A TEACHER-DIRECTED, GUIDED DISCOVERY ACTIVITY FOR ADVANCED PHYSICAL SCIENCE STUDENTS

FEATURES OF THIS ACTIVITY

- **Problem solving**
- **Cooperative learning**
- **Requires student reasoning**
- **Requires student initiative**
- **Teaches careful observation**
- **Illustrates the development of a hypothesis**
- **Learning to use a chemical handbook**
- **Learning to use the activity series of metals**
- **Laboratory determination of density**
- **Learning about both physical and chemical properties of elements**

THE PROBLEM: TO DETERMINE WHAT A PENNY IS MADE OF

SETTING:

- **An instructor leads the activity.**
- **Students, seated at tables, work in groups of 3 or 4.**
- **The "communicator" of each group speaks for the group.**
- **It is assumed that the students:**

  1. **have access to chemical handbooks.**
  2. **understand the basic concept of density.**

GETTING STARTED

- **Instructor gives each group a penny**

TQ:* **Pass the penny around. Each person should look at it, feel it, drop it and listen to the sound it makes. Think about it. <u>Do not alter it in any way</u>-- just carefully observe it and jot down your observations.**

Then answer the question:
WHAT IS A PENNY MADE OF?
(Be as specific as possible.)

You should observe, confer, and decide on a group answer with reasons for that answer.

ASR: copper**

Reasons for answer are varied.

***TQ = Teacher's Direct Question To Students**

****ASR = Anticipated Student Response**

DEVELOPING A HYPOTHESIS

- **Class' hypothesis: A penny is made of copper.**

- **Students will look for physical and chemical evidence to either prove or disprove the hypothesis.**

TQ: Where would information about the <u>physical</u> properties of copper be found?

ASR: In a chemical handbook

- **Handbooks are distributed to student groups**

TQ: Report a physical property of copper to support our hypothesis.

ASR: Copper metal has a reddish color, just like the penny.

- **The hypothesis is strengthened.**

- **Students also report the density of copper: 8.92 g/mL**

USING THE ACTIVITY SERIES TO INTRODUCE CHEMICAL PROPERTIES

- **Instructor distributes copies of the activity series of metals to students.**

TQ: **Select metals that would <u>not</u> be in a penny.**

ASR: **Top 5 metals; they react with H_2O to produce H_2 gas.**

Bottom 4 -- Ag, Au and Pt are used in jewelry; too expensive to use in pennies. Hg is a liquid.

TQ: **What <u>chemical</u> test would be useful?**

ASR: **Put penny in an acid to see if bubbles of H_2 are evolved.**

- **Instructor distributes 3 M HCl in small containers.**

TQ: **Put the penny in the acid. Describe what you see and give me your conclusion.**

ASR: **No bubbles; therefore no reaction**

- **Hypothesis that a penny is made of copper is further strengthened.**
- **Instructor collects containers of HCl.**

RETURN TO PHYSICAL PROPERTIES -- DISCUSSION OF DENSITY

- **If the density of a penny is the same as that of copper (8.92 g/mL), our hypothesis would be strengthened even more.**

TQ: How would you determine the density of a penny?

ASR: $\text{density} = \dfrac{\text{mass}}{\text{volume}}$

Find mass by weighing.

Find volume via formula for cylinder, $\pi r^2 h$

TQ: This approach won't work. Examine your penny and tell me why.

ASR: Volume will be in error. A penny does not have a flat face. It has a "rim"; also engraving on both faces.

TQ: What is another way to determine the volume of a penny?

ASR: Displacement of water

DENSITY DETERMINATION AND A BIG SURPRISE

- **Students are told to determine the density of a penny using water displacement to find volume. They are urged to be very observant and report anything that they find interesting or surprising.**

- **Supplied: Balances and 10-mL graduated cylinders graduated in 0.1 mL increments**

- **After weighing pennies, student find they won't fit in the graduated cylinders. "What do we do?"**

TQ: Larger cylinders not available. <u>You</u> find a solution.

ASR: Cut the penny.

TQ: Much easier to break a penny than cut it. Take pliers and break the penny approx. in half.

