Gizmos

Name: ______________________________________ Date: ________________________

Student Exploration: Equilibrium and Concentration

Vocabulary: chemical equilibrium, concentration, equilibrium, equilibrium constant, reaction quotient, reversible reaction

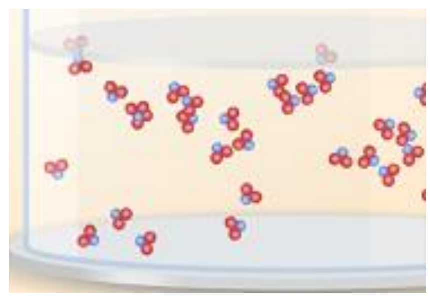
Prior Knowledge Questions (Do these BEFORE using the Gizmo.)
Gary has $5,000 in his bank account and earns a modest salary. Every month he pays for rent, food, utilities, and entertainment.

A. How will Gary's account change if he saves more than he spends? _________________

B. How will Gary's account change if he spends more than he saves? _________________

C. What happens if Gary spends exactly as much as he saves? _____________________

Gizmo Warm-up
If Gary spends exactly as much as he earns, his savings will be in **equilibrium**. Equilibrium occurs when two opposing processes occur at the same rate, leading to no net change. In the *Equilibrium and Concentration* Gizmo, you will investigate how equilibrium can occur in chemical reactions.



To begin, check that **Reaction 1** is selected. Set **Moles NO_2** to 8 and **Moles N_2O_4** to 0.

1. Click **Play** (▶) and observe the colliding molecules. What do you notice? _______________

____

In the Gizmo, a blue flash appears every time two reactants combine to form a product. A red flash appears every time a product dissociates into reactants.

2. Click **Reset** (↺), and set **Moles NO_2** to 0 and **Moles N_2O_4** to 8. Click **Play**.

What do you notice now? ____

3. When a reaction can proceed in either direction, it is a **reversible reaction**. Based on what you have observed, is the synthesis of NO_2 into N_2O_4 a reversible reaction? Explain.

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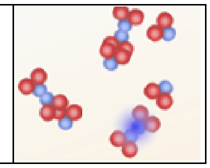
Activity A: **Reversible reactions**	Get the Gizmo ready: • Click **Reset**. **Reaction 1** should be selected. • Set **Moles NO_2** to 8 and **Moles N_2O_4** to 0. • Move the **Sim. speed** slider all the way to the right.	

Question: What are the characteristics of reversible reactions?

1. Predict: Suppose you began with 8 moles of NO_2 in the chamber. What do you think will happen if you let the reaction go for a long time? ___________________________________

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2. Test: Click **Play**. Select the BAR CHART tab and check that **Moles** is selected. Observe the bar chart for about 30 seconds. As time goes by, what do you notice about the bars representing moles NO_2 and moles N_2O_4?

   ____

3. Observe: Click **Pause** (⏸). Select the GRAPH tab. Click the (–) zoom control on the horizontal axis until you can see the whole graph. What do you notice?

   ____

   This situation, in which the overall amounts of reactants and products does not change significantly over time, is called a **chemical equilibrium**.

4. Record: On the BAR CHART tab, turn on **Show data values**. How many moles of NO_2 and N_2O_4 are there right now? Moles NO_2 ___________ Moles N_2O_4 ___________

5. Calculate: Suppose all the NO_2 molecules were synthesized into N_2O_4. Given the equation $2NO_2 \rightleftarrows N_2O_4$, how many moles of N_2O_4 would be produced? _______________

6. Experiment: Click **Reset**. On the INITIAL SETTINGS tab, set **Moles NO_2** to 0 and **Moles N_2O_4** to 4. Click **Play**. Click **Pause** when the bars of the bar chart stop moving very much.

   A. List the current amounts of each substance: Moles NO_2 ______ Moles N_2O_4 ______

   B. How do these results compare to starting with 8 moles of NO_2? ________________

   ____

(Activity A continued on next page)

Activity A (continued from previous page)

7. Summarize: In each trial, you started with the same amounts of nitrogen and oxygen. In this situation, did the equilibrium amounts change depending on the direction of the reaction?

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8. Set up the Gizmo: Click **Reset** and select the EXPERIMENT tab on the left. On the INITIAL SETTINGS tab on the right, select **Reaction 2**. Set **Moles NO** to 5, **Moles NO_2** to 5, and **Moles N_2O_3** to 0. What are the reactants and product of this reaction?

   Reactants: __________ __________ Product: __________

   (Note: In this reaction, some of the NO_2 reactants combine to form N_2O_4, as in reaction 1.)

