U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

ENERGY EDUCATION AND WORKFORCE DEVELOPMENT

Modeling the Process of Mining Silicon Through a Single Displacement / Redox Reaction

Grades: 9-12

Topic: Solar

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Modeling the Process of Mining Silicon Through a Single-Displacement/Redox Reaction

Authors:

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Course/Grade Level: 10th-12th grade Environmental Science, Chemistry and/or Physics

***National Science Education Standards by the National Academy of Sciences*:**

Content Standard A – Science as Inquiry
- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard B- Physical science
- Structure of atoms
- Structure and properties of matter
- Chemical reactions
- Motions and forces
- Conservation of energy and increase in disorder
- Interactions of energy and matter

Content Standard E- Science and Technology
- Abilities of technological design
- Understandings about science and technology

Content Standard F- Science in Personal and Social Perspectives
- Personal and community health
- Population growth
- Natural resources
- Environmental quality
- Natural and human-induced hazards
- Science and technology in local, national, and global challenges

Content Standard G- History and Nature of Science
- Science as a human endeavor
- Nature of scientific knowledge
- Historical perspectives

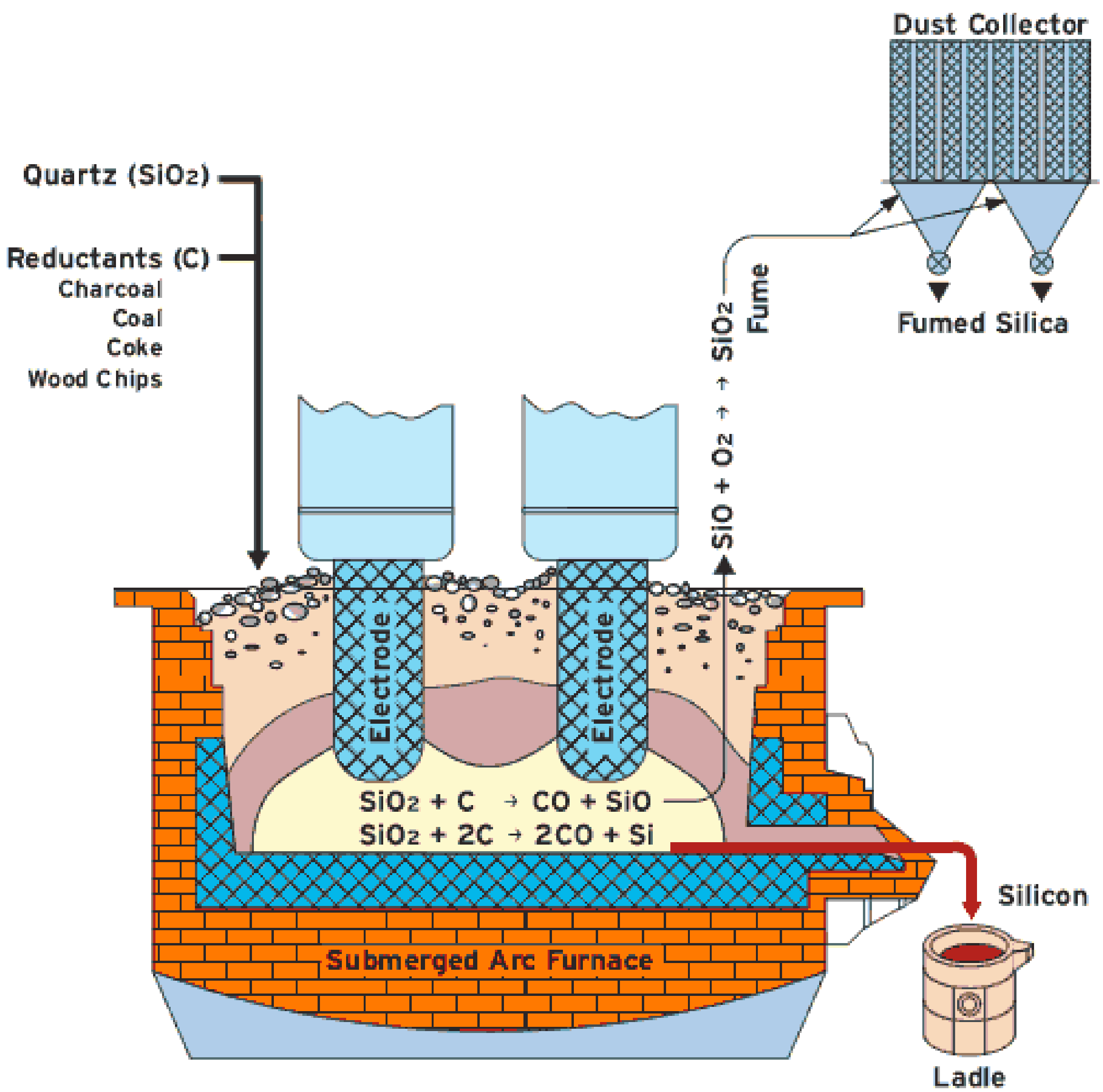
Teacher overview:

