Name: ______________________________________ Date: ________________________

Student Exploration: Equilibrium and Pressure

[Note to teachers and students: This Gizmo™ was designed as a follow-up to the Equilibrium and Concentration *Gizmo. We recommend doing that activity before trying this one.]*

Vocabulary: Dalton's law, Le Châtelier's principle, partial pressure, pressure

Prior Knowledge Questions (Do these BEFORE using the Gizmo.)
A typical scuba tank has a volume of 11 liters and can support a diver for one hour. An adult breathes about 3 liters of air with each breath.

1. How can an 11-liter tank give a diver enough oxygen for one hour? ________

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2. Why are diving cylinders made of thick, reinforced aluminum or steel?

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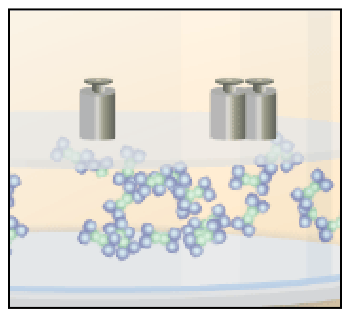
Gizmo Warm-up
Gases consist of billions of tiny particles in constant motion, colliding with each other and the walls of the container. The sum of all these collisions creates **pressure** on the walls of the container. In theory, any amount of gas can be squeezed into a container if the container is strong enough to withstand the gas pressure.



The *Equilibrium and Pressure* Gizmo shows a mixture of gases in a chamber. The lid of the chamber can move up or down.

1. Check that **Reaction 1** is selected. Use the **Moles NO_2** slider to increase the number of NO_2 molecules in the chamber. How does this affect the volume of the chamber?

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2. Notice the weights on the lower right side of the Gizmo. Drag several of these weights to the lid. How does this affect the volume of the chamber?

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Activity A: **Dalton's law**	Get the Gizmo ready: • Remove all weights from the lid. • Set **Moles NO_2** and **Moles N_2O_4** to 0.	

Introduction: In a mixture of gases, each gas contributes a **partial pressure** to the total pressure in the chamber. Because the chamber has a moveable piston, the pressure inside is equal to the pressure on the lid. In this Gizmo, the units of pressure are megapascals (MPa).

Question: How do individual gases contribute to the total pressure in a chamber?

1. Observe: Set **Moles NO_2** to 2 to add 2 moles of NO_2 gas to the chamber.

   A. The total pressure (*P*) on the chamber is shown next to the weights, at bottom right.

      What is the total pressure in the chamber? __________

   B. Select the BAR CHART tab and select **Pressure**. Turn on **Show data values**.

      What is the pressure of NO_2? P_{NO2} = __________

2. Observe: Set **Moles N_2O_4** to 2 to add 2 moles of N_2O_4 gas to the chamber.

   A. What is the total pressure on the chamber? __________

   B. What are the partial pressures of NO_2 and N_2O_4? P_{NO2} = _______ P_{N2O4} = _______

   C. What is the sum of the partial pressures of NO_2 and N_2O_4? __________

   Dalton's law states that the total pressure in a container is equal to the sum of the partial pressures: $P = P_1 + P_2 + ... + P_n$

3. Explain: Why doesn't the total pressure increase when more gas is added to the chamber? (Hint: What would you see if the volume of the chamber was fixed?)

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4. Analyze: A molecule of N_2O_4 has twice the mass as a molecule of NO_2. What do you notice about the partial pressure exerted by 2 moles of NO_2 compared to the partial pressure exerted by 2 moles of N_2O_4?

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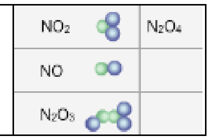
   At a given temperature, the partial pressure exerted by a gas depends only on the quantity of the gas, not on its mass. Thus a mole of a light gas such as hydrogen (H_2) exerts the same pressure as a mole of a heavier gas such as dinitrogen tetroxide (N_2O_4).

Activity B: **Partial pressure and equilibrium**	Get the Gizmo ready: • Select **Reaction 2**. • Move the **Sim. speed** slider all the way to the right.	

Introduction: In the *Equilibrium and Concentration* Gizmo, you found that reversible reactions eventually result in chemical equilibrium. Chemical equilibrium is reached when the rates of the forward and reverse reactions are the same. The constant K_c describes the ratio of products to reactants at equilibrium. A similar equilibrium can be calculated based on partial pressure.

Question: How can partial pressure be used to measure equilibrium?

1. Review: What is the formula of K_c for reaction 2? Assume [NO] is the equilibrium concentration of NO, [NO_2] is the equilibrium concentration of NO_2, and [N_2O_3] is the equilibrium concentration of N_2O_3.

   K_c = ___________

2. Gather data: Experiment with a variety of initial partial pressures of NO, NO_2, and N_2O_3. For each set of initial partial pressures, use the Gizmo to determine the equilibrium partial pressures of each gas. Run three trials for each set of initial conditions. Use the data you collect to fill in the first four columns of the table. (Note that some NO_2 molecules combine to form N_2O_4, so there may be less free NO_2 than NO.)

