Micro to Macro: Linking Microstructure to Material Properties

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Abstract of Module:

Traditional high school chemistry includes minimal exposure to the solid state. In an effort to connect science into the real world and introduce engineering design into the curriculum a unit of study was created to include solid materials. This unit consisted of a number of modules that led the students on a journey of discovery that took them from a real world look at the materials around them towards the development of a microscopic model which was used to explain the macroscopic properties observed earlier in the unit.

This module focuses on explaining how macroscopic properties are connected to the microstructure of a material. If an instructor chooses to focus solely on this module it is suggested that they allow 2 - 3 weeks of class time. Alternatively, components of this module can be interwoven through a traditional chemistry curriculum and can be used to formulate innovative laboratory experiments.

Objective:

- To develop a model that links macroscopic properties to microstructure.
- To investigate and apply some principles of material engineering and design.

Student Learning Objectives (Students will be able to - SWBAT):

- Develop a model for metallic bonding based on previous knowledge of covalent and ionic bonding.
- Identify materials by relating their properties to the intermolecular forces of attraction and bond type (ionic, covalent, and metallic).

- Use their knowledge of bonding, physical properties and periodic trends to predict the general composition of the solid materials that they have collected in a previous module (See: "Investigation of Material Properties").
- Use their model to predict and test how thermal and mechanical treatments will affect microstructure and consequently, the macro-level properties of the metals.

Keywords: Solid State, Chemistry, Material Properties, Classification, Periodic Table, Bonding, Heat Treatment, Crystal Structure, Metals, Deformation, Modeling

Grade Level: Grade 6 through Grade 12

Prerequisite Knowledge:
Before attempting this module students should have a basic knowledge of ionic and covalent bonding, periodic trends, and a basic concept of kinetic theory and depictions of molecular structures. They should be familiar with the terminology used to describe properties of solids.

Equipment & Supplies:
- Bunsen burner
- 2 Tongs
- Paper Clips
- Bobby Pins
- Pennies
- 250 mL Beaker
- Sodium Hydroxide (6M)
- Zinc Powder
- Safety Equipment

Curriculum Overview:
This curriculum was developed based on the need to connect science to the real world and to incorporate engineering design practices into the curriculum (NGSS). Students are surrounded by objects engineered with solid state materials but are given little exposure to solids in high school chemistry. The overall flow of the curriculum is to begin with a recognition that the materials around them are made of chemical elements. Students then worked to characterize and classify those materials for further study. As an understanding of atomic and molecular structure and bonding develops, students then reconcile what they observed macroscopically with their developing understanding of microstructure. Further experimentation and investigation is then conducted to verify their model.

Overall Sequence and Instructor Notes:

1. **Links between bonding and observed properties will be presented (some of this material may be presented prior to module)**

Bonding will be introduced based on periodic trends and atomic structure. Covalent (polar and nonpolar) and ionic bonding will be presented with rationales and examples. Students will work to develop links between bonding and the material properties that they have been investigating in the first module. Whiteboarding/brainstorming with connections to periodic trends, atomic structure and bond characteristics should be utilized at this point. Students will be led to developing a model of metallic bonding due to the inability of ionic and covalent bonds to fully explain properties of some materials. Once student groups have developed some sort of model for bonding, a discussion to get some sort of class consensus would be helpful.

Key concepts to stress are delocalization of valence electrons (sea of electrons); positive metal ions; electrostatic attraction between delocalized electrons and positive ions. Connections to resulting properties that should be made are summarized below. Since much of the behavior of metallic bonds depends on Coulomb forces (electric force) it is worth demonstrating the force and showing Coulomb's Law to students. This can be reinforced with sticky tape demonstrations or other electrostatics investigations.

Strong bonds = strong material, hard to fracture. High melting/boiling points result when it is hard to pull atoms apart. Transition metals tend to have particularly high melting points and boiling points since 3d electrons are delocalized as well as the 4s. The more electrons you can involve, the stronger the attractions tend to be.

Electrostatic attractive forces, electron sea = ability to deform without breaking (malleability, ductility). Positive ions remain surrounded by negative electrons as they move. Compare and contrast to ionic crystals and fracture.

Delocalized electrons = Electrical and thermal conductivity. Electrons are free to move, creating electric current. Thermal effects are also related to increased motion and non-directionality of bonding of positive ions.