9. Observe: Recall that a blue flash appears every time two reactants combine to form a product. A red flash appears every time a product dissociates into reactants. Click **Play**.

   A. At first, do you notice more blue flashes or red flashes? _______________________

   B. What do you notice about the frequency of blue and red flashes as time goes by?

   ____

   C. Click **Reset**. This time, start the experiment with 0 moles of NO and NO_2 and 5 moles of N_2O_3. Click **Play**. What do you notice about the red and blue flashes now?

   ____

10. Explain: Think about how the numbers of blue and red flashes reflect the rates of the forward (reactants → products) and reverse (products → reactants) reactions.

   A. What happens to the rate of the forward reaction as the reactants are consumed?

   ____

   B. What happens to the rate of the reverse reaction as the products are produced?

   ____

   C. Why do reversible reactions *always* result in chemical equilibria? _______________

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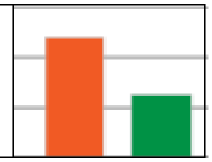
Activity B: **The equilibrium constant**	Get the Gizmo ready: • Click **Reset**. Select **Reaction 1**. • Set **Moles NO_2** to 2 and **Moles N_2O_4** to 7.	

Introduction: When investigating the rates of reactions, it often is useful to consider the **concentrations** of reactants rather than the total number of moles. Concentrations are often expressed in moles per liter, or mol/L. Brackets are used to signify concentration. For example, “$[H_2]$ = 5.0 M” means the concentration of hydrogen gas in a chamber is 5.0 moles per liter.

Question: What are the characteristics of reactions in equilibrium?

1. Record: On the BAR CHART tab, select **Concentration**. Check that **Show data values** is on. If necessary, use the arrows to adjust the scale of the chart.

   A. What are the current concentrations of each compound?

   $[NO_2]$ ___________ $[N_2O_4]$ ___________

   B. Click **Play** and wait for equilibrium to become established. Click **Pause**. What are the approximate equilibrium concentrations?

   $[NO_2]$ ___________ $[N_2O_4]$ ___________

2. Calculate: The value K_c represents the ratio of products to reactants in a reaction at equilibrium. The greater the amount of products relative to reactants, the higher the resulting value of K_c. For a general reaction between gases: $aA(g) + bB(g) \rightleftharpoons cC(g) + dD(g)$, K_c is calculated as follows:

$$K_c = \frac{[C]^c[D]^d}{[A]^a[B]^b}$$

   For the current reaction, $2NO_2 \rightleftharpoons N_2O_4$, we have:

$$K_c = \frac{[N_2O_4]}{[NO_2]^2}$$

   Based on the current concentrations of NO_2 and N_2O_4, what is K_c? ____________________

   Show your work here:

(Activity B continued on next page)

Activity B (continued from previous page)

3. Gather data: Experiment with a variety of initial concentrations of NO_2 and N_2O_4. For each set of initial concentrations, use the Gizmo to determine the equilibrium concentrations of each substance. In the last column, find K_c for that trial. Run three trials for each set of initial conditions.

Initial $[NO_2]$	Initial $[N_2O_4]$	Equilibrium $[NO_2]$	Equilibrium $[N_2O_4]$	K_c

4. Calculate: Find the average value of K_c for each set of three trials.

   Trials 1-3: __________ Trials 4-6: __________ Trials 7-9: __________

5. Analyze: What do you notice about the values of K_c? ______________________________

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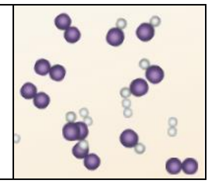
   In general, the value of K_c will be constant for a given reaction at a constant temperature, no matter the starting concentrations. That is why K_c is known as the **equilibrium constant**. In this Gizmo, the values of K_c will vary somewhat because there is a very limited number of molecules in the chamber.

6. On your own: Use the Gizmo to find K_c for **Reaction 4**: $H_2 + I_2 \rightleftharpoons 2HI$. Collect data at least 10 times and average your results to get the best approximation of K_c. Show your data and work on a separate sheet of paper.

   (Hint: Because of the coefficient "2" in front of HI, you will have to square the concentration of HI to find K_c.)

   K_c = __________

Activity C: Reaction direction	<u>Get the Gizmo ready</u>: • Click **Reset**. Check that **Reaction 4** is selected. • Set **Moles H_2** to 5, **Moles I_2** to 5, and **Moles HI** to 3.	

