Teacher Pages

Forensic Metallurgy – A Challenge in Basic Measurements

Logistics:

Audience: This activity is intended for physical science students in high school (or middle school assuming some algebra experience).

Time: 80 minutes, easily divided between multiple class periods

Abbreviated Materials List:

- Volumetric vessels (graduated cylinders and measuring cups)
- Rulers
- Balances or scales
- Magnets
- Nails (copper, aluminum, brass, galvanized steel, stainless steel)
- Student-made alcohol calorimeters
- Boiling water
- String
- Sticker Labels
- Calculators
- Hand lenses (magnifying glasses)
- Coins from ancient China (purchased from eBay for less than $0.40/each)

A more descriptive list of materials with specifications and explanations is found later in this document.

Next Generation Science Standards: HS PS1-3, HS PS3-1, HS PS3-4

Objectives: The students will:

- Learn to measure specific heat capacity
- Identify the metals in a coin by measuring various bulk properties
- Consider the limitations imposed by measurement uncertainties

Background Information:

Before metal working was mastered, people had to barter or trade to get what they needed from others. Metals made money practical since they were universally valued and could be minted into standardized coins.

Farmers around the world occasionally discover caches of coins that were buried long ago. Such coins can sometimes be purchased on eBay for a few dollars each. Similar offerings on eBay, however, are modern reproductions being offered as authentic relics. Authentic coins from ancient China were usually made from alloys of copper, with up to half of the mass being lead, tin, or zinc. Alloys of copper and tin are commonly called "bronze", while alloys of copper and zinc are known as "brass". Either could contain a significant fraction of lead. Iron was used, usually in pure form, when scarcity of other metals made them too expensive.

One way to identify an unknown metal is to measure its specific heat capacity. Specific heat capacity is the amount of heat energy required per unit of mass to raise the temperature of a substance by one degree. In this investigation, units of J/(g C) will be used. The metals under examination have little freedom of motion due to the constraints of their crystalline structure. Thermal inputs primarily produce an increase in molecular vibration. The associated increase in kinetic energy is measurable as a temperature increase. For this reason, metals have relatively low specific heat capacities, compared with water or alcohol which can store internal energy in other modes. What distinguishes the specific heat capacity of one metal from another is primarily the difference in atomic mass.

Suggested Inquiry Approach:

Have students form groups of two.

Wearing laboratory gloves is optional, but requiring students to wear them will reinforce the impression that they might be working with items of real historical and monetary value.

Give each group one coin and their student pages (but <u>not</u> the three supplemental pages).

Show students where their other materials are located and emphasize that many items are shared and should not be moved from their current location.

Students begin by devising experiments of their own to identify the metals used in the coin. At first, they have few specific instructions and are limited to their current knowledge, which will vary between individuals, groups, and classes. If they glance at the table of material properties, they will immediately see four physical properties which might be measured for comparison.

Show students the equipment available for experimentation. Allow them to look at it closely, but not to begin using it until you have approved their plan.

First see what they can do on their own. If they propose an experiment, and seem to understand how to do it, let them continue without further guidance. Safety comes first, of course, so give appropriate cautions about working with boiling water and any metal placed in that water.

Once they have done the procedures with which they already have some familiarity, suggest other experiments. You may, at this point, hand them one of the supplementary sheets which gives further guidance on how to do certain measurements.

Be sure that all students eventually measure specific heat capacity, as this concept is useful for mastering several performance expectations of the Next Generation Science Standards. Students can measure the specific heat capacity of their coins by heating them in boiling water before immersing them in an alcohol calorimeter and noting the final equilibrium temperature. **For safety reasons, keep an eye on the boiling water**. The water should be kept boiling so students know the temperature is 100 degrees C. Make sure that students have attached a labelled string to their coin before it goes into the pot. Keep the label out of the water. Coins may be removed from the pot after 3 minutes (although longer will do no harm). Use the strings for handling, as the coins will be too hot to touch.

Students may wish to measure hardness by scratching known metals with their coin. You should allow this but caution students not to leave any more marks on the coin than absolutely necessary. Every mark would decrease the value of an ancient artifact.

An iron coin will certainly be attracted to a magnet. A very weak attraction would suggest a bronze or zinc alloy made with recycled metals, which could contain iron as a contaminant.

Whenever possible, encourage students to consider the importance of accuracy and uncertainty in measurement. Remind them that every time they record a measurement, they are responsible for expressing their uncertainty through the use of significant figures or some similar method.