Large number of delocalized (valence) electrons = luster since electrons are free to move and can match frequency of light hitting the metal. Some light is absorbed by electrons making the surface warmer and also gives metals their opacity. Metals can lose their luster when surfaces are rough or covered in oxides creating more diffuse reflection.

2. **Crystal structure, dislocations and defects will be further linked to material properties**

Crystal structure will be introduced in terms of why it happens and what it looks like. Key ideas include: the unit cell, close-packed structures, and connections to macroscopic properties.
Hands-on activities include
1. Close packed plane simulation (chalk, markers, dowels, fingers) to show what creates an easier surface for movement
2. Models of BCC and FCC. Stacking planes for FCC (abcabc) vs HCP (abab)

(*Some background information follows and should be presented to students on an appropriate level. It is suggested that ideas of symmetry, balanced forces and a low-energy equilibrium state form guiding principles at a level that makes sense to students.)*

The ideas that are key to the crystal structure found in metals are that they are bonds between a group of like positive atoms, lending itself to a symmetrical arrangement and that the crystal lattice creates the closest possible arrangement between the positive ions (which repel each other) and the delocalized electrons, which are attracted to the cations. It is therefore the lowest energy state due to a balance between repulsive and attractive forces. (Force is the slope of the energy vs. position curve, so a minimum in the energy curve represents a net force of zero). An analogy to items falling to the lowest gravitational potential energy site is helpful here. The periodic arrangement of metal ions is easily demonstrated by shaking marbles in a container and noting the organized arrangement that they form. A side view of multiple layers clearly indicates how layers "nest" in interstitial sites, adding to the periodicity in a vertical direction. It is also useful to demonstrate the disruptions in structure that occur if some different size "atoms" are introduced.

The strength of a metal lies in the relative ease with which planes (layers) can glide past each other with little disruption in the bonding symmetry of the arrangement due to the delocalization of the bonding electrons. It is therefore reasonable to infer that any disruption in symmetry will make it harder to deform a metal and will limit its response in the elastic region.

Defects that disrupt symmetry can be viewed as straining the crystal lattice (distorting bonds). Defects can be categorized as point (vacancies and impurities), line (dislocations) and planar (grain boundaries). Presenting pictures or depictions of these defects that highlight resulting non-symmetry or regions with numerous "disruption" (grain boundaries) in the structure gives students a strong visual sense of how the micro-structure can affect properties.

3. **Connections between composition, processing and properties will be investigated and verified. Alloying, heat treatment, and phase changes will be modelled.**

This final part of the module is designed to provide experimental verification of the model students have developed. By manipulating properties through various chemical, physical and thermal methods students can test their ideas. It is critical that the instructor require students to make predictions prior to the activities and that student groups brainstorm microstructural behavior to explain their experimental observations.

Alloying from pennies – chemical effects

Paper Clip activity – fatigue and work hardening (physical effects)

Bobby Pin activity – annealing, quenching, and tempering (thermal effects)

Extension: Engineering use and design of materials and material systems will be introduced and applications can be investigated. A discussion of composite material, joining techniques, sustainability, and the material demands of new technologies can lead to a variety of engineering-oriented STEM projects. Please contact the authors if you would like further information.

Module Procedure for Students:

- **Properties and Bonds:** Procedures for students are included in the handout.

- **Development of 2D Model of Metallic Bonding:**

1. Students are being asked to develop a model for metallic bonding that helps reconcile the discrepancies between the properties observed in metals and the currently studied models for ionic and covalent bonding. To do this have the students work in groups to brainstorm (on the whiteboards) and decide on one model that explains the various and contradicting properties (i.e. hard (more ionic), but not brittle (more covalent)) that metals have (see note 1). **Be sure to explain that searching for answers online is not allowed (finding the model online would defeat the purpose of this activity).**
2. When each group of students has developed a working model for metallic bonding have a each group choose a representative to take the models on the whiteboards and display them in way that they can all be viewed by everyone in the class simultaneously. Have the class analyze the models by looking for and discussing similarities and differences. Give them permission to ask the representatives questions about various aspects of the models in the process of analyzing them.
3. Finally, have the class consolidate the models that were developed by the individual groups and create a class model of metallic bonding that can then be compared to the existing model of metallic bonding which can be found online. An analysis can then be made comparing the two models of metallic bonding (the class model vs the accepted model).

