Oakland Schools Chemistry Resource Unit

Kinetic Molecular Theory & Gas Laws

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Kinetic Molecular Theory and Gas Laws

Content Statements:

C2.2 Molecules in Motion:

Molecules that compose matter are in constant motion (translational, rotational, and vibrational). Energy may be transferred from one object to another during collision between molecules.

C3.4 Enthalpy and Entropy:

All chemical reactions involve the rearrangement of the atoms. In an exothermic reaction, the products have less energy than the reactants. There are two natural driving forces: (1) toward minimum energy (enthalpy) and (2) toward maximum disorder (entropy)

C4.5 Ideal Gas Law:

The forces in gases are explained by the ideal gas law

C5.2 Chemical Changes:

Chemical changes can occur when two substances, elements, or compounds interact and produce one or more different substances whose physical and chemical properties are different from the interacting substances. When substances undergo chemical change, the number of atoms in the reactants is the same as the number of atoms in the products. This can be shown through simple balancing of chemical equations. Mass is conserved when substances undergo chemical change. The total mass of the interacting substances (reactants) is the same as the total mass of the substances produced (products).

Content Expectations:

C2.2c: Explain changes in pressure, volume, and temperature for gases using the kinetic molecular model.

C3.4g: Explain why gases are less soluble in warm water than cold water.

C4.5a: Provide macroscopic examples, atomic and molecular explanations, and mathematical representations (graphs and equations) for the pressure-volume relationship in gases.

C4.5b: Provide macroscopic examples, atomic and molecular explanations, and mathematical representations (graphs and equations) for the pressure-temperature relationship in gases.

C4.5c: Provide macroscopic examples, atomic and molecular explanations, and mathematical representations (graphs and equations) for the temperature-volume relationship in gases.

C5.2f: Predict volumes of product gases using initial volumes of gases at the same temperature and pressure.

Instructional Background Information

Kinetic Theory: all matter consists of tiny particles that are in constant motion

Kinetic Theory Assumptions (characteristics of an Ideal Gas): These statements are made only for what is called an ideal gas. They cannot all be rigorously applied (i.e. mathematically) to real gases, but can be used to explain their observed behavior qualitatively.

Source: Chem Team (http://dbhs.wvusd.k12.ca.us/webdocs/GasLaw/Basics-of-KMT.html)

1. All matter is composed of tiny, discrete particles (molecules or atoms).

2. Ideal gases consist of small particles (molecules or atoms) that are far apart in comparison to their own size. The molecules of a gas are very small compared to the distances between them.

3. These particles are considered to be dimensionless points which occupy zero volume. The volume of real gas molecules is assumed to be negligible for most purposes.

This above statement is NOT TRUE. Real gas molecules do occupy volume and it does have an impact on the behavior of the gas. This impact WILL BE IGNORED when discussing ideal gases.

4. These particles are in rapid, random, constant straight line motion. This motion can be described by well-defined and established laws of motion.

5. There are no attractive forces between gas molecules or between molecules and the sides of the container with which they collide.

In a real gas, there actually is attraction between the molecules of a gas. Once again, this attraction WILL BE IGNORED when discussing ideal gases.

6. Molecules collide with one another and the sides of the container.

7. Energy can be transferred in collisions among molecules.

8. Energy is conserved in these collisions, although one molecule may gain energy at the expense of the other.

9. Energy is distributed among the molecules in a particular fashion known as the Maxwell-Boltzmann Distribution.

10. At any particular instant, the molecules in a given sample of gas do not all possess the same amount of energy. The average kinetic energy of all the molecules is proportional to the absolute temperature.

Adapted from Chemistry, 2008, Prentice Hall

Gas pressure: is the result of simultaneous collisions of billions of rapidly moving particles n a gas with an object (such as its container)

Vacuum: an empty space with no particles and, therefore, no pressure

Atmospheric pressure: results from the collisions of atoms and molecules in air with objects; atmospheric pressure decreases as one climbs a mountain because the density of Earth's atmosphere decreases as elevation increases

Barometer: a device used to measure atmospheric pressure

Units of pressure: atmosphere, Pascal, barr, torr, mm of Hg,

Pressure Unit Equalities:

1 atmosphere = 101.3 kilopascals

1 atmosphere = 760 mm Hg = 760 torr

1 atmosphere = 14.70 pounds per square inch

Avogadro's number = 6.02×10^{23} particles per 1 mole

Ideal gas constant = R = 8.31 (L · kPa)/(K · mol)

Ideal gas molar volume = 22.4 Liters per 1 mole (at STP)

Compressibility: a measure of how much the volume of matter decreases under pressure; gases are easily compressed because of the space between the particles in a gas

Four variables used to describe a gas:

Factor	Symbol	Common unit	Relationship to pressure	Why pressure is affected
Pressure	P	Kilopascals, atmospheres		
Volume	V	Liters	inverse	If one decreases the size of a container (volume, ex: piston), particles collide with walls of container more frequently
Temperature	T	Kelvin	Direct	As temperature increases, the kinetic energy of the gas particles is increasing. Gas particles with more kinetic energy strike their walls of their container with more force
Number of representative particles	n	Moles	Direct	More particles, more collisions with walls of the container

Gas Laws:_The following are organized by name of the law, brief description, and mathematical equation. Focus on whether the relationship between the variables is inversely proportional or directly proportional. Student should be able to determine the relationship from creation of graphs, interpreting graphs, and analysis of the algebraic equations.

Boyle's Law: Pressure and Volume

If temperature and amount of gas is constant, as the volume of a gases container decreases, the pressure of the gas increases (inverse)

$P_1 \times V_1 = P_2 \times V_2$

Misconception warning: you may need to distinguish between an elastic container (ex: balloon) and a non-elastic container (ex: scuba tank). Boyle's law is best described using non-elastic containers as an example. The law says as volume decreases, as when a piston is pushed down, the contained gas has more collisions with the wall of the container so pressure increases. Or if one transfers a given amount of a gas from a small scuba tank to a larger scuba tank, the pressure is less in the large scuba tank due to an increase in volume. This misconception can arise when one is dealing with a stretchy container, such as a balloon. As one adds gas to a balloon, the balloon expands (volume increases) due to an increase in the number of collisions (pressure) between the contained gas and the inner walls of the balloon. This could result in the student drawing the conclusion that pressure and volume share a direct relationship.

Charles' Law: Temperature and Volume

If pressure and amount of gas is constant, as the temperature of an enclosed gas increases, the volume increases (direct)

$V_1 \times T_2 = V_2 \times T_1$

Gay-Lussac's Law: Pressure and Temperature

If volume and amount of gas is constant, as the temperature of an enclosed gas increases, the pressure increases (direct)

$P_1 \times T_2 = P_2 \times T_1$

Combined Gas Law

A single expression that combines Boyle's, Charles', and Gay-Lussac's laws; only the amount of gas is held constant (see above). Number of moles is held constant.

$P_1 \times V_1 \times T_2 = P_2 \times V_2 \times T_1$

Ideal Gas Law

This equation makes the assumption that in most environments, real gases behave like an ideal gas. An ideal gas does not actually exist, but real gases differ from the ideal gas concept only at low temperatures and high pressures (Why? Real gases have volume and there are attractions between the particles). For a more thorough description of ideal gas assumptions, please refer to the Kinetic Theory Assumptions at beginning of this section (Instructional Background).

$PV = nRT$; R is the ideal gas constant

Dalton's Law of Partial Pressures

In a mixture of gases at constant volume and temperature, the total pressure is the sum of the partial pressures of the gases

$P_{total} = P_1 + P_2 + P_3 + \ldots$

Graham's Law

The rate of effusion (or diffusion) of a gas is inversely proportional to the square root of the gas's molar mass. Restate: The larger the molar mass of a particular gas, the slower it diffuses.

$$v_1 / v_2 = \sqrt{d_2 / d_1}$$

Diffusion: tendency of molecules to move toward areas of lower concentration until the concentration is uniform throughout

Effusion: gas escapes through a tiny hole in its container

Terms and Concepts

Kinetic Molecular Model	Pressure-Temperature Relationship	Pressure-Volume Relationship
Temperature-Volume Relationship	Rotational Motion	Translational Motion
Vibrational Motion	Density	Kinetic Energy
Solution	Solubility	Limiting Reagent
Direct and Inverse Relationships	Diffusion	Ideal Gas Law
Dalton's Law of Partial Pressures	Avogadro's Law (representative particles and volume)	Effusion
Graham's Law of Diffusion (mass and rate)	Vacuum	Combined Gas Law
Gay-Lussac's	Enthalpy	Solute
Entropy	Absolute Zero	Limiting Reagent
Excess Reagent	Kelvin scale	Order
Disorder	Molar mass	Vapor pressure

Instructional Resources

Chem Team Main Menu (great resource for any topic)
http://dbhs.wvusd.k12.ca.us/webdocs/ChemTeamIndex.html

Chem Team: Kinetic Molecular Theory and Gas Laws
http://dbhs.wvusd.k12.ca.us/webdocs/GasLaw/KMT-Gas-Laws.html

Various Chemistry tutorials, including Gas Laws:
http://www.ausetute.com.au/index.html

Norton Chemistry—tutorials for Ideal Gas Law and Molecular Speed, as well as background info:
http://www2.wwnorton.com/college/chemistry/gilbert/overview/ch8.htm

Gas Law Simulation:
http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/flashfiles/gaslaw/boyles_law_new.html

Gas Law background info
http://www.av8n.com/physics/gas-laws.htm

PhET: gas law simulation
http://phet.colorado.edu/simulations/sims.php?sim=Gas_Properties

University of Oregon Virtual Pressure Chamber Simulation
http://jersey.uoregon.edu/vlab/Piston/index.html

Kinetic Molecular Theory and Gas Laws

Activity #1 –The Effect of Temperature on Solubility of Gases

Questions to be investigated

What is the relationship between temperature and solubility of a gas?

