SCIENCE DETECTIVE'S NOTEBOOK #3:

GAS LAWS

Produced by:

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Simulations for Chemistry Learning

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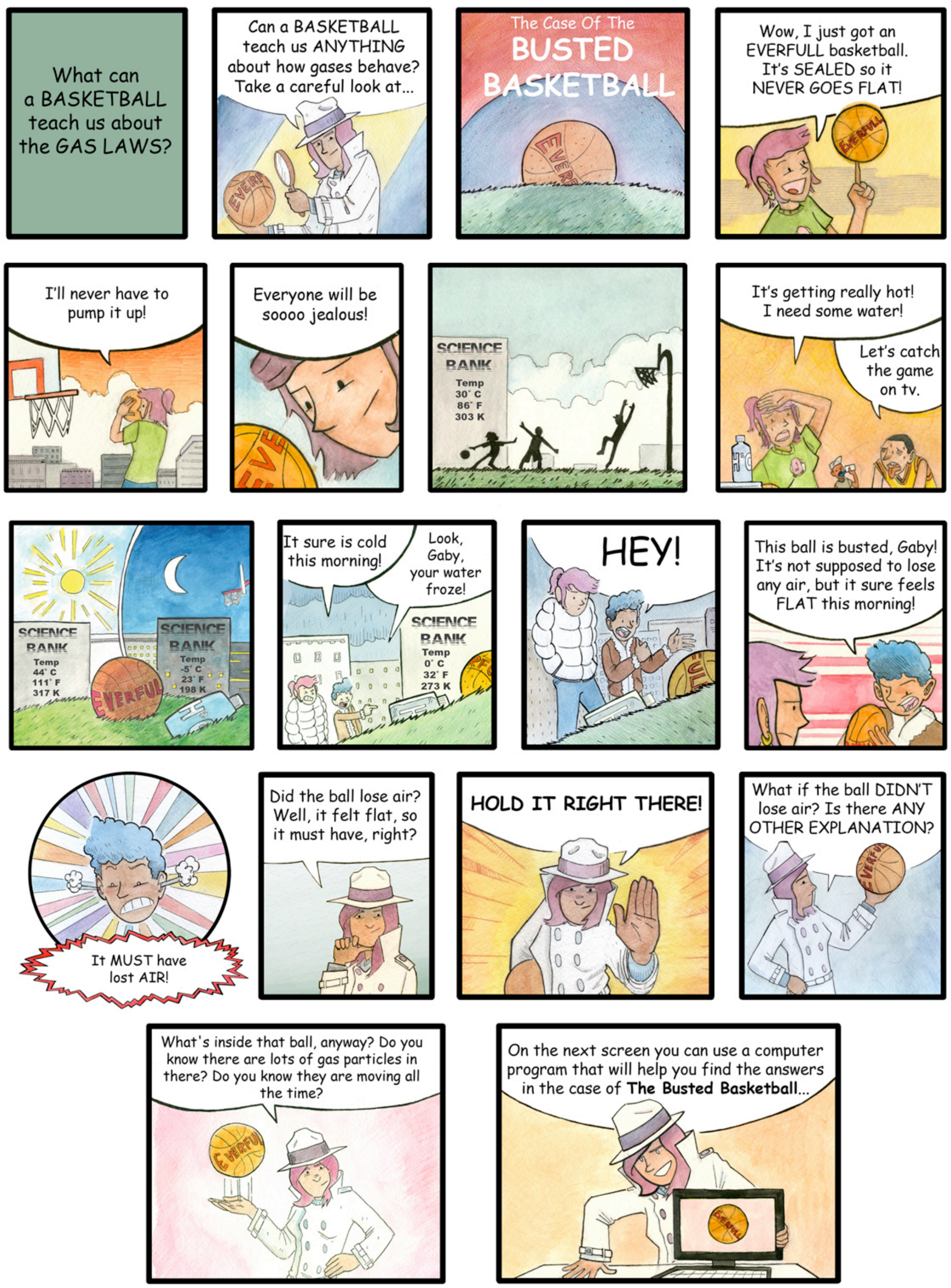
ENTRY 1: MAKE OBSERVATIONS AND PROPOSE A HYPOTHESIS

The Case of the Busted Basketball



Entry 1A: One of the *variables* that is important in the story is the *pressure* of the basketball. Based on the story, what other variable is important?

