8. Percent Oxygen in Air

Objectives
Students learn about the components of air and how to determine the percent of oxygen in air. Through this investigation, students:

- Observe a chemical reaction involving different states of matter
- Describe pressure at the molecular level
- Explain how the variables temperature, volume, and concentration affect the pressure of gases

Procedural Overview
Students gain experience conducting the following procedures:

- Use an absolute pressure sensor to measure changes in pressure as atmospheric oxygen reacts with steel wool (iron)
- Determine the percent of oxygen in air from the measured pressure difference

Time Requirement
- Preparation time 10 minutes
- Pre-lab discussion and activity 45 minutes
- Lab activity 40 minutes

Materials and Equipment
For each student or group:
- Data collection system
- Absolute pressure sensor
- Sensor extension cable
- Quick-release connector
- Tubing connector
- Tubing, 1- to 2-cm
- Beaker, 150-mL
- Test tube, 25-mm x 150-mm
- One-hole stopper to fit the test tube
- Stir rod
- White vinegar (~5% acetic acid), 50 to 60 mL
- Steel wool, fine mesh (#000), 1.0 g
- Paper towels
- Glycerin, 2 drops

1 Included with most PASCO absolute pressure sensors.
Percent Oxygen in Air

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Particulate nature of matter
- States of matter

Related Labs in This Guide

Labs conceptually related to this one include:

- Boyle's Law

Using Your Data Collection System

Students use the following technical procedures in this activity. The instructions for them (identified by the number following the symbol: "*) are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

- Starting a new experiment on the data collection system *(1.2)
- Connecting a sensor to the data collection system *(2.1)
- Recording a run of data *(6.2)
- Displaying data in a graph *(7.1.1)
- Adjusting the scale of a graph *(7.1.2)
- Finding the coordinates of a point in a graph *(9.1)
- Saving your experiment *(11.1)
- Printing *(11.2)
**Background**

Air is a mixture made up of approximately 78% nitrogen, 21% oxygen, and 1% of several other gases including argon, carbon dioxide, and water vapor. In this lab, students calculate the percent of oxygen in the air by measuring initial air pressure and air pressure after oxygen has been removed from the air, and determining the difference.

Oxygen is removed from the air using a chemical reaction. The reaction between oxygen and iron was chosen because iron reacts with oxygen in the air, but not with nitrogen. Nitrogen molecules simply bounce off the iron, while the oxygen atoms collide and stick to the iron forming a new substance, iron(III) oxide (rust).

\[ 3O_2(g) + 4Fe(s) \rightarrow 2Fe_2O_3(s) \]

Steel wool is the source of iron. Steel is an alloy of iron with a very small amount of carbon. Most brands of steel wool are lightly coated with oil or some other rust inhibitor. The students remove the rust inhibitor by rinsing the steel wool in vinegar. The vinegar “washing” also creates a moist, slightly acidic environment that increases the reaction rate.

Solids, liquids, and gases all exert pressure on their surrounding surfaces. Since pressure is the dependent variable in this experiment, it is important that students understand pressure at the molecular level. Pressure is the force applied over an area. Pressure is measured in units of pascal (Pa) or as a newton (N) per square meter, where (1 Pa = 1 N/m²). The newton is the standard unit for measuring force. At the molecular level, air pressure, like all pressure involving gases, results from molecules colliding with a surface. The greater the number of collisions there are per second, the greater the air pressure.

The temperature, volume, and amount of gas present all affect the frequency of gas particles colliding and thus the air pressure. When air is heated, the particles move faster (greater kinetic energy) causing more collisions per second and therefore increasing the pressure (Gay-Lussac’s law). Cooling, on the other hand causes air molecules to move slower, resulting in fewer collisions and less pressure.

When the volume of a container holding a constant number of gas particles increases, the pressure decreases (Boyle’s law). This is because the particles have more space in which to move and therefore collide with the walls of the container less often. The opposite is also true: less volume for the gas particles to move in results in a higher pressure because the molecules have less space in which to move and therefore hit the surfaces more frequently.

Air pressure is also dependent on the number of gas particles present (Avogadro's law). The more particles there are in a given container, the more frequently the walls of the container will be struck, causing greater pressure. The opposite holds true also: the fewer the particles present, the lower the resulting pressure.

