What A Gas!

**STATE OF MICHIGAN BENCHMARKS**

C 1.1 f – Predict what would happen if the variables, methods, or timing, of an investigation were changed.

C2.2c – Explain changes in pressure, volume, and temperature of a gas using the kinetic molecular model

C4.3A – Recognize that substances that are solids at room temperature have stronger attractive forces than liquids at room temperature, which have stronger attractive forces than gases at room temperature.

C4.5x – The forces of gases are explained by the ideal gas law.

**TYPE OF INQUIRY**

Guided inquiry

**TIME**

Teacher Prep: 30 minutes to set-up Activity II and III. – one time set-up.

Activity Time:
- Prelab: 5 minutes
- Activity: 60 minutes
- Post-lab activity and discussion: 30 minutes

**EDUCATIONAL OBJECTIVES**

The purpose of the activity is for students to learn the postulates of the kinetic molecular theory. However, the theory is never mentioned in the activity. Instead it is all described as properties of gases.

1. Students will be able to describe the following three postulates of the kinetic molecular theory from experimental data and observations.
   a. Gas pressure is caused by the random collision of gas particles with the walls of the container.
   b. Gas particles have no attraction between them.
   c. The average kinetic energy of the gas particles is directly proportional to the Kelvin temperature of the gas.

2. Students will explain the relationship between gaseous temperature, pressure, and volume based on experimental data and observations.

**PREREQUISITE KNOWLEDGE**

Kinetic energy, states of matter, understanding of temperature, pressure, and volume

**SAFETY**

The only safety concerns are overheating the hamster cage or students being cut if they break a capillary tube.
MATERIALS
Assumed for 7 student lab stations – working in groups of 3 or 4
Equipment: 100 mL beakers (14), 100 mL graduated cylinders (7), rubber stopper size 4 (7),
Capillary tubes – one end closed (at least 7), vegetable oil, Sudan Red also known as
Sudan III biological stain (Flinn Scientific Catalog – about $9 for 5 grams), ice, stop
watches (7), thermometers (7), rulers (7), hot water
Other equipment:
*Hamster exercise cage (2) purchased at pet store in 7” for $5 and 11.5” (optional) for $15
*PVC Pipe fittings purchased at any hardware stores
  (1) 3x2 PVC coupling -used with 7” hamster cage ($3)
  (1) 3”PVC Spigot Flange – used with 11.5’ hamster cage ($4)
* Clear Packaging tape
* Small Styrofoam balls (5 for each hamster cage)
* Hair dryer (make sure the hair dryer fits into the PVC pipe)
* Background Handout – see pg 7 of the student handout.
* Post-Lab Activity – see pg 9-10 of this handout and pg 9-10 of the student handout. Pass
this out after completing the lab.

PRELAB ACTIVITY SET-UP
Activity I: Background on Gases.
The purpose of this activity is for the students to learn some terminology and background
information. Make enough copies of the handout (pg 7 of student handout) for each lab
station. If possible laminate the copies so they may be used every year.

Activity II: Investigating the Motion of Gas Particles. (Adapted from Guzdziol, n.d.)
Materials: small Styrofoam balls, hair dryer, hamster exercise ball and PVC fittings.
The purpose of this activity is to demonstrate the gas collisions and how they are related
to gas pressure and temperature. The activity can be done with 1 or 2 hamster cages.
Construct the model according to Figure 1.

Figure 1:
Remove one of the doors to the hamster cage. Place the PVC fitting over the opening. Tape the fitting onto the hamster cage with the packaging tape. Put the Styrofoam balls into the hamster cage. Place the hairdryer into the PVC fitting and turn it on. The Styrofoam balls should fly around the cage. If nothing occurs, try a more powerful hairdryer. Repeat the same procedure with the larger hamster cage and fitting. Since the hamster cage does not have many openings, the cage may become hot when the hairdryer is used. To prevent the hamster cages from rolling around, place them on a roll of masking tape.

When the hairdryer is turned on students should see the particles colliding with each other and the side of the container. As the temperature is increased (modeled by switching from a LOW to HIGH dryer setting) the number of collisions should increase in the cage. The larger ball is to show students that when the same gas (same Styrofoam balls) are placed in a larger container there are less collisions between gas particles.

One possible misconception that may form during this activity is that molecules move faster when heated because some external force pushes them. During the post-lab discussion make sure that students understand that heat does not “push” gas particles around.