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Entry 1B: Which of these variables is the *independent* variable?

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Entry 1C: Which of these variables is the dependent variable?

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Entry 1D: Identify clues (observations) in the story that might explain how the ball could feel flat even if it did not lose air. Place all your observations in the table below.

Table 1: Laying out the clues	
Clue #1	
Clue #2	
Clue #3	
Clue #4	

Entry 1E: Using the observations you just identified, propose a hypothesis involving temperature and pressure for why the ball felt flat.

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ENTRY 2: EXPLORE A MODEL TO TEST YOUR HYPOTHESIS

Use the GAS LAWS SIMULATION to test your hypothesis.

Entry 2A: Which temperature scale is used in this simulation?

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Entry 2B: What three variables does this simulation allow you to investigate?
List them in the table below:

Table 2:	
Variable	Unit of measurement
1.	
2.	
3.	

Entry 2C: Use the simulation to test your hypothesis from Entry 1E.

- Create 10 plot points in the simulation and draw the graph below.
- Don't forget to label the X and Y-axes!

Entry 2D: Does the evidence from your exploration support your hypothesis? Why or why not?

ENTRY 3: MAKE GENERALIZATIONS TO GENERATE A LAW

Entry 3A: The relationship you just explored between two variables is a famous gas law. Note that when you were exploring the relationship between these two variables, the third variable in the gas law simulation was held constant.

Complete the table:

Independent Variable	Dependent Variable	Constant (didn't change)

Now, summarize what you have learned:

Entry 3B:

As the ________________________ increases, the
(independent variable)

______________________ ____________________________.
(dependent variable) *(increases or decreases)*

Entry 3C:

As the ______________________ decreases, the
(*independent variable*)

____________________ ________________________.
(dependent variable) *(increases or decreases)*

Entry 3D: Using the terms *directly proportional* or *inversely proportional*, describe the general relationship between the two variables:

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ENTRY 4: SYNTHESIZE WHAT YOU LEARNED

Apply your understanding to "The Case of the Busted Basketball"

Entry 4A: Compare and contrast the basketball in the story and the closed container in the simulation.

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Entry 4B: Compare and contrast the air in Gaby's basketball and the gas in the simulation.

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Entry 4C: The law you have explored is called *Amontons' Law*. How does it help you explain what happened to Gaby's basketball?

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Guillaume Amontons (1633-1705) was a French physicist and scientific instrument inventor. He became deaf at an early age, perhaps through an infection. Although he did not go to university, he studied mathematics and the physical sciences at home.

His law relates pressure and temperature. One of the instruments he made was a thermometer, which used air instead of mercury. He realized that for people to study the effect of hot and cold, accurate thermometers were needed. He was able to show that the pressure of a gas increased by one third when the temperature went from cold to the boiling point of water.

He also suggested that if temperature could be made low enough pressure would disappear, so he seems to be the first person to think about the possibility of absolute zero.

ENTRY 5: EXPLORE ANOTHER GAS LAW: BOYLE'S LAW

Entry 5A: Working with the gas laws simulation, choose to lock the temperature between 300K and 550K. Record that temperature:

____

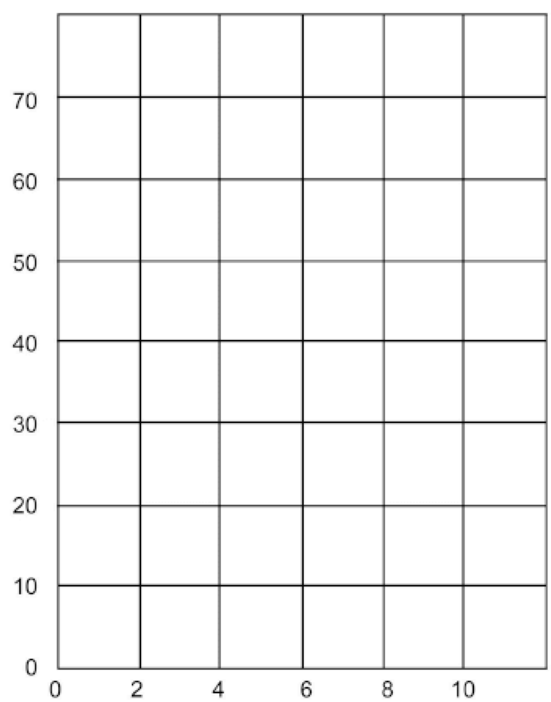
Entry 5A: Complete the table for this entry:

Independent Variable	Dependent Variable	Constant (doesn't change)

Entry 5B: Complete the following graph by varying the pressure.