Introduction: For a reversible reaction with equilibrium constant K_c, it often is useful to know in which direction the reaction will proceed given the starting amounts of reactants A and B and products C and D. This is done by calculating the **reaction quotient**, Q_c:

$$Q_c = \frac{[C]^c[D]^d}{[A]^a[B]^b}$$

Question: How can you predict the direction of a reversible reaction?

1. <u>List</u>: Select the BAR CHART tab. What are the initial concentrations of each substance?

   $[H_2]$ ________ $[I_2]$ ________ [HI] ________

2. <u>Calculate</u>: Use the equation above to find Q_c for the current reaction.

   A. What is the current value of Q_c? ___________

   B. In activity B, what value of K_c did you arrive at for this reaction? ___________

   C. How does Q_c compare to K_c? ____

3. <u>Analyze</u>: Recall that Q_c is equal to the ratio of product concentrations to reactant concentrations.

   A. If there is an excess of products, will Q_c be greater than or less than K_c? ___________

   B. If there is an excess of reactants, will Q_c be greater than or less than K_c? __________

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

   Explain: ____

   D. When the reaction begins, do you expect [HI] to increase or decrease? ____________

   Explain: ____

4. <u>Test</u>: Click **Play**. What happens to [HI]? ____

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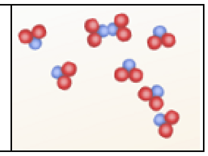
Extension: **Equilibrium calculations**	Get the Gizmo ready: • Click **Reset**. Select **Reaction 1**. • Set **Moles NO_2** to 0 and **Moles N_2O_4** to 6.	

Goal: Given K_c and initial concentrations, calculate equilibrium concentrations.

1. List: Select the BAR CHART. What is the initial concentration N_2O_4? $[N_2O_4]_{initial}$ = ________

2. Experiment: Click **Play** and wait for a few seconds. Click **Pause** before equilibrium is reached.

   A. What is the current concentration of N_2O_4? $[N_2O_4]$ = ________

   B. How much has the concentration of N_2O_4 gone down? ________

   C. What is the current concentration of NO_2? $[NO_2]$ = ________

   D. In general, if $[N_2O_4]$ is reduced by *x*, how much does $[NO_2]$ increase? _____________

   This result may be surprising. It is true because at constant pressure, the overall density of particles in the container remains constant. So, if the concentration of one substance is reduced by *x*, the concentration of the other substance increases by *x*.

3. Manipulate: Begin with the general equation for K_c: $K_c = \dfrac{[C]^c[D]^d}{[A]^a[B]^b}$.

   A. What is the equation for K_c for the reaction $2NO_2 \rightleftharpoons N_2O_4$? K_c =

   B. In this experiment, the initial concentration of NO_2 is zero. If the concentration of N_2O_4 is reduced by *x* at equilibrium, the equilibrium concentration of NO_2 is equal to *x*. Substitute the following values into the equation you wrote in step A:

   $[N_2O_4] = ([N_2O_4]_{initial} - x)$ $[NO_2] = x$

   K_c =

   C. In activity A, you discovered that K_c for this reaction was close to 0.042. Substitute this value and the initial concentration of N_2O_4 into your equation.

   =

   D. Rearrange the terms of your equation to form a quadratic equation in the form $ax^2 + bx + c = 0$.

   = 0

(Extension continued on next page)

Extension (continued from previous page)

4. Solve: Because the equation is in the form $ax^2 + bx + c = 0$, you can use the quadratic formula (shown below) to solve for x. Ignore negative solutions because the concentrations cannot be negative. Show your work.

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

5. Predict: Based on the value for x, what do you expect the equilibrium concentrations of NO_2 and N_2O_4 to be?

   $[NO_2]$ ___________ $[N_2O_4]$ ___________

   Check your work by solving for K_c using $K_c = \frac{[N_2O_4]}{[NO_2]^2}$ K_c = ___________

   If you don't get the correct value of K_c, recheck your work.

6. Test: Click **Play** and wait for equilibrium to be established. What are the actual equilibrium values of each substance?

   $[NO_2]$ ___________ $[N_2O_4]$ ___________

   How close were these results to your predicted results? ______________________________

   ____

7. Challenge: Suppose you begin with 6 moles of NO_2 and 5 moles of N_2O_4. Assuming a value for K_c of 0.042, predict the equilibrium concentrations of NO_2 and N_2O_4. (Use the Gizmo to determine the initial concentrations.) Show your work on a separate sheet of paper. After you have made your predictions, click **Play** and record the experimental results.

   Predicted: $[NO_2]$ ________ $[N_2O_4]$ ________

   Experimental: $[NO_2]$ ________ $[N_2O_4]$ ________