Lab: Molar Mass of Dry Ice

FOR THE TEACHER

Summary
In this lab, students will use gas laws to calculate the molar mass of dry ice and then use the information to identify the compound that makes up this substance.

Grade Level
High school

Objectives
By the end of this lesson, students should be able to
- use the ideal gas law in combination with molar mass to complete calculations.
- describe observations regarding the physical change of sublimation.

Chemistry Topics
- Gas Laws
- Molar Mass

Time
Teacher Preparation: 1 hour
Lesson: 1 hour

Materials
- 250 mL Erlenmeyer flask with stopper
- balance (an analytical balance is strongly recommended in order to provide enough significant figures to get a reasonably reliable answer)
- thermometer
- student safety goggles and lab aprons
- 1 - 2 kg of dry ice (purchase from store the day of the lab and store in a cooler) - this is actually enough for multiple classes. The dry ice should be broken up into roughly large marble-sized pieces and then placed (by the instructor) into the flask for the students.
- timer

Safety
- Wear gloves. Dry ice is extremely cold and can cause frostbite if it has direct contact with skin. Only maneuver the dry ice with proper handling equipment. Students should not touch the dry ice.
- Always wear safety goggles when handling chemicals in the lab.
- Students should wash their hands thoroughly before leaving the lab.
- When students complete the lab, instruct them how to clean up their materials and dispose of any chemicals.
Teacher Notes

- This activity will involve the teacher making an early before-school run to get the dry ice since it sublimes too rapidly to store overnight. A one to two kilogram chunk should last for the day as long as it's kept in a cooler and only smaller chunks are broken off for student use. I have found that large grocery stores (such as Meijer and Wal-Mart) carry dry ice. Local butchers and convenience stores may also carry it.
- In my first-year chemistry classroom this activity comes mid-way through the year as part of our physical states unit (more specifically regarding gases). Students have already done some paper-and-pencil calculations regarding gas law calculations so that they already have some familiarity with the math involved in doing this.

Cross-Disciplinary Extensions

Connect to Reading
A possible extension question includes: Manufacturing dry ice is not simply a matter of getting the substance cold enough to freeze. Use appropriate sources to describe how dry ice is produced and give two major uses for this substance.

Connect to Writing
Students prepare their results as part of a lab report that includes the following sections: purpose, data (including a properly presented data table), calculations/analysis, conclusions, and follow-up/extension questions.

Connect to Social Studies
Have a class discussion regarding an unexpected impact of carbon dioxide - the deadly release of this gas from a volcanic lake in the 1980s. This can help students to realize that the chemistry they learn in the classroom really does help them to understand the "real world" and to explain otherwise mysterious phenomena.

The History Channel's This Day in History: Gas Cloud Kills Villagers

FOR THE STUDENT

Lesson

What’s that Gas?

Background
As we have seen in our class work, the ideal gas law (PV = nRT) can be very useful in calculating a number of variables for gases. Today you will use this gas law to find the molar mass of a gas when the identity of the gas isn't known!

Objective
Collect simple measurements of a gas in order to calculate its molar mass.

Materials

- 250 mL Erlenmeyer flask
- dry ice
- stopper
- balance
- thermometer
- graduated cylinder
- timer

**Safety**
- Students are not permitted to touch the dry ice. The dry ice is extremely cold and can cause frostbite if directly touched with skin.
- Always wear safety goggles when handling chemicals in the lab.
- Wash your hands thoroughly before leaving the lab.
- Follow instructions explaining how to clean up your materials and dispose of any chemicals.

**Procedure**
1. Obtain the day's atmospheric pressure from your instructor.
2. Obtain a dry Erlenmeyer flask and an appropriately sized stopper. With the stopper inserted into the flask, find the mass on the balance and record.
3. Remove the stopper and obtain a small piece of dry ice from the instructor. This piece should be about 1/3 the size of the stopper (do not put the stopper on yet).
   *Warning:* Do NOT touch the dry ice with your bare hands; severe frostbite may result!
4. Allow the dry ice to sublime in the flask *without disturbing the flask*. Be sure to observe this process and record any qualitative observations.
5. Using a timer, wait three minutes after the dry ice has completely sublimed and then carefully place the thermometer into the flask to record the temperature. Carefully remove the thermometer.
6. Insert the stopper into the flask, obtain the mass, and record.
7. Remove the stopper and tip the flask upside down, shake it around so that the gas is completely "poured out" from the flask. Repeat steps #2 – 6 again for at least one more trial.
8. Find the exact volume of the flask by filling it completely with water and inserting the stopper (some water will be pushed out by doing this). Remove the stopper and then find the volume of the flask by measuring the volume of water using a graduated cylinder. Record the volume of the flask.

**Data**

<table>
<thead>
<tr>
<th>Results</th>
<th>Trial #1</th>
<th>Trial #2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current Atmospheric Pressure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mass of empty Erlenmeyer Flask &amp; Stopper</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Observations of Sublimation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature in Erlenmeyer Flask after Sublimation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mass of Erlenmeyer Flask &amp; Stopper after Sublimation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume of Erlenmeyer Flask</td>
<td></td>
<td></td>
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</tbody>
</table>
**Analysis**

To find the molar mass (and allow you to confirm the identity of what makes up dry ice) there are two things that must be applied. First, remember that molar mass has units of grams per mol. This means that we will need to find the mass of the dry ice in grams and divide that by the moles.

1. Perform the following calculations to get the mass of the gas (sublimed dry ice that remained in the flask) that you collected:
   a. The density of air is 1.29 g/L. Use this along with the volume of the flask to calculate the mass of air that is contained in the flask.
   b. Next, take the mass from 1(a) and subtract it from the mass of the flask and stopper. This gives the mass of the empty flask and stopper.
   c. Subtract your value from 1(b) from the mass of the flask with the sublimed dry ice. This gives the mass of the unknown gas.

The second calculation is to find the moles of the gas. Fortunately this is pretty easy to find!

2. Use the pressure, temperature, and volume of the collected gas along with the ideal gas law to calculate the moles of gas.

Now, the molar mass can be easily found!

3. Use your mass from 1(c) and the moles from 2 to calculate the molar mass in units of grams per mol.

4. Consider the following possibilities for the formula of dry ice: H\textsubscript{2}O, CO, CO\textsubscript{2}, NH\textsubscript{3} or O\textsubscript{2}. Based on your results from #3 identify the gas that makes up dry ice by comparing the molar masses to what was calculated in the lab.

**Extensions:**

5. Explain how the following errors would impact the final calculated molar mass of the gas (*reminder – giving an “it will throw things off” answer will NOT receive credit*).
   a. Room temperature was incorrectly recorded as being too high (for example it was really 23°C but was recorded as being 32°C).
   b. Rather than actually finding the entire volume of the flask the experimenter saw that it was labeled as being a 250 mL flask and just used that number for the volume.

6. You can calculate the density of this gas using information that was collected in this lab. Use your gas mass from 1(c) and the volume of the flask to calculate the density of this gas. Use this value to explain why the flask is able to be filled up and push out the air.