The method used in this experiment to determine the percent of oxygen in the air works because of Dalton’s law of partial pressures. Dalton’s law of partial pressures states that the total pressure of a gas mixture is the sum of the partial pressures of each individual gas in the mixture. Therefore, air pressure is equal to the pressure of nitrogen plus the pressure of oxygen plus the pressure of all other gases present in the air. When oxygen is removed, the air pressure will be reduced by an amount directly proportional to the percent of oxygen in the air.

\[ \% \text{oxygen} = \frac{\text{change in pressure}}{\text{initial pressure}} \times 100 \]
Pre-Lab Discussion and Activity

The Concept of Pressure

Introduce the concept of pressure by comparing the pressure exerted in high heel shoes versus tennis shoes.

1. If a woman is wearing high heels on a soft dirt surface, she will sink into the ground. The same woman, however, wearing tennis shoes on the same surface will not sink at all. Why? What is the difference in the two scenarios and how does this difference explain whether or not the woman will sink?

The difference is the shoes that the woman is wearing. More specifically, the surface area touching the ground is significantly different. When the woman is wearing high heels, her body weight exerts force on the ground over a very small area. This creates a lot of pressure and she sinks. When the woman is wearing tennis shoes, she exerts the same force (her body weight) over a larger area and does not sink (she is exerting less pressure).

Calculating Pressure

Provide the students with a mathematical understanding of pressure by comparing the pressure exerted by a textbook in two different positions. Place a textbook on a table in front of the class with its largest side down. Stand a second textbook up on its edge. Write the dimensions and mass of the textbook on the board. (The following dimensions may be used: textbook dimensions, 10.0 in. x 10.0 in. x 2.0 in. textbook weight (force of gravity on the book), 5.0 lb) Explain that the idea of the "amount of force on each square" is called pressure. Write the definition of pressure on the board. Pressure is the force acting on a specific area.

2. Which book is exerting more pressure per unit area on the table? Explain.

The book standing on its edge is exerting more pressure per unit area. Both books have the same mass and are therefore exerting the same force, but the book standing on its edge is supporting the weight over a smaller area.

3. If the book is lying on its side how much of the force (weight) is felt over each square inch?

The weight of 5.0 lb is being shared over 100 square inches (the area touching the table). So each square inch of the book supports 0.05 lb.

4. How much force (weight) does each square inch support when the book is sitting on its edge?

There are fewer square inches (in.²) in contact with the table so each square inch must support more weight. The book still weighs 5.0 lb, but there are only 20 in.² sharing the weight. So each square inch supports 0.25 lb.

5. What is the equation for pressure? Calculate the pressure each book is exerting on the table?

Pressure = \( \frac{\text{Force}}{\text{Area}} \)

The book lying on its side: \( P = \frac{5.0 \text{ lb}}{10 \text{ in.} \times 10 \text{ in.}} = 0.05 \text{ lb/in.}^2 \)

The book sitting on its edge: \( P = \frac{5.0 \text{ lb}}{10 \text{ in.} \times 2 \text{ in.}} = 0.25 \text{ lb/in.}^2 \)
6. What are the units of pressure in the above example? What are the units in the SI system?

In the above example, pressure was measured in pounds per square inch. In the SI system, the unit of force is newton (N) and the unit for area is square meters (m²). A newton ((kg·m)/s²) is the standard unit of force containing the units for both mass as well as the acceleration due to gravity; combined, these can be thought of as “weight”. A N/m² is also called a pascal (Pa). One pascal of pressure is really small, so it is common to measure pressure in kilopascals (kPa).

**Pressure at the Molecular Level**

Explain to the students that in solids and liquids, the atoms or molecules are all in contact with each other. Because of this, all the molecules contribute to the force on the table. Stack two textbooks on top of each other and hold a third text book in your hand. Explain that each book on the table contributes its weight to the total force and pressure being exerted just like each molecule in a solid or liquid contributes all of its weight to the pressure being exerted.

Molecules that make up a gas, however, are different because they are not in contact with each other. A gas particle could be thought of as a third book that is falling toward the stack of books. Drop the third book onto the stack of books. The falling book does not contribute any force to the surface of the table until it hits the stack. For gases, it is the number of collisions that create pressure. End the discussion by showing the students a picture or a video of gas molecules colliding with the surface of their container.

7. Using the textbook example, explain pressure at the molecular level?

The molecules that make up the book are exerting a force (their weight) onto the table.

8. How is the pressure exerted by molecules different if the molecules are in a solid or liquid state versus a gaseous state?