Activity III: Effects of Temperature on the Volume of a Gas. (Adapted from Tanis, 2003)

Materials: vegetable oil, capillary tubes, Bunsen burner, Sudan III biological stain, thermometer

The purpose of this activity is to understand the relationship between the temperature of a gas and the volume it occupies. Since capillary tubes easily break, make extras if you have more than one section. To make the capillary tube/oil apparatus, first add a few particles of the Sudan III to the oil in order to dye it pink/red. Heat the capillary tube in a Bunsen burner flame. Wave the tube in the flame so it doesn’t melt. Once it is hot, quickly place the open end into a small beaker of colored oil. Capillary rise and the partial vacuum formed in the tube upon cooling will draw the oil into the tube. Make sure the oil is drawn into the tube otherwise the oil will be forced out of the tube when the gas inside is heated. (See pg 6 of this handout.) Be careful when heating the capillary tubes, they will become very hot and can bend or melt if over headed. Once the tubes are set-up, they will keep for years.

Activity IV: Attractive Forces Between Molecules. (Adapted from Wiseman, 1979)

The purpose of this activity is to show the weak attractive forces between gas particles. According to the kinetic theory, there are no forces of attraction between ideal gas particles. For this activity we are assuming that the particles are ideal. No pre-lab setup is necessary but make sure that the stopper fits in the graduated cylinder but is also able to slowly slide to the bottom of the cylinder.

Activity V: Motion of Particles Continued.

The purpose of this activity is to further study the motion of gas particles. If classroom computers are not available this activity can be omitted or can be done as a demonstration with the whole class. The only set-up necessary may be to bookmark the website.
DAY OF ACTIVITY SET-UP
The following materials should be set-up at every lab station except Activity II (one set-up only).

Activity I: Handouts (Pg 7 of student handout) – enough copies for every station.

Activity II: Hamster cage with PVC attachment (1 or 2), 5 Styrofoam balls/hamster ball, hairdryer.

Activity III: Capillary tube with oil (1), 100 mL beakers (2), ice, hot water, rulers, thermometer (1).

Activity IV: 100 mL graduated cylinder (1), #4 stopper (1), stop watch (1).

Activity V: Computer with internet access.

PRELAB / ENGAGEMENT OF ACTIVITY
Introduce the activity by telling students that they will be studying some properties of gases. The handout for Activity I is the engagement activity.

FACILITATION
With 7 lab stations, have students complete each activity at their lab tables except Activity II. This activity can be set-up in the front of the room and student groups can take turns completing it. The activities can be completed in any order, except Activity I should be completed first. If there are fewer students, the activity can be done as stations. Each lab station is a different activity and students rotate for each activity. If only a teacher computer is available (no student computers), Activity V can be done as a full class demonstration instead of a group activity.

For Activity II, students should hold the hairdryer at a 30° angle. This will allow the Styrofoam balls to travel around the hamster cage. During Activities II and V, one important idea to stress is the definition of pressure. Make sure that students understand that pressure is the frequency/number of collisions not the forces of the collisions. While the students are working on the computer simulation, the teacher should ask questions to help the students discover this.

In Activity III make sure students understand that there is air in the tube (below the oil) and that it is the air that is expanding and contracting as the temperature changes. Also during Activity IV Question #1, check student answers and make sure they correctly answer that the graduated cylinder is full of air. Student may incorrectly assume that nothing is in the cylinder.

MISCONCEPTIONS
In my classes I have seen that many students have difficulty with the concept of temperature and pressure on a particulate level. Most recognize that temperature is related to how fast particles travel but don’t understand that is the average kinetic energy of the molecules. This is most likely due to a lack of understanding of the concept of kinetic energy. In addition, students have misunderstandings regarding pressure. They confuse the frequency of gas
collisions with the force of gas collisions. Finally, many incorrectly believe that gas collisions cause temperature (Kautz, Loverude, Heron, & McDermott, n.d.).

ANSWERS TO QUESTIONS

Activity I: Background on Gases
1. List some basic properties of gases. Gases are expandable and compressible. They fill their container. They exert gas pressure and temperature.

2. What causes gas pressure? What are some units of pressure?
The collision of gas particles with other particles or the walls of a container. Pounds per square inch (Psi), Pascals (Pa), mmHg, atmospheres (atm)

3. What does the temperature of a gas measure? Gas temperature is measured in what unit?
The average kinetic energy of the gas particles. Kelvins

4. What is kinetic energy? The energy caused by the motion of particles.

5. Use the definition of kinetic energy to define temperature.
Temperature is the average kinetic energy of the particles. As the particles move faster, the temperature of the gas should increase.

