Metal from Rocks

KEY CONCEPT

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.

SKILLS:	***Observing, Recording, Investigating, Modeling***
TIME:	***50 minutes***
AUDIENCE:	***Teachers and students, grades 5 - 8.***

OBJECTIVE

To 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.

Background for teachers

CONTENT FOCUS

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

Here, cupric sulfate pentahydrate ($CuSO_4 \cdot 5H_2O$) is mixed with finely ground rock or dirt. Cupric sulfate is soluble in water, so this 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 step depends on the relative solubilities of the cupric sulfate and rock in water. If cupric sulfate were not soluble in water, different solution would have to be used to leach the cupric sulfate from the rock mixture.

The copper is separated from the solution by precipitating the copper metal on an iron paper clip. (Reduction of the cupric ion in solution to copper metal and oxidation of the iron paper clip to ferrous sulfate in solution.) The reaction can be written:
$CuSO_4$ (aq) + Fe (s) $\rightarrow$ Cu (s) + $FeSO_4$ (aq)
Cu^{+2} + Fe (s) $\rightarrow$ Cu (s) + Fe^{+2}

The paper clips need to be only 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). 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 in one step, 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:

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

ADVANCE PREPARATION

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 $CuSO_4 \cdot 5H_2O$ plus 95 g rock.)

TIPS

- 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.

- 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 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.

- 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.

The Activity

MATERIALS

For each student:

- Styrofoam bowl with holes poked in the bottom
- 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 plastic cup for processing tank

PROCEDURE

1. Prepare the leach pad by punching holes in the Styrofoam bowl. Punch holes up the side on one side so the solution can drip out of the side of the tilted apparatus. The bowl with holes in 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 on an overturned bowl.
6. Leach the heap by squirting water gently all over the heap until at least 10 mL 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 to withdraw about 10 mL from the bottom of the leach heap plate. Place the 10 mL in a clear 9 oz cup.
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 may not have gotten wet.*
2. How could those problems be overcome? *The fines could be eliminated through agglomeration. Solutions 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.*

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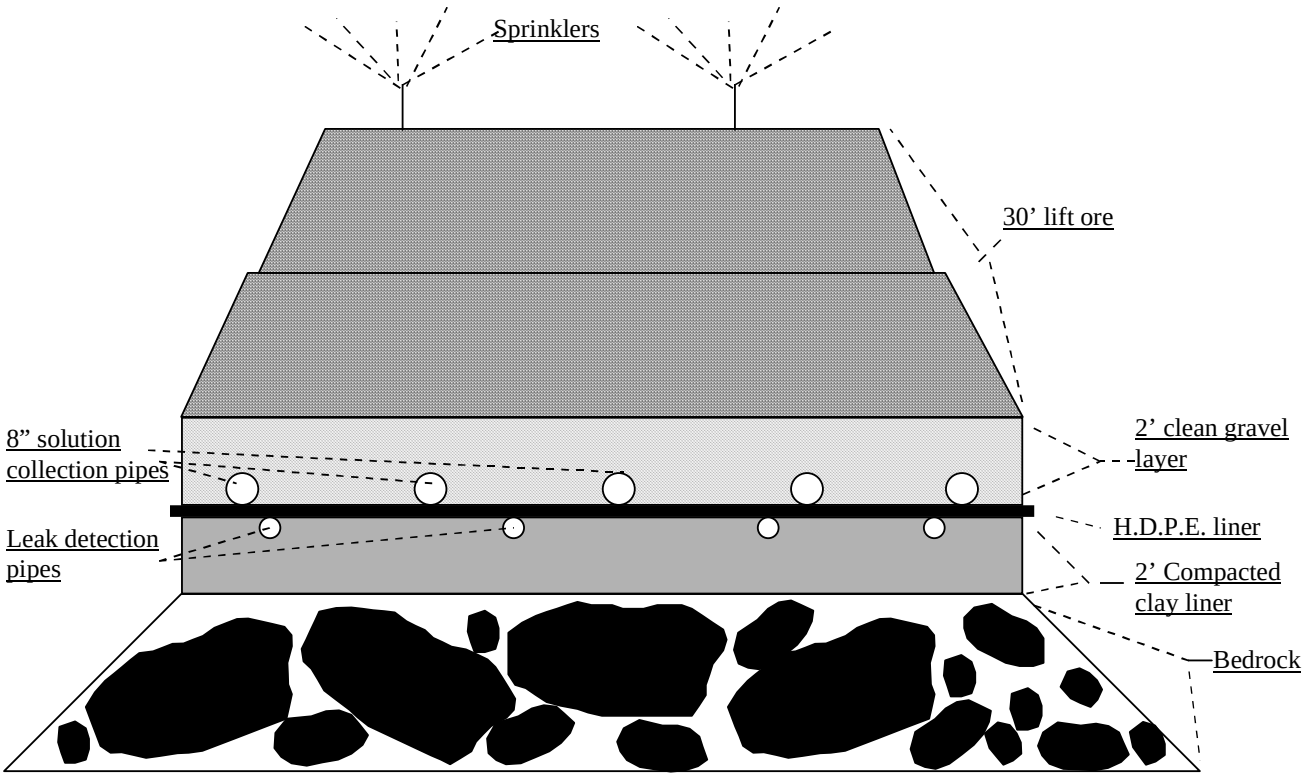
Leach Pad Diagram