In solids and liquids, all the molecules are touching each other all the time and thus always contribute to a constant force and pressure. Molecules in the gaseous state, on the other hand, are bouncing around. They contribute to the force when a collision occurs. Collisions are how gas molecules create pressure.
Temperature, Volume, and Air Pressure

Engage the students in a discussion about air pressure and the ways in which pressure can be altered by having students change the temperature and then the volume of air inside a syringe.

Have students set the volume of a syringe to about 20 mL and then connect it to a data collection system. While monitoring pressure in the digits display, have students observe what happens as they heat the air inside the syringe by holding the syringe in the palm of their hand. Next, have students change the volume of the air in the syringe by pushing the plunger in, compressing the gas. Help students analyze their results by explaining what is happening at the molecular level.

9. What are some possible ways to increase the pressure of the air inside the syringe?
Increase the number of collisions by either: 1) increasing the temperature, 2) increasing the number of molecules, or 3) decreasing the size of the container.

10. What do you notice about the pressure when you hold the syringe in the palm of your hand? Why?
The pressure goes up because the gas molecules get warmer. Warmer things move faster so the gas molecules hit the walls inside the syringe more often and with more force producing more pressure.

11. Why is it possible to compress the gas? How does it change the pressure? Why?
The gas can be compressed because there is space between the gas molecules. The molecules can move into this space and essentially squish closer together.
The pressure increased because the molecules hit the walls more often. The molecules hit the walls more often because they did not have to travel as far to hit the walls.

Types of Molecules in Air

Discuss the different types of molecules that make up air and explain that each type of molecule contributes to the pressure exerted by air. This observation is summarized in Dalton’s law of partial pressures which states that the total pressure of a gas mixture is the sum of the individual pressures of each type of gas.

Introduce the idea that the number of molecules in a closed container can be increased or decreased through chemical reactions. Explain the chemical reaction that will be performed in this lab and end the discussion by having the students perform a sample calculation using provided pressure data.

Write the following equation on the board:

\[
\text{oxygen gas + iron (steel wool) } \rightarrow \text{ rust}
\]

\[
3\text{O}_2(g) + 4\text{Fe(s)} \rightarrow 2\text{Fe}_2\text{O}_3(s)
\]
12. What types of molecules are in the air in your syringe?

Air is a mixture made of nitrogen molecules, oxygen molecules, and a very small amount of other molecules such as argon, carbon dioxide, water vapor, and others.

13. All of the molecules in air are bouncing on the walls and contributing to the total gas pressure. Imagine there were 100 gas molecules. If 50 of them were nitrogen, then what percent of the observed pressure is due to nitrogen molecules?

Half (50%) of the collisions would be nitrogen molecules so half of the pressure would be from nitrogen.

14. We have seen that altering the temperature causes the pressure to either increase or decrease because the number of collisions and the force of the collisions both change. We have also seen that decreasing the volume of the container increases the pressure by increasing the number of collisions. The final variable that affects the pressure is the actual number of gas molecules. How can the number of gas molecules in a closed container change?

The number of gas molecules can either be increased or decreased through a chemical reaction.

15. In this lab, oxygen molecules in the air will bounce into the iron atoms in the steel wool. If the collision is just right, the oxygen reacts with the iron and creates a new molecule (rust). How will the gas pressure be affected as the reaction proceeds? Why?

The gas pressure should decrease because the number of gas molecules should decrease. Before the reaction, oxygen molecules moved freely as a gas. After the reaction, the oxygen will be bonded to the iron in a newly formed solid (rust).

16. How will measuring a change in pressure help you determine the percent of oxygen in the air?

The amount that the pressure decreases is proportional to the percent of oxygen in the air.

\[
\% \text{ oxygen} = \frac{\text{change in pressure}}{\text{initial pressure}} \times 100
\]

17. If the starting pressure of the gas in a test tube is 100 kPa and the final pressure is 75 kPa, what was the change in pressure? What percent of the gas molecules were removed?

The change in pressure is 25 kPa (100 kPa – 75 kPa).

\[
\% \text{ gas lost} = \frac{25 \text{ kPa}}{100 \text{ kPa}} \times 100 = 25\%
\]

Lab Preparation

Although this activity requires no specific lab preparation, allow 10 minutes to gather the equipment needed to conduct the lab.
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**Safety**

Add this important safety precaution to your normal laboratory procedures:

- Vinegar is a weak acid. Avoid contact with the eyes and wash your hands after handling glassware, steel wool, and equipment.

