UNIT 1

Matter and the Rise of Atomic Theory

The Art of the Meticulous

Unit Overview

Since the first time early humans lit a fire and cooked food, people have been manipulating the matter around them. That's what chemistry is – the manipulation of matter – and it has been performed since long before the word "chemistry" ever existed. Every person does chemistry every day, and not just the chemistry that is going on inside the human body.

Ancient people became adept at manipulating materials with the goal of creating products to improve their lives. For example, they fired clay to make ceramics and mixed herbs to create medicines. Eventually, humans tried to create models and theories to explain why certain chemical manipulations worked. This is the point at which chemistry became "a science."

Our goal in this first unit is to show how chemistry evolved from manipulating materials for practical purposes to Dalton's first atomic theory of matter. It is a story that will start with Democritus around 400 BCE and go to the dawn of the 1800s, when modern scientific methods transformed the way people approached doing chemistry.

Learning Objectives and Applicable Standards

Participants will be able to:

1. Trace the origins of chemistry back to prehistoric times.
2. Understand the scientific method and the use of models in chemistry.
3. Define chemistry broadly as the accumulated knowledge, skills, methods, procedures, and theoretical framework that people use to manipulate matter to serve human needs.
4. Trace how phlogiston and other now-discredited chemical theories came to be replaced by a more scientific model of matter based on particles.
5. Show how the work in the late 1700s and early 1800s set the stage for the chemical revolution that followed.

Key Concepts and People

1. **Origins of Chemistry:** Chemistry started as a set of practices that were passed from generation to generation, with gradual improvement over time but without a detailed theory to guide progress. Chemistry became a formal discipline when researchers began to analyze chemical processes in meticulous detail in order to gain an understanding of their observations.

2. **Chemistry in the Ancient World:** Metallurgy is chemistry's oldest ancestor. It gradually expanded, starting with metals that appear in nature as pure elements, like copper and gold, and later moving to metals that required processing, like iron.

3. **Arab Contributions:** Jābir ibn Hayyān and other Arabs began pioneering the chemical sciences in the 7th century when Europe was in the Dark Ages.

4. **Alchemy:** Nicolas Flamel and Paracelsus developed instruments, techniques, and knowledge of chemical substances and early medical chemistry, which contributed to the rapid advance of chemistry in the 18th century.

5. **Antoine Lavoisier and Other Advances:** Antoine Lavoisier disproved phlogiston theory and demonstrated that oxygen is a substance that combines with metals and can be released again as a gas. This led other researchers, including Joseph Proust and Claude Berthollet, to further define matter as small, indivisible particles that combine in different ways to make all the materials we know.

6. **Proust's Law of Definite Proportions:** All elements combine to make compounds in the same ratios, indicating that there must be a fundamental component that is replicated over and over.

7. **Dalton's Atomic Theory:** John Dalton postulated that matter is made up of small indivisible units called atoms. He then built on the work of Proust and Berthollet to theorize that atoms could only combine together in simple whole number ratios.

Video

This program traces the story of how humans have always practiced chemistry; how, over time, it developed from a practical discipline into a science. Today, we keep up the chemists' tradition to refine and purify substances. A current, real-life application of the "art of the meticulous" is the refining and purification of pure silicon from a common material—silica sand—for advanced electronics, such as cell phones and solar cells.

VIDEO CONTENT

Host Introduction

After a general introduction to the field of chemistry, the host, Dr. Chris Morse, a professor of chemistry at Olin College, introduces chemistry as a discipline and sets the stage for a silicon theme. He walks down a beach and explains that silicon is a component of sand and it is the cornerstone of modern electronic technologies.

History of Chemistry
"The Origins of Chemistry"

This historical overview of chemistry begins with the Greek philosopher Democritus's theory of "atomos." Other Greek philosophers like Aristotle came to believe that all matter was made of four elements: air, earth, fire, and water. Harvard Historian, Dr. Ahmed Ragab, explains Jābir ibn Hayyān's important contributions to early chemistry.

