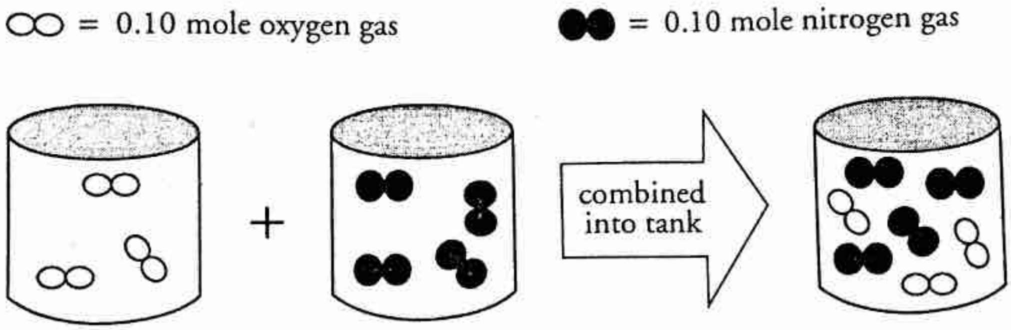
Partial Pressures of Gases

How do mixtures of gases affect the overall pressure?

Why?

It would be nice if chemists only worked with pure samples of gas. However, there is an ever present gas mixture that chemists must consider in all situations—air. When we use air as a source of oxygen for chemical reactions, we must be able to calculate the moles, volume and pressure of the oxygen in that mixture. In this activity, you will learn how to mathematically calculate the pressure of a gas that is present in a mixture of other gases.

Model 1 – A Mixture of Gases



	Tank A	Tank B	Tank C
Volume	10.00 L	10.00 L	10.00 L
Temperature (K)	298 K	298 K	298 K
Moles O_2 gas	0.30 mol	0	0.30 mol
Moles N_2 gas	0	0.40 mol	0.40 mol
Pressure O_2 (atm)	0.73 atm	0	0.73 atm
Pressure N_2 (atm)	0	0.98 atm	0.98 atm
Total Pressure	0.73 atm	0.98 atm	1.7 atm

1. Consider Model 1. What do all three tanks have in common?

They have the same volume

2. Determine the moles of oxygen gas and the moles of nitrogen gas for each tank in Model 1 and enter those values in the table.

3. Use the Ideal Gas Law to calculate the pressure of the oxygen gas in Tank A. Enter that value in the Model 1 table.

$$PV = nRT$$

$$P(10.00L) = (0.30mol)(0.0821 \frac{L \cdot atm}{mol \cdot K}) 298K$$

$$P = 0.73 atm$$

4. Use the Ideal Gas Law to calculate the pressure of the nitrogen gas in Tank B. Enter that value in the Model 1 table.

$$P(10.00L) = (0.40mol)(0.0821 \frac{L \cdot atm}{mol \cdot K}) 298K$$

$$P = 0.98 atm$$

5. Consider the total pressure in Tank C. Propose an explanation for the pressure in Tank C and be prepared to share your reasoning with the class.

The pressure of tank C is the pressure of tank A + B added together

STOP

Read This!

Consider a single oxygen gas molecule in Tank C of Model 1. From its perspective nothing changed when it moved from Tank A to Tank C. The volume available to move in is still 10.00 L. The temperature is still 298 K. It will still hit the sides of the tank just as often and just as hard as it did before it was combined with the nitrogen gas sample, assuming gas molecules are very small. Therefore, the pressure that the group of oxygen molecules exerts in Tank C is the same as the pressure that they exerted in Tank A. However, in Tank C we call the pressure that the oxygen molecules exert against the container walls a **partial pressure** because it is not the only gas contributing to the total pressure of the gas mixture in the tank.

6. Enter the partial pressure values for oxygen gas and nitrogen gas in Tank C of Model 1.

7. Write a mathematical equation to show the relationship between the partial pressures of oxygen gas (P_{O_2}) and nitrogen gas (P_{N_2}) and the total pressure (P_T).

$$P_{O_2} + P_{N_2} = P_T$$

8. With your group, write a statement describing how combining the gases at constant temperature and volume affected the pressure of each gas.

Read This!

Dalton's Law of Partial Pressures states that the total pressure exerted by an ideal gaseous mixture is equal to the sum of the partial pressures of each individual component in the mixture.

$$P_T = P_1 + P_2 + P_3 \ldots \text{or } P_T = \sum P_i$$

9. A chemistry student uses a pressurized tank to add 0.20 atm of a third gas, Gas Z, to tank C in Model 1.

a. What is the partial pressure of the component gases after the addition of Gas Z?

