METALS FROM ROCKS

INTRODUCTION

Copper is leached from finely ground rock and recovered by reduction on iron paper clips. The activity models a heap leach pad and the procedures for recovering some metals, including gold.

OBJECTIVE

Students will understand the structure of a heap leach pad and the chemistry involved in leaching and recovering the metal from solution by making a model using copper as the recovered metal.

SAFETY

Wear chemical splash goggles.

CONTENT FOCUS

Some compounds of metals are soluble in a solution, the specific solution depends on the type of metal and the compound. These metals can be dissolved from a finely ground rock, and the solution with the metal compound can be recovered for further processing.

In this model, cupric sulfate pentahydrate ($CuSO_4 \cdot 5H_2O$), commonly called copper sulfate, is mixed with finely ground rock or dirt. Cupric sulfate is soluble in water, so this copper compound is leached from the rock mixture with water. The water is collected in a plate for further study. Interferences can include other compounds in the dirt mixture which are also water soluble.

This dissolution step to separate the copper from the rock is possible because the cupric sulfate is more soluble in water than the rock. If cupric sulfate were not soluble in water, a different solution would have to have been used to leach the cupric sulfate from the rock mixture.

The copper is then recovered from the solution by precipitating the copper metal onto an iron paper clip. (The chemical reaction is actually the reduction of the cupric ion in solution to copper metal and oxidation of the iron paper clip to ferrous sulfate in solution. As expressed in the half reactions below, the reaction is actually the transferral of two electrons from the iron metal to the cupric ion in solution to make the iron ion and copper metal.) The reaction can be written:

$CuSO_4$ (aq) + Fe (s) → Cu (s) + $FeSO_4$ (aq) (complete reaction)

Cu^{+2}(aq) + Fe (s) → Cu (s) + Fe^{+2}(aq) (net ionic reaction)

Fe (s) → Fe^{+2}(aq) + $2e^-$, and Cu^{+2}(aq) + $2e^-$ → Cu (s) (half reactions)

The paper clips need to be iron, not nickel coated. Steel wool can be used also.

Not only does the paper clip become the characteristic copper color, but the blue color of the copper ion in solution disappears from the solution, indicating that the copper ion (Cu^{+2}) has been removed from solution.

RELATION TO MINING

- *Leach Pad*
  The structure of the leach pad actually used in mining is designed for efficient leaching and environmental safety. In a mine, the construction of the leach pad begins with placement on

the bottom of about 12 inches of a non-permeable layer of clay. On top of that is a system of pipes to detect any possible leaks in the pad. This is covered with a plastic sheet (80 mil or 80/1000 inches thick). On top of the sheet is the system of pipes with holes to collect the solution as it comes through pile of rocks. This is covered by a porous layer of rock. Then, the ore is heaped on top. The leaching solution is introduced to the heap with a sprinkler system.

- *Recovery of the metal*
  The solution with the dissolved metal from the ore is collected and sent to the processing plant. The metal in the solution may be concentrated first in a step separate from the reduction, but eventually the metal ions in solution are reduced to the metal either by precipitation onto a more reactive metal as in our model, or by "electrowinning," a process in which an electric current passes through the solution and the metal deposits on the cathode of the electric cell.
  The solution which no longer has any metal in it can be reused on the leach heap.
- *Reclamation of the leach heap*
  Everything in mining must be returned to a condition as nearly natural as possible. This means the leach pad must be made environmentally benign by rinsing or bio-processing so the water which flows off of the heap meets drinking water standards. The slopes of the heap must be stabilized as a natural slope, and the hill must be planted with natural grasses and shrubs.
- *Gold Recovery*
  Although gold leaching is not as visible as copper leaching, the most common method of leaching gold uses cyanide, oxygen and water as a leaching solution (the oxygen comes from air):

  $$4Au + 8NaCN + O_2 + 2H_2O \rightarrow 4NaAu(CN)_2 + 4NaOH$$

ADVANCE PREPARATION (by teacher)
Prepare the finely ground rock either by grinding some rock in a ball mill, or by sieving mixed rocks, or using sand. Mix in powdered cupric sulfate pentahydrate to form a 5% mixture with the rock (5 g $CuSO_4$ $5H_2O$ plus 95 g rock.)