Host Science Explanation
"Separating the Beach"

In this demonstration Dr. Chris Morse separates out sand, salt, and water from a mixture of sand and saltwater. First he passes the mixture through a filter to separate the solids from the liquids. Then, using a distillation apparatus, he is able to separate the salt from the water in the seawater.

Real World Application
"Sand to Sun"

Solar World uses silicon to manufacture solar photovoltaic panels in Oregon. This segment explains the chemistry behind this process.

History of Chemistry
"The History of Oxygen"

Dr. Michal Meyer of the Chemical Heritage Foundation discusses Lavoisier's experiments that allowed him to disprove phlogiston theory and isolate and measure the elements oxygen, nitrogen, and hydrogen. Lavoisier was further able to demonstrate that water was not an element, but rather a compound of hydrogen and oxygen.

Laboratory Demonstration
"Making Water the Hard Way"

Daniel Rosenberg, Lecture Demonstrator at Harvard University, demonstrates that combining two parts hydrogen gas and one part oxygen gas makes water.

Current Chemistry Research
"Atomic Manipulation"

Dr. Tonio Buonassisi, a professor at the Massachusetts Institute of Technology, studies how to make solar panels more efficient. He and his team are researching the next generation of photovoltaics by examining the purity of the silicon and how it is formed and processed.

Unit Text

Content Overview

The text of this first unit parallels the video, but includes more detail and less emphasis on specific real-world examples. The unit begins by setting up the scientific method. It uses chemistry to help explain the nature of science, specifically that scientific investigations are conducted through careful observation, measurement, and experimentation designed to explain why something happens. Chemistry is a science that requires meticulous attention to detail and relies on careful measurements. This unit emphasizes the difference between precision and accuracy.

The text then provides an overview of 2,000 years of models developed to explain the chemical changes that occur in nature as well as through human activities. Failed models, such as phlogiston theory, are shown to be part of the process that led to the development of a better, more robust science of chemistry.

The unit culminates in Dalton's theory, which explained that atoms were tiny particles that make up all matter. The rules predicted by his theories guided the renaissance of chemistry research during the 1800s.

Sidebar Content

An Official Language for Chemistry: In 1787 Antoine Lavoisier published *Methode de Nomenclature* (*Essay on Chemical Nomenclature*), a book that proposed a system for naming and classifying chemicals.

Interactives

Historical Timeline of Chemistry

The Historical Timeline of Chemistry is directly related to Unit 1. This interactive illustrates how different discoveries build upon, disprove, or reinforce previous theories. This not only reinforces basic chemistry concepts, but also emphasizes the nature of science. Scientists mentioned in this unit are listed on the timeline.

During the Session

Before Facilitating this Unit

Generally, we recommend watching the videos first before reading the written units. Some of the video segments directly relate to the suggested group activities or in-class demonstrations. For example, the "History of Oxygen" video segment complements the group exercise "Debating Phlogiston vs. Oxygen" and the "Democritus' Air Displacement Demonstration." Similarly the "Separating out the Beach" video segment relates to the separation exercise presented in this guide.

Tips and Suggestions

1. **Find out ahead of time what your students know about this topic.** Many times, students will hold some of the same misconceptions that early scientific thinkers did.

2. **Some students are confused about the nature of science.** The content and the history in this unit provide a good opportunity to discuss what science is in general.

3. **Some students don't see the relevance of studying the history of science.** To counter this, emphasize that many "facts" that we are convinced of today may turn out to be wrong by future generations. Use this as a way to reinforce the nature of science.

4. **In the West, we tend to discount the scientific contributions made by people of other cultures.** Jabir and the other Arab scientists are excellent talking points for analysis of the factors that might lead toward Eurocentrism and offer the opportunity to bring a multicultural perspective to an introductory chemistry class.

Starting the Session: Checking Prior Thinking

You might assign students a short writing assignment based on the following questions, and then spend some time discussing prior thinking. Many chemistry courses begin with a unit on measurement. This historical introduction to how chemists' tools, measurements, and procedures gradually improved can be the launching point for a detailed look at measurement in chemistry labs today.