Objectives

Determine relationship between temperature and solubility of a gas. Infer a general rule of thumb for gas solubilities and temperature

Materials

3 - 250 ml beakers
Root Beer
Hot Plate
3 Large Test Tubes
Ice
Beaker Tongs
Test Tube Rack
3 1-holed Rubber Stoppers (#4)
100 ml Grad Cylinder

Safety Concerns

Always wear safety goggles and a lab apron to protect eyes and clothing.

When you use hot plate, confine any long hair and loose clothing. Do not heat glassware that is broken, chipped, or cracked. Use tongs or hot mitt to handle heated glassware and other equipment because hot glassware does not look hot.

Always clean up the lab and all equipment after use, and dispose of substances according to proper disposal methods. Wash your hands thoroughly before you leave the lab after all lab work is finished.

Real-World Connections

Why do small bubbles appear just before water is about to boil?

If global warming is actually occurring, what is the potential impact on the ecological stability water environments?

Why is pop kept in a refrigerator?

Sources

Adapted from Craig T. Riesen's website:
http://moodle.oakland.k12.mi.us/clarenceville/course/view.php?id=27

Procedure / Description of Lesson

Procedures

1. Obtain a piece of cardboard for your table top and then set out all the materials listed above out of your lab station or the teacher.

2. You will need to obtain three 250 ml beakers and three large test tubes from the teacher.

3. Add water to TWO of the 250 ml beakers up to the 150 ml mark.

4. Add ice to the third 250 ml beaker up to the 100 ml mark and then add water up so that the ice/water mixture will have a volume at the 150 ml mark.

5. Place one of the other two beakers (already containing 150 ml of water) on the hot plate and set the hot plate on the highest setting until the water boils. Set the hot plate on "1-2" after that.

6. Set aside the last 250 ml beaker with water up to the 150 ml mark.

7. Place three large test tubes next to each other in your test tube rack.

8. Add 40 ml of root beer to each test tube using a graduated cylinder. DO THIS BY THE SINK!

9. Place a 1-holed rubber stopper into each of the test tubes.

10. Place the ice/water beaker and the beaker with water from the tap on a section of the cardboard that is easy to get to.

11. Once the 250 ml beaker on the hot plate is at a full boil, use the beaker tongs and set the beaker on the cardboard next to the other two 250 ml beakers.

12. Quickly INVERT one test tube of root beer into each 250 ml beaker and hold the test tube as vertical as possible. Do NOT rest the inverted test tube on the bottom of the 250 ml beaker.

13. Observe each test tube until there are NO bubbles formed or released inside.

14. Set the test tubes back in the test tube rack in order from ice/water to tap water to boiling water.

Calculations and Data

1. Shade in the table to the right, showing the level of root beer remaining in each test tube.

1. Ice 2. Water	3. Tap Water	4. Boiling Water

2. Which beaker produced the most bubbles?

Conclusions and Questions

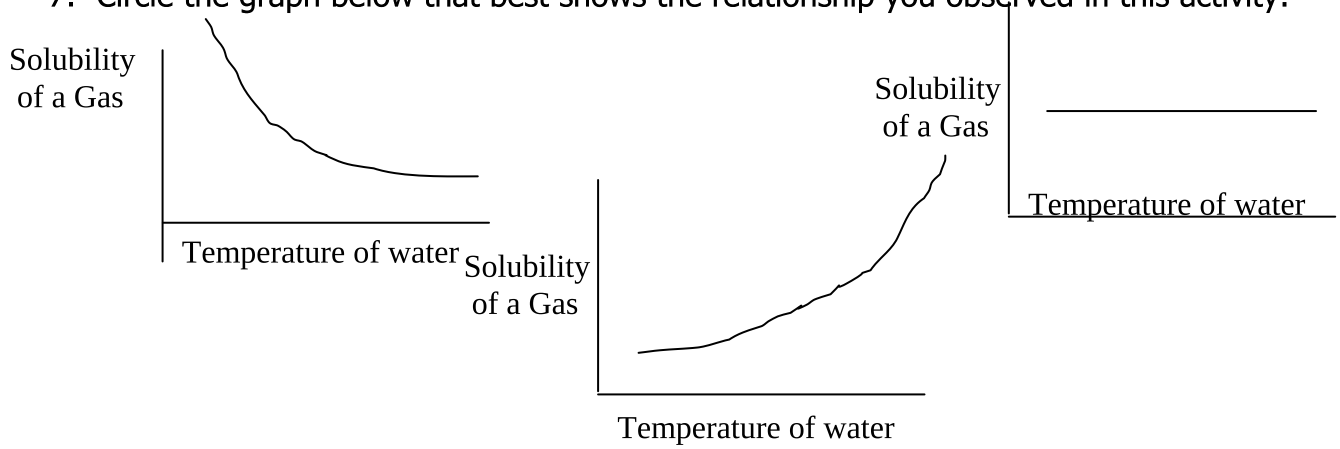
3. What gas do you think is bubbling in the water when the test tubes are inverted?

4. What does the term "solubility" mean?

5. What is the relationship between the temperature and the solubility of a gas (if the temperature increases, what happens to the solubility of the gas in the soda pop)? What evidence do you have for this?

6. If global warming is really true, how will this affect the amount of oxygen in the ocean, lakes and water supplies?

7. Circle the graph below that best shows the relationship you observed in this activity:



8. Would you call this a direct or inverse relationship?

Assessment Ideas

Demonstration/activity (see Activity #3 for details): Soda Hot Rod

Gases: Kinetic Molecular Theory and Gas Laws

Activity #2 – Gas Law Virtual Lab: Boyle's and Charles' Law

Questions to be investigated

How does the volume of space a gas is able to occupy affect the pressure exerted by the gas on its container?

How does the temperature of a gas the volume of space occupied by the gas?

Objectives

Determine the relationship between a gas's pressure and volume.

Collect data to construct and analyze a graph of pressure and volume.

Determine the relationship between a gas's temperature and volume.

Collect data to construct and analyze a graph of pressure and volume.

Teacher Notes

Verify students will be able to access the necessary websites; see "assessment ideas" for increasing the math level.

Materials

Computer with internet access

Safety Concerns

No lab concerns (virtual lab), but follow your district's internet usage policy

Real-World Connections

What pressure do I need to store helium at to fill a balloon, if my helium tank is this volume? How many balloons can I fill with a tank at this pressure and volume?

How much air is available in a diving tank at this volume and pressure? Will the tank break if it heated too much at this pressure and volume?

Why do compressed containers (like shaving cream) burst open when put on an airplane? Why do shampoo bottles pop open?

In international soccer competitions, the ball's mass must be between 450 -410 g, and pressure must be between 0.6-1.1 atm. How does the amount of air or air temperature affect these values?

