Demo: Ideal Gas Law using Carbon Dioxide

Summary
In this demonstration, students observe dry ice sublime while the CO$_2$ gas fills a balloon. They then calculate the moles and volume of CO$_2$ produced.

Grade Level
High school

Objectives
By the end of this lesson, students should be able to
- calculate moles from mass.
- calculate gas volume from density.
- discuss implications of gas density.
- describe phase changes of CO$_2$.
- use gas laws to calculate moles and volume.
- convert between Celsius and Kelvin.

Chemistry Topics
This lesson supports students’ understanding of
- Gases
- Gas laws
- Ideal gas

Time
Teacher Preparation: 10 minutes
Lesson: 30 minutes

Materials
For each group:
- Balance
- Erlenmeyer flask
- String
- Meter stick
- Balloon
- Dry ice
- Crucible tongs

Safety
- Always wear safety goggles when handling chemicals in the lab.
- Dry ice is very cold and can cause skin to freeze. Wear gloves and handle with tongs.

Teacher Notes
- Depending on the difficulty level you want, you could have students work through the calculations on their own, or they could work through them as a class.
Lesson

Explore

1. Flush flask with CO₂ by placing a small piece of dry ice in the flask. Place a balloon over the neck of the flask to allow it to stretch with the sublimed CO₂.
2. Remove the balloon. Find the mass of the flask, balloon, and CO₂. At this point, the balloon will still have some air in it, since the CO₂ displaced the air that was in the flask.
3. Add another piece of CO₂ to the flask. Quickly replace the balloon on the neck of the flask. Measure the mass of the system quickly.
4. Allow to sublime. Make sure flask is at room temperature and dry on the outside.
5. Measure the circumference of the balloon with a piece of string. This balloon should now be filled with mostly CO₂. Measure the length of the string in cm. Calculate volume (cm³) and convert to liters.
6. Repeat with a second piece of dry ice.

Explain

This activity can be adapted at several levels. The geometry is relevant for middle school and above. The chemistry is a phase change between the solid and gas phases of CO₂. Moles of gas can be calculated from the mass and volume can then be calculated from density. The gas law calculations can be done from either moles to volume or volume to moles, depending on where the teacher wants to put the emphasis. Volume must be converted from cm³ to L. Temperature must be converted to Kelvin.

CO₂ is obtainable in the solid state. It rapidly sublimes at room temperature. The density of the gas makes it easy to contain and work with. Assuming STP, the density of CO₂ can be calculated as 44 g / 22.4 L or 1.80 g/L. This is denser than air, allowing for use of an Erlenmeyer flask to contain the experiment.

The first step allows for the measurement of the mass of the system. This includes the Erlenmeyer flask and the balloon. I have found 250-mL Erlenmeyer flasks and 12” helium quality balloons work very well. The next step is to fill the flask with CO₂ so that the measurements of the sublimed CO₂ in the balloon are consistent. A piece of dry ice (solid CO₂), about 10 cm² is added to the flask. (Crucible tongs work well to break apart the dry ice into appropriately sized pieces and place into the flask.) As the CO₂ sublimes, the air in the flask is pushed out by the denser CO₂ leaving the flask filled with only CO₂.

Without tipping the flask, another piece of dry ice is added to the flask and the neck of the balloon quickly placed over the mouth of the flask. The CO₂ with fill the balloon as it changes state. Because the flask was already filled with CO₂, it can be assumed that the volume of the balloon, when all the dry ice is sublimed, is due to the measured piece of dry ice. This first filling of the balloon is not used for calculations. It allows the balloon to stretch to enable further repetitions.

Repeat the process by removing the balloon and adding another piece of dry ice. Measure the mass of the system with the CO₂ quickly before the CO₂ has a chance to warm. Allow the dry ice to sublime completely. Do not make volume measurements until the dry ice is gone and the flask warmed to room temperature. This can be done carefully with your gloved
hands. Without warming, ice will condense on the outside of the flask and interfere with final volume and add mass to the flask.

The volume of the balloon is calculated by measuring its circumference. This is done with string, which can be measured with a meter stick. The radius can be calculated by solving for \( r \) in the equation: \( C = 2 \pi r, \quad r = C/2\pi. \)

Using the equation for the volume of a circle, \( V = 4/3 \pi r^3 \), volume is then calculated using the value of \( r \) derived from the circumference measurement.

Gas law calculations can be done using either the number of moles from the initial mass calculation and solving for volume or by using the volume calculations and solving for number of moles. The pressure can be obtained from a barometer, assuming atmospheric pressure to be equal to the pressure inside the balloon. Temperature needs to be changed to Kelvin.

\[
P V = nRT \quad V = nRT/P \quad n = PV/RT
\]

I have found the three volumes to compare pretty well if all the measurements are done carefully.

For lower-level chemistry, the initial mass to moles to volume from density is a challenge. The academic classes take it to the circumference measurements and honors level classes can do all the calculations and put it together in lab report format.

**FOR THE STUDENT**

**Student Activity Sheet: Demonstration of Ideal Gas Law**

1. Mass of CO\(_2\) __________________________
   
   convert the mass of CO\(_2\) to moles:

2. Determine the volume of CO\(_2\) from mass using the following equation
   
   \[
   V = \frac{m}{D}
   \]
   
   (density of CO\(_2\) is about 1.80 at 25 °C)

3. Calculate the volume of the blloon from the balloon’s circumference:
   
   \[
   C = 2 \pi r \quad r = \frac{C}{2\pi}
   \]
   
   \[
   V = \frac{4}{3} \pi r^3 \quad V = \frac{4}{3} \pi \left( \frac{C}{2\pi} \right)^3
   \]

4. Calculate volume from the ideal gas law  
   \[
   PV = nRT
   \]
   
   \( P \sim 101kPa \) or look up the atmospheric pressure for greater accuracy
   
   \( n = \) calculated value from step 1
   
   \( T = \) room temperature
   
   \( R = \) given
   
   \( V = ? \)