When performed with typical high school lab equipment, most measurements in this activity will have but one or two significant figures. Few of their answers will match any material on the reference table. The closest match for density may well be different than the closest match for specific heat capacity. At best, students may be able to eliminate half of the possibilities. Logic and inference should allow them to narrow the field somewhat but there is no expectation that students will arrive at a "right answer". This is by design, but may prove uncomfortable for students unused to such inquiry activities.

One challenging aspect of identifying metals in this activity is that the reference table has no values for alloys such as bronze or brass (the most common metals used in ancient Chinese coins). Copper, lead, tin, and zinc may be mixed in so many different proportions, that no useful tables of properties exist. It can be expected, however, that the specific heat capacity and density of an alloy will fall between the table values for the alloy's constituent metals. Hardness is more complicated and some alloys, including bronze, are harder than any of their constituent metals.

Debrief Questions:

- Did the various tests you performed all point to the same answer?
- Which tests seemed the most useful or reliable? Why?
- Have you considered the possibility that your coin is a modern counterfeit?

Extensions:

- What metals are used to make modern US coins? Test one to see if your assumptions are correct.
- Research ancient Chinese coins to identify the coin you have been using. This page, owned by a private collector, is a good place to start: http://chinesecoins.lyq.dk/
- Research coin operated machines to learn how they detect counterfeit coins.

Materials – the Details:

- **Volumetric vessels**: Provide a few **graduated cylinders** and **measuring cups**. Don't hesitate to provide equipment which is inappropriate or unusable, such as cylinders too small to admit a coin, or so large that a single coin will produce no useful change in meniscus height. Assessing the suitability of laboratory equipment is an important skill.
- **Rulers**: Find a variety, the older and cheaper the better. Put students in the position of having to compare instruments in order to select the best. Yes, they may have to share if they want to use the best ruler. Vernier calipers can make very accurate measurements if your students know how to use them. But students may come to question the value of that accuracy when they realize that the shape of most coins is not-quite round and thicknesses are not consistent across the coin.
- **Balances** or **scales**: If you have a variety available, set out instruments with differing levels of accuracy. Don't bother to point out the difference. Do have at least one instrument which measures to the tenth of a gram. If your students have never used a

triple beam balance, see if you can find one so they can experience the power of "old-school" instruments.

- **Magnets**: Any will work, but providing various types will give students pause as they consider what they know about magnetism.
- **Nails**: Copper, aluminum, brass, galvanized steel, and stainless steel nails can all be found in a large hardware store. These are needed for scratching coins as a relative hardness test. Galvanized steel nails are plated with a thick coating of zinc, which is a metal of interest. Avoid "common" steel nails as these are generally coated with a very thin layer of unspecified corrosion protection which makes scratch results ambiguous.
- **Alcohol calorimeters** can be made by placing a **3-oz Dixie cup** inside a **6-oz Styrofoam cup**. Insert a **thermometer**, preferably an inexpensive alcohol immersion model with gradients of no more than one or two degrees C. These often have an upper range limit of 50 degrees, so be sure students know not to put them in boiling water. They may have a thin plastic backing which needs to be trimmed in order for the bulb to reach the bottom of the calorimeter. If electronic thermometers are available, make one or more available for use. Add just enough isopropyl alcohol to cover the coin and thermometer bulb. One bottle is more than enough for a whole class. **Isopropyl alcohol is flammable. Instruct students to keep it away from open flame.**

- **Boiling water**: A large flask or hot pot is needed to keep a supply of water boiling. Two or three per class is recommended.
- **String**: Students will tie a length of string to their coins before lowering them into the boiling water. The string is used to extract the hot coin and move it to the calorimeter.
- **Sticker labels**: There may be several coins-on-strings in the boiling water at once. Students can use these, on the dry end of the string, to identify their coin.
- **Coins**: One coin per pair of students is needed. Obtain these by doing a search on eBay using search terms such as "ancient Chinese coins". They are generally sold in lots of 10, 50 or 100 and can usually be found for less than $0.40 per coin. Avoid the shiny brass coins, often sold as good luck tokens for Chinese holidays. Look for coins which claim to be hundreds of years old, which look corroded and worn. The best sets have a wide variety of coins, rather than 50 of the same type. These "ancient" coins are most likely counterfeit, but use the same metals as the coins minted in antiquity. Shipping times may be one month or more so plan to order well in advance.

References:

For more information about the metallurgy of the coins:

Metallurgical Analysis of Chinese Coins at the British Museum (British Museum Research Paper) by Helen Wang, Joe Cribb, Michael Cowell, and Sheridan Bowman.

This collection of studies can be downloaded as a free pdf from the British Museum at http://www.britishmuseum.org/research/publications/research_publications_series/2005/analysis_of_chinese_coins.aspx