- While you are collecting the data, record the data points on the graph
- You need to collect 10 data points

Label the axes and add a title!

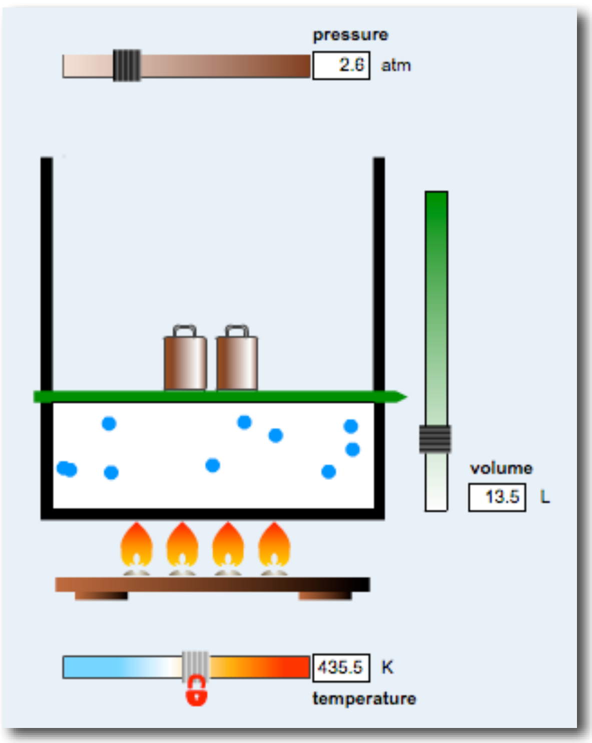


Entry 5C: How are *pressure* and *volume* related?

- As you increase the pressure, the volume

  ____

  (increases/decreases)



- As you decrease the pressure, the volume

  ____

  (increases/ decreases)

- This means that pressure and volume are

  ____

  (inversely proportional/ directly proportional)

Robert Boyle (1627-1691) published what would become known as "Boyle's Law" in 1662, describing the relationship between *pressure and volume* of a gas at a constant temperature remains within a closed system.

Many consider Boyle, who was born in Ireland, to be the first modern chemist. He is also considered a pioneer of scientific method and wrote about physics, philosophy, and theology.

ENTRY 6: EXPLORE ANOTHER GAS LAW: CHARLES' LAW

Entry 6A: Now that you have used the gas laws simulation several times, identify the variables that you have not explored yet:

Complete the table:

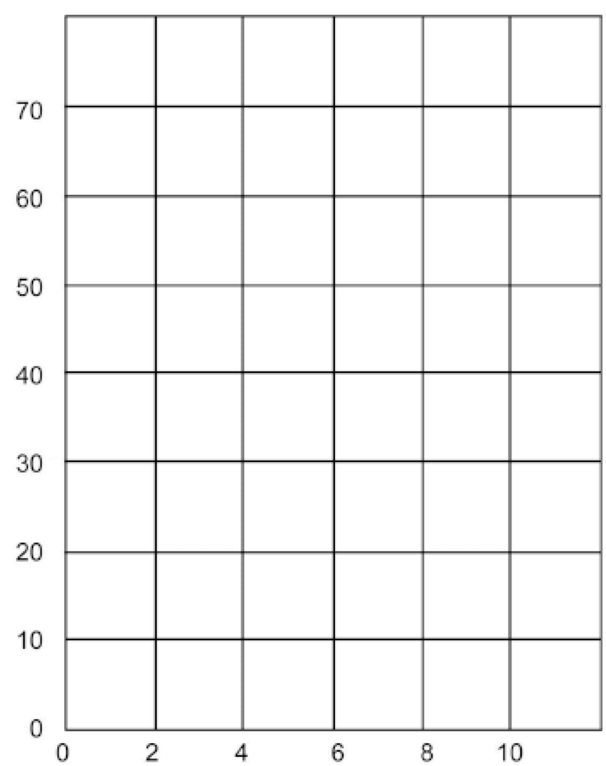
Independent Variable	Dependent Variable	Constant (doesn't change)

Entry 6B: Use the gas laws simulation to explore the relationship between these variables.

Complete the following graph by varying the temperature.

