Landmark Lesson Plan:

Joseph Priestley, Discoverer of Oxygen

Grades: 9-12
Subject areas: Chemistry and History
Based on "Joseph Priestley House," a National Historic Chemical Landmark

The following inquiry-based student activities are designed for use in high school lesson planning. The handout and activities will help students understand how chemistry was practiced during Joseph Priestley's time (1733-1804), developments leading to the discovery of oxygen, the historical context of scientific discoveries made at this time, and related developments in chemistry that took place during the late 1700s and early 1800s.

The activities are designed as a ready-to-go lesson, easily implemented by a teacher or his/her substitute to supplement a unit of study. In chemistry, the activities relate to identifying physical and chemical properties, nomenclature, and the scientific process. In history, the themes are the chronology of scientific discoveries and the relationships between England, France and America in the late 1700s.

All resources are available online at www.acs.org/landmarks/lessonplans.

While these activities are thematically linked, each is designed to stand alone as an accompaniment for the handout. Teachers may choose activities based on curricular needs and time considerations.

- Take a few minutes to introduce the lesson with a few conversation starters. What historical events were occurring between 1750 and 1800? Who are some major scientists in history, and what did they discover (Isaac Newton's Law of Universal Gravitation; Nicolaus Copernicus' demonstration of the sun as center of the solar system; Marie Curie's theory of radioactivity and discovery of radium and polonium)? How have science and society evolved in the last 10, 50, 100, 250 years?
- Distribute the **Activities** selected for the class.
- Have students read the handout on **Joseph Priestley, Discoverer of Oxygen**.
- After class use the **Answer Guide** for student feedback and discussion.

Student Activities with Objectives

Anticipation Guide for Handout on "Joseph Priestley, Discoverer of Oxygen" (10-20 min.)
- Students read the handout and explore their own ideas about chemical discoveries made in the 1700s that are fundamental to the modern chemical sciences.

History Exercise: Chronology of the Discovery of Gases (10-15 min.)
- Students chronologically order events in the reading.
- Students recognize the different names and properties of common gases when they were first being examined in the 1700s.

Exploring the Scientific Process (25-30 min.)
- Students analyze information from the reading and relate it to scientific processes.

Properties of Oxygen Gas (15-20 min.)
- Students categorize properties of oxygen gas as chemical or physical.
- Students determine the importance of the properties of oxygen gas in identifying it as an element.

Nomenclature Exercise (10-15 min.)
- Students use inductive reasoning to discover a rule for naming compounds that contain oxygen.

Joseph Priestley, Discoverer of Oxygen

Some 2,500 years ago, the ancient Greeks identified air—along with earth, fire and water—as one of the four elemental components of creation. That notion may seem charmingly primitive now, but it made excellent sense at the time. The idea persisted until the 1700s and might have endured even longer had it not been for a free-thinking English chemist and maverick theologian named Joseph Priestley, who discovered the gas we now know as oxygen in 1774.

Early Beliefs about Air

In the mid-1700s—the time of the Industrial Revolution—the concept of an element was still evolving. Scientists had distinguished no more than two dozen or so elements.

However, it wasn't clear how air fit into that system. Nobody knew what air was.

The most pressing issue in chemistry and physics at this time was to determine what exactly happens when something burns. The prevailing theory was that flammable materials contained a substance called “phlogiston” (from the Greek word for “burn”) that was released during combustion.

For example, the theory held that when a candle burned, phlogiston was transferred from it to the surrounding air. When the air became saturated with phlogiston and could contain no more, the flame went out. Breathing, too, was a way to remove phlogiston from a body.

A typical test for the presence of phlogiston was to place a mouse in a container and measure how long it lived. When the air in the container could accept no more phlogiston, the mouse would die.

Emerging Understanding

British chemists were especially prolific in studying air. In 1754, Joseph Black identified what he called "fixed air" (now known as carbon dioxide) because it could be returned, or fixed, into the sort of solids from which it was produced. In 1766, Henry Cavendish produced “flammable air,” a gas which Lavoisier would name hydrogen, from the Greek words for "water maker."