As the popularity of photovoltaic (PV) cells and integrated circuits (IC) increases, the need for silicon also increases. Silicon is one of the most used materials in these two industries. It is an inexpensive and abundant semiconductor. However, the process of producing pure silicon adds to the cost and most people do not understand how it is done.

One of the first steps of producing silicon is a process called carbonthermic reduction. Silicon dioxide (SiO_2), which is found in beach sand and quartz, is melted down in a caldron at a temperature of 1450 degrees Celsius. Coke and other forms of carbon are then added to the mixture, because at this high a temperature the oxygen has more of an affinity to the carbon than the silicon. A current is then run through the solution. (See figure 1). As the impurities float to the top of the mixture, carbon monoxide (CO) vaporizes out of the solution and the metallurgical grade silicon (MGS) is siphoned off the bottom. Although there are more steps needed to produce silicon for the IC and PV industries, this initial step can be modeled in a high school laboratory through a single displacement redox reaction.

Solar Cells made of silicon.

Figure 1. Carbothermic reduction model



PLEASE NOTE:
This lesson includes ideas for a teacher to use in a variety of topics, including types of chemical reactions, modeling, the nature of science and technology, renewable energy sources, semiconductors and silicon use. However, there will be specific references for use in a chemistry class. Use this module as you see fit for your objective.

You may introduce this lesson however you see fit, depending on what curricular topics you are covering.

Some suggestions for introducing this lesson:

1. Pass around some computer chips, circuit boards, PV /solar cells, LEDs, laser pointers, silicon rubber, silicon wafers or anything else that is a silicon based product. Ask the students what they have in common. Lead them to say that they all have silicon in them.
2. Ask them where silicon comes from. The students may not know.
3. Do an internet search and find pictures of mining production or any other images that would enhance the lesson. Share these with the students. A good Web site is http://www.simcoa.com.au/process.htm
4. Talk to them about the uses and importance of silicon in the solar energy and computer industries.
5. Discuss what a model is and explain how the lab will be a model of silicon production.
6. Review single displacement and/or redox chemical reactions. Perform a demonstration. An example is magnesium and hydrochloric acid. The reaction would be as follows: $Mg + HCl \rightarrow MgCl_2 + H_2$ (gas)

This is a short lesson that can be incorporated into a variety of possible topics, including:

- Renewable energy sources
- Separation of mixtures
- Modeling and simulation
- Types of reactions (This lesson involves a single displacement and a redox reaction.)
- Stoichiometry
- Nature of science and technology

The following could be included if the lesson plan involves actually using a solar cell or a light emitting diode (LED):

- Electricity
- Efficiency of a device
- Conduction/semi conduction
- p-n junctions

Objectives: When finished with this module, students should be able to:

- Compare and contrast various renewable and non-renewable sources of energy, in terms of abundance, cost structure, and environmental impact.
- Describe the function of and uses of photovoltaic devices.
- Describe the properties of silicon that make it important in the fields of photovoltaics and integrated circuits.
- Describe the process of mining for silicon.
- Perform and describe a laboratory that involves a single displacement reaction.