- While you are collecting the data, record the data points on the graph
- You need to collect 10 data points

Label the axes and add a title!



Entry 6C: Summarize how these two variables are related in Charles' Law: ______________________________

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Jacques Charles (1746-1823) came up with the law that bears his name in 1787, while studying the effect of *temperature on the volume* of a gas kept at constant pressure.

Charles was a French physicist, inventor, mathematician, and balloonist. He was the first balloonist to use hydrogen gas instead of hot air.

His law describes the way gasses expand when heated.

ENTRY 7: APPLY YOUR NEW UNDERSTANDING TO "THE CASE OF THE BUSTED BASKETBALL"

Entry 7A: Based on what you have learned about the gas laws, should Gaby complain to the basketball manufacturer? Why or why not?

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ENTRY 8: PUT IT ALL TOGETHER: THE COMBINED GAS LAW

Every day the National Oceanic and Atmospheric Administration (NOAA) sends up 102 weather balloons from sites in the US, the Caribbean, and the Pacific to help weather forecasting. The balloons lift up instruments into the atmosphere. Those instruments collect data on air pressure, temperature, and relative humidity from the Earth's surface to over 20 miles (about 100,000 feet) up in the sky. When the balloon reaches 100,000 feet, it pops, sending the instruments back to Earth. Together, the three laws you have explored in this study guide make up **The Combined Gas Law**. This Law can help us to understand why weather balloons pop.


Courtesy: NOAA

The Combined Gas Law allows you to calculate an outcome when you have three variables (pressure, volume, and temperature). It is based on the formulas for all of the individual gas laws.

Here are the mathematical equations for the individual gas laws:

Boyle's Law

$$P_1V_1 = P_2V_2$$

Charles' Law

$$V_1/T_1 = V_2/T_2$$

Amontons' Law

$$P_1/T_1 = P_2/T_2$$

[NOTE 1: Amontons did not develop this formula for his Law. That came later]

[NOTE 2: All calculations require you to use Kelvin units for temperature.]

- If we multiply all three laws, we get *The Combined Gas Law*, which can be represented as:

$$P_1V_1/T_1 = P_2V_2/T_2$$

The Combined Gas Law can help you to calculate any one of the three variables if you know the other two variables, but it *cannot* tell you which variable caused another variable to change.

See if you can do a couple of calculations using the Combined Gas Law:

1. A helium-filled weather balloon has a volume of 10.0L at 300K and a pressure of 1.0 atm (~101 kPa) when it is released. What will be the volume of the balloon once it has reached an altitude where the pressure is 0.1 atm (~10 kPa) and the temperature is 240K?

Entry 8A:
What is V_1 in this question? ______________________

Entry 8B:
Want is P_1? ____

Entry 8C:
What is P_2? ____

Entry 8D:
What is T_1? ____

Entry 8E:
What is T_2? ____

Entry 8F:
What is the unknown? ____________________________

Entry 8G:
Use the Combined Gas Law to calculate this unknown in the space below.

$P_1V_1/T_1 = P_2V_2/T_2$

2. A 220.0 mL sample of helium gas is in a cylinder with a movable piston at 101 kPa (~1.0 atm) and 275 K. The piston is pushed in until the sample has a volume of 95.0 mL. The new temperature of the gas is 310.0 K. What is the new pressure of the sample?

Entry 8H:

Calculate P_2: ______________________________

(use the space below for your calculations)

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

Entry 8I: Something Extra:

Think about Gaby's basketball: what might happen to a car tire in summer and in winter? Use the gas laws to explain that.

GAS LAWS LAB NOTEBOOK

ENTRY 1: DO IT NOW!

Entry 1A: Using what you know about the Gas Laws from the simulation, label the axes on this graph.