The partial pressure of the components remain the same

b. What is the total pressure in the tank with all three gases present? Show your work.

$P_{N_2} + P_{O_2} + P_Z = P_T$ = 0.73 atm + 0.98 atm + 0.20 atm = 1.9 atm

c. A chemistry student performs a reaction in the tank which consumes all of the oxygen gas. Assuming the temperature and volume of the tank remain constant, determine the partial pressures of the remaining gases as well as the total pressure in the tank. Explain your answer.

10. A scuba tank contains a mixture of oxygen and helium gases. Before the dive, the partial pressure of oxygen gas is 0.65 atm and the partial pressure of helium is 0.38 atm.

a. What is the total pressure in the scuba tank before the dive?

$P_{O_2} + P_{He} = P_T$ 0.65 atm + 0.38 atm = 1.03 atm

b. After the dive, the partial pressure due to the oxygen gas is reduced by 80%. Calculate the final partial pressure of oxygen in the tank.

20% O_2 remains   .20(0.65 atm) = 0.13 atm

c. If the total pressure in the scuba tank after the dive is 0.21 atm, what is the partial pressure of the helium gas? Show your work.

0.21 atm − 0.13 atm = 0.08 atm = P_{He}

Model 2 – Air

Composition of Dry Air		
Nitrogen	78.084%	
Oxygen	20.948%	
Argon	0.934%	
Carbon Dioxide	0.035%	

11. Consider the information provided in Model 2. Discuss with your group how you might illustrate air as a mixture of molecules in the tank in Model 2. Draw a particulate illustration of air.

12. On a particular day, the air pressure in the chemistry lab is 1.137 atm. Discuss with your group how you might perform the following calculations, and then do them. Show your work so that you can refer back to these calculations later.

   a. What is the partial pressure of oxygen in the room on that day?

   $.20948(1.137\text{ atm}) = \boxed{.2382\text{ atm}}$

   b. How many moles of oxygen molecules would be in a 10.0-L sample of air from the room on that day (assume room temperature is 22 °C)? Show your work.

   $PV = nRT$

   $(.2382\text{ atm})(10.0\text{L}) = n\left(0.0821\frac{\text{L}\cdot\text{atm}}{\text{mol}\cdot\text{K}}\right)(295)$

   $\boxed{n = 0.098\text{ moles}}$

13. A student wants to burn a 1.00-g sample of ethanol (C_2H_5OH) in a jar containing air. Assuming the air in the jar is at standard atmospheric pressure and room temperature (22 °C), what volume will the jar need to be in order to hold enough oxygen for complete combustion?

   a. Write a balanced chemical reaction for the combustion of ethanol.

   $C_2H_5OH + 2O_2 \longrightarrow 2CO_2 + 3H_2O$

   b. Calculate the moles of oxygen needed to completely combust the ethanol.

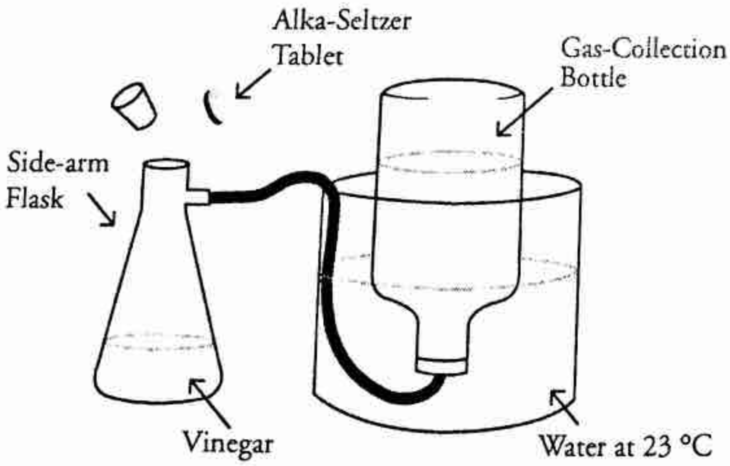
   $1.00\text{g } C_2H_5OH\left(\frac{1\text{ mol } C_2H_5OH}{46.06\text{ g } C_2H_5OH}\right)\left(\frac{2\text{ mol } O_2}{1\text{ mol } C_2H_5OH}\right) = \boxed{0.0434\text{ mol } O_2}$

   c. Calculate the partial pressure of oxygen in the jar.