- **Investigation of a 3D Model of Metal Packing Structures:**

1. Provide the students with enough small marbles or beads to create one layer on the bottom of the petri dish or beaker (normal sized only). Have the students place the marbles into the container and give them a gentle shake. They should make observations and drawings that note the way the marbles organize themselves within the container (on whiteboards so that they are easily compared to each other’s). Have the students do this several times. They should see that the marbles consistently organize themselves into geometrical patterns.

2. Provide the students with enough marbles to create a second layer of marbles in the container. Have them repeat the first step this time observing the way the layers stack on top of each other. They should see that the top layer of marbles tends to fall into the gaps created by the bottom layer of marbles.

Steps 1 & 2 are used to demonstrate how atoms can arrange themselves into various packing structures based on the idea of finding the lowest gravitational potential energy site.

3. Introduce the alloying process by providing students with marbles of different sizes. If they are given significantly smaller marbles or BB's they can shake the container and note the final position of the BBs (the interstitial spaces). If the students are given slightly smaller or larger marbles they should use one finger to push the marbles into an established lattice. Have them observe and note the effects on the lattice of this type of addition.

- **Defects in Packing Structure:**

1. Give the students the "Defects in Packing Structure" handout.
2. Using the image on the top of the handout help them to identify and label each type of defect that is presented as they work to describe and/or define the defects.
3. Using the desks and themselves have the students develop moving models that are representative of each type of defect. (Ex. Use the desks to create a uniform lattice, the students being the sea of electrons. Time them as they walk through the uniform lattice (from one side of the room to the other). Then have the students create a change or defect in the lattice and time them as they walk through the modified lattice. They should be able to generalize from this how the electrical conductivity of a metal is affected by changing the structure of the lattice. You might provide them with a general statement such as anything that makes it more difficult for "atoms/electrons" to get through the lattice = less ductile, less electrically conductive and more hard.) Use the results of their modeling to fill in the handout.
4. It is important (and more fun for all) if the students are allowed to use their creativity to figure out how they will simulate each type of defect. (Depending on time not all defects may be explored.)

- **Gold Penny Lab:** Procedures for students are included in the handout.

- **Paper Clip Fatigue Lab:** Procedures for students are included in the handout.

- **Can the Mettle of a Metal be Improved? Lab:** Procedures for students are included in the handout.

* Teachers are encouraged to read through the handouts and provide extra support to their students based on the ability of each group.

** Students should be directed to reflect on models for metallic bonding that they produced as well as the work that was done on the Defects in Metal Packing Structure handout to help them answer the post lab questions for the Gold Penny Lab, Paper Clip Fatigue Lab and the Can the Mettle of a Metal be Improved? Lab.

Supporting Handouts (appended below):

- **Properties and Bonds** (Use this handout when addressing **instructor note 1**)
- **Defects in Metal Packing Structure** (Use this handout when addressing **instructor note 2**)
- **Gold Penny Lab** (Use this handout when addressing **instructor note 3**)
- **Paper Clip Fatigue** (Use this handout when addressing **instructor note 3**)
- **Can the Mettle of a Metal be Improved?** (Use this handout when addressing **instructor note 3**)

Author Bio

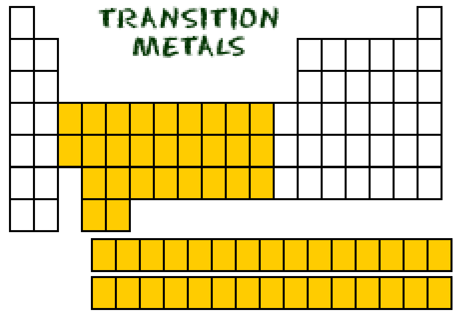
Ann Kaiser is a STEM Education Consultant and CEO of ProjectEngin LLC, a firm providing professional and curriculum development services focused on the inclusion of engineering in K-12 education. A graduate of Columbia University's School of Engineering (B.S. Metallurgy and Materials Science) and the School of International and Public Affairs, Ann is a former metallurgical engineer with 16 years of experience in secondary education. Ann was named a Fulbright Distinguished Teacher in 2013, and researched the role of engineering in secondary physics curriculum in Singapore. She has been a presenter and keynote speaker at numerous national and international conferences.