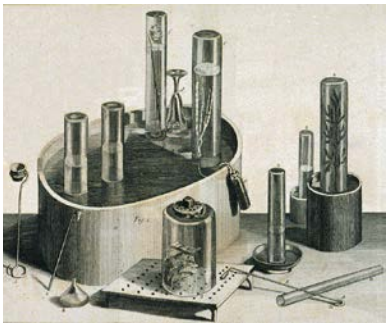
In 1772, Daniel Rutherford found that when he burned material in a bell jar, then absorbed all the "fixed air” by soaking it up with a substance called potash, a gas remained. Rutherford dubbed it "noxious air" because it asphyxiated mice placed in it. Today, we call it nitrogen.

Priestley’s Investigations

The next major discovery came from Joseph Priestley.

Priestley systematically analyzed the properties of different "airs" using the favored apparatus of the day: an inverted container on a raised platform that could capture the gases produced by various experiments below it. The container could also be placed in a pool of water or mercury, effectively sealing it. Within the container further tests could be done to determine if a gas would sustain a flame or support life.

In the course of these experiments, Priestley made an enormously important observation: A flame would extinguish itself and a mouse would suffocate when placed in the sealed jar. However, putting a green plant in the jar and exposing it to sunlight would "refresh" the air, permitting the flame to burn and the mouse to breathe. Perhaps, Priestley wrote, "the injury which is continually done by such a large number of animals is, in part at least, repaired by the vegetable creation." Thus he observed that plants release oxygen into the air—the process known to us as photosynthesis.



Laboratory equipment used by Priestley in the 1700s.

Discovery of Oxygen

On August 1, 1774, Priestley conducted his most famous experiment. Using a 12-inch-wide glass lens, he focused sunlight on a lump of mercuric oxide in an inverted glass container placed in a pool of mercury. The colorless, odorless, and tasteless gas emitted from the lump caused a flame to burn intensely and kept a mouse alive about four times as long as a similar quantity of air.

Priestley called his discovery "dephlogisticated air" on the theory that it supported combustion so well because it had no phlogiston in it. Hence it could absorb the maximum amount during burning.

Whatever the gas was called, its effects were remarkable. "The feeling of it in my lungs," Priestley wrote, "was not sensibly different from that of common air, but I fancied that my breast felt peculiarly light and easy for some time afterwards. Who can tell but that in time, this pure air may become a fashionable article in luxury. Hitherto only two mice and myself have had the privilege of breathing it."

The Chemical Revolution

Shortly after his discovery, Priestley visited France and met Antoine Lavoisier, another scientist investigating gases.

It turned out that “dephlogisticated air” was the clue Lavoisier needed to develop his theory of chemical reactions—the "revolution" in chemistry that would finally dispel the phlogiston theory.

Burning substances, Lavoisier argued, did not give off phlogiston; they took on Priestley’s gas. Lavoisier called the gas "oxygen" from the Greek word for acid-maker, because it combines with non-metals to produce acids.

Joseph Priestley

Joseph Priestley was born in Yorkshire, England, in 1733. Around the age of 19, he was encouraged to study for the ministry. And study, as it turned out, was something Joseph Priestley did very well.

Aside from what he learned in the local schools, he taught himself Latin, Greek, French, Italian, German and a smattering of Middle Eastern languages, along with mathematics and philosophy. This preparation would have been ideal for study at Oxford or Cambridge, but as a Dissenter (someone who was not a member of the Church of England) Priestley was barred from England's great universities.

Instead, he enrolled at Daventry Academy, a celebrated school for Dissenters. After graduation, he supported himself, as he would for the rest of his life, by teaching, tutoring and preaching.

In 1773, the Earl of Shelburne asked Priestley to serve as a sort of intellectual companion, tutor for the earl's offspring, and librarian for his estate. The position provided access to social and political circles Priestley could never have gained on his own, while leaving ample free time for the research that would earn him a permanent place in scientific history.

Despite his scientific successes, Priestley still suffered for his religious beliefs. In 1780 he was asked to leave the estate.

