrate the physical meaning of thermodynamic principles and properties to include: heat capacity, thermal conductivity, melting temperature, and thermal expansion.
CHAPTER 18
MAGNETIC PROPERTIES

"Demonstration of Magnetic Domain Boundary Movement Using an Easily Assembled Videocam-Microscope System," John W. Patterson, NEWU 91, pp. 309-312 and EMSET. Observation of domain motion within a ferrimagnetic garnet crystal is possible using an apparatus composed of a home video camera, a ten-power microscope objective lens, and a small adjustable-beam flashlight. The light source is mounted on one side of and shines through the crystal; the video camera focuses on the other side of the crystal through the objective lens. A magnet brought into close proximity of the crystal causes the domains to move which may monitored and recorded by the video camera.

"Fluids with Magnetic Personalities," Glenn S. Kohne, NEWU 94, pp. 505-510 and EMSET. This paper describes three demonstrations that employ magnetorheological materials—materials the viscosity of which are dependent on the strength of surrounding magnetic fields, in this case, iron filings suspended in a liquid (i.e., some type of oil such soybean oil).

The first demonstration simply demonstrates the magnetorheological effect. The magnetorheological fluid is poured into a clear plastic container, and stirred with a spatula—fluid behavior is observed. Now when magnets are placed against the container sides, the once fluid now becomes a rigid solid such that a bar bridge between the two magnets may be formed using the spatula.

In the second demonstration, the flow rate of the magnetorheological fluid may be varied by placing a magnet near a piece of tubing through which the fluid flows from one container to another.

The magnetorheological fluid may perform as a magnetic brake. When a motor-driven disk in the shape of a fan is immersed and rotated in a magnetorheological fluid, as the external magnetic field is increased it is observed that the current drawn by the driving motor (at fixed voltage) also increases.

"High $T_c$ Superconductors: Are They Magnetic?" Robert D. Shull, NEWU 88, pp. 1-5 and EMSET. This paper describes several demonstrations involving phenomena experienced by superconducting materials—in this case YBa$_2$Cu$_3$O$_{7-x}$. This first is to determine whether YBa$_2$Cu$_3$O$_{7-x}$ is diamagnetic or either paramagnetic or ferromagnetic below its critical temperature. The second phenomenon is the Meissner effect. And the third phenomenon involves a difference in magnetic behavior depending on whether a magnetic field is present or absent when the superconductor is cooled to below its $T_c$.

CHAPTER 19
OPTICAL PROPERTIES

"Plastic Part Design Analysis Using Polarized Filters and Birefringence," J. L. Wickman, NEWU 93, pp. 355-360 and EMSET. A commercially available injection molded transparent/translucent plastic part, while being rotated, is examined using a polariscope. The presence of photoelastic fringe patterns indicates the presence and location of residual stresses. A tensile or compressive load is applied using a loading fixture, at which time stressed regions begin to take on color. Analysis of these fringes during loading can be used to locate various...
features of the molding apparatus (e.g., gates, parting lines, etc.) from which an isometric drawing of the part may be made. Whether or not the plastic part meets the design criteria specified by the manufacturer may be determined.