Specific Chemistry Objectives:

- Determine the number of moles of copper produced in the reaction of aluminum and copper sulfate.
- Determine the number of moles of aluminum used up in the reaction of aluminum and copper sulfate.
- Determine the ratio of moles of aluminum to moles of copper.
- Determine the number of atoms and formula units involved in the reaction.

Time allotted: 1-2 class periods.

Vocabulary (depending on where this lesson fits into the curriculum)
photovoltaic
solar energy
ore
mine
crystal
semiconductor
redox reaction
single displacement reaction

Resource Materials:

Reagents:
copper sulfate (solid)
aluminum (foil or wire)
1.0 molar HCl *(if using the specific chemistry lesson)*

Apparatus:

250 ml beaker	goggles
drying oven	lab apron
graduated cylinder	steel wool
wash bottle stirring rod	balance
tongs	funnel
ring stand	filter paper

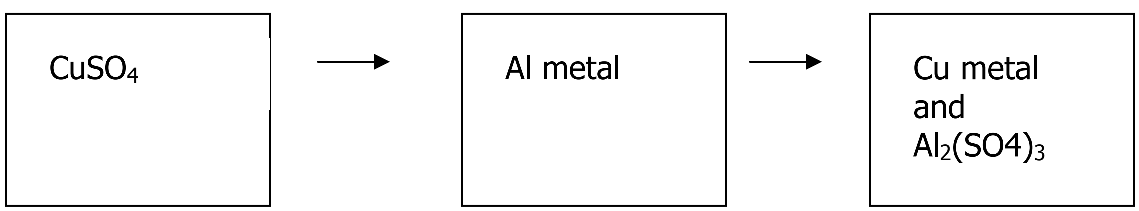
Prerequisite knowledge (depending on where this lesson fits into the curriculum):
Renewable energy, especially solar energy
Semiconductors
Photovoltaics
Modeling
Types of reactions
Stoichiometry

Main activities
The main activity is to carry out a single displacement/redox reaction of copper sulfate ($CuSO_4$) and aluminum metal (Al) to form copper metal (Cu) and aluminum sulfate [$Al_2(SO4)_3$]. This will model the single displacement/redox reaction of separating silicon (Si) from silicon dioxide (SiO_2). This reaction can also be done using an iron nail instead of aluminum, or by substituting 1.0 molar copper chloride for copper sulfate. You may also want to do two or all three of these reactions to enhance your lesson.

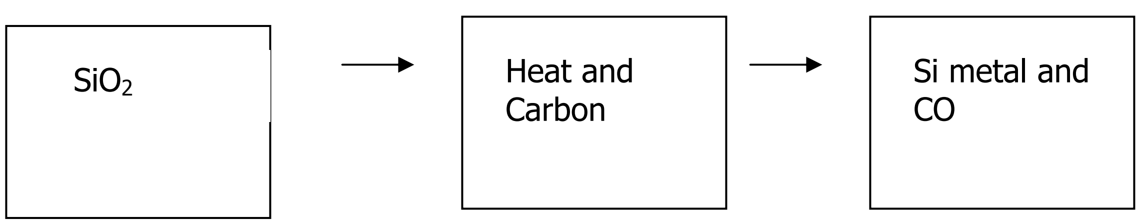
We suggest having samples of beach sand, quartz, coke (or any other form of carbon), and a piece of silicon and discuss what is being represented in the model (See figure 2).

Figure 2. Schematic of the model.

The following diagram represents this simulation:
(Model)



(**Real production of silicon)**



The actual activity that the students will perform is attached to the end of this module. It is written specifically for a chemistry class, so you may need to modify it to fit your lesson.