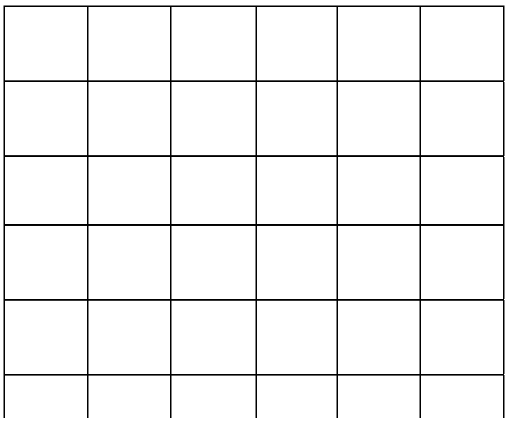
Sources

Derived from Iowa State University's Virtual Labs and Craig T. Riesen (Mr. Riesen's lab can be found at http://moodle.oakland.k12.mi.us/clarenceville/course/view.php?id=45

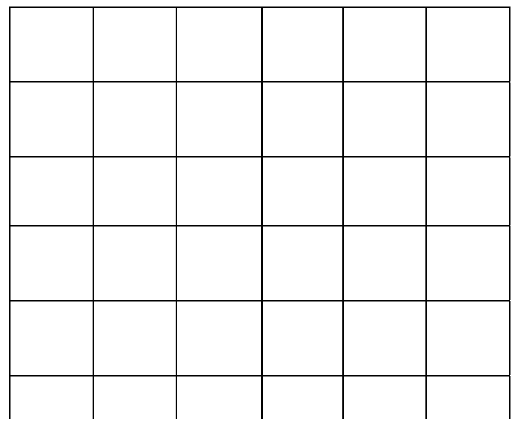
Procedure / Description of Lesson

1. Before starting the Virtual Labs, make a prediction of the relationship between gas pressure and volume, and then gas temperature and volume. Make your predictions using a written prediction and by drawing a line in the graphs below. In the first graph, volume is on the vertical axis and pressure is on the horizontal axis. In the second graph, volume is on the vertical axis, and temperature is on the horizontal axis.

Volume vs. Pressure



Volume vs. Temperature



<u>Boyle's Law: Pressure versus Volume</u>

Boyle's Law: go to the following:
http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/flashfiles/gaslaw/boyles_law_graph.html

2. Choose a substance to test in the "Testing" dialog box. Start with "Air" if available.

3. Use the plunger to push the syringe up to the "10 ml" mark and let go. You should notice that the values of Volume and Pressure are precisely listed in the table.

4. Record these Volume and Pressure values in your data table to the right.

Air	
Volume (ml)	**Pressure (psi)**

5. Now move the plunger to push the syringe to the "15 ml" mark and let go. Record these Volume and Pressure values in your date table below.

6. Repeat these procedures for the 20, 25 and 30 ml marks of the syringe. Record all values.

“	**”**
Volume (ml)	**Pressure (psi)**

7. Now, chose a different substance to test: Hydrogen, Oxygen or Helium and repeat all procedures, filling in the data table to the left. Be sure to name the substance in the table.

Boyle's Law

8. Make a graph of ONE of your substances.

a. Label "**Volume (ml)**" on the horizontal axis.
b. Label "**Pressure (psi)**" on the vertical axis.
c. Begin at "0" and use increments of "**5**" for volume & "**10**" for Pressure.
d. Plot your data using "X"s.
e. Draw a **CURVED** line graph to represent the points.

9. State if the relationship between volume and pressure is direct or inverse. How do you know?

10. Predict what you think will happen to the volume of a gas if the pressure keeps increasing. Do you think the volume of a gas will eventually be zero? Explain.

Procedures for Charles' Law: Go to the following: http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/flashfiles/gaslaw/charles_law.html

1. Click on "Show Data Table".
2. Move the "slider" (*at the bottom*) all the way to the right. A graph will appear as the piston goes up. Allow the piston to go all the way to the top … where it will stop.
3. Close the graph by clicking on "Close" at the lower left corner of the graph.
4. Record the Volume (cm^3) and Temperature (K) in the data table to the right. The values are listed in the table on the internet site.
5. Now move the "slider" to the left about 2 cm (*it will be under the red dot*). The graph appears again. Once the plot stops, record your Volume and Temperatures in the table.

Air	
Volume (cm^3)	**Temperature (K)**

6. Move the "slider" to the left again about 2 cm so that is under the "K". Record the Volume and Temperature values in the data table.
7. Repeat these procedures two more times. Record all values in the data table.
8. Click on the "Show Plot" button of the internet data table.
9. Make a <u>graph</u> of ONE of your substances.
   a. Label "**Volume (cm^3)**" on the vertical axis.
   b. Label "**Temperature (K)**" on the horizontal axis.
   c. Use increments of "**10**" for volume and "**100**" for temperature. Both axes should begin at "0".
   d. Plot your data using "X"s. Draw a **STRAIGHT** "best fit" line to represent all the points.
10. State whether the relationship between volume and temperatu
    How do you know?

Charles' Law

11. Extrapolate your line so that it crosses both the x and y axes. What is the temperature at this point? What is the volume? This point is called Absolute Zero. Look in your book on or on the web to find what this means. Describe the motion of particles at this temperature.

Assessment Ideas

Michigan Merit Curriculum requires students to recognize a relationship between the pressure, volume, and temperature of a gas and to create and interpret graphs. One may want to provide sample graph and ask students to match it with selections of data or predict which variable relationship is being represented in the graph.

Indicate the relationship between the pairs of gas variables by writing "**I**" for increase, "**D**" for decrease, or "**NBA**" for will **n**ot **b**e **a**ffected.

a. If the temperature decreases, the average kinetic energy of the particles will
b. If the number of moles of gas decreases the gas pressure will
c. The temperature of the gas increases, the gas pressure will
d. If the temperature decreases, the rate of diffusion will
e. If the mass of the individual gas particles decreases, the rate of diffusion will

In the gas stations, a student made sure the cap was on the syringe, inserted a marshmallow, than tried WITH DIFFICULTY to <u>push</u> the plunger as far into the syringe as you could. Use the symbols "**I**" for increases "**D**" for decreases, or "**S**" for remains the same to explain what was happening to the gas in the syringe.

a. The distance between the gas particles
b. The size of the marshmallow
c. The mass of the gas
d. The volume occupied by the gas
e. The moles of gas
f. The amount of collisions with other gas particles and the walls of the plunger
g. The amount of force required by you to "decompress" the air

Determine if the relationship is direct (D), inverse (I), or no relationship (NR).

a. Volume of a non-stretchy container (like the syringe) and the pressure of the gas within the container
b. Volume of a flexible container (like a balloon) and the temperature of the gas within the balloon
c. Temperature of a gas and the pressure of the gas

The math level can be upgraded by requiring student to calculate values of pressure, volume, temperature, and number of moles using the various gas law equations. Students should be able to determine from the question which equation is appropriate, rearrange the equation to solve for the missing variable, enter the given values in for the appropriate variable, and calculate the missing information.

Kinetic Molecular Theory of Gases worksheet:
http://misterguch.brinkster.net/kineticmoleculartheory.pdf

Boyle's Law worksheet:
http://moodle.oakland.k12.mi.us/clarenceville/file.php/45/Boyle_s_Law_Worksheet.doc

Charles Law worksheet:
http://moodle.oakland.k12.mi.us/clarenceville/file.php/45/Charles_Law_Worksheet.doc

Kinetic Molecular Theory and Gas Laws

Activity #3 – Demonstrations and Station Lab Activities

Questions to be investigated

How does pressure affect volume?

How does temperature affect pressure and volume?

How do gases travel through a room?

What are characteristics of most gases?

Objectives

Observe impact of atmospheric pressure

Determine relationship between volume, pressure, temperature, number of moles, solubility of a gas, and rate of diffusion.

Teacher Notes

The procedure contains 4 parts: (1) a list of examples for Kinetic-Molecular Theory and gas laws, (2) recommended examples for Gas Stations Lab with a student lab sheet, (3) recommended examples for the inquiry-based Reverse Gas Stations—CSI Style Lab , and (4) demonstration recommendations.

Materials

Varies based on chosen activities—see procedure for details. Common materials would be:
Balloons
Syringes
Hot plate
2 liter of soda
Empty soda cans
Beakers
Tape measure
Marshmallows (or Peeps)
Alka-Seltzer tablets
Film canister (Fugi type, not Kodak)
Fizz Keeper

Safety Concerns

Try every demo, activity, example before allowing students to perform or observe

Students should be wearing goggles and aprons for all student-performed activities, and goggles for most of the demonstrations

Most balloons contain latex, unless you specifically buy non-latex balloons

See procedure for specifics

Real-World Connections

How do planes fly?

Why do soda cans fizz when opened (or spray if shaken then opened)?

How does an odor "fill" a room?

Why does tire pressure decrease in the winter?

Why is it recommended that one keep aerosol cans, soda cans, etc…out of warm temperatures?

What is diving condition "the bends"? How is it caused and cured?

Sources

I take no credit for the creation of any of these examples. I have seen them performed at several conferences and they are available on several websites.

Mike Heinz (FLINN presenter) provided the Reverse Gas Station—CSI style concept: http://www.niles-hs.k12.il.us/michei/gaslaw.htm

Procedure / Description of Lesson

There is an absolute plethora of demonstrations, quick labs, and real-world examples that can be used to describe and assess understanding of the gas law and kinetic molecular theory concepts, and the list below contains only those that I have tried with success. I would recommend using some of these to introduce gas laws, some for group discussion/lab activity, and others for assessment (formative and summative). The level of inquiry can also be varied. After the list of examples are suggestions as to which to use as Gas Stations, Reverse, Gas Stations (CSI version), and demonstrations.