Application of National Science Education Standards

The National Science Education Standards (NSES) applied in this activity are listed here. (National Research Council, *National Science Education Standards*, National Academy Press, Washington, DC, 1996)

Professional Development (for the teacher) (NSES pp. 55 - 73)

Standard A: (NSES p. 59) Professional development for teachers of science requires learning essential science content through the perspectives and methods of inquiry. Science learning experiences for teachers must

- Involve teachers in actively investigating phenomena that can be studies scientifically, interpreting results, and making sense of findings consistent with currently accepted scientific understanding. *The heap leach model requires observations to be interpreted and conclusions to be drawn from the interpretations. For example, the solution of copper sulfate appears at the collection point of the leach system: From where did the copper come? The iron paper clip turns orange in the copper sulfate solution and the solution becomes a light greenish color: What are the reactions occurring here?*
- Address issues, events, problems, or topics significant in science and of interest to participants. *Mining is an industry important to Nevada. In order that intelligent decisions be made when needed, the general public must have some knowledge of the basic science being applied. Extraction of the ore and reclamation of the site are important economically and environmentally. These topics are integral to the activity.*

Standard B: (NSES P. 62) Professional development for teachers of science requires integrating knowledge of science, learning, pedagogy, and students; it also requires applying that knowledge to science teaching. Learning experiences for teachers of science must

- Connect and integrate all pertinent aspects of science and science education. *The activity draws on a number of aspects of science that can be more or less emphasized: engineering, chemistry, ecology. The inquiry method presented in the activity (augmented with the notes) lets the teachers and students investigate the model and its applications modeling an open ended investigation.*
- Occur in a variety of places where effective science teaching can be illustrated and modeled, permitting teachers to struggle with real situations and expand their knowledge and skills in appropriate contexts. *Ideally, this activity modeling a heap leach system at a mine takes place at a mine so teachers can recognize the similarities of the model they make in a small scale with visible chemicals to the large scale leaching with chemicals that are not visible to the eye. The effective teaching model presented here is the inquiry based investigation of a model with immediate reference to the real situation.*
- Address teachers' needs as learners and build on their current knowledge of science content, teaching, and learning. *The building of the model is a concrete exercise in which all can participate. The understanding of the exercise will vary according to experience; but that variation in understanding is acceptable and part of the design of the activity. This activity models ways in which variations in understanding may be accommodated within population of science students in a class.*

Standard C: (NSES p. 68) Professional development for teachers of science requires building understanding and ability for lifelong learning. Professional development activities must

- Provide opportunities to learn and use the skills of research to generate new knowledge about science and the teaching and learning of science. *The heap leach activity at a mine provides teachers with contact with other scientists who are involved in scientific research. Teachers gain experience in the application of scientific research and an understanding of the nature of such research. Even the brief contact with research science will model the quest for lifelong learning. These skills that the scientist develops are the same the teacher would use in researching the area of instructional methods.*

Standard D: (NSES p. 70) Professional development programs for teachers of science must be coherent

and integrated. Quality preservice and inservice programs are characterized by

- Integration and coordination of the program components so that understanding and ability can be built over time, reinforced continuously, and practiced in a variety of situations. *The collaboration among people during the heap leach activity as a part of the Operation Chemistry training is best developed if that interaction is maintained over time. Teachers maintain contact among each other with computer addresses and meetings throughout the year. Contact with the mine scientists can be maintained in a similar manner and renewed with follow-up visits to the mine and involvement with subsequent levels of the Operation Chemistry program.*
- Collaboration among the people involved in programs, including teachers, teacher educators, teacher unions, scientists, administrators, policy makers, members of professional and scientific organizations, parents and business people, with clear respect for the perspectives and expertise of each. *The heap leach activity presented at a mine site provides as part of an Operation Chemistry workshop provides immediate contact with other teachers, teacher educators, scientists, members of professional and scientific organizations, and business people. This interaction in a situation of studying a scientific problem increases the interaction and discussion among all the groups.*

Science Content Standards (for the students) (NSES pp. 121 - 207)

Science As Inquiry
Content Standard A: (Grades 5-8) (NSES pp. 143-148) As a result of activities in grades 5 - 8, all students should develop abilities to do scientific inquiry and understandings about scientific inquiry.