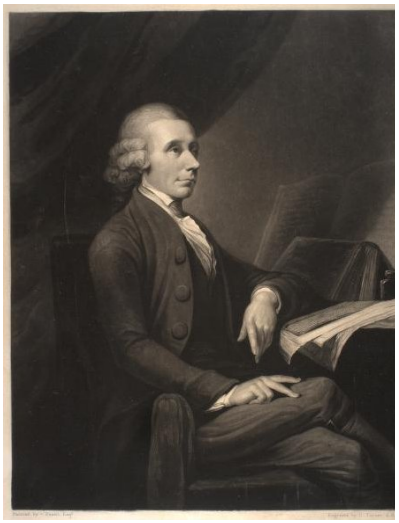
Priestley’s unorthodox religious writings and support for the American and French revolutions so enraged his countrymen that he and his wife were forced to flee England.

Joseph and Mary set sail for America on April 8, 1794. They built a house in the town of Northumberland, Pennsylvania, to be near their sons.

There Priestley continued his research, isolating carbon monoxide (which he called "heavy inflammable air") and founding the Unitarian Church in the United States. For the most part, he led a quiet and reflective life—especially after his friend Thomas Jefferson was elected president in 1800.

On February 3, 1804, Priestley began an experiment, but found himself too weak to continue. He went to his bed in his library, never again to emerge. On February 6, he summoned one of his sons and an assistant. He dictated some changes in a manuscript.

When he was satisfied with the revisions, he said "That is right. I have now done." Minutes later he died painlessly, ending what Jefferson called "one of the few lives precious to mankind."



Joseph Priestley, 1783.

Student Name: _____ Date: _____ Period: _____

Anticipation Guide for Handout on Joseph Priestley, Discoverer of Oxygen

Before reading the handout, consider the statements below. In the first column, write “A” or “D” to indicate your agreement or disagreement with each statement.

As you read the handout, compare your thoughts with information from the article, writing “T” or “F” to indicate whether the statement is true or false. Write notes from the reading that support or refute the statement in the spaces below.

Me	Text	Statement
		In the early 1700s, scientists understood the composition of air.
		In the early 1700s, scientists understood why things burn.
		Oxygen was discovered before 1800.
		Priestley gave his discovery the name oxygen.
		Priestley understood the chemical changes involved when things burn.
		Priestley was a devout member of the Church of England.
		Priestley discovered carbon monoxide.
		Priestley moved to America seeking religious and political freedom.
		Priestley founded the Unitarian church in the United States.
		Priestley was primarily a scientist.

Student Name: _____ Date: _____ Period: _____

History Exercise: Chronology of the Discovery of Gases

1. Using the handout provided, put the following historical events in chronological order, from earliest to latest. Provide the year of the event, if known.

	Order	Year	Event
a.	_____	_____	Priestley discovers oxygen gas.
b.	_____	_____	Priestley visits Antoine Lavoisier in France.
c.	_____	_____	Priestley discovers carbon monoxide.
d.	_____	_____	Priestley attends Daventry Academy.
e.	_____	_____	Priestley begins working for the Earl of Shelburne.
f.	_____	_____	Priestley flees England for the United States.

2. Using the handout provided and other resources, answer the following questions.

   a. What period in modern history was happening in Europe and America at the time of Priestley's discoveries?

   b. What was the relationship between the United States and England at the time of Priestley's discoveries?

   c. How does Priestley's work relate to the French Revolution?

3. Use information from the reading to complete the table below.

Name of gas today	Year of discovery	Common name at the time of discovery	Person who first isolated the gas
Carbon dioxide			
Hydrogen			
Oxygen			
Nitrogen			
Carbon monoxide			

Student Name: _____ Date: _____ Period: _____

Exploring the Scientific Process

Refer to the reading about the discovery of oxygen by Joseph Priestley. As with all scientific information, especially new discoveries, you should think about:

- *What do we know? How do we know it? What is the evidence? Why should we care?*

1. Beginning Ideas: What was Priestley trying to find out?

2. Tests: How did he try to find out? What did he do?

3. Observations: How did Priestley know that what he discovered was different from ordinary air?

4. Claims: What did Priestley claim?

5. Evidence: What evidence was there to support his claim?

6. More Evidence: How did Priestley's work come to be accepted by the scientific community? What other scientists replicated his work? How did they help interpret Priestley's work?