Gabriel Rodriguez is a Teacher of Chemistry at La Salle Academy, a private catholic school. A graduate of Rhode Island College (B.A. Biology, Chemistry minor, M. Ed. Advanced Studies in Teaching and Learning), Gabriel has seven years of experience in secondary education. Gabriel has focused his time on developing labs and activities that would engage learners with the task of *doing science*, in contrast to performing science experiments. Most recently, Gabriel has been constructing pedagogies for improving science literacy by using choice, self-assessment and opportunities for revision. He has been a presenter at various local and regional conference

PROPERTIES AND BONDS

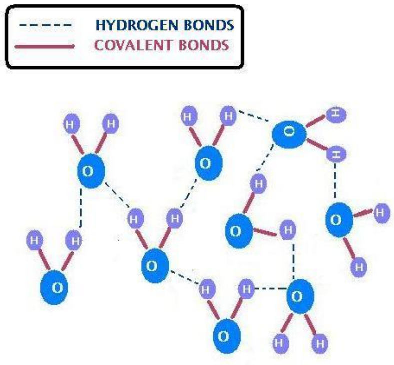
Names:

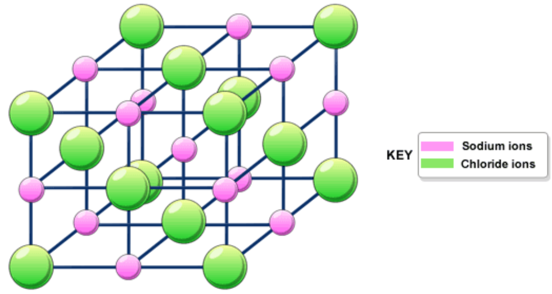
Go back to your Periodic Table of Stuff and identify the metals that you have listed. Record those metal materials in the left column. List the properties of those materials in the right column.



MATERIAL	PROPERTIES

Notes:





COVALENT **IONIC**

List as many properties of metals as you can identify in the column on the left, then in the column on the right indicate whether a covalent or an ionic would do a better job of explaining the property. If you are sure put a star next to the type of bond. If you are not so sure, put a question mark next to the bond type.

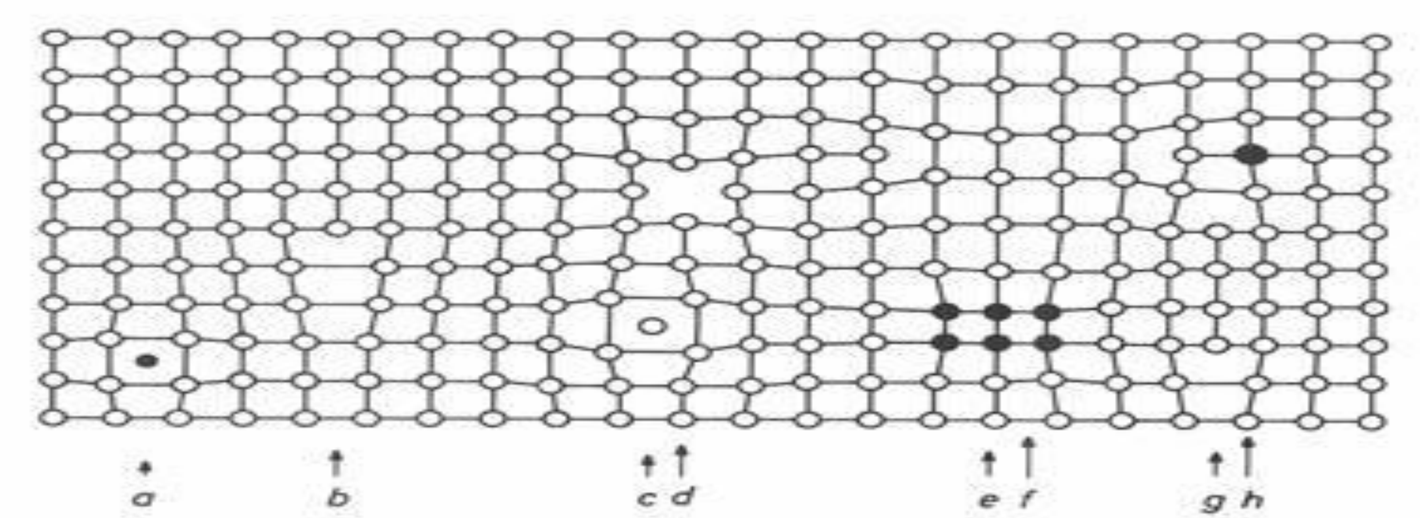
PROPERTY	BOND TYPE (ionic/covalent)	REASON FOR CHOOSING BOND TYPE