**Sequencing Challenge**

The steps below are part of the Procedure for this lab activity. They are not in the right order. Determine the proper order and write numbers in the circles that put the steps in the correct sequence.

1. Measure and record the initial pressure.
2. Clean the steel wool with vinegar so that oxygen can react with the iron.
3. Create a closed container with air and steel wool.
4. Measure the final pressure value.
5. Calculate the percent oxygen in air.

**Procedure with Inquiry**

After you complete a step (or answer a question), place a check mark in the box (□) next to that step.

**Note:** Students use the following technical procedures in this activity. The instructions for them (identified by the number following the symbol: *) are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

**Set Up**

1. □ Start a new experiment on the data collection system. *(1,2)*

2. □ Connect the absolute pressure sensor to the data collection system using a sensor extension cable. *(2,1)*

![Extension cable image]
3. □ Connect the quick-release connector to the stopper using the tubing connector and the 1- to 2-cm piece of tubing by following the steps below. Use the picture as a guide.

   a. Insert the thicker end of the tubing connector into the hole in the stopper. If this is difficult, add a drop of glycerin.

   b. Connect the 1- to 2-cm piece of tubing to the other, thinner end of the tubing connector.

   c. Insert the barbed end of the quick-release connector into the open end of the 1- to 2-cm piece of tubing. If this is difficult, add a drop of glycerin.

4. □ Insert the quick-release connector into the port of the absolute pressure sensor and then turn the connector clockwise until fitting "clicks" onto the sensor (about one-eighth turn).

5. □ Create a graph display of Pressure (kPa) versus Time. 

6. □ What are the dependent and independent variables in this experiment? In what units are these variables measured?

   The dependent variable is the pressure in units of kilopascals (kPa).

   The independent variable is the time that the reaction is allowed to occur in units of seconds (s).

7. □ Predict what will happen to the pressure as the reaction occurs?

   The pressure decreases as the oxygen gas is consumed by the reaction with iron.

8. □ Obtain enough fine mesh steel wool to fill a large test tube about ⅔ full (approximately 1.0 g).

9. □ Stretch the steel wool apart so that a large amount of surface area is exposed.

10. □ Clean the steel wool by soaking it in a 150-mL beaker containing approximately 60 mL of vinegar for about one minute. Use a stir rod to fully rinse the steel wool in the vinegar.

11. □ Why do we need to rinse the steel wool in vinegar?

   Rinsing removes the protective coating from the iron so that the oxygen molecules can collide directly with the iron atoms. The vinegar also provides a moist, slightly acidic environment that will cause the reaction to occur faster (increase the rate of the reaction).
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12. □ Remove the steel wool from the beaker of vinegar and wring it out, draining the vinegar into the beaker.

13. □ Stretch apart the steel wool and thoroughly dry it with paper towels.

14. □ Change the paper towels and dry it again.

15. □ Stretch the steel wool apart and shake it in the air to make sure it is dry.

16. □ Put the steel wool in a large test tube making sure that a large surface area is still exposed. Do not pack the steel wool into the bottom of the test tube.

**Note:** You may have to gently tap the test tube to get the steel wool to slide down into the test tube.

**Collect Data**

17. □ Place the stopper into the top of the test tube and immediately start collecting data. ◆ (6.2)

**Note:** You may have to adjust the scale of the graph to observe any changes taking place. ◆ (7.1.2).

18. □ What molecules are contributing to the pressure you are recording on your data collection system? Be specific.

The pressure is coming from the nitrogen, oxygen, and very small amount of other molecules that make up the air inside the test tube.

19. □ Write a sentence explaining the reaction occurring in the test tube. Explain where each substance comes from and its physical state (solid, liquid, or gas).

Oxygen gas from the air is reacting with solid iron in the steel wool to form rust, which is a new solid.

20. □ What is happening to the pressure as the reaction occurs? Why?

The pressure is decreasing because the oxygen gas is being incorporated into a solid and therefore is removed from the air.

21. □ Write down at least three changes you observe taking place in the test tube.

Water condenses on the side of the test tube, the test tube gets hot, and the steel wool turns brown/orange.