1. What is chemistry?

2. What is the difference between craftsmanship and science?

3. What makes an experiment "scientific"?

4. What is the scientific method?

Before Watching the Video

Students should be given the following questions to consider while watching:

1. When was chemistry invented?

2. What were the first practical uses of chemistry?

3. What major historical events provided the context for the transformation of chemistry into a science?

4. Has the definition of chemistry changed over time? If so, how?

5. How did the development of tools contribute to chemistry as a science?

Watch the Video

After Watching the Video

Use these additional questions as follow-up, either as a group discussion or as short writing assignments.

1. Revisit your answer to the question, "What is chemistry?" Do you wish to change your answer now?
2. What happens when two different theories are created for explaining the same thing?
3. What did each of the following scientists do that was different than their predecessors?
   a. Jabir
   b. Lavoisier
   c. Dalton
4. How does chemistry research advance today? What are the most significant differences between Lavoisier's laboratory practices and today's? What are the similarities?

Group Learning Activities

Debating Phlogiston vs. Oxygen

Objective

This activity helps students think about how scientists form hypotheses based on their observations.

Students can take sides and debate the question of phlogiston vs. oxygen theories. Ask them to form groups and work for 5-10 minutes to come up with a convincing argument for their side. Then have a debate where members of each group present their position, followed by a counterargument from the other group. What evidence can they produce to support each argument?

Separation Exercise

Objective

This activity is designed to help students think about how chemists use properties of chemicals and tools to purify substances and separate mixtures. Chemists separate out substances in a mixture by taking advantage of the chemical properties of the different components within a mixture. In this activity, participants are given a mixture of objects and some tools and are asked to separate the mixture. Students will need to strategize how the tools available can best exploit the different properties of the objects in order to separate them all out.

List of materials

- Small bucket or large beaker (one per group)
- Sand (handful per group)
- Object that floats in water: woodchips, cork, Styrofoam ball, etc. (handful per group—choose only one type)
- Magnetized object: paperclips, screws, nails, etc. (handful per group—choose only one type)
- Lightweight object that is easily blown: feathers, pieces of paper/ confetti (handful per group—choose only one type)
- Heavy object that is not magnetized: buttons, marbles, coins, construction blocks

NOTE: It is important to only have one type of object from each of the groups listed above. For example you want to have either woodchips or cork, not both. You don't want to have multiple objects that have the same properties.

- Magnets (one per group)
- Sieves (one per group)
- Large beaker of water (one per group)
- Trays or pans
- Water

Setup

1. For each group participating in the activity combine sand, floating objects, magnetized objects, lightweight objects, and heavier objects into a small bucket or large beaker. Make sure items are well mixed.

2. Provide each group with a magnet, a sieve, and a large beaker of water. Trays or pans can be used to keep the work area tidy.

Procedure

1. Separate the different components of the mixture. You may use the tools provided to help you sort.

2. Record your methods and reasons for separating the objects the way you did.

Discussion

It is likely that not all the groups will separate the components in the same way. Lead a discussion to compare the different ways groups chose to separate out their mixtures.

What are some of the advantages of doing it one way or another? For example, did any groups use the water to float some of the objects? Did they use the water before or after they separated out the sand? Did any group spread out the mixture on a surface and blow the feathers or paper away from the rest of the mixture? The following questions can help students reflect on this exercise. If possible, have students record their responses to the questions in a journal.

1. If you were to do this exercise again, how would you separate the objects? Why?
2. How does this exercise mirror how chemists separate different substances?
3. How do tools help advance separation techniques? What would you do differently if you did not have a sieve or if you did not have a magnet?
4. How do tools help advance chemistry as a science?

Hazards

There is no increased risk of harm to do this activity.

Disposal

There are no special disposal considerations.

In-Class Chemical Demonstrations

Democritus' Air Displacement Demonstration

Objective

This simple demonstration shows that air is matter – it takes up space. In this demonstration a covered glass funnel is inserted into a tank of water. The water does not go up the funnel since air is trapped inside. Because air is made of matter, it takes up space and will prevent other matter from entering that space. When the finger covering the hole of the funnel is removed, the air can escape allowing the water to travel up the funnel.