EXAMPLES

Title	Concepts	Materials (goggles and aprons are assumed)	Directions
1. Observing Gas Pressure	Atmospheric pressure	Small glass with smooth even rim, water, index card	Fill the glass to the rim with water. Place the index card on the top of the glass. Working over a sink, use one hand to press the index card firmly to the top of the glass. Then quickly invert the glass, keeping the hand in place. Remove your hand from the index card. Card stays due to atmospheric pressure.
2. Kinetic Energy and Frequency of Collisions	KE, pressure	Clear plastic container; marbles	Begin by shaking the container gently then increase shaking to demonstrate adding energy to a gas
3. Observing volume changes	Volume, temperature	Balloon, pen, freezer, tape measure, warm light	Inflate balloon and secure; measure diameter. Insert balloon into freezer for 30 min, measure diameter (decreases). Place balloon under warm light for 30 min, measure diameter (increases).
4. Bell jar and marshmallows	Pressure, volume, atmospheric pressure	Vacuum pump, bell jar, marshmallows	Place marshmallows in bell jar and vacuum out the air. Marshmallow (mostly air) volume expands due to lack of atmospheric pressure.

5. Escaping Gases	Effusion, mass	2 round identical balloons, two different gases with different molar masses to fill balloons, tape measure	Fill one balloon with one gas, then the other balloon to equal diameter with the other gas. Next day, measure diameter of each balloon. The larger the mass of the gas particles, the slower they diffuse
6. Soda Hot Rod	Temperature, pressure, volume, solubility	2 liter of diet soda (easier clean up),metal rod which fits in 2 liter bottle, lab burner, large pan	Place unopened 2 liter in large pan; heat rod; have student open 2 liter and drop in rod; stand back. Heat from metal rod causes temperature of solution to increase, gas solubility decreases w/ increase in temp (gas also becomes less dense)
7. Can Crusher	Temperature, pressure, volume	Hot plate, water, soda can, tongs, large bowl of ice	Add about 15 ml of water to empty soda can, heat until boiling, invert can into bowl of ice;
8. Marshmallow Mafia (marshmallows under pressure)	Pressure, volume, compressibility of gases	Marshmallows, syringe, syringe cap, water Peeps are great substitutes	Remove plunger on syringe, place marshmallow inside, cover end with cap and press down; New marshmallow in syringe, push plunger in, add cap, pull plunger out; Fill syringe with water and try to compress
9. Invisible Gas	Diffusion, occupy space of container	Ammonia, water, "fish tank", phenolphthalein,	One beaker contains ammonia, another contains water with a drop of phenolphthalein; place both under the fish tank and the water/phenolphthalein forms a pink ring at the surface; ammonia gas fills its container and interacts with the phenolphthalein in the water
10. Pop Your Top	Pressure, volume,	Goggles! Fugi film canister, Alka-Seltzer tablet, water	Half fill film canister with water, add crushed Alka-Seltzer, immediately add lid and stand back; carbon dioxide gas formed in reaction exerts so much pressure it pops the top off the canister

11. Hot and Cold Medicine	Temperature, volume	Syringe, hot plate, 2 beakers, ice, water (syringe can be replaced with a balloon)	Heat one beaker of water and add ice to another beaker of water. Note volume of air in syringe. Place syringe in each water sample and compare. Volume increases in warm water, decreases in cold
12. Dippy Bird	Vapor pressure, diffusion	http://www.howstuffworks.com/question608.htm	See site
13. Ketchup Torture	Pressure, volume	2 liter pop bottle, syringe, ketchup packet, fizz keeper	Fill 2 liter with water; drop in ketchup packet; add air to syringe and drop in 2 L; Pump fizz keeper; as air is pumped out (pressure decreases) packet expands
14. Balloon in a Bottle version 1		2 liter, balloon, water, nail, hammer	Slip the balloon inside the neck of the bottle and stretch the mouth of the balloon over the bottle top. Take a deep breath and try to blow up the balloon inside the bottle. Remove the balloon, fill the soda bottle to the brim with water, and then seal it with a cap. Punch a small hole with a nail and hammer in the side of the bottle, close to the base. Remove the nail, uncap the bottle, and empty the water out the top. Place the balloon in the bottle again (Step 1) and try to blow up the balloon. Quite a difference! Blow hard until the balloon fills most of the bottle (a little water left in the bottle helps). Place a finger (or thumb) over the nail hole when you stop blowing. Now, move your finger.
15. Bottle Temperature	Temperature, volume, pressure	Aquarium thermometer, 2 liter, fizz keeper	Place thermometer in 2 liter and observe temp; pump fizz keeper 10 times and observe temp; repeat

16. Balloon in a bottle version 2	Temp, volume, pressure	Balloon, Erlenmeyer flask, hot plate, water	A small amount of water is heated in the flask to boiling; the flask is removed from the heat and a balloon is placed over the opening; as the water vapor condenses the balloon is pushed into the flask
17. Depressing Headlines	Air pressure	Newspaper, old yard sticks or wood of similar size	A yard stick is placed under a newspaper that is spread out to increase surface area; about 20 in of yard stick extends over edge of table; student "karate chops" the end of the yard stick and it should break where the paper is holding it down (about 300 psi on ruler vs. 9000+ psi on paper)
18. Potato gun	Pressure, volume	http://www.stevespanglerscience.com/experiment/00000147	See site—basically a ramrod is used to push air which launches the potato

Gas Station Lab

The Gas Station lab is a series of mini-activities performed by the students. While no math is used, students are to determine why each observed phenomenon occurs and relate their explanation to gas pressure, volume, temperature, amount, or characteristics of an ideal gas. This has been successful as an introductory activity (which we keep referring back to) and as an assessment activity. Each station is set up at its own lab table, so the students travel. Directions for each station can be found below. For the materials required at each station, please refer to the list above. All activities should be performed by the teacher prior to assigning the activities to students. Students should be wearing aprons and goggles at all times.

The Can Crusher

There should be cans with water already steaming on a hot plate, but if not the add 10-15mL to an empty soda can and place it on the hot plate. Turn the hot plate on high and observe the opening in the top of the can. As soon as you see steam coming out of the top of the can, use the beaker tongs to quickly a) dump the hot water in the sink and then INVERT and SUBMERGE the can in the tub of ice water.

a. What happens?
b. As the can is being heated, what replaces the air in the can?
c. Before moving on to the next questions, set a can of water with 15 mL of water on a hot plate for the next group
d. Compare the gas pressure in the can with atmospheric pressure outside the can:
   1. BEFORE you immerse it in the ice water.
   2. AFTER you immerse it in the ice water.
e. What causes the pressure inside the can to decrease and what does this indicate about the relationship about between gas pressure and temperature?
f. Which postulate or law was observed?

Marshmallow Mafia (Mallows under Pressure) Choose 2 marshmallows and draw a face on each. Remove the plunger on the syringe, and place a marshmallow inside. Cover the end of the syringe with the syringe cap and press down on the plunger.

a. What happens? Use words AND draw the face.

Repeat with a new marshmallow, but this time place the marshmallow inside the syringe (NO CAP yet), push the plunger in until it is just touching the top, and *then* cover the end of the syringe with the syringe cap. Pull the plunger out.

b. What happens this time? Use words AND draw the face.
c. Explain in detail what happens to the marshmallow as you change the position of the plunger. What does this tell you about the relationship between pressure and volume?
d. Which postulate or law was observed?

REMOVE YOUR MARSHMALLOWS

Invisible Gas

Under the aquarium, there is one beaker (beaker #1) containing a liquid. Please do not touch it. IF the liquid is NOT colorless, tell your teacher immediately so she can get another sample for you to use. Take the empty beaker (beaker #2) from the table, fill it about half way with water, and put 2 drops of "solution A" into it. Place it under the aquarium next to Beaker #1.
Observe for 5 minutes. After you are finished, remove Beaker #2, rinse it in the sink and leave it on the table for the next group. Leave Beaker #1 under the large container.

a. What did you observe?
b. What is the probable identity of the chemical in solution A based on how it reacted in the aquarium (you don't need to know the EXACT chemical, but the TYPE of chemical)?
c. Make a drawing describing what you think occurred. Please use labels when needed.
d. What does this experiment tell you about the properties of gases?
g. Which postulate or law was observed?

Escaping Gases

Pick up and observe each balloon. Use all of your senses to observe them carefully.

a. What did you observe for each balloon?
b. Is there an odor coming from any of the balloons? If so, why is this happening? What does this indicate about the molecules producing the odor, and what does it indicate about the molecules making up the balloon's walls?
c. For one of the balloons, make a drawing describing what is occurring on a molecular level. Find the term in that describes this phenomenon.
d. Which postulate or law was observed?

