**Unit 12: Thermochemistry & Equilibrium Name: \_\_\_\_\_\_\_\_­\_\_\_\_\_\_\_\_\_**

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| **Learning Target** |
| 1. I CAN state and describe the four states of matter based on energy, arrangement of particles, movement, shape and volume
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| 1. I CAN state and describe the phase changes between the states of matter and describe whether they are endo- or exo-thermic
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| 1. I CAN apply the states of matter and phase changes to a heating and cooling curve
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| 1. I CAN identify and describe the difference between an endothermic and exothermic reactions, and provide a real life example
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| 1. I CAN identify and describe an endothermic or exothermic reaction based on a potential energy diagram
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| 1. I CAN calculate the enthalpy of a reaction from a potential energy diagram
 |
| 1. I CAN state the five factors that affect rates of reactions and describe how the rates are affected using kinetic theory
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| 1. I CAN describe a catalyst and how it affects activation energy
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| 1. I CAN describe Le Châtlier’s Principle.
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| 1. I CAN state how the stresses of temperature, pressure, and change in concentration affect a reaction
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| Chemistry Important Dates!  |
| Monday | Tuesday | Wednesday | Thursday | Friday | Saturday | Sunday |
| May 15 | 16 | 17 | 18 | 19 | 20 | 21 |
| 22 | 23 | 24 | 25 | 26 | 27 | 28 |
| 29 | 30 | 31 | June 1 | 2 | 3 | 4 |

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**Phase Changes/States of Matter:**

**Notes on Heating and Cooling Curves Draw BOTH curves and include all phase changes that occur.**

* Solid 🡪 Liquid \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
* Liquid 🡪 Solid \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
* Liquid 🡪 Gas \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
* Gas 🡪 Liquid \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
* Solid 🡪 Gas \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
* Gas 🡪 Solid \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Heating and Cooling Curves**

Heating and Cooling Curve

* When changing from solid to liquid, the substance isn’t entirely\_\_\_\_\_\_\_\_\_\_\_ until the graph has a \_\_\_\_\_\_\_\_\_\_\_\_ slope
* At point A the substance is \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
* At point B the substance is \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
* At point C the substance is \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
* At point D the substance is \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
* At point E the substance is \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_



**Cooling Curve for Water**

**Identify the sections where the following phases are found:**

1) \_\_\_\_ Only a gas 2) \_\_\_\_ Only a solid 3) \_\_\_\_ Only a liquid

**Identify which letter would be appropriate for each question: More than one letter may be required**

4) \_\_\_\_\_\_\_ Freezing (if cooling) 5) \_\_\_\_\_\_\_ Particles are the farthest apart

6) \_\_\_\_\_\_\_ Liquid phase is present 7) \_\_\_\_\_\_\_ All areas where only one phase is present

8) \_\_\_\_\_\_\_ Evaporation 9) \_\_\_\_\_\_\_ All areas where multiple phases are present

10) Moving from letter B to C, energy will be \_\_\_\_\_ 11) Moving from point D to C, energy will be \_\_\_\_

12) At what time would liquid particles first appear? 13) What **number** represents when particles are only gas?

14) How much **time** was the solid state present? 15) What number contains both solid and liquid phase?

16) What time would the particles begin to freeze? 17) From number 2 to number 3, energy will be \_\_\_\_\_\_\_\_.

**Student Exploration: Collision Theory**

**Warm-Up:**

1. Suppose you added a spoonful of sugar to hot water and another to ice-cold water. Which type of water will cause the sugar to dissolve more quickly?
2. Suppose you held a lighted match to a solid hunk of wood and another match to a pile of wood shavings. Which form of wood will catch fire more easily?

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**1st Block: FFVD9NNMTH 3rd Block: T9V7C5XRLH 4th Block: NDBZCBRFHT**

**Introduction:**