Activity II: Investigating the Motion of Gas Particles
Observations:

<table>
<thead>
<tr>
<th></th>
<th>Low Speed</th>
<th>High Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small Cage</td>
<td>Move around cage.</td>
<td>Move faster than low speed.</td>
</tr>
<tr>
<td>Big Cage</td>
<td>Move less than in the small cage.</td>
<td>Move faster than the low speed but less than the high speed in the small cage.</td>
</tr>
</tbody>
</table>

A. In this model, what do the Styrofoam balls and hamster cage represent? 
The Styrofoam balls represent the gas particles in a container.

B. When the hairdryer is changed from LOW speed to HIGH speed, this represents a temperature change. What is happening to the temperature of the gas when the hairdryer goes from LOW to HIGH? 
The temperature increases.

C. As the temperature increases what happens to the number of collisions between the particles and the wall of the container? 
The number of collisions increases.

D. What happens to the gas pressure, when the temperature changes? It increases.

E. Write a rule for what happens to the pressure of a gas as the temperature is increased (given the same volume).
As the temperature of a gas inside a container increases, the pressure exerted by the gas increases.
F. When moving to the larger cage what have we changed about the container?
   *The volume*

G. Describe how the collision of the gas particles in the large cage compares to the collision in the small cage. *There are fewer collisions in the large cage.*

H. As a result of changing the size of the container, what has happened to the gas pressure inside of the container? *There is less gas pressure.*

I. Write a rule for the relationship between volume and pressure (given the same temperature).
   *As the volume of a container decreases, the pressure inside the container increases.*

### Activity III: Effects of Temperature on the Volume of a Gas

#### Diagram:

<table>
<thead>
<tr>
<th>Water Temperature</th>
<th>Height of air</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold Water 10 °C</td>
<td>30 mm</td>
</tr>
<tr>
<td>Hot Water 50 °C</td>
<td>50 mm</td>
</tr>
<tr>
<td>Room Temperature</td>
<td>40 mm</td>
</tr>
</tbody>
</table>

A. What happened to the space below the oil when the tube was placed in the cold water?
   *The height of the gas decreased. Or the volume of the gas decreased.*

B. What happened to the space below the oil when the tube was placed in the hot water?
   *The height of the gas (volume of the gas) increased.*

C. The term for the amount of space that the gas in the tube occupies is known as _____?
   *Volume of the gas.*

D. Why is it necessary to keep the tube in the water when you make your measurements?
   *Otherwise the volume will change because the temperature will change.*

E. Write a rule for the relationship between the answer to “C” and the temperature of the gas.
   *As the temperature of the gas increases, the volume of the gas increases*

### Activity IV: Attractive Forces between Molecules.

1. Look at the 100 ml graduated cylinder. At this time what is inside it?
   *Air molecules.*
2. Drop a rubber stopper into the graduated cylinder. Observe how long it takes to reach the bottom.
   *Answers will vary, typically a few seconds.*

3. Now fill the graduated cylinder with water. Drop the rubber stopper into the graduated cylinder. How long does it take to reach the bottom?
   *Answers will vary, typically several minutes.*

A. One factor that determines the state of matter of a substance is the attractive forces between the particles. The stronger the attractive forces the closer the particles are to each other. Based on this activity how do the attractive forces in a liquid compare to those in a gas?
   *The attractive forces between liquid particles are stronger than those between gas particles.*

B. How do you know that there is a difference between the attractive forces?
   *It took longer for the stopper to travel through the water.*

C. Write a statement that compares the attractive forces between particles in a liquid and gas.
   *The attractive forces between particles in liquids are stronger than those between gas particles.*

**Activity V: Motion of Particles Continued**

1. Go to the following website: [http://intro.chem.okstate.edu/1314F00/Laboratory/GLP.htm](http://intro.chem.okstate.edu/1314F00/Laboratory/GLP.htm)

2. What are the temperature, pressure, and volume of the particles?
   \[ T = 273.15 \text{ K} \quad P = 1.01 \text{ atm} \quad V = 22.40 \text{ L} \]

3. Observe the particle with the red center.

4. Are all the particles moving at the same speed as the one with the red center?
   *No, every particle is not moving at the same speed.*

5. Does the particle with the red center always move at the same speed? In other words does it ever speed up or slow down? When does the speed change?
   *No it does not always move at the same speed. It speeds up after a collision with another particle.*

6. Click ENABLE TRACKING. Observe the particle. Describe the motion of the particle.
   *Travel in a straight line.*

   b. When does the particle change direction?
   *After the particles collide with another particle or the wall of the container.*

7. Click DISABLE TRACKING. Click PAUSE. If the volume was decreased to 10 L, PREDICT what do you expect would happen to the number of collision. The pressure of the gas?
The number of collisions should increase so the pressure should increase.

b. What do you think would happen to the temperature?
   The temperature should stay the same.