Notes:

DEFECTS in METAL PACKING STRUCTURE

Name ____

In the space below identify and label each of the defects shown below.



Type of Atomic Arrangement/Defect	**Description of Defect**
Tight Packing	
Vacancy	
Interstitial Defect	
Substitutional Defect	
Dislocation	
Grain Boundary	

Complete each statement by inserting the appropriate change to arrangement or defect.

TYPE OF ARRANGEMENT / DEFECT	**MORE / LESS DUCTILE**	**MORE / LESS ELECTRICALLY CONDUCTIVE**	**MORE / LESS HARD**	**MORE IONIC / MORE COVALENT**
Atoms packed far apart VS Atoms packed close together	**As atoms are packed closer together metals become _____ ductile.**	**As atoms are packed closer together metals become ________ electrically conductive.**	**As atoms are packed closer together metals become ________ hard.**	**As atoms are packed closer together metals become more _______________.**
Heating up the metal VS Cooling down the metal	**As atoms get hotter metals become _______ ductile.**	**As atoms get hotter metals become ________ electrically conductive.**	**As atoms get hotter metals become ________ hard.**	**As atoms get hotter metals become more _______________.**
VACANCY IN PACKING STRUCTURE	**As the amount of vacancies increases metals become _______ ductile.**	**As the amount of vacancies increases metals become ________ electrically conductive.**	**As the amount of vacancies increases metals become ________ hard.**	**As the amount of vacancies increases metals become more _______________.**
INTERSTITIAL DEFECT	**As the amount of interstitial defects increases metals become _______ ductile.**	**As the amount of interstitial defects increases metals become ________ electrically conductive.**	**As the amount of interstitial defects increases metals become ________ hard.**	**As the amount of interstitial defects increases metals become more _______________.**
SUBSTITUTIONAL DEFECT	**As the amount of substitutional defects increases metals become _______ ductile.**	**As the amount of substitutional defects increases metals become ______ electrically conductive.**	**As the amount of substitutional defects increases metals become ___________ hard.**	**As the amount of substitutional defects increases metals become more __________.**
DISLOCATION	**As the amount of dislocations increases metals become _______ ductile.**	**As the amount of dislocations increases metals become ________ electrically conductive.**	**As the amount of dislocations increases metals become ________ hard.**	**As the amount of dislocations increases metals become more _______________.**
More grain boundaries VS Less grain boundaries	**As the amount of grain boundaries increases metals become _______ ductile.**	**As the amount of grain boundaries increases metals become ________ electrically conductive.**	**As the amount of grain boundaries increases metals become ________ hard.**	**As the amount of grain boundaries increases metals become more _______________.**

EXTENSION:
The heat from a fire will very quickly travel from the fire through a piece of metal to the other end of the metal. Thus, metals are said to have high thermal conductivity. Thermal conductivity is the property of metals that has us all reaching for oven mitts before pulling the turkey out of the oven.

1. **Please use the space below to DISPLAY a model that can explain metals high thermal conductivity.**
2. **Please provide 2 justifications for the model that you have created.**

NOTE: The <u>model</u> that you create should show the metal at the <u>atomic level</u>. This means <u>drawing atoms</u> with <u>"some other stuff"</u> that would show <u>how the placement of the atoms contributes to the fast transfer of heat</u>.

Answer Key: Complete each statement by inserting the appropriate change to arrangement or defect.