Pop Your Top

MAKE SURE EVERYONE AROUND YOU IS WEARING GOGGLES! Fill the film canister about half full with water. Crush or crumble an antacid tablet. Quickly put the lid back on, and STAND BACK.

a. What did you observe?
b. What properties of gas resulted in the popping of the top?
c. Write the balanced chemical equation for this reaction (one reactant is water, the other can be found on the label). First an acid was formed then it broke down to a gas.
d. Which postulate or law was observed?

Hot and Cold Medicine

There are 2 containers of water—one cold and one hot. Place the syringe in each container and observe the effects.

a. What did you observe (2 observations, 1 per water temp)?
b. What does this experiment show about the relationship between the volume of a gas and its temperature?
c. Which postulate or law was observed?

Reverse Gas Station Lab—CSI Style

This concept was introduced to me by FLINN presenter Mike Heinz, and one of his variations can be found at http://www.niles-hs.k12.il.us/michei/gaslaw.htm. In order to make the Gas Stations more inquiry based, more interesting, and hold the students more accountable, Mike flipped the concept of Gas Stations around so the students only saw the aftermath. Mike sets the scene by meeting with his students in the hall, providing them with flashlights (because in CSI they never turn the lights on), and covering his door with crime scene tape. They are told they have to determine what led to the demise of Agent 0.0821, whose "body" is lying on the floor of the lab. On each lab table is the remnant of a typical gas station—what you would expect to see if someone performed the activity but didn't clean up. Students are told they will have to explain what occurred at a station, give evidence, re-create the events in front of the class, and explain based on gas laws and kinetic molecular theory. They will not know until the next day (presentation day) which station they will be responsible for showing to the class. Students are given one class period to make observations, try out the stations for themselves, re-create the events that lead to the remnants, and take notes. My students usually need at least 15 minutes per station to really grasp the concepts well enough to be able to explain to a class. The following are suggested activities for the Reverse Gas Stations and what should be left on the lab table:

Soda Hot Rod - rod in a 2 L, a mess of soda, hot plate/burner, another rod, more unopened soda bottles

Can Crusher - can crushed in a bowl of ice held w/ tongs, hot plate, several empty soda cans

Marshmallow Mafia - squished and elongated marshmallows (drawing faces before distorting helps clarify) and syringe, several extra marshmallows

Invisible gas - beakers labeled to contain water and phenol, beaker w/ unknown liquid (ammonia), upturned fish tank

Pop your top - open fugi film container containing left over products, a mess on the desk, cap a distance from bottom of canister, extra Alka-Seltzer tablets

Balloon in a bottle version 2 - Erlenmeyer flask containing "blown up" balloon and water, hot plate, additional balloons and flasks

Depressing headlines - sheet of spread out newspaper with broken yard stick; extra yard sticks and newspaper

Demonstration Suggestions:

Any of the examples in the list make fine demonstrations (particularly the potato gun). The students perform them in one of the stations labs. If the chapter is introduced with one of the Gas Station Lab activities, the example can be used again as a demo in order to gauge growth of conceptual understanding.

Assessment Ideas

Any of the examples listed in the procedure can be used for both formative and summative assessment. Students should be able to identify which variables are being manipulated in each example, focus on the relationship between the variables (inverse, direct, no relationship), and predict the effect on one or more variables if a variable is changed. Each example also reinforces the mathematical equations associated with each gas law; therefore numerical values could be associated with several of the examples and used for predicting changes in variables.

The examples above do more than just clarify gas laws—they also can be used to infer/reinforce ideal gas assumptions and characteristics of a gas. To assess students overall understanding of these concepts, FLINN has an activity called "Life on Planet V". Students are told to imagine they are relocated to Planet V, a planet just like Earth, but with no atmosphere at all. They are given a list of a series of devices (follows) and asked how these devices work on Earth, which would still work on Planet V, would they work the same, and could modifications be made for those which would not work? Example items are: suction cup, candle, match, flashlight, paper airplane, vacuum cleaner, water squirt gun, helicopter, baseball and bat, golf, parachute, swing, helium balloon, air bag, blow dryer, Frisbee, dynamite, drinking straw, broom, paint, bicycle, bicycle pump, flag, light stick, plant, bow and arrow, smoke detector, and syringe. The purpose is not to get the "right" answers, but to get the students thinking and talking about air, what it is made of, atmospheric pressure, and tie in the science.

Kinetic Molecular Theory and Gas Laws

Activity #4 – Determining the Ideal Gas Constant

Questions to be investigated

How are pressure, volume, temperature, and amount of a gas related?

Objectives

Determine the value of the Ideal Gas Constant (R) by gathering data to first determine the value of P, V, n, and T then applying the data to the Ideal Gas Equation.

Teacher Notes

Prepare 3.0 M HCl by adding one part 12.0 M HCl to three parts distilled water

Precut strips of magnesium ribbon approximately 1 cm in length

The student who adds the HCl to the graduated cylinder should be wearing gloves. The same student can also invert the graduated cylinder in the beaker.

The constructed copper wire cages must be wrapped tightly enough to secure the strip of magnesium. Students may find it useful to test their Mg + cage in the beaker of water before using it in the experiment. The wire cages can be re-used.

Although the magnesium ribbon should be completely consumed by the HCl, there is a possibility that some will remain. If so, mass the remaining Mg and subtract the remaining amount of Mg from the initial amount of Mg to determine the amount of Mg that reacted.

The atmospheric pressure of the laboratory can be determined if a barometer is available. However if no barometer is available, and approximate value for the atmospheric pressure of the area can be found on The Weather Channel website (www.weather.com). Choose "metric" for the units.

Waste disposal: Have students dilute the contents of the beaker and, with more water, pour the liquid down the drain. Then they should rinse and dry the beaker. Dispose of excess 3.0 M HCl by pouring it into a beaker of cold water and neutralizing the acid with solid sodium carbonate or bicarbonate. Pour the neutralized solution down the drain. Retain the copper wire for other uses.

Suggestion:

This lab can be performed with any metal that is above copper and hydrogen on the Activity Series, such as iron, aluminum, calcium, and zinc. Different groups can try different metals and compare R values.

Upper level students with extended math capabilities should be able to determine the values of P, V, n, and T with little instruction. Be sure to emphasize the units used in the ideal gas equation for the accepted value of R (different units yield different values of R). As a matter of fact, students can simply be instructed to derive the information required to determine R based on the data collected from this investigation; in other words, give them no direction for calculations except to find R by showing the work and justifying their thought process.

A completely inquiry version of a lab very similar to this one, but using less corrosive chemicals, can be found at http://teacherknowledge.wikispaces.com/Gas+Constant+Inquiry+Lesson

Materials

Per lab team
Magnesium ribbon (about 1 cm per team)
10 cm of thin-gauge copper wire
One-hole rubber stopper to fit graduated cylinder
Graduated cylinder, 10 mL
Beaker, 400 mL
Room temperature water
Gloves (for the student inverting the graduated cylinder)
3 M Hydrochloric acid
Wash bottle of de-ionized water
Thermometer
Laboratory balance
Table of vapor pressures of water
Method of determining atmospheric pressure (in room barometer would be ideal)
Goggles, Aprons

Safety Concerns

Wear goggles and lab apron at all times. Hydrochloric acid (HCl) is corrosive. Avoid spills and contact with your skin and clothing. If HCl comes in contact with your skin or clothing inform the teacher and flush the acid with large quantities of water. Neutralize any acid spills on the work surface with baking soda. When inserting the stopper into the graduated cylinder, tap it down gently to avoid breaking the top of the cylinder.

Real-World Connections

What pressure do I need to store helium at to fill a balloon, if my helium tank is this volume? How many balloons can I fill with a tank at this pressure and volume?

How much air is available in a diving tank at this volume and pressure? Will the tank break if it heated too much at this pressure and volume?

Why do compressed containers (like shaving cream) burst open when put on an airplane? Why do shampoo bottles pop open?

In international soccer competitions, the ball's mass must be between 450 -410 g, and pressure must be between 0.6-1.1 atm. How does the amount of air or air temperature affect these values?

Sources

Prentice Hall Lab Manual Chemistry: Connections to Our Changing World, 1996

Procedure / Description of Lesson

Introduction:

The ideal gas law is represented by the formula PV = nRT, where R is the ideal gas constant. In this laboratory investigation you will experimentally determine the value of R. To do this, you must first determine the values of the other variables in the ideal gas equation. You will generate and collect a sample of hydrogen gas and determine the number of moles, pressure, volume, and temperature produced under laboratory conditions.