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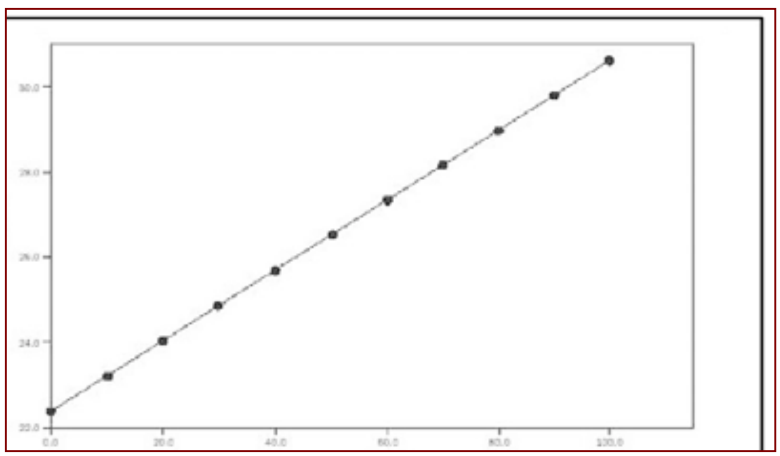

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Entry 1B: What does the graph tell you about the relationship between the variables?

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Entry 1C: Which quantity is held constant?

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Entry 1D: Using what you know about the Gas Laws from the simulation, label the axes on this graph.

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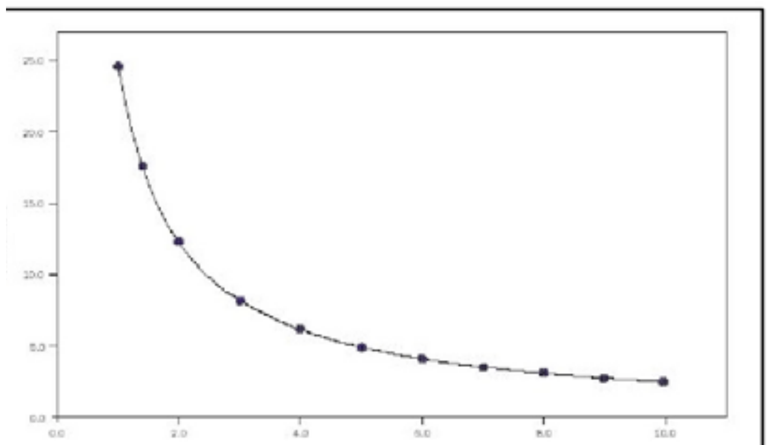

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Entry 1E: What does the graph tell you about the relationship between the variables?

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Entry 1F: Which quantity is held constant?

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Entry 1G: Why was Gabriella's basketball flat in the COLD morning when it was full during the WARM afternoon?

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Knowing what we know about pressure, volume and temperature, the Combined Gas Law relates all 3 of these variables.

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

Let's try some more practice problems using The Combined Gas Law:

Entry 1H: The gas in a 0.717 L cylinder of a diesel engine exerts a pressure of 0.9 atm at 300 K (27°C) The piston suddenly compresses the gas to 48.6 atm and the temperature rises to 820 K (547 °C). What is the final volume of the gas? What are the temperature and pressure at STP? (Check Table A). Show your work.

Entry 1I: What pressure (in atm) will be exerted by a tank of natural gas used for home heating if its volume is 19.6 L at STP and it is compressed to 6.85 L at 24C?

Entry 1J: How much higher is this than normal atmospheric pressure?

Entry 1K: The human lung has an average temperature of 310 K (37°C). If one inhales Alaskan air at 1 atm and 28.9 °C and then holds it, to what pressure will the air in the lungs rise?

Entry 1L: If a human lung can withstand 2 atm of pressure, do you think the lungs will burst?

Entry 1M: Explain how you are able to make this claim.

ENTRY 2: LAB/DEMO

Aim: Use simulations to discover how pressure, temperature and volume are related according to Amontons', Boyle's and Charles' Laws.

Important Concepts: There are three Gas Laws

Amontons' Law: Relates temperature and pressure at constant volume.

- **Temperature** – *independent*
- **Pressure** – *dependent*
- **Volume** – constant