TYPE OF ARRANGEMENT / DEFECT	MORE / LESS DUCTILE	MORE / LESS ELECTRICALLY CONDUCTIVE	MORE / LESS HARD	MORE IONIC / MORE COVALENT
Atoms packed far apart VS Atoms packed close together	As atoms are packed closer together metals become LESS ductile.	As atoms are packed closer together metals become MORE electrically conductive.	As atoms are packed closer together metals become MORE hard.	As atoms are packed closer together metals become more student choice w/ rationale.
Heating up the metal VS Cooling down the metal	As atoms get hotter metals become MORE ductile.	As atoms get hotter metals become LESS electrically conductive.	As atoms get hotter metals become LESS hard.	As atoms get hotter metals become more student choice w/ rationale.
VACANCY IN PACKING STRUCTURE	As the amount of vacancies increases metals become LESS ductile.	As the amount of vacancies increases metals become LESS electrically conductive.	As the amount of vacancies increases metals become MORE hard.	As the amount of vacancies increases metals become more student choice w/ rationale.
INTERSTITIAL DEFECT	As the amount of interstitial defects increases metals become LESS ductile.	As the amount of interstitial defects increases metals become LESS electrically conductive.	As the amount of interstitial defects increases metals become MORE hard.	As the amount of interstitial defects increases metals become more student choice w/ rationale.
SUBSTITUTIONAL DEFECT	As the amount of substitutional defects increases metals become LESS ductile.	As the amount of substitutional defects increases metals become LESS electrically conductive.	As the amount of substitutional defects increases metals become MORE hard.	As the amount of sub. defects increases metals become more student choice w/ rationale.
DISLOCATION	As the amount of dislocations increases metals become LESS ductile.	As the amount of dislocations increases metals become LESS electrically conductive.	As the amount of dislocations increases metals become MORE hard.	As the amount of dislocations increases metals become more student choice w/ rationale.
More grain boundaries VS Less grain boundaries	As the amount of grain boundaries increases metals become LESS ductile.	As the amount of grain boundaries increases metals become LESS electrically conductive.	As the amount of grain boundaries increases metals become MORE hard.	As the amount of grain boundaries increases metals become more student choice w/ rationale.

<u>Gold Penny Lab</u>

In this lab, you will be converting a regular penny into a "gold" penny. In doing so, you are following a tradition that goes back to the earliest days of chemistry.

The modern practice of chemistry started with the study of alchemy in medieval Europe and the Middle East. Alchemists believed that by doing certain chemical reactions, you could turn cheap metals into gold. Some of them did, anyway – the others would convince people that they could do this and sell them the secret. By the time anybody realized that the "secret" didn't work, they'd be long gone with the money.

In this lab, you'll be doing a reaction in which copper appears to turn into gold. We'll talk about what really happens later…

Safety:

In this lab, it is very important that you wear your goggles **AT ALL TIMES**. The chemicals that we are working with are extremely dangerous, and can cause serious injury if an accident occurs! THIS IS NOT A JOKE OR EXAGGERATION!!!

PROCEDURE:

1. Place about 1-2 grams of granular zinc in an evaporating dish.
2. Add enough of the 3 <u>M</u> NaOH solution to cover the zinc and fill the dish about half full.

(CAUTION: NaOH IS A VERY STRONG BASE AND WILL LEAD TO SEVERE BURNS IF SKIN CONTACT OCCURS AND THE NaOH IS NOT WASHED OFF QUICKLY!!!)

3. Warm the Zn, NaOH solution high over the Bunsen burner flame for a while (2 – 3 minutes). If the solution begins to boil, turn off the heat for a while.
4. Use tongs to place your shiny new pennies carefully into the solution. Do not put them on top of each other. Spread them out.
5. Leave the pennies in the warm dish for 5-10 minutes or until they have a uniform silver coating on both sides of the pennies. (You may choose to continue to warm the solution with the pennies in it.)
6. Remove the pennies, wash them by dipping them in a beaker of tap water, and then gently blot them dry with paper towels. Do not rub! If you want to keep one of the pennies silver, DO NOT perform the next steps.
7. Using tongs hold the silver-coated penny by the edge and <u>gently</u> heat the penny near the top of the burner flame. After a few seconds of heating, the "gold" color should appear. Heat the coin uniformly on both sides to give a uniform "gold" color.
8. Be careful not to touch the **<u>HOT</u>** pennies or tongs for a few minutes until they have had an opportunity to cool off.
9. Set the coin down to cool, wash it again, and blot it dry. Enjoy your new "gold"!!!