Init. P_{NO} (MPa)	**Init. P_{NO2} (MPa)**	**Init. P_{N2O3} (MPa)**	**Eq. P_{NO} (MPa)**	**Eq. P_{NO2} (MPa)**	**Eq. P_{N2O3} (MPa)**	$\frac{P_{N2O3}}{P_{NO} \cdot P_{NO2}}$

3. Calculate: In the last column of the table, calculate the ratio of equilibrium partial pressures as shown. What do you notice about the values in the last column? ___________________

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(Activity B continued on next page)

Activity B (continued from previous page)

5. Analyze: The equilibrium constant can be expressed in terms of partial pressure (P) or concentration. The symbol K_p is used when partial pressure calculations are used. For the general chemical equation aA(g) + bB(g) ↔ cC(g) + dD(g) we have:

$$K_p = \frac{(P_C)^c (P_D)^d}{(P_A)^a (P_B)^b} \qquad K_c = \frac{[C]^c [D]^d}{[A]^a [B]^b}$$

(Note: The symbols a, b, c and d represent coefficients for substances A, B, C, and D.)

How are the equations for K_p and K_c similar? ____

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6. Explore: Select **Reaction 3**. In this reaction, a solid (C) reacts with a gas (CO_2) to produce another gas (CO). To see how the solid affects the equilibrium, record the equilibrium partial pressures of CO_2 and CO for each initial amount of C. Leave the last column blank for now.

Initial C (moles)	**Initial CO_2 (moles)**	**Initial CO (moles)**	**Equilibrium P_{CO2} (MPa)**	**Equilibrium P_{CO} (MPa)**	K_p
30	8	8			
40	8	8			
50	8	8			
60	8	8			

7. Analyze: If possible, compare your results to those of your classmates. Based on your results, how does the initial amount of carbon (C) affect the equilibrium partial pressures of the two gases? Are there any consistent trends in the data?

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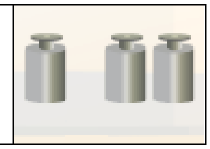
8. Calculate: Because solids do not contribute to the pressure in the chamber, the amount of solid does not affect the equilibrium partial pressures of the gases. To calculate K in this reaction, ignore the solid:

$$K_p = \frac{{P_{CO}}^2}{P_{CO2}} \qquad K_c = \frac{[CO]^2}{[CO_2]}$$

Use this equation to calculate K_p for each trial and fill in the last column of the table.

9. Think and discuss: On a separate sheet, explain why the amount of solid does not affect the equilibrium as long as there is enough solid to cover the bottom of the container.

Activity C: **Le Châtelier's principle**	Get the Gizmo ready: • Click **Reset**. Select **Reaction 2**. • Set **Moles NO**, **Moles NO_2**, and **Moles N_2O_3** to 5.	

Introduction: In the *Equilibrium and Concentration* Gizmo, you learned that you can predict the direction of a reaction by comparing the reaction quotient (Q_c) with the known equilibrium constant K_c. You can do the same thing using partial pressures:

$$Q_p = \frac{(P_C)^c (P_D)^d}{(P_A)^a (P_B)^b}$$

Question: How do changes in pressure affect the reaction equilibrium?

1. List: Click **Play** ( ). Select the BAR CHART tab, allow the reaction to proceed to equilibrium, and then click **Pause** ( ). What are the equilibrium partial pressures?

   P_{NO} ________ P_{NO2} ________ P_{N2O3} ________

2. Calculate: Calculate K_p for this reaction. K_p = ___________

3. Predict: If you add weight to the lid, it increases the pressure on the chamber.

   A. How do you expect increasing pressure on the chamber to affect the partial pressures of the gases? ____

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   B. How do you expect the increased pressure to affect the equilibrium? ______________

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4. Calculate: Add all five weights to the lid.

   A. What is the partial pressure of each substance now?

   P_{NO} ________ P_{NO2} ________ P_{N2O3} ________

   B. Calculate Q_p for this setup. Q_p = ___________

   C. In the current situation, is there an excess or products or reactants? ______________

   Explain: ____

(Activity C continued on next page)

Activity C (continued from previous page)

5. Test: Click **Play**. Allow the reaction run until it reaches equilibrium again.

   A. What is the partial pressure of each substance now?

      P_{NO} ________ P_{NO2} ________ P_{N2O3} ________

   B. Calculate K_p for this setup. K_p = ___________

   C. How does this value of K_p compare to the value you found before? ______________

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   D. As the experiment reached equilibrium again, did the reactants or products increase?

      ____

As the pressure on the system increased, the reaction shifted toward the side with fewer molecules—in this case the products. You may have noticed the volume of the chamber decreased slightly as the reaction proceeded. This is an example of **Le Châtelier's principle**, which is the tendency of a system in equilibrium to shift in response to a change.

6. Apply: Select **Reaction 5**. If you were making water (H_2O) from oxygen (O_2) and hydrogen (H_2), would it be an advantage to increase the pressure? Explain your answer, and then use the Gizmo to check your work.

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7. Think and discuss: Why do you think increasing the pressure has the effect of shifting the equilibrium toward the side with fewer molecules? If possible, discuss your answer with your classmates and teacher.

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