7. Reflection: Did Priestley's discovery overturn some popular theories of the day? Please explain.

8. Your Reflection: Why was Priestley's discovery important? Why should we care about Priestley's discovery today?

Student Name: _____ Date: _____ Period: _____

Properties of Oxygen Gas

Use the handout provided to list chemical and physical properties of oxygen gas in the chart below. Think about how the properties were useful in isolating oxygen gas and determining its importance.

Physical Properties	**Importance or Significance in Priestley's Discovery**

Chemical Properties	**Importance or Significance in Priestley's Discovery**

Student Name: _____ Date: _____ Period: _____

Nomenclature Exercise

Use the hints provided to study the formulas and names of oxygen-containing compounds below. Mark your observations in the column provided. Hints:

- *How many elements are in each compound?*
- *Do all of the names contain "ox" or "oxi"?*
- *What is similar about the suffixes?*

Compound	Name	Observations
MgO	Magnesium oxide	
$MgSO_4$	Magnesium sulfate	
$MgSO_3$	Magnesium sulfite	
K_2O	Potassium oxide	
$KClO_4$	Potassium perchlorate	
$KClO_3$	Potassium chlorate	
$KClO_2$	Potassium chlorite	
$KClO$	Potassium hypochlorite	
Na_2SO_4	Sodium sulfate	
Na_2SO_3	Sodium sulfite	

Now, using your observations, try to formulate a "rule" for how to name compounds containing oxygen.

Joseph Priestley, Discoverer of Oxygen Answer Guide
Anticipation Guide

Me	Text	Statement
(answers will vary)	***F***	**In the early 1700s, scientists understood the composition of air.**
	F	**In the early 1700s, scientists understood why things burn.**
	T	**Oxygen was discovered before 1800.**
	F	**Priestley gave his discovery the name oxygen.**
	F	**Priestley understood the chemical changes involved when things burn.**
	F	**Priestley was a devout member of the Church of England.**
	T	**Priestley discovered carbon monoxide.**
	T	**Priestley moved to America seeking religious and political freedom.**
	T	**Priestley founded the Unitarian church in the United States.**
	F	**Priestley was primarily a scientist.**

Joseph Priestley, Discoverer of Oxygen Answer Guide
History Exercise: Chronology of the Discovery of Gases

1. Using the handout provided, put the following historical events in chronological order, from earliest to latest. Provide list the year of the event, if known.

	Order	Year	Event
a.	***3***	***1774***	Priestley discovers oxygen gas.
b.	***4***	***no date***	Priestley visits Antoine Lavoisier in France.
c.	***6***	***no date***	Priestley discovers carbon monoxide.
d.	***1***	***no date***	Priestley attends Daventry Academy.
e.	***2***	***1773***	Priestley begins working for the Earl of Shelburne.
f.	***5***	***1794***	Priestley flees England for the United States.

2. Using the handout provided and other resources, answer the following questions.

   a. What major events in history were happening in Europe and America at the time of Priestley's discoveries?

   The Industrial Revolution (circa 1750-1850), the American Revolution (1774-1783), and the French Revolution (1789-1799).

   b. What was the relationship between the United States and England at the time of Priestley's discoveries?

   Priestley's discovery of oxygen in 1774 took place during the beginning of the American Revolution, when colonists separated from England and founded the United States of America.

   c. How does Priestley's work relate to the French Revolution?

   Priestley visited Lavoisier in France following his discovery of oxygen in 1774. Priestley supported the French Revolution.

3. Use information from the reading to complete the table below.

Name of gas today	**Year of discovery**	**Common name at the time of discovery**	**Person who first isolated the gas**
Carbon dioxide	**1754**	**Fixed air**	**Joseph Black**
Hydrogen	**1766**	**Flammable air**	**Henry Cavendish**
Oxygen	**1774**	**Dephlogisticated air**	**Joseph Priestley**
Nitrogen	**1772**	**Noxious air**	**Daniel Rutherford**
Carbon monoxide	**Between 1794 and 1804**	**Heavy inflammable air**	**Joseph Priestley**

Joseph Priestley, Discoverer of Oxygen Answer Guide
Exploring the Scientific Process

Refer to the reading about the discovery of oxygen by Joseph Priestley. As with all scientific information, especially new discoveries, you should think about:

1. Beginning Ideas: What was Priestley trying to find out?

   He was examining different "airs."