The hydrogen gas is generated in a graduated cylinder from the reaction between magnesium and hydrochloric acid. By wrapping the magnesium ribbon in a copper wire cage, you can ensure that the magnesium ribbon will remain in the acid environment. Hydrochloric acid is in excess in the reaction so that the moles of hydrogen gas produced may be determined from the moles of magnesium that react.

Procedure:

1. Wear goggles and aprons
2. Mass the provided strip of Magnesium.
3. Wrap the copper wire around the magnesium ribbon, making a cage that surrounds the ribbon. Leave a handle of copper wire approximately 6 cm long. The idea here is to secure the magnesium ribbon so it does not float freely in the graduated cylinder.
4. Insert the handle end of the copper wire into the one-hole stopper. When the stopper is inserted into the graduated cylinder (in step 8), the copper wire cage and Mg ribbon will be inside the cylinder.
5. Fill the 400 mL baker or other container approximately half full with room temperature water.
6. While wearing gloves, add approximately 3 mL of 3.0 M Hydrochloric acid to the graduated cylinder. CAUTION: HCl is corrosive. Avoid contact with skin or clothing. Flush any spills with water and notify your teacher.
7. Using the wash bottle of deionized water, drizzle water down the inner side of the graduated cylinder so to avoid mixing. Because HCl has a greater density than water, the acid will remain at the bottom of the cylinder. Add enough water to fill the graduated cylinder, BUT keep in mind that you will be adding the rubber stopper do not fill all the way to the top.
8. Insert the stopper into the graduated cylinder by tapping gently so as to avoid cracking the cylinder. The copper wire cage should be suspended at the top of the cylinder. Holding your gloved finger over the hole in the rubber stopper, quickly invert the cylinder into the beaker of water. When the top of the cylinder is underwater you may remove your finger. Hold the graduated cylinder vertically in the beaker.

9. Notice the appearance of the acid solution inside the cylinder. Record any indication of a chemical reaction.
10. When the Mg ribbon is no longer reacting, tap the side of the cylinder to release any trapped bubbles.
11. Let the cylinder sit for 5 minutes. Using the thermometer, read and record the temperature in the beaker.
12. Ask your teacher for the atmospheric pressure in the lab and record. Use the provided atmospheric pressure to determine the water vapor pressure from the provided reference table.
13. Lift the graduated cylinder slightly until the levels of water inside and outside (w/in the beaker) are the same.
14. Read and record the volume of gas in the cylinder. Remember that you are reading an inverted cylinder.
15. Dispose of chemicals as directed by the teacher.

Observations:

Mass of Mg ribbon: ______

Temperature of the reaction system: ______

Atmospheric pressure: ______

Water vapor pressure at system temperature (from table): ______

Volume of gas produced: ______

Water Vapor Pressure Table

Temperature (°C)	Pressure (mmHg)	Temperature (°C)	Pressure (mmHg)	Temperature (°C)	Pressure (mmHg)
0.0	4.6	19.5	17.0	27.0	26.7
5.0	6.5	20.0	17.5	28.0	28.3
10.0	9.2	20.5	18.1	29.0	30.0
12.5	10.9	21.0	18.6	30.0	31.8
15.0	12.8	21.5	19.2	35.0	42.2
15.5	13.2	22.0	19.8	40.0	55.3
16.0	13.6	22.5	20.4	50.0	92.5
16.5	14.1	23.0	21.1	60.0	149.4
17.0	14.5	23.5	21.7	70.0	233.7
17.5	15.0	24.0	22.4	80.0	355.1
18.0	15.5	24.5	23.1	90.0	525.8
18.5	16.0	25.0	23.8	95.0	633.9
19.9	16.5	26.0	25.2	100.0	760.0

Calculations:

In order to the algebraic equation PV = nRT to solve for R, you must first find the values of P, V, n, and T.

1. Determine n (number of moles of Hydrogen gas produced)
   a. Write the balanced chemical equation for the reaction between Mg and HCl
   b. Determine the number of MOLES of Hydrogen produced using the starting amount of reactants. Assume HCl was in excess.
2. Determine the value of P in ATMOSPHERES (pressure of the Hydrogen gas produced). Calculate the pressure of H_2 gas collected by subtracting the water vapor pressure from the atmospheric pressure. If needed, convert unit of pressure to atmospheres.
3. Determine the value of V (volume of Hydrogen gas produced) in LITERS.
4. Determine the value of T (temperature of Hydrogen gas produced) in KELVINS.
5. Using the determined n, P, V, and T, calculate the observed value of the gas constant where R = PV/nT. Include all units in your answer.

Analysis and Conclusion Questions:

1. What evidence of a chemical reaction did you observe?
2. At the end of the reaction, how did the appearance of the copper wire compare with that of the magnesium ribbon? What can you conclude about the effect of HCl on copper wire?
3. Using the accepted value for the ideal gas constant and the observed value (calculation 5), determine the percent error for [100% **x** (accepted – observed)/accepted]. Accepted value = 0.0821 atmL/molK
4. Provide suggestions as to why the observed value of R differed from the accepted value of R. Explain the possible sources of experimental error in this investigation and the effect the error may have on the results.
5. If all other conditions remained the same, how would the value of R be affected if your investigation made use of a gas other than hydrogen? Explain.

Answer Key:

Calculations:

Calculation 1: mass of Mg x (1 mole Mg/molar mass Mg) x (coeff of H2/ coeff of Mg) = moles of H2

Calculation 2: atmospheric pressure – water vapor pressure = pressure of H2;

If these pressures are in mmHg, convert to atm with the unit equality 1 atm = 760. mmHg

Calculation 3: Remember the graduated cylinder was inverted! Convert to Liters using 1000 mL = 1 Liter

Calculation 4: if the temperature obtained from the thermometer is in Celsius, convert to Kelvin using K = degree Celsius + 273

Calculation 5: It is recommended that students first rearrange the variables of the ideal gas equation to solve for R before plugging in values [R = (PV)/(nT)] Their units should be (atm x Liters) / (mol x K)

Analysis and Conclusion Questions

Question 1: bubbles appeared near the magnesium, heat was generated, Mg disappeared

Question 2: copper wire appeared unchanged. It did not take part in the reaction. Copper does not react w/ HCl b/c Cu is below H on the activity series

Question 3:

Question 4: sources of error include the following: experimental error in the measurements of the volume, temperature, and pressure of the gas; small sample of gas generated; escaped pieces of Mg that did no react

Question 5: The value of R would not change. It is dependent on the values of the pressure, temperature, volume, and number of moles of the gas. Under the same conditions, these variables would be the same for any gas.

Assessment Ideas

Calculate values using ideal gas law equation

Determine relationship of each variable based on ideal gas law equation and make predictions

How would increasing (any of the variables) affect the R valued determined in the lab?

How would the accepted expression for R change if the unit was Pa L / mol ^{o}C?

Was the hydrogen gas generated in the lab an Ideal Gas? Explain by comparing characteristics of a real gas and an ideal gas.

Under which conditions is a real gas most like an ideal gas?

Under which conditions is a real gas most unlike an ideal gas?

Which of the following gases would you expect to deviate most from ideal behavior: O_2, He, H_2, H_2O, N_2, HCl, NH_3? Consider intermolecular attractions.

Kinetic Molecular Theory and Gas Laws

Activity #5 – Testing for Dissolved Oxygen

Questions to be investigated

What is the relationship between solubility of a gas and temperature?

Is the there enough of a difference in the amount of dissolved oxygen of the water samples to cause damage to the fish?

Objectives

Collect and analyze data to determine the relationship between solubility of a gas and temperate

Measure the concentration of oxygen in a sample of water

Graph the relationship between the concentration of a gas and temperature

Infer a general rule of thumb for gas solubilities and temperature

Relate changes in gas solubility to a fish kill

Teacher Notes

Lab could be modified to allow students to determine which characteristic of the fish environment is the likely cause of death. Provide students with enough detail of the characteristics of the dead fish so that students could research the cause of death, and then reach the conclusion that oxygen deprivation is the likely cause. Keep in mind, too much oxygen can also kill the fish. Suggestions for student investigation would be water temp and dissolved oxygen, rainfall, water flow, dissolved molecular substances, carbon dioxide levels, heavy metals, pH, nitrate and phosphate levels, and organic carbon.

Be sure the jars used are heat resistant

Do not use dissolved oxygen test kits that make use of the Winkler method or other titrimetric methods, because of the dangerous chemicals and the difficulties related to disposal.

Explain that to prevent the oxygen content from changing as the samples change in temperature, it is important to keep them sealed in containers that are almost entirely full and free of air. The refrigerated water sample must come to room temperature before testing.

Demonstrate the use of the dissolved oxygen test procedure you will use.

Disposal: The water samples may be rinsed down the drain. If using dissolved oxygen kits, follow manufacturer's disposal methods.