Evaluation

Specific to chemistry lesson:

1. Determine the number of moles of aluminum used and copper produced.
2. Determine the initial number of moles of copper sulfate.
3. Determine the ratio of moles of aluminum used to moles of copper produced.
4. Write a balanced equation for this reaction.

Suggested questions:
You could also have students work in groups and prepare a presentation.

1. Describe and give a history of "Silicon Valley."
2. What is a PV (solar cell) and what are its uses? What is possible for the future of PVs?
3. What properties of silicon (or any semiconductor) make it widely used in the field of integrated circuits and solar energy?
4. Describe, illustrate, and give an example of a semiconductor, conductor and insulator.
5. Explain renewable energy. What are other sources, besides the sun? Do you feel it is important for the government to spend money on renewable energy research? Why or why not?
6. Computers are constantly being updated and need to be replaced. What problems can this cause for landfills? What options do consumers and businesses have?
7. Why is knowing the crystal shape of a molecule important to understanding its properties? Describe and illustrate 3 crystal shapes.
8. What is a model? Give an example, other than the one in this lab. Why are models used? (Especially in science!)
9. Explain how this lab modeled the production of silicon. Be sure to explain each step and what it is modeling.
10. Describe a single displacement reaction. Write and balance the reaction from this lab.
11. Describe a redox reaction. Explain what is being reduced and oxidized in this reaction.
12. Carbon monoxide is a greenhouse gas that is emitted during this process of producing silicon. Explain what a greenhouse gas is and the problems they can cause. Do you think society or the government should invest in developing more silicon to cut down on these emissions? Why or why not?
13. Many other industries use silicon. Name a few and what needs to be done to the MGS to make it useful for their industry.

Student Section:

1. Calculate the grams of $CuSO_4$ needed to make 50 ml of a 1 molar solution. Show your work here. You may not move on until your teacher has initialed this section.

Teacher's initials

2. Read through the lab. Prepare a data table for all of the measurements and calculations you will be performing. You may not move on until your teacher has initialed this section.

Teacher's initials

3. Place an empty 250 ml beaker on the balance. Tare the balance and add the amount of copper sulfate crystals you calculated in step 1 to the beaker. Record the exact amount.

4. Add 50 ml of deionized water to the beaker. Swirl the beaker around to dissolve all of the copper sulfate crystals.
5. Obtain two clean, dry pieces of aluminum wire. Find the mass of the aluminum and record it.
6. Place the nails into the solution and leave them undisturbed for about 20 minutes. During that time you should see the formation of copper in the beaker. At the same time, some of the aluminum will be used up. Observe and record in your data table what you see.
7. After the reaction is complete, use the tongs to carefully pick up the aluminum wires one at a time. Use deionized water in a wash bottle to rinse off any remaining copper from the aluminum before removing them completely from the beaker. If necessary, use a stirring rod to scrape any excess copper form the aluminum. Set the aluminum aside to dry on a paper towel.
8. After the aluminum is completely dry, find the mass of them and record it.
9. *To decant* means to pour off only the liquid from a container that is holding both solids and liquids. Decant the liquid from the solid. Pour the liquid into another beaker so that you can still recover the solid if you over pour. (**NOTE:** You may want to use the remaining liquid solution to grow some crystals!)

10. After decanting, rinse the solid again with about 25 ml of deionized water. Decant again three or four more times.
11. Wash the solid with about 25 ml of 1.0 hydrochloric acid. Decant again, then clean the solid with 25 ml of deionized water.
12. Obtain a piece of filter paper and write your name on it in pencil. Mass the filter paper and record.
13. Filter the copper and water and allow the water to completely drain. Put the damp filter paper into a drying oven until it is completely dry.
14. When it is dry, mass the filter paper and the copper and record the results.
15. Clean up as per your instructor's directions.

(Optional) Do a laboratory report.