22. □ When the pressure has stabilized (after about 20 to 30 minutes), stop data collection. ◆ (6.2)

23. □ Save the data file and clean up your lab station according to the teacher’s instructions. ◆ (11.1)
Data Analysis

1. □ Determine the initial and final pressures and write them in the Table 1 below. \(^{(9.1)}\)

Table 1: Initial and final pressure

<table>
<thead>
<tr>
<th>Initial Pressure (kPa)</th>
<th>105.21</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final Pressure (kPa)</td>
<td>83.31</td>
</tr>
</tbody>
</table>

2. □ Calculate the change in pressure.

Initial pressure (kPa) – final pressure (kPa) = change in pressure (kPa)

\[
105.21 \text{ kPa} - 83.31 \text{ kPa} = 21.9 \text{ kPa}
\]

3. □ Calculate the percent oxygen in air.

\[
\frac{\text{change in pressure (kPa)}}{\text{initial pressure (kPa)}} \times 100 = \% \text{ oxygen}
\]

\[
\frac{21.9 \text{ kPa}}{105.21 \text{ kPa}} \times 100 = 20.8\% \text{ oxygen}
\]

4. □ Sketch or print a copy of the graph of Pressure (kPa) versus Time (s). Label the overall graph, the x-axis, the y-axis and include units on the axes. \(^{(11.2)}\)
Analysis Questions

1. Why did the pressure graph flatten out after a while? (Hint: think about what is happening to the amount of oxygen in the test tube.)

The oxygen in the test tube was being used up. When it was gone, the graph became flat.

2. Why was the pressure not reduced to zero?

The pressure did not make it to zero because there were still other molecules, including nitrogen, carbon dioxide, water vapor, and argon in the test tube. They continued bouncing into the walls, causing pressure.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Gases are often described as having no definite shape and filling the container they occupy. Explain what is happening at the molecular level to give gases these properties.

The gas molecules bounce around and do not bond together. They move through space in a straight line until they hit a wall, so they occupy the entire volume of any size container.

2. Explain why solids have a definite shape.

The molecules or atoms in a solid are bonded together in a fixed pattern. They cannot move around to fill the container.

3. Chemical reactions stop when one of the reactants is used up. This reactant is called the *limiting reactant* because it limits the amount of product that is made. In this lab, rust was the product. What was the limiting reactant?

The pressure stopped changing when the oxygen in the test tube was all used up. This makes oxygen the limiting reactant.

Multiple Choice Questions

Select the best answer or completion to each of the questions or incomplete statements below.

1. Which of the following variables affects the pressure of a gas?

   A. The number of gas molecules
   B. The temperature of the gas molecules
   C. The volume of the container the gas molecules are in
   D. All of the above
2. If you increase the temperature of a gas, what will happen to the pressure?
   A. It will stay the same
   B. It will increase
   C. It will decrease
   D. Not enough information

3. If you increase the number of gas molecules in a container, what will happen to the pressure?
   A. It will stay the same
   B. It will increase
   C. It will decrease
   D. Not enough information

4. Approximately what percentage of air is made up of oxygen gas?
   A. Less than 5%
   B. 20%
   C. 70%
   D. More than 80%

5. Pressure is best described as
   A. A force spread out over an area
   B. The motion of molecules
   C. The space between molecules in a gas
   D. A strong force

Key Term Challenge
Fill in the blanks from the list of words in the Key Term Challenge Word Bank.

1. Pressure is a force spread out over an area. Gas pressure is caused by gas molecules flying through space and bouncing off surfaces. If the collision rate increases, the pressure goes up. An increase in temperature causes greater pressure because the gas molecules are moving with more kinetic energy, and therefore are moving faster. A decrease in volume causes an increase in pressure because the gas molecules are closer together and have less distance to travel to hit the walls of the container, so collisions are more frequent. At a given temperature, all gas molecules contribute to the total pressure. If 70% of the gas molecules in a container are nitrogen, then 70% of the pressure will be due to the nitrogen molecules.
Extended Inquiry Suggestions

Have students design an experiment to determine if other metals corrode in the presence of oxygen.

Have students determine the ideal amount of steel wool to use in this lab.

Have students determine the ideal size of a test tube to use in this experiment.

Have students determine the effects of altitude on the percent of oxygen in the atmosphere.

Discuss the following questions with students:

- Does changing the amount of steel wool change the calculated percentage of oxygen?
- Does changing the amount of air available (by using different sizes of test tubes) change the calculated percentage of oxygen?

Have students design an experiment to determine the amount of oxygen in the atmosphere using a water displacement method (see illustration) instead of the absolute pressure sensor. How do the results compare?