8. Change the Volume to about 10 L and then Click RESUME.

9. Did the temperature change? Record it here. No it did not change. 275.25 K

10. Based on the result from Question #9, what does that tell you about the average kinetic energy of the particles?
    The average kinetic energy does not change.

11. Observe the collisions that are occurring between the particles and the walls of the container. Compare the collisions before and after the volume was changed. There are more collisions than before.

12. What is the pressure? 2.15 atm

13. Were your predictions correct? Explain. Answers may vary. Explanations should include a description of gas behavior at the particulate level.

14. Click RESET and PAUSE.

15. If the temperature is changed to 100 K, PREDICT what should happen to the number of collision between gas particles. What should happen to the gas pressure?
    The number of collision should decrease so the pressure should decrease.

16. Change the Temperature to about 100K and click RESUME. Observe the speed and number of collisions that are occurring now. Compare the collisions before and after changing the temperature.
    The particles are moving slower and there are fewer collisions.

17. Were your predictions correct? Explain. Answer may vary. Explanations should include a description of gas behavior at the particulate level.

GOING FURTHER QUESTIONS
1. The warning an aerosol hairspray can states: Do not store at a temperature above 120°F (50 °C). What happens if the hairspray is heated above this temperature?
   The can could explode.

b. In terms of the particles, explain how this occurs if the hairspray is heated above 120°F?
   At higher temperature the particles will move faster causing greater pressure. The pressure will become too great for the container and escape (explode).
2. If a student brings hot French fries into the classroom, eventually everyone in the room can smell them. Explain how/why this happens?

The smell of the French fries is caused by gas particles. Since the gas particles have no forces of attraction they are free to move and collide with all the particles in the room. Since gases will fill their container, the smell eventually fills the room.

3. In the reading, it stated that the atmospheric pressure was lower at high elevations. Why is this? (Hint: Think about what holds that atmosphere around the Earth).

The force of gravity is what holds the atmosphere around the Earth. Since the force of gravity is less at higher elevations, then there are fewer air particles so the atmospheric pressure is lower.

4. In the reading, good weather is associated with high atmospheric pressure. In terms of the air particles what does high atmospheric pressure mean?

High atmospheric pressure means that there is higher air density. So there will be more air particles in a given area.

5. The reading states that air particles travel from high atmospheric pressure to low, what does this statement mean?

Air particles move from a high concentration to a low concentration.

POSTLAB DISCUSSION/ACTIVITY

After completing the experiment discuss the activity and answers to the questions. If no student computers were available for Activity V, complete this activity as a class demonstration with the teacher’s computer. Even if the activity was completed as written, it may be helpful to repeat parts or all of Activity V. In particular, point out that gas particles at the same temperature do not all travel at the same speed. Also note that changing the temperature of the gas increases the frequency of the collision but not the force of the collisions. At this time also discuss Activity II, stressing that this is an analogy of the movement of gas particles. In particular, point out that gas particles do not move because of an external force (hairdryer) pushing them. Nor does an increase in temperature on gas particles mean that more force is pushing on the particles. Finally point out that the particles travel in a straight line until they collide with something. In the hamster cage, the Styrofoam balls may just travel in circles along the surface of the ball. This may give students the impression this is the correct motion of the particles.

As a final wrap up for the activity, give students the “Postulate of the Kinetic Molecular Theory- Post Lab Activity” (page 9-10 of the student handout). At this point introduce the Kinetic molecular theory and its postulates. Students can complete the handout as a class, lab group or individually.
REFERENCES


POSTULATES OF THE KINETIC MOLECULAR THEORY

Post Lab Activity

In this experiment, you studied the postulates of the Kinetic Molecular Theory of Gases. The postulates state the following:

1. Gases consist of tiny particles (atoms or molecules).
2. The particles are constantly moving. They randomly travel in a straight line until they collide with another particle or wall of the container. These collisions cause the pressure exerted by a gas.
3. The collisions between gas particles are elastic. When the particles collide the kinetic energy of the molecules is conserved.
4. Gas particles have no attraction or repulsion to each other.
5. The average kinetic energy of the gas particles is directly proportional to the Kelvin temperature of the gas.

