Answer Key: Deriving the Gas Laws

Prelab Questions
Discuss with your partners.

1. What does it mean when we say that two variables vary directly?
   When one variable goes up, the other variable goes up. Both variables vary in the same direction.

2. What does it mean when we say that two variables vary inversely?
   When one variable goes up, the other goes down. The variables vary in opposite directions.

3. Using the variables x and y and the constant k, show how to represent using a formula:
   a. A direct relationship: \( k = \frac{n}{V} \)
   b. An inverse relationship: \( k = xy \)

Station 1
How are volume (V) and # of particles (n, moles) related?

1. Blow up a balloon (only one balloon per lab group). Do not tie it off.
2. Determine a general equation relating # of particles (n) and volume (V), using a constant (“k”):
   \( k = \frac{n}{V} \)
3. Derive an equation using \( n_1, n_2, V_1 \) and \( V_2 \). This is Avogadro’s Law:
   \( \frac{n_1}{V_1} = \frac{n_2}{V_2} \)
4. Draw the balloon before and after you blew it up. Show the gas particles inside each. Show the motion of the particles with arrows. Throw the balloon away.

<table>
<thead>
<tr>
<th>Before</th>
<th>After</th>
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<tr>
<td>Answer will vary</td>
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Station 2
How are volume and temperature related?

1. Choose a small syringe that is at room temperature (or close). Gently move the plunger in and out slightly to make sure it is not stuck. Seal the syringe with some air in it (about 5-7 mL). Record the starting volume of air and the ambient room temperature below.
2. Put the sealed syringe in the ice water bath. Leave the syringe in for 2-3 minutes.
   - Record the temperature of the ice bath.
   - Record the new volume of air in the syringe in mL. If it has not changed, push slightly on the plunger to see if it will move.
3. Put the syringe into a warm water bath. Leave the syringe in for 2-3 minutes.
   - Record the temperature of the warm water bath.
   - Record the volume of air in the syringe in mL. If it has not changed, pull slightly on the plunger to see if it will move.

<table>
<thead>
<tr>
<th></th>
<th>Temperature, °C</th>
<th>Volume, mL</th>
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<tbody>
<tr>
<td>Room temp.</td>
<td></td>
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<tr>
<td>Ice bath</td>
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<tr>
<td>Warm water bath</td>
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4. Remove the syringe from the warm water bath and dry it off.
   a. Come up with a general equation relating temperature \(T\) and volume \(V\), using a constant (“k”): \(k = V/T\)
   b. Derive an equation using \(V_1\), \(V_2\), \(T_1\), and \(T_2\). This is Charles’ Law: \(V_1/T_1 = V_2/T_2\)
   c. Draw the syringe and how the air particles look in the syringe. Show the entire area containing the gas particles. Use arrows to represent movement – larger arrows = moving faster.

*Clean-up: If you are the last group to use the warm water bath, turn the hot plate off.

Station 3
How are pressure and volume related?

1. Use a Sharpie to draw a smiley face on a mini-marshmallow and place it in the syringe.
2. Place the plunger in to the 50mL mark.
3. Screw the cap onto the syringe.
4. Observe what happens to the marshmallow when you depress the plunger, and when you pull it out.
5. Record each volume below the boxes. (Do not press so hard that the syringe leaks.)
   a. Come up with a general equation relating pressure (P) and volume (V), using a constant (“k”): \( k = PV \)
   b. Derive an equation using \( P_1, P_2, V_1, \) and \( V_2 \). This is **Boyles’ Law**: \( P_1V_1 = P_2V_2 \)
   c. Draw pictures of the marshmallow and syringe with the plunger at the 50mL mark, with the plunger depressed, and with it pulled out past 50 mL. **Show the air particles as well! Remember there are air particle inside the marshmallow!**

| Volume: 50 mL | Volume: ____mL | Volume: ____mL |

*Clean-up: Remove the cap and remove the marshmallow. **Throw away** the marshmallow. (Do not eat it!)

**Part II**
- Determine an equation relating pressure, volume and temperature, using \( P_1, P_2, V_1, V_2, T_1, \) and \( T_2 \).
- This is the **Combined Gas Law**: \( P_1V_1/T_1 = P_2V_2/T_2 \)

**Part III**
One equation, combining all of these variables.
- Determine a single equation that relates all four variables and a constant. All of the relationships you discovered in Part I must still be valid. Arrange so that there no variables in a denominator (nothing looks like a fraction. (for example, instead of \( k = x/y \), use \( ky = x \)) Put the constant on the same side of the equation as temperature. This is the **ideal gas law**:

\[
PV = knT
\]
Part IV
Finding the ideal gas constant, R

- The constant in the equation you found in Part III is called the “ideal gas constant”. We use the variable “R” for this constant.
- Find the value and units of the ideal gas constant, R.
- Some hints:
  - What do you know about molar volume? At what conditions is this value valid?
  - You may use either atm or kPa as the pressure unit.
  - Do you think the temperature unit should be in °C or K?
  - Use three significant figures.

- The ideal gas constant, \( R = 0.0821 \text{ L*atm/mol*K} \) or \( 8.31 \text{ L*kPa/mol*K} \)