Teacher's key:

1. Determine the number of moles of aluminum used and copper produced.
   Final mass of copper(g) x 1mole/63.5g =
   Final mass of aluminum (g) x 1mole/27.0g=
2. Determine the initial number of moles of copper sulfate.
   8.1gx 1mole/162.5g = .05 moles
3. Determine the ratio of moles of aluminum used to moles of copper produced.
   2 moles Al: 3 moles Cu
4. Write a balanced equation for this reaction.
   $3\ CuSO_4 + 2\ Al \rightarrow Al_2(SO_4)_3 + 3\ Cu$

From the student section:

1. 50ml x 1L/1000ml x 1mol/1L x 162.5 grams/1mol = 8.1 grams
2. An example of a data table could look like this:

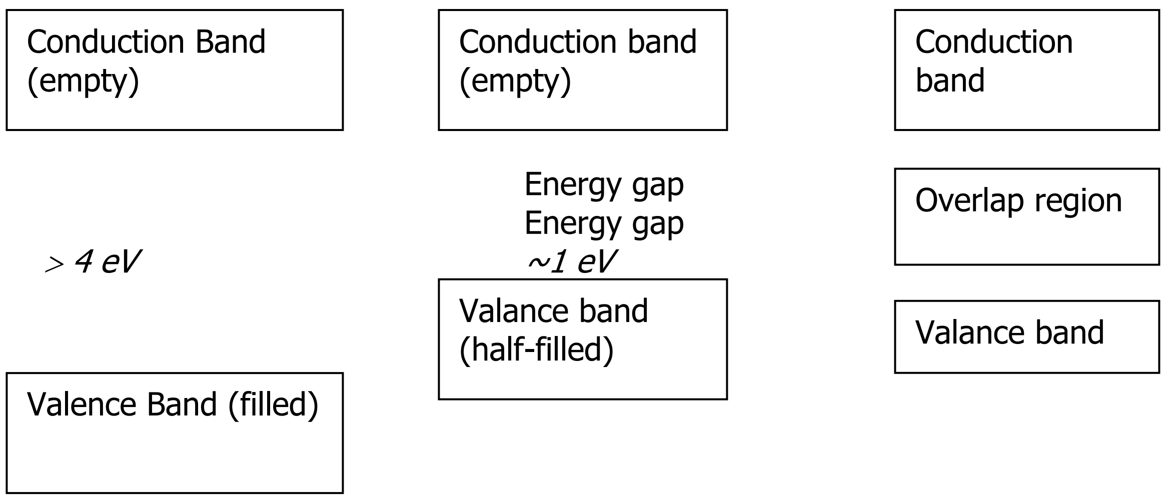
	Mass (g)	Observations
Initial copper sulfate		
Initial aluminum metal		
Final aluminum metal		
Δ aluminum metal		
Final copper metal		

Suggested questions:

1. Describe and give a history of "Silicon Valley."
   (Answers may vary.)
   http://www.siliconvalleyonline.org/history.html.
2. What is a PV (solar cell) and what are its uses? What is possible for the future of PV's?
   (Answers may vary.)
   A solar cell is a device that is produced to take light energy from the sun and transfer it into electrical energy. It is used to generate electricity for use homes, small electrical devices and some cars (in conjunction with another form of energy). In the future, entire cities could be powered by solar cells, and many forms of transportation could be powered by them.
3. What properties of silicon (or any semiconductor) make it widely used the field of integrated circuits and solar energy?
   Semiconductors have a wide enough band gap that allows them to produce a sufficient amount of energy when a p-n junction is formed. They also can easily be doped to improve their efficiency.