Answer the following questions regarding the activity and the kinetic molecular theory.

A. Which of the following postulates were studied during this experiment? (2 points)
   *Postulate 1, 2, 4, 5.*

B. For each postulate studied, complete the following:
   a. State which activity studies the corresponding postulate (activities may be used more than once).
   b. Describe the activity and explain how it furthered your understanding of the postulate.

1. Gases consist of tiny particles (atoms or molecules). (3 points)
   *Activity II and V. In activity II- particles are small Styrofoam balls and in Activity V the particles are small particles.*
2. The particles are constantly moving. They randomly travel in a straight line until they collide with another particle or wall of the container. These collisions cause the pressure exerted by a gas. (3 Points)
   Activity II and V. Activity II used a model to show particle collisions. Activity V used a simulation to show the collisions. Tracking showed that the particles move in a straight line until there was a collision with something else.

3. The collisions between gas particles are elastic. When the particles collide the kinetic energy of the molecules is conserved. (1 point)
   Not Studied. Though students may answer with Activity V and state that the collisions in the simulation are elastic. But this is not necessary.

4. Gas particles have no attraction or repulsion to each other. (3 points)
   Activity IV. In the activity we dropped the stopper in a graduated cylinder full of air and one full of water. Then we measured how long it took for the stopper to fall to the bottom of the cylinder. The stopper fell faster in the cylinder full of air because there are no attractive forces between the gas particles to slow down the stopper.

5. The average kinetic energy of the gas particles is directly proportional to the Kelvin temperature of the gas. (3 points)
   Activity V. During the simulation we watched the gas particles moving. The particles did not all move at the same speed even though they were the same temperature. They all moved faster when the temperature was increased and slower when the temperature was decreased.

RUBRIC FOR SCORING THE POST LAB ACTIVITY

Question A = 2 points total (1/2 point for each correct postulate identified)

Question B
   Postulate 1 = 3 points total (1 point for correct activity + 2 points for correct description)
   Postulate 2 = 3 points total (1 point for correct activity + 2 points for correct description)
   Postulate 3 = 1 point total (recognizing that we did not study elastic collisions)
   Postulate 4 = 3 points total (1 point for correct activity + 2 points for correct description)
   Postulate 5 = 3 points total (1 point for correct activity + 2 points for correct description)
ASSESSMENT
Since this is an introduction activity students can be given a grade of “credit/no credit” for completing the activity. The post laboratory activity can be used as a formal assessment of understanding. In addition the following questions can be used to on a quiz or chapter test for further assessment (Adapted from Alexander, 1995).

1. Two containers of argon are shown below. The containers are at constant temperature and contain the same number of particles. Answer the following questions regarding the gases in the two containers.

   ![Constant T](image)

   - a. True or False  The speed of Ar in both containers is the same.
   - b. True or False  The kinetic energy of Ar in both containers is the same.
   - c. True or False  The force with which the Ar atoms collide with their containers is the same in both containers.
   - d. True or False  The frequency with which the Ar atoms collide with the walls of the container is the same in both containers.

Solution: Since the containers are at the same temperature, the speed of the particles and kinetic energy of the particles is the same. The force that the particles collide will be the same but the frequency of the collisions will be different. The particles in the smaller container will collide with the sides of the container more often than the larger container. The increased number of collisions in the smaller container will result in a higher pressure.
2. Two containers of Helium at constant volume are shown below. Both containers have the same number of particles of helium.

<table>
<thead>
<tr>
<th>Constant Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Diagram" /></td>
</tr>
<tr>
<td><img src="image2.png" alt="Diagram" /></td>
</tr>
</tbody>
</table>

Temp = 127 °C  Temp = 27 °C

a. True or False The speed of the He atoms in both containers is the same.

b. True or False The force with which the He atoms collide with the walls of the container is the same in both containers.

c. True or False The frequency with which the He atoms collide with the walls of the container is the same in both containers.

Solution: At higher temperatures, the speed of the He atoms increases. The greater velocity gives the gas particles more energy so they collide with the walls of the container with greater force. A greater velocity also means that the He atoms will collide with the sides of the container with higher frequency. As a result the container at the higher temperature will have more collisions and a higher pressure than the container at a lower temperature.