REACTIONS:

1. The first reaction involves the plating of the penny with a coating of zinc. The granular zinc reacts with the hot sodium hydroxide solution to form soluble sodium zincate, Na_2ZnO_2. This substance is then converted to metallic zinc when it contacts the surface of the penny. This results in a loosely held zinc coating on the surface of the copper.

2. The second reaction involves the heating of the penny to fuse together the zinc and copper metals to give an alloy (homogeneous metal mixture) known as brass. Brass varies from 60-82% Cu and from 18-40% Zn.

POST-LAB QUESTIONS:

Complete # 1 – 3 before the end of class.
Complete # 4 – 5 at home TYPED. Due Date to be announced

1. What was the function of the sodium hydroxide in the evaporating dish?

2. Why did the penny turn gold when heated in the burner flame?

3. How does an alloy meet the definition of a solution?

4. Define the terms:
    a. Interstitial Alloy:

    b. Substitutional Alloy:

    c. You used zinc and copper to make an alloy. What is the name of your alloy and what type of alloy (interstitial or substitutional) is it?

5. Explain why alloys tend to have more beneficial properties than the metals that they are made from. Provide an example.

PAPER CLIP FATIGUE

Materials such as metals (aluminum, iron, copper, etc.), ceramics (silicon, carbide, & porcelain), or polymers (milk jugs made of polyethylene) are tested by scientists and engineers to reveal certain mechanical properties, such as the maximum stress a material can withstand before it fails. The stress at which a material breaks is a measure of its strength. During use a material may degrade, which may cause it to fail at much lower stresses. For example, if a material is loaded over and over again and then fails it has undergone what is known as fatigue.

Fatigue is a very common mode of failure for materials and has been studied for centuries. Fatigue occurs every day in objects that you are familiar with. For example, airplane wings fatigue thousands of cycles on every flight and bridges fatigue every time a car drives over them. However, just because a material is undergoing fatigue does not mean it will break. In fact, engineers run careful experiments so that they can be sure that things will not break due to fatigue while you are using them.

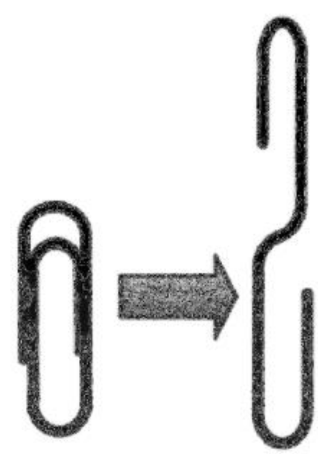
Fatigue properties of different materials vary with material quality, material source, type of stress, and duration of stress. Since paper clips are not high tech materials, they are usually made from cheap steels that have little strength and where variability in quality is not important.

OBJECTIVE:
Test the fatigue resistance of different types of paper clips.

MATERIALS:
2 paperclips - 1 large and 1 small

TEST:

1. **Open your large paper clip so it resembles a backwards "S".**
2. **Use the edge of the lab table to bend the paperclip to a 90 degree angle.**
3. **Bend the paperclip back so that it is straight again (back to the "S" shape).**
   This counts as ONE LOADING CYCLE.
4. **Repeat until the paperclip breaks. Make sure to count the number of times that you bent your paperclip. Record the NUMBER OF LOADING CYCLES in the table. (If your paper clip breaks in mid cycle it DOES NOT COUNT in the "NUMBER OF CYCLES TO FAILURE".**
5. **Repeat the experiment with your small paperclip.**



QUANTITATIVE DATA:

	Load Cycles to Failure (Number for Group)	Number of Cycles to Failure (Class Average)
Small Paperclip		
Large Paperclip		

THINKING SCIENTIFICALLY:

Give three reasons why different paper clips may break at different numbers of bends?

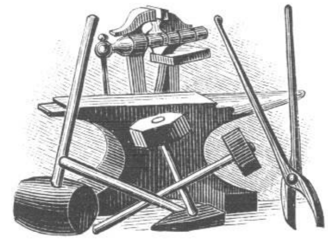
CONCLUSION:

1. What are some possible sources of error in your results?

2. Excluding the errors you reported, what changes would you make to the experiment in order to yield more accurate results? Explain your reasoning.

3. If you were designing the World's best paper clip, what design criteria would you use? Explain each.

CAN the METTLE of METAL be IMPROVED?