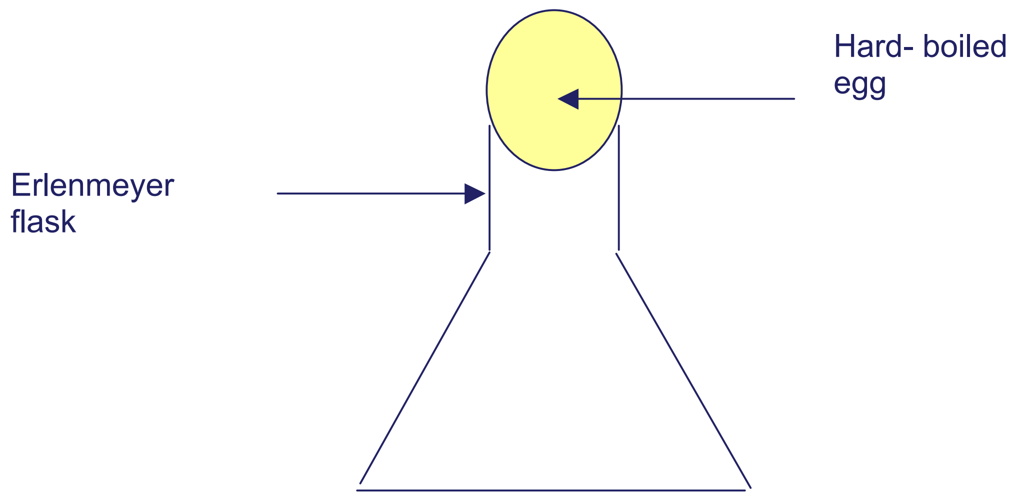
Boyle's Law: Relates pressure and volume at constant temperature.

- **Pressure** – *independent*
- **Volume** – *dependent*
- **Temperature** – constant

Charles' Law: Relates temperature and volume at constant pressure

- **Temperature** – *independent*
- **Volume** – *dependent*
- **Pressure** – constant

Demonstration/Lab: *Erlenmeyer flask & egg*



Entry 2A: *Predict*

What do you predict will happen if we heat the air in the flask and then put a peeled hard-boiled egg on the open top of the flask?

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Entry 2B: *Confidence*
What did you learn from the simulation that makes you confident about your prediction?

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Entry 2C: *Collect* your equipment:

- Narrow-mouthed Erlenmeyer flask (about 500 mL) or bottle that is similar
- Medium hard-boiled egg
- Hair dryer or something similar
- Tripod or clamp stand
- Thermometer

Entry 2D: *Perform* your experiment

1. Clamp the flask to the stand or place it on a tripod
2. Heat the flask with the hair dryer for about three minutes.
3. Measure and record the temperature of the air in the flask at this time (T_1). (Celsius degrees plus 273 = Kelvin)

- T_1 = _____________K

- What must P_1 be at this time? You can use your understanding of the relationship between internal and external pressure to work this out and suggest a likely value.

  P_1 = _______________atm

4. Then immediately place the egg on the mouth of the flask as shown in the previous illustration.

Entry 2E: *Observe* what happens to the egg

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- Record the temperature of the flask.

  T_2 __________________

Use the mathematical formula for the relationship between Temperature and Pressure to calculate the final pressure. Show your work.

Entry 2F: *Explain* your original prediction was supported or not supported by the evidence you just collected.

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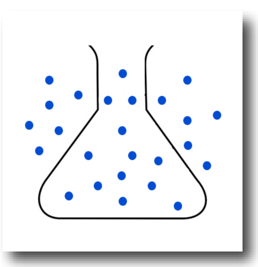
Entry 2G: We can represent the gas molecules in a flask as dots (a bit like the dots in the model you just used).



Before you start heating the flask, the particles inside the flask are at the same temperature as particles outside. Use your knowledge from the previous simulations to describe how the particles will be moving.

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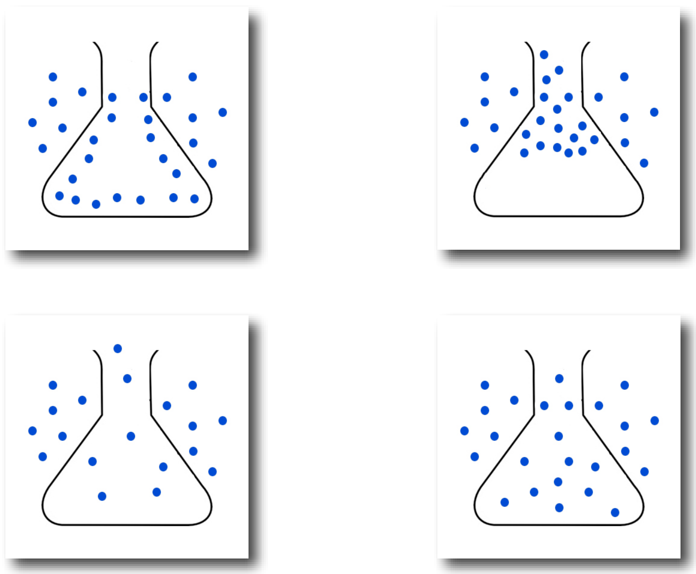
Entry 2H: Predict how the molecules inside the flask will be organized after three minutes of heating. Circle the image that is most like your prediction.