2. Tests: How did he try to find out? What did he do?

   He used a magnifying lens to focus sunlight on mercuric oxide placed in an inverted glass container (bell jar) in a pool of water or mercury.

3. Observations: How did Priestley know that what he discovered was different from ordinary air?

   The gas caused a flame to burn intensely, and kept a mouse alive about four times longer than ordinary air. Priestley noticed that he felt different when he breathed it.

4. Claims: What did Priestley claim?

   He claimed that the gas had no phlogiston in it.

5. Evidence: What evidence was there to support his claim?

   His observations about the flame, mouse, and his own breathing, based on the phlogiston theory.

6. More Evidence: How did Priestley's work come to be accepted by the scientific community? What other scientists replicated his work? How did they help interpret Priestley's work?

   Priestley visited Lavoisier in France. Lavoisier realized that when substances burn they combine with oxygen.

7. Reflection: Did Priestley's discovery overturn some popular theories of the day? Please explain.

   Yes, the phlogiston theory was abandoned after Lavoisier's explanation of burning.

8. Your Reflection: Why was Priestley's discovery important? Why should we care about Priestley's discovery today?

   Individual answers will vary.

Joseph Priestley, Discoverer of Oxygen Answer Guide
Properties of Oxygen Gas

Use the handout provided to list chemical and physical properties of oxygen gas in the chart below. Think about how the properties were useful in isolating oxygen gas and determining its importance.

Physical Properties	Importance or Significance in Priestley's Discovery
Does not dissolve easily in water or mercury	**Priestley collected oxygen gas over water and mercury.**
Colorless	**Made it difficult to detect.**
Odorless	**Made it difficult to detect.**
Tasteless	**Made it difficult to detect.**

Chemical Properties	Importance or Significance in Priestley's Discovery
Produced by green plants	**Priestley observed photosynthesis, but did not explain it.**
Permits candles to burn	**A candle burned longer in oxygen gas than in air.**
Can be breathed by animals	**Priestley and mice breathed oxygen gas without harm.**
Combines with non-metals to produce acids	**Lavoisier named oxygen after the Greek word for acid-maker.**

Joseph Priestley, Discoverer of Oxygen Answer Guide
Nomenclature Exercise

Use the hints provided to study the formulas and names of oxygen-containing compounds below. Mark your observations in the column provided. Hints:

- *How many elements are in each compound?*
- *Do all of the names contain "ox" or "oxi"?*
- *What is similar about the suffixes?*

Compound	Name	Observations
MgO	Magnesium oxide	**2 elements; ends in –ide**
$MgSO_4$	Magnesium sulfate	**3 elements; ends in –ate**
$MgSO_3$	Magnesium sulfite	**3 elements; ends in –ite**
K_2O	Potassium oxide	**2 elements; ends in –ide**
$KClO_4$	Potassium perchlorate	**3 elements; ends in –ate**
$KClO_3$	Potassium chlorate	**3 elements; ends in –ate**
$KClO_2$	Potassium chlorite	**3 elements; ends in –ite**
$KClO$	Potassium hypochlorite	**3 elements; ends in –ite**
Na_2SO_4	Sodium sulfate	**3 elements; ends in –ate**
Na_2SO_3	Sodium sulfite	**3 elements; ends in –ite**

Now, using your observations, try to formulate a "rule" for how to name compounds containing oxygen. *Possible answers:*

If the name ends in –ide, the compound contains two elements and includes "ox" in the name.

If the name ends in –ite or –ate, the compound contains three elements, including oxygen, and does not include "ox" in the name.

The difference between –ite endings and –ate endings is difficult to determine, but if you know the –ate formula, the –ite compound has one less oxygen atom.