Materials

- Ice, 200 g
- 600 mL beaker
- Beaker tongs
- Hot mitt
- Jars with screw on lids, 4
- Bunsen burner
- Gas tubing
- Ring stand
- Ring clamp
- Sparker
- Wire gauze with ceramic center
- Hot plate (optional)
- Thermistor probe (optional)
- Alternate option:
- Dissolved oxygen test kit with 4 test ampoules, or dissolved oxygen meter
- Thermometer

Safety Concerns

Always wear safety goggles and a lab apron to protect eyes and clothing. If you get a chemical in your eyes, immediately flush the chemical out at the eyewash station while calling to your teacher. Know the location of the emergency lab shower and eyewash station and the procedure for using them

When you use a Bunsen burner, confine any long hair and loose clothing. Do not heat glassware that is broken, chipped, or cracked. Use tongs or hot mitt to handle heated glassware and other equipment because hot glassware does not look hot.

Always clean up the lab and all equipment after use, and dispose of substances according to proper disposal methods. Wash your hands thoroughly before you leave the lab after all lab work is finished.

Real-World Connections

Why do small bubbles appear just before water is about to boil?

If global warming is actually occurring, what is the potential impact on the ecological stability water environments?

Would using a nuclear power plant instead of a traditional power plant not affect water temperature?

Why do most aquariums monitor water temperature?

Why is pop kept in a refrigerator?

Sources

Holt Chemfile C Inquiry Experiment Modern Chemistry 2004 Holt, Rinehart, and Winston

Procedure / Description of Lesson

Situation

The company you work for has been hired as an expert witness in a lawsuit. The local chapter of Bass Anglers Unlimited has been disturbed by recent declines in the population of bass in Pulaski Lake. There have been several fish kills, in which large numbers of fish have died at the same time and floated to the surface of the lake, creating a terrible smell and fouling the water. The anglers claim that the fish kills begin shortly after the R. C. Throckmorton Power Plant came on line, and they are seeking a court order to shut down the plant. The machinery in the power plant uses water from the lake as a coolant and then returns the water to the lake.

The anglers say that something in the returned water is killing the fish. The utility company operating the power plant points out that they use a closed system that prevents the water from coming into direct contact wit the machinery in the plant. They say that the water is just as pure when it comes out as when it goes in; it's just a little warmer. The court has asked you to investigate whether there is a scientific basis for the anglers' claim.

Background

Fish rely on the oxygen dissolved in water to live. The water passes through their gills, which remove the oxygen. The less oxygen in the water, the harder the gills have to work to get enough oxygen to keep the fish alive. The normal lake temperature is between 15oC and 17oC. Another witness, a biology professor specializing in ichthyology (the study of fish), has testified that if the oxygen content of the water dips below 90% of the normal value at these temperatures or rises above 113% the normal value at these temperatures, the fish will suffer long-term damage or death. The temperature of the water returned to the lake from the power plant is 28oC. To measure the change in dissolved-oxygen content over this temperature range, you can use tap water, which has a mineral content similar to that of lake water.

Problem

In order to evaluate these claims, you will need to do the following:

Prepare water samples at several different temperatures

Measure the dissolved oxygen content in parts per million, ppm, for each one

Graph the relationship between temperature and the solubility of dissolved oxygen

Extrapolate to determine the solubility of dissolved oxygen at 16oC and 28oC

Compare the solubilities to determine if there is enough difference to cause damage to the fish

Procedure

Part 1: preparation

1. Use the data table to record your results
2. Label four jars ice water, room temp, 50°C, and 100°C

Part 2: sample preparation

Data Table		
Water	Temperature (°C)	Dissolved O_2 (ppm)
Ice water		
Room temp.		
50°C		
100°C		

3. Add approximately 50 g of ice to 100 mL of tap water in the ice water jar. Let the ice water mixture stand for 5 min. Measure its temperature with a thermometer or a thermistor probe to the nearest 0.1°C. The temperature should be near 4°C. Record the temperature in the Data Table. Add more ice until the jar is filled to the rim. Screw on the lid and place the sample in an ice chest or refrigerator overnight.
4. Fill the room temp jar with tap water. Leave the jar open. Let it sit out overnight where it will not be disturbed. You will measure the temperature of this sample tomorrow.
5. If you are using a Bunsen burner, set up the right stand, ring clamp, and wire gauze over the burner so that they will hold a beaker. If you are using a hot plate, continue with step 6.
6. Pour approximately 450 mL of tap water into a 600 mL beaker, and gently heat it to about 50°C. Maintain 50°C as closely as possible for 5 min. Measure the temperature of the water with a thermometer or a thermistor probe to the nearest 0.1°C. Record the temperature in the Data Table. Using beaker tongs to hold the

hot beaker, carefully fill the jar labeled 50^{o}C with the warm water. Fill the container to the rim. Screw on the lid, and store the jar in a safe place.

7. Heat the remaining water to boiling (approximately 100^{o}C). Allow the water to boil for about 30 min. Measure the temperature of the water with a thermometer or a thermistor probe to the nearest 0.1^{o}C. Record the temperature in the Data Table. Using beaker tongs to hold the hot beaker, carefully fill the jar labeled 100^{o}C with the boiling water. Fill the container to the rim. Using a hot mitt, screw on the lid and store the jar in a safe place.

Part 3: Sample Testing

8. On the following day, retrieve your samples. Allow the refrigerated water sample to come to room temperature with the lid on.
9. Measure the temperature of the water in the room temp jar with a thermometer or a thermistor probe to the nearest 0.1^{o}C. Be sure to disturb the water as little as possible. Record the temperature in the Data Table.
10. If you are using a dissolved oxygen probe or meter, it may be necessary to calibrate it using a standardized solution. Ask your teacher for instructions. If your teacher indicates this is unnecessary, continue with step 11.
11. Disturbing the water as little as possible, measure the dissolved oxygen content of each sample, and record the value to the nearest 0.1 ppm in the Data Table. If you are using a dissolved oxygen test kit, you will be comparing the colors of standard solutions to the colors of your tested solutions. Estimate the measured concentrations to the nearest 0.5 ppm.

Disposal

If you used chemical test kits, dispose of the ampoules and reactants in the containers designated by your teacher. Rinse the samples down the drain. Clean all equipment.

Analysis and Conclusion Questions

1. Organizing Data: Make a graph of your data, with a temperature (in ^oC) plotted on the horizontal axis and O_2 concentration (in ppm) plotted on the vertical axis. Draw a straight line that best fits the data.
2. Interpreting graphics: Refer to the graph from question 1, and explain in your own words the relationship between temperature and the solubility of oxygen in water.
3. Analyzing methods: Why was it important to disturb the water as little as possible when measuring the dissolved-oxygen content?
4. Applying methods: Often, when water is heated, small bubbles appear long before boiling begins. Explain why these bubbles form (Hint: use the concept of solubility in your explanation).
5. Interpreting graphics: Using the graph from question 1, interpolate to determine the concentration of oxygen in the water at 16^oC and at 25^oC.
6. Interpreting graphics: Using the format shown below, determine the equation for the line you drew on the graph in question 1. (Hint: if you have a graphing calculator, use the STAT mode to enter your data and make a linear regression equation using the LinReg function from the STAT menu).

   Oxygen concentration = m(temp) + b
7. Analyzing conclusions: Calculate the expected concentration of oxygen in the water at 16^oC and 28^oC using the equation determined from question 6.
8. Evaluation conclusions: Earlier in the trial, the ichthyologist testified that fish receiving less than 90% or more than 112% of the oxygen normally available at 16^oC would suffer long-term damage. From questions 5 and 7, determine whether between 90%-112% of oxygen available 16^oC is available at 28^oC. Is it likely that the water is damaging the fish?
9. Evaluating conclusions: During cross-examination, the attorney for the power plant suggests that, because you tested tap water instead of water taken directly from the power plant, your solubility results are irrelevant and the power plant's water could have even more oxygen in it than the original cold water. Is the attorney correct? Why or why not?
10. Evaluating conclusions: Later in the cross-examination, the attorney for the power plant asks whether your results establish conclusively that fish died because of warmer water and for no other reasons. What do you say?
11. Designing Experiments: Assuming that you had unlimited laboratory resources and access to all of the lake, what other tests would you perform to be more certain of your results?

12. Evaluation methods: The judge has asked for the opinions of all expert witnesses about a proposed settlement. The power plant proposes to insert a device to bubble oxygen through the warm water as it is released into the lake. Will this solve the problem? Explain why or why not, using the principles of solubility.
13. Related ideas: The power plant supplies thousands of households with their electricity. The judge has asked for possible solutions that will keep the power plant working and prevent further damage to the fish. What do you suggest?

Answer Key:

Question 1:

Question 2: As the temperature increases, the solubility of oxygen decreases.

Question 3: if the water had been disturbed, bubbles could have trapped some oxygen.