- Identify questions that can be answered through scientific investigations. *In the activity, students encounter questions such as "What is happening? Did all the copper get rinsed from the heap? Can the copper be leached faster?" and others that the student can develop.*
- Design and conduct a scientific investigation. *To answer the questions such as those above, the student can devise investigations to collect data and arrive at an answer.*
- Use appropriate tools and techniques to gather, analyze, and interpret data. *The student can use a series of standards to determine the amount of copper still present in the leach solution, graph the concentrations versus amount of solution put on the model heap leach, change the conditions and proceed again.*
- Develop descriptions, explanations, predictions, and models using evidence. *The students will be using a model. This is an opportunity to draw the parallels between the object (the mine heap leach system for gold) and the model before they develop such models themselves. The use of this model and serve as "model" for the development of other models.*
- Think critically and logically to make the relationships between evidence and explanations. *The model heap leach activity provides the opportunity to make changes in the system so relationships between evidence and explanations can be checked.*
- Recognize and analyze alternative explanations and predictions. *Students can consider their explanations for the precipitation of copper on the paper clip, particularly discussing if it is copper.*
- Communicate scientific procedures and explanations. *Students can tell about experiments they may conduct, the procedure, the results, and the conclusion.*
- Use mathematics in all aspects of scientific inquiry. *Concentrations of copper can be quantified. If the amount of copper sulfate originally placed in the "ore" is measured, it should be possible to calculate the time needed to rinse the leach heap until the copper in the solution reaches a certain concentration. Scale the model up to represent the size of a mine leach heap.*
- Understandings about scientific inquiry. *In working with the model, students can become aware of problems the mine engineers must consider in designing a heap leach system. The students can vary some parameters, collect data, and find the best design for their model.*

Content Standard B: Physical Science (NSES p. 149-154) As a result of their activities in grades 5 - 8, all students should develop an understanding of the properties and changes of properties in matter.

- A substance has characteristic properties. *The properties of the "ore" can be observed: copper sulfate dissolves in the water while most of the*

rock does not. Some fine particles get through the filter.

- Substances react chemically in characteristic ways with other substances to form new substances with different characteristic properties. *Students observe the reduction of copper ions to copper metal, and the dissolution of iron from the paper clip. The loss of the characteristic color of the copper sulfate solution (blue) indicates the loss of copper. The precipitate is orange, the characteristic color of copper. Students also observe the formation of the dark blue copper-ammonium complex.*

Content Standard B: Physical Science (NSES p. 176-181) As a result of their activities in grades 9 - 12, all students should develop an understanding of chemical reactions.

- Chemical reactions occur all around us, for example in health care, cooking, cosmetics, and automobiles. *Students observe chemical reactions in the model heap leach system and at the mine in the mining and recovery of gold.*
- A large number of important reactions involve the transfer of either electrons (oxidation/reduction reactions) or hydrogen ions (acid/base reactions) between reacting ions molecules, or atoms. *Students will observe the reduction of copper ions to copper metal and oxidation of iron metal to iron ions.*
- Chemical reactions can take place in time periods ranging from the few femtoseconds required for an atom to move a fraction of a chemical bond distance to geologic time scales of billions of years. *The reactions students use in the model and observe at the mine site are the same reactions that took place to form the deposit of metals in this spot on earth.*

Content Standard D: Earth and Space Science (NSES p. 158-161) As a result of their activities in grades 5 - 8, all students should develop an understanding of the structure of the earth system.

- Water is a solvent. As it passes through the water cycle, it dissolves minerals and gasses and carries them to the oceans and playas. *Students observe the dissolution of copper from the model leach heap.*

Content Standard D: Earth and Space Science (NSES p. 187-190) As a result of their activities in grades 9-12, all students should develop an understanding of geochemical cycles.

- The earth is a system containing essentially a fixed amount of each stable chemical atom or element. Each element can exist in several different chemical reservoirs. Each element on earth moves among reservoirs in the solid earth, oceans, atmosphere, and organisms as part of geochemical cycles. *Students explore the extraction of metals concentrated in the specific mine site by geochemical processes.*
- Movement of matter between reservoirs is driven by the earth's internal and external sources of energy. These movements are often accompanied by a change in the physical and chemical properties of the matter. *Students explore in the activity and observe in the mine matter moving between reservoirs of elements.*

Content Standard G: History and Nature of Science (NSES p. 170-171) As a result of activities in grades 5 - 8, all students should develop understanding of science as a human endeavor.

- Women and men of various social and ethnic backgrounds—and with diverse interests, talents, qualities, and motivations—engage in the activities of science, engineering, and related fields. *In a visit to the mine site, students will see and interact with people employed there. Mining involves a variety of fields of science and engineering.*