Entry 2I: So long as the hair dryer is heating the air inside the flask, what can you say about the internal pressure of these heated gas molecules inside the flask and the air pressure outside?

Entry 2J: As the gas molecules inside the flask cool down, what does the external air pressure do to the egg?

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Entry 2K: At this point, how does the internal air pressure of the flask compare with the external air pressure?

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Entry 2L: What evidence (observation/fact) allows you to say this?

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Entry 2M: Explain what happened at the molecular level to the gas particles in this flask. Use your calculated P_2 and your observations from the demonstration.

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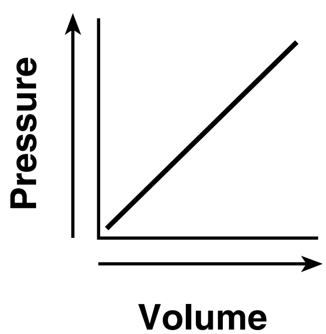
Summary Table of Concepts/Theories and Simulations:

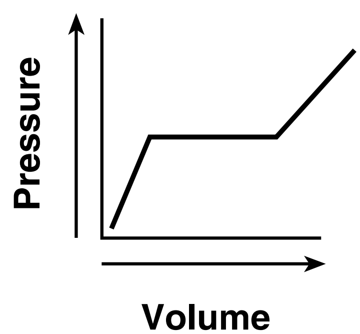
	Diffusion	*KMT*	*Gas Laws*
Variables	Temperature, atomic mass & time for diffusion	Pressure & temperature	Pressure, temperature, & volume
Examples	Tea in hot water; oxygen in bloodstream; gases used in WWI trenches	Boiling water & the lid popping off	Balloon rising with temperature; forcing gases into a smaller container
Simulation Narrative	Punk & Popcorn	Deserted Dessert	Busted Basketball
Lab/Demo	Food coloring & agar plate	Heating & cooling balloon on flask	Erlenmeyer flask & egg

ENTRY 3: EXTENSION ACTIVITIES

Entry 3A: Circle the graph that represents the relationship between pressure and volume for a sample of an ideal gas at constant temperature.



(1)



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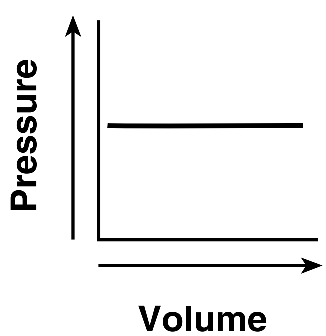

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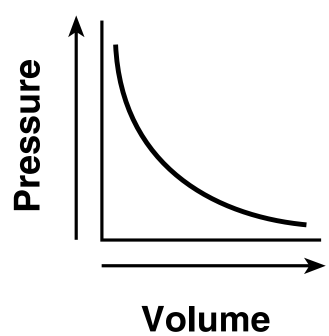
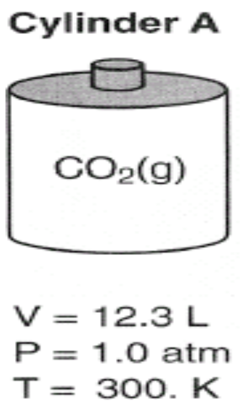


(4)

Entry 3B: Cylinder *A* contains 22.0 grams of $CO_2(g)$. The volume, pressure, and temperature is indicated underneath the diagram of the cylinder.



The temperature of the $CO_2(g)$ is increased to 450. K and the volume of cylinder *A* remains constant.

Show a correct numerical setup for calculating the new pressure of the $CO_2(g)$ in cylinder *A*.

Entry 3C: Air bags are an important safety feature in modern automobiles. An air bag is inflated in milliseconds by the explosive decomposition of $NaN_3(s)$. The decomposition reaction produces $N_2(g)$, as well as Na(s), according to the unbalanced equation below.

$NaN_3(s) \rightarrow Na(s) + N_2(g)$

When the air bag inflates, the nitrogen gas is at a pressure of 1.30 atmospheres, a temperature of 301 K, and has a volume of 40.0 liters. In the space below calculate the volume of the nitrogen gas at STP. Your response must include *both* a correct numerical setup and the calculated volume.