Question 4: As temperature increases, the amount of gas that the water can hold decreases. Any amount of gas that is no longer soluble forms bubbles.

Question 5-7 varies with graph

Question 8: determine graph ppm O_2 and equation ppm O_2; answers will vary; Answers should show warm water does not have enough oxygen for fish.

Question 9: The attorney is incorrect because solubility will follow the same general pattern for all samples of water, whether taken from the tap or not.

Question 10: These tests do not conclusively establish that the fish kills were due solely to the water. They establish only that this warm water could be harmful to fish.

Question 11: Answers will vary. Students may suggest testing the water at the plant and in the lake and dissecting the dead fish.

Question 12: This will not work because the water will not be able to keep this additional oxygen dissolved at the warmer temperatures and it will simply bubble away

Question 13: Answers will vary. Students should indicate some way to restore water to its original temperature or not to return it to the lake at all. Some students may suggest pouring the coolant water into containment ponds or tanks to cool off before being returned or recirculated.

Assessment Ideas

Relate the effect of temperature and pressure on a gas to the model of a gas given by the kinetic molecular theory.

Relate temperature of a given amount of gas to its density. Re-explain how temperature affects solubility of a gas by incorporating density of the gas.

Use demos from activity 3: Escaping gases, invisible gas

Kinetic Molecular Theory and Gas Laws

Activity #6 – Diffusion of Two Gases

Teacher Notes

Suggestion to increase inquiry level and focus on the concept of the relationship between mass and rate: Rather than providing the students with the introduction (see procedure), you may want to start the day before with a brief demonstration. Using two balloons fill one with air and the other with helium. Ask students to predict how the balloons will change in the next 24 hours. Measure the diameter of each. The next day, the helium balloon should have lost a larger percent of the contained gas than the balloon filled with air. This leads directly into concept covered in the lab. Prior to the lab, explain to the students that they will be observing a reaction between a strong acid and a strong base. If students are already familiar with acid-base reactions, they will already know to look for the formation of a salt. If students have not observed acid-base reactions prior to this point, a quick demonstration in the fume hood will demonstrate salt formation. Focus student discussion on the movement of gases: while particles of any gas are in constant random motion, why do some types of gas particles move at a quicker rate than others?

In order to see a ring appear within 5 minutes, use 6 M solutions of hydrochloric acid, ammonia, and sodium hydroxide need to be used. 3 molar solutions will also work, but it will take more time for the reaction to occur. Prepare all solutions in a fume hood, and store stock solutions COVERED in the fume hood.

Prepare cotton swabs in the fume hood. Using a marker, assign a color to each chemical and mark one end of several cotton swabs. In this lab, green is used for ammonia, red for hydrochloric acid, and yellow for sodium hydroxide. Dip the cotton swabs in solution just before students are ready to pick them up.

Materials

Gloves
Clear, colorless plastic straw
Cotton swab
Marking pen (fine-tip Sharpies work well)

Safety Concerns

Wear goggles and aprons at all times in the laboratory. Gaseous ammonia (NH_3), sodium hydroxide (NaOH) and hydrogen chloride (HCl) molecules are irritating to skin, nasal passages, and eyes. Hydrochloric acid solution is corrosive. Wear gloves. Do not sniff these solutions. Do not let these solutions contact your skin or clothing. When the cotton swaps containing these solutions are no longer needed, deposit them in the assigned beaker, in which water will be used to dilute the chemicals.

Real-World Connections

Why do balloons filled with helium deflate more quickly than balloons filled with air?

Graham's law was used in WWII to extract uranium-235 for use in nuclear reactions

Why is nitrogen added to "high-performance" tires?

Sources

Adapted and modified from Prentice Hall Lab Manual *Chemistry: Connections to Our Changing World*, 1996

Procedure / Description of Lesson

Introduction

Have you ever noticed how quickly a helium balloon deflates? A common latex balloon filled with helium will lose much of its gas overnight, yet the same balloon filled with air will remain inflated for several days. Why is this so? The kinetic-molecular theory states that gases consist of tiny particles in constant random motion. These particles have mass, and they frequently make elastic collisions with each other and the walls of their container. Different gases, however, differ in the rate at which they are able to move among each other (diffusion) or through tiny openings (effusion), such as a hole in a balloon.

Thomas Graham recognized that the different rates of movement of gas particles at constant temperature are related to the molar masses of the gases. Graham's law compares the rates of diffusion or effusion of any two gases as follows: Under constant temperature and pressure, the rate of diffusion or effusion of two gases is inversely proportional to the square roots of their molar masses. Mathematically, Graham's law may be expressed as a ratio:

$$(m_1 / m_2)^{1/2} = r_2 / r_1$$

In this formula r_1 is he rate of diffusion (or effusion) of a gas and r_2 is the rate of diffusion (or effusion) of a second gas. Similarly, m_1 and m_2 are the respective molar masses of the two gases.

In this laboratory investigation, you will compare the rates of diffusion of ammonia and hydrochloric acid, and sodium hydroxide and hydrochloric acid. These gases react to form a white salt that appears as a ring in the reaction tube. By measuring where the salt ring forms, you will be able to use Graham's law to find the relative rates of diffusion of the gases.

Procedure:

1. On your table should be a pair of gloves for each student participating in the lab, tray, a straw, a beaker, and a fine-point permanent marker. One student should ½ fill the beaker with water, and one student should bring the tray over to the fume hood to obtain a pair of cotton swabs. For your first trial, use the swab with the green dot (ammonia) and the swab with the red dot (hydrochloric acid). Note that each swab has a wet end and a dry end marked with a particular color of dot. Use the tray to transport the cotton swabs back to your lab table.
2. Using a fine point permanent marker, mark the straw at the points approximately 2 cm from the ends. These marks represent the starting points from which the gases will diffuse. Measure and record the total distance between these two marks.
3. While one person holds the straw steady, another person should simultaneously insert the two swaps in opposite ends of the straw. The swabs should penetrate to the points you previously marked.
4. Watch for the formation of a white aerosol ring inside the tube. Mark this point with the sharpie. The ring consists of tiny crystals of ammonium chloride (NH_4Cl). Measure and record the distance traveled by the HCl gas from its initial mark to the point where the ring forms. Do the same for the NH_3 gas.
5. Remove the cotton swabs and immediately place them beaker of water your prepared in step 1. This precaution will minimize the escape of HCl and NH_3 gas into the laboratory. It will also dilute the concentrated solutions and allow them to neutralize each other.
6. Repeat steps 1-5 using a different straw and using cottons swabs with hydrochloric acid (red dot) and sodium hydroxide (yellow dot).
7. Dispose of materials as directed by the teacher. Wash hands with soap and water.

Data Table

Reaction between NH_3 and HCl	Distance (cm)
Total distance between the starting marks	
Distance traveled by the NH_3 gas	
Distance traveled by the HCl gas	
	Distance (cm)
Reaction between NaOH and HCl	
Total distance between the starting marks	
Distance traveled by the NaOH gas	
Distance traveled by the HCl gas	

Analysis and Conclusion Questions:

1. Write a balanced chemical equation to describe each reaction observed.
2. Give a possible reason for the location of the salt ring in each trial.
3. For each trial, calculate the ratio (acid/dbase) of the distances traveled by the gases.
4. Using the molar masses of the gases and Graham's law, calculate the ratio of diffusion of ammonia to the diffusion rate of HCl, and the rate of diffusion of sodium hydroxide to the diffusion rate of HCl.
5. Compare the values calculated for questions 4 and 5. Are these results consistent with Graham's law? Explain with evidence.
6. Suppose the distance between the solutions in the straw is 40.0 cm. Use Graham's law to calculate the distance the ammonia and hydrochloric acid gases would travel before they collide.

Assessment Ideas

Consider a balloon filled with helium and a balloon filled with air. Explain why the balloon deflates more quickly if it is filled with helium than if filled with air.

Compare the rates of loss of helium from a Mylar balloon and a latex balloon.

You are given a container of 1 mole of chlorine gas and 1 mole of argon gas. Both gases are at STP. Your answer choices are "chlorine", "argon", "both are the same", or "neither", and you can indicate your choice by checking the appropriate box.

	Chlorine	Argon	Both are the same	Neither
a. Which sample has FEWER atoms?				
b. Which sample has a greater mass?				
c. Which sample has a greater density?				
d. Which sample has a greater average kinetic energy?				
e. If there was an identical pinhole in both containers, which sample would diffuse the quickest?				
a. Which gas is an ideal gas?				

A Q-tip soaked in NH_3 and another Q-tip soaked in H_2SO_4 are placed in opposite ends of a straw.

a. Will the reaction occur closer to the NH_3 end or the H_2SO_4 end?

b. Explain why the reaction occurred near the end you chose:

c. Which law did you use to determine the answer to this question?