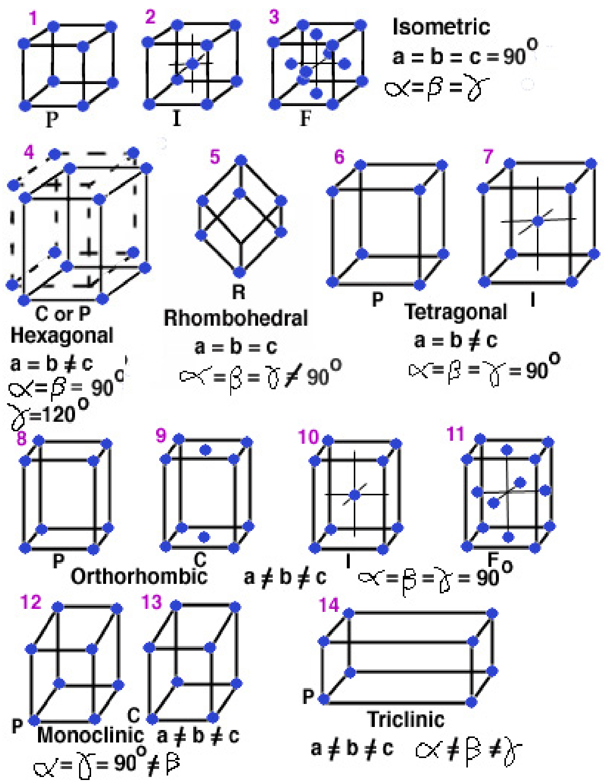
4. Describe, illustrate and give an example of a semiconductor, conductor and insulator.
   In an insulator, there is a large potential between the conduction and valence band (> 4 eV), in a semiconductor the potential is between 1 and 2 eV, and in a conductor the eV is << 1.

   Insulator Semiconductor
   Conductor



A diamond is an insulator, silicon is a semiconductor, and copper is a conductor.

5. Explain renewable energy. What are other sources, besides the sun? Do you feel it is important for the government to spend money on renewable energy research? Why or why not?
   (Answers may vary.)
   Renewable energy is a form of energy that can be replaced at a faster rate than it is used. Other sources of renewable energy are wind, geothermal, biomass, tidal and hydrogen.
6. Computers are constantly being updated and need to be replaced. What problems can this cause for landfills? What options do consumers and businesses have?
   They are taking up a lot of space in the landfills; are made with materials, such as gold and copper, that could be recycled; and they leak toxic metals such as cadmium, chromium, lead and mercury. Customers and businesses have the option to take their old computers to be recycled or donated.
7. Why is knowing the crystal shape of a molecule important to understanding its properties? Describe and illustrate 3 crystal shapes.
   The crystalline shape of a molecule determines its properties and characteristics. The 6 main shapes are: ***Isometric (or Cubic), Hexagonal, Rhombohedral, Tetragonal, Orthorhombic, Monoclinic, and Triclinic***



8. What is a model? Give an example other than the one in this lab. Why are models used? (Especially in science!)
   (Answers may vary.)
   A model is a representation of a process or structure that is too small or too large to see with the human eye. Another example of a model is a map. Many concepts, especially in science, are too small or large to be studied with the human eye. Models are made so that these concepts can be studied and taught.
9. Explain how this lab modeled the production of silicon. Be sure to explain each step and what it is modeling.
   Refer to Figure 2.
10. Describe a single displacement reaction. Write and balance the reaction from this lab.
    (Answers may vary.)
    A + BC → AC + B
    $3\ CuSO_4 + 2\ Al \rightarrow Al_2(SO_4)_3 + 3\ Cu$
11. Describe a redox reaction. Explain what is being reduced and oxidized in this reaction.
    A redox reaction involves the reduction of one element and the oxidation of another. In this reaction, the copper is being reduced and the aluminum is being oxidized.
12. Carbon monoxide is a greenhouse gas that is emitted during this process of producing silicon. Explain what a greenhouse gas is and the problems they can cause. Do you think society or the government should invest in

developing more production of silicon to cut down on these emissions? Why or why not?
(Answers may vary.)
A greenhouse gas is a gas in the atmosphere that traps thermal energy. If too many greenhouse gasses are in the atmosphere, global warming can occur.

13. Many other industries use silicon. Name a few and what needs to be done to the MGS to make it useful for their industry.
(Answers may vary.)
Other industries that use silicon are steel, petroleum, rubber, caulking and medical. The MGS must be purified and grown into perfect crystals in order to be used.