ASR: (After penny is broken.) There is another metal inside the penny!

- **Hypothesis is invalidated! A penny seems to be mostly another metal clad with a thin layer of copper.**

REASONING BASED ON DENSITY VALUES

- **Student groups proceed with experimental determinations of the density of a penny.**
- **Groups report their experimental values for the density of a penny; findings are posted.**

Average results: around 7.2 g/mL

- **The assumption is made that only two metals are involved and that they are not alloyed.**
- **The outer metal is almost certainly copper. But what is the inner metal?**

TQ: If we assume that:

(1) the outer metal is copper (D = 8.92);

(2) only a relatively small amount of copper is present;

what can you tell me about the density of the inner metal?

ASR: The density of the inner metal will be slightly less than our average experimental results for the density of a penny.

RETURN TO THE ACTIVITY SERIES

- **An attempt will be made to identify the inner metal from a number of possible metals by the process of elimination.**
- **Put the activity series back on the overhead projector.**

TQ: Suggest a chemical test that you could perform to get more information.

ASR: Test a broken penny with HCl.

- **Instructor again distributes 3 M HCl in small containers.**

TQ: Put the broken pennies into the acid. Describe what you see.

ASR: Bubbles (of H_2, we assume) are rapidly produced at the exposed surface of the inner metal. No bubbles are seen on the outer metal.

- **Instructor collects containers of HCl.**

TQ: Refer to the activity series. On the basis of the reaction with HCl, what possible metal could the inner metal of the penny be?

ASR: Al, Mn, Zn, Cr or Fe

USING DENSITY VALUES AND SOLUBILITIES TO FURTHER ELIMINATE METALS

- **A "shortened" activity series accompanied by density values is projected for students to study.**

TQ: **What elements can be eliminated from the five now under consideration? Why?**

ASR: **Al and Fe can be eliminated on the basis of their densities.**

- **Mn, Zn and Cr are left as possibilities**

TQ: **We've ignored the "solubilities" column of the chemical handbook up till now. Look up solubility information for Mn, Zn, and Cr. If the abbreviations used are unfamiliar, look up their meanings.**

ASR:

Mn:	**s dil a**
Zn:	**s a, alk**
Cr:	**s dil H_2SO_4, HCl**

AMPHOTERISM OF METALS

TQ: **What do we do next?**

ASR: **Put the broken penny into an NaOH solution to see if the inner metal dissolves. If it dissolves, it is zinc; if it does not dissolve, Mn and Cr are the two possibilities.**

TQ: **The test suggested is appropriate. However, it requires hot, very concentrated NaOH solution. Too dangerous for students. If the test were done, the inner metal would indeed dissolve with evolution of H_2 bubbles. (Zn, like Al, is an amphoteric metal.)**

Once again, WHAT IS A PENNY MADE OF?

ASR: **A penny is made of two metals. The inner metal, zinc, is coated with another metal, copper. The amount of zinc is much greater than the amount of copper.**

ACTIVITY (OR REPLACEMENT) SERIES OF SOME COMMON METALS

Name of Element	Reactivity
potassium barium calcium sodium magnesium	React with cold or hot water to produce hydrogen gas.
aluminum manganese zinc chromium iron	React vigorously with acids to produce hydrogen gas.
cadmium nickel tin lead	React sluggishly with acids to produce hydrogen gas.
hydrogen	
copper antimony bismuth mercury silver	React only with oxidizing acids, such as HNO_3 and H_2SO_4. No hydrogen gas is produced.
gold platinum	React only with *aqua regia*

METALS REMAINING AFTER SUBTRACTING THE VERY REACTIVE METALS AND THE COINAGE METALS FROM THE ACTIVITY SERIES -- DENSITIES LISTED

Name of Element	Density (g/cc)
aluminum	2.70
manganese	7.20
zinc	7.14
chromium	7.20
iron	7.86
cadmium	8.64
nickel	8.90
tin	5.75 (α), 7.28 (β), 6.52 (γ)
lead	11.34
hydrogen	
copper	8.92
antimony	6.68
bismuth	9.80