PRE-LAB DISCUSSION:

Metals are used for many different purposes. Two hundred years ago, the town blacksmith produced nails, hammers, wheel rims, knives, and horse shoes from the same basic metal. In some applications, a metal must be able to bend easily without breaking, whereas in other cases the metal must resist bending. Today metallurgists can produce these results by using different metals, alloying metals, and by heat treating metals. The substitution of a different metal or using a special alloy is often costly. Therefore heat treatment of a common metal is often the most cost efficient method of producing a metal that has the properties required in a specific application. Most metals respond to heat treatment, but the treatment temperatures are unique for different metals.

OBJECTIVE:

To determine the effects of annealing, quenching, and tempering on metals.

MATERIALS:

Bunsen burner, tongs, beaker, bobby pins, hair clip, single strand steel wire

PROCEDURES:

CONTROL

Straighten the bobby pin and determine the number of loading cycles to break in two (use the edge of the table to bend the bobby pin in the same way that you did in the paperclip lab). Record this on the chart.

ANNEALING (Heating and SLOW COOLING)

1. STRAIGHTEN a bobby pin THEN heat the bobby pin to RED HOT by holding it over the flame with the tongs. It must remain red hot for THIRTY SECONDS. Then GRADUALLY LIFT IT STRAIGHT UP until it is about ONE FOOT OVER THE FLAME. Let the sample COOL GRADUALLY IN THE AIR for about THREE MINUTES.

2. After the bobby pin has cooled determine the number of loading cycles to break in two (use the edge of the table to bend the bobby pin in the same way that you did in the paperclip lab). Record this on the chart.

QUENCHING (Heating and QUICK COOLING)

1. STRAIGHTEN a bobby pin THEN heat the bobby pin to RED HOT by holding it over the flame with the tongs. It must remain red hot for THIRTY SECONDS. When the thirty seconds pass QUICKLY PLACE the bobby pin in a beaker of COLD WATER.
2. After the bobby pin has cooled determine the number of loading cycles to break in two (use the edge of the table to bend the bobby pin in the same way that you did in the paperclip lab). Record this on the chart.

TEMPERING (Heating THEN Quick Cooling THEN WEAK Heating THEN Slow Cooling)

1. STRAIGHTEN a bobby pin THEN heat the bobby pin to RED HOT by holding it over the flame with the tongs. It must remain red hot for THIRTY SECONDS. When the thirty seconds pass QUICKLY PLACE the bobby pin in a beaker of COLD WATER. <u>THEN</u> REHEAT the bobby pin ONLY until it BEGINS to glow orange. <u>THEN</u> let the sample COOL GRADUALLY IN THE AIR for about THREE MINUTES.

2. After the bobby pin has cooled determine the number of loading cycles to break in two (use the edge of the table to bend the bobby pin in the same way that you did in the paperclip lab). Record this on the chart.

DATA:

	CONTROL	**ANNEALING**	**QUENCHING**	**TEMPERING**
LOAD CYCLES TO FAILURE (NUMBER for GROUP)				
LOAD CYCLES TO FAILURE (CLASS AVERAGE)				

THINKING SCIENTIFICALLY:

1. Draw a before and after picture that shows how the microstructure of the metal changed when the metal was annealed. (A short description can be included to help clarify the illustration.)

   a. How did the properties of the metal change after annealing

   b. Use the changes in microstructure (drawn by you above) to explain the change in properties.

2. Draw a before and after picture that shows how the microstructure of the metal changed when the metal was quenched. (A short description can be included to help clarify the illustration.)

    a. How did the properties of the metal change after quenching?

    b. Use the changes in microstructure (drawn by you above) to explain the change in properties.

3. Draw a before and after picture that shows how the microstructure of the metal changed when the metal was tempered. (A short description can be included to help clarify the illustration.)

    a. How did the properties of the metal change after tempering?

    b. Use the changes in microstructure (drawn by you above) to explain the change in properties.

4. Which treatment produces the ***hardest*** metal? [HINT: To answer this question correctly, you must first review the technical definition of the term "hardness".] Explain.

5. Which treatment produces the ***strongest*** metal? [HINT: To answer this question correctly you must first review the technical definition of the term "strong".] Explain.