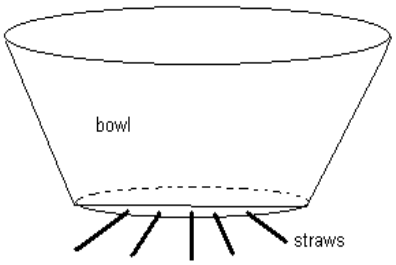
MATERIALS (for each student)

- Two Styrofoam bowls, one with coffee stirrer straws inserted on the side as near to the bottom of the bowl as possible (or, with holes poked in the bottom)
- Three coffee stirrer straws, cut into about 5 cm lengths
- Coffee filter
- Styrofoam plate
- Finely ground rock or sand
- Cupric sulfate pentahydrate, powder ($CuSO_4 \cdot 5H_2O$)
- Squirt bottle for water leaching solution
- Iron paper clips
- Clear 9oz (or whatever size is available) plastic cup for processing tank
- Plastic pipettes or regular straws to be used as a pipette.

PROCEDURE (Student instructions)

1) Prepare the leach pad by inserting coffee stirrer straws into the side of the Styrofoam bowl

close to the bottom (see drawing). The bowl with coffee stirrers inserted represents the pipes with holes in that lead the solution with the dissolved metal to the collection troughs.



2) Place filter paper in bowl to keep ore rock in the bowl. The filter paper represents the rock that covers the perforated collection pipes.
3) Build the leach heap by putting the mixture of crushed rock and cupric sulfate into the bowl lined with the coffee filter.
4) Place the bowl with the crushed rock on a Styrofoam plate. This plate represents the plastic liner at the bottom of the leach heap. The impermeable clay layer is represented by the work table.
5) Tilt the whole apparatus by lifting one side up onto an overturned bowl.
6) Leach the heap by squirting water gently all over the heap until at least 10 mL (about a tablespoon) of water with dissolved cupric sulfate have collected at the bottom of the Styrofoam plate.
7) Take the solution (pregnant solution) to the processing plant by using a pipette (or straw) to withdraw about 10 mL from the bottom of the leach heap plate and place it in a clear cup. The pipette represents the pipes that take the pregnant solution to the processing plant.
8) Recover the copper from solution by adding a paper clip. Record the observations after the paper clip is added to the solution.

EXTENSIONS

1) Study reclamation of a heap leach pad by removing the soluble metals from the pile through repeated rinsing. (How is it possible to tell that the pile is clean? Analyze for chemicals that are limited by drinking water standards. In this case, check for copper in solution by adding ammonium hydroxide. The dark blue ammonium-copper complex extends the visible detection limit of copper.)
2) Prepare the heap leach pad for reclaimed use. (What else must be considered? Slope stability, soil preservation methods)

SUGGESTED FOLLOW-UP (DISCUSSION)

1) What problems were encountered with the leaching? *The fines in the "ore" sample clogged the filter. The solution did not go all the way through the heap. Some of the heap may not have gotten wet.*
2) How could those problems be overcome? *The fines could be eliminated through agglomeration with cement (but this doesn't work for the cupric sulfate leaching because the cupric sulfate bonds to the cement). Solutions that make the leach solution wet the rock (wetting agents or detergents) could be added to the leach so the rocks got completely wet. The angle of the heap pad could be changed and the spraying could be placed carefully so the solution has to go through the whole leach heap.*

TEACHER TIPS

1) Nickel coated paper clips do not react as readily as uncoated iron paper clips with the copper in the copper solution, so use non-coated paper clips or steel wool.
2) The precipitation of the copper metal generally produces an orange precipitate on the iron paper clip. The precipitate starts out black, and gradually takes on an orange color as more copper precipitates. Occasionally, nice copper crystals form. This normal orange color of the copper metal can be mistaken for rust (hydrated iron(III) oxide). Observations can show that this is not the material formed. A control in which a paper clip is dropped into plain

water does not produce the orange precipitate as does the experimental situation in which copper is present in solution. Notice that the blue color of the copper sulfate solution disappears as the amount of orange precipitate on the paper clip increases. This means the copper is being removed from solution.

3) Washing the heap for reclamation may take prohibitively long. If so, continue with a discussion of how the situation might be improved at an actual mine. First, the ore would probably be nearly completely recovered, so washing to remove residual ore metal would probably not be so important. Trace metals might be a problem and require some special treatment to immobilize or remove those metals. Bacteria play an important part in preparing the heaps for reclamation because bacteria have been developed specifically to remove problem metals from the system.

Leach Pad Diagram