List of Materials

- Clear glass funnel
- Clear glass tank of water

Procedure

1. Place your finger over the end of an inverted clear glass funnel.
2. Ask the students what will happen when the open end of the funnel is placed face down into a tank of water.

3. Place the funnel into the water and then, after students have predicted the result, release your finger from the short end and let the water seek its own level.

Discussion

These questions can help guide students to think about what they learned from observing this demonstration.

1. What did you observe?
2. How did what you observe compare to what you thought would happen?
3. Why did the water not go up the funnel when a finger covered the hole
4. What happened when the finger was released from the hole? Why?

Hazards

Glass is slippery when wet. Be careful not to break the glass funnel.

Disposal

There are no special disposal considerations.

Going Deeper (In-Class Discussion or Reflection)

Instructors should allow up to 30 minutes for discussion at the end of the session, or students can use the time to reflect on one or more of these questions in journals.

1. Why do you think the phlogiston theory was so popular? What aspects of it appeal to "common sense"?
2. Why do you think humans have named the eras of civilization after chemical innovations (Stone Age, Bronze Age, Iron Age, etc.)?
3. Lavoisier was executed by guillotine following the French Revolution. What might the impact have been on history if his wife, Marie Anne Paulze Lavoisier, had not worked to publicize their results?
4. What do you think science is?
5. How does discovering the properties of the materials around you and developing tools based on that help advance chemistry?

Before the Next Unit

Learners should read the Unit 1 text if they haven't already done so. They may wish to read one or more of the reading assignments from the list below, or, if you choose to have them use the course materials outside of class, they can watch the Unit 2 video and/or read the Unit 2 text as an assignment before the next session.

References and Additional Resources

Djerassi, Carl and Roald Hoffman. *Oxygen.* Wiley, February 2001.

Salzberg, Hugh. *From Caveman to Chemist: Circumstances and Achievements* (American Chemical Society, 1991).

Jackson, Joe. *A World on Fire: A Heretic, an Aristocrat, and the Race to Discover Oxygen*. (Viking, 2005).

Lavoisier, Antoine. *Elements of Chemistry In a New Systemic Order, Containing all the Modern Discoveries.* Project Gutenberg e-book. Released December 28, 2009. http://www.gutenberg.org/ebooks/30775

Levore, Trevor H. *Transforming Matter: A History of Chemistry from Alchemy to the Buckyball*, (Johns Hopkins University Press, 2011).

U.S. National Institute of Health, National Library of Medicine, "Paracelsus and the Medical Revolution of the Renaissance: A 500th Anniversary Celebration," http://www.nlm.nih.gov/exhibition/paracelsus/index.html.

For Professional Development

In addition to watching the videos, reading the text, and going through the activities listed in the course guide, participants taking this course for professional development should read the following papers and answer the corresponding reflection questions, then complete the professional development assignments.

Further Reading and Reflection Questions

Horton, Christopher. Student Alternative Conceptions in Chemistry. *California Journal of Science Education*, 7(2), 2007. Accessed June 25, 2013. modeling.asu.edu/modeling/Chem-AltConceptions3-09.doc

1. Do you remember ever holding any of the misconceptions discussed in this article? If so, do you remember how you came to reconcile your way of thinking?

2. How can you use this information about misconceptions to inform how you teach?

McComas, William F. "The Principle Elements of the Nature of Science: Dispelling the Myths." In *The Nature of Science in Science Education*, ed. W.F. McComas, 53-70.
Netherlands: Kluwer Academic Publishers, 1998. Accessed June 25, 2013.
http://www.toriah.org/articles/McComas-ScienceMytrhs-1998.pdf

1. How does the information in this unit help clarify any of the myths discussed in the reading?

Do any of the materials in this unit have the potential to perpetuate any of the myths mentioned in this paper? What are ways that you could address these issues in the classroom?

Professional Development Assignments

1. After reading the papers above and reflecting on the questions presented, develop a lesson plan designed to teach the material presented in this unit.

2. Using a group activity or classroom demonstration presented in this course guide, show how you would implement it in your classroom. Where would it fit into your curriculum or standards? Would you change the demonstration or activity in any way? How would you assess student learning?