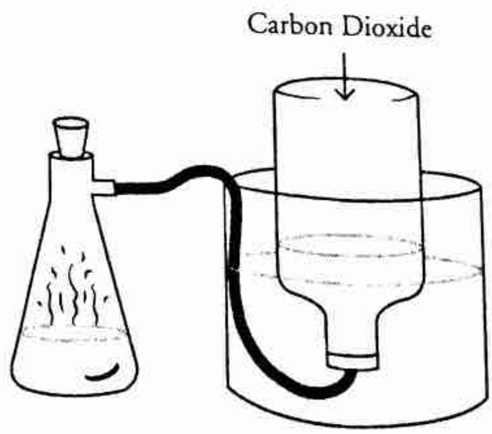
   d. Calculate the volume of oxygen needed in the jar.

Model 3 – Collecting Gases over Water

Before Reaction



During Reaction



14. According to Model 3, what gas is being produced by the reaction in the side-arm flask?

carbon dioxide

15. Describe how the gas is being collected as it is produced in Model 3.

16. Assuming the gas-collecting bottle was initially completely filled with water, what gas(es) are present in the bottle after the reaction? *Hint:* Consider what gas is always present when liquid water is present.

$CO_2(g) + H_2O(g)$

17. Considering your answer to Question 16, write a mathematical equation to show how the total pressure inside the bottle might be calculated using partial gas pressures.

$P_{CO_2(g)} + P_{H_2O(g)} = P_{Total}$

18. The vapor pressure of water is well known, and dependent only on the temperature of the liquid water sample.

Water temperature (°C)	Vapor pressure (mmHg)
20	17.5
21	18.7
22	19.8
23	21.1
24	22.4

a. Use the table above to determine the vapor pressure (and therefore the partial pressure) of water in the gas-collecting bottle in Model 3. Convert the value to atmospheres.

$P_{H_2O} = 21.1\ mmHg\left(\frac{1\ atm}{760\ mmHg}\right) = 0.278\ atm$

b. If the atmospheric pressure in the lab and in the bottle is 0.989 atm, what is the partial pressure of the gas collected?

$P_{CO_2} = P_{total} - P_{H_2O} = 0.989\ atm - 0.278\ atm$

$P_{CO_2} = 0.711\ atm$

c. How many moles of gas would be collected if the volume of the bottle is 1.00 L? (Assume the liquid water that was originally in the bottle has been completely pushed out by gas.)

$PV = nRT \quad 0.711\ atm(1.00\ L) = n\left(0.0821\ \frac{L \cdot atm}{mol \cdot K}\right)$

$n = 0.0293\ mol\ CO_2$

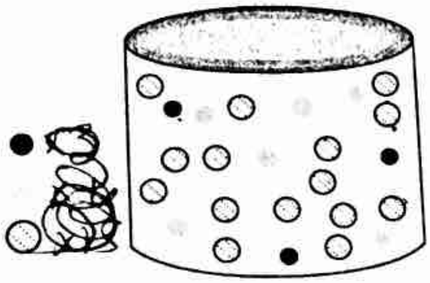
19. Would Dalton's law hold true if two of the gases in the mixture reacted with each other to form a gaseous product? Discuss this in your group and be prepared to justify your answer to the class.

yes!

Extension Questions

Model 4 – Mole Fraction

Gas	Partial Pressure, P_i	Moles	Mole Fraction, X_i
Helium	0.35 atm	0.100	0.125
Argon	0.70 atm	0.200	0.250
Krypton	1.75 atm	0.500	0.625



20. Consider the tank of gas illustrated in Model 4. What is the total pressure in the tank?

2.8 atm

21. According to Model 4, what is the symbol for mole fraction?

X_i

22. Use the data in Model 4 to derive a mathematical equation for mole fraction. Brainstorm possible equations with your group and divide the work to check each idea. When you think you have the correct equation, check to see that it can be used to successfully calculate all three mole fractions in the table in Model 4.

$$\frac{\text{moles}_i}{\text{Total moles}}$$

23. The mole fraction of a gas, X_i, can be used with the total pressure of the gas mixture, P_T, to calculate the partial pressure of the gas, P_i. Derive a mathematical equation for this relationship and check to see that it works using your answer in Question 20 and the data in Model 4.

$$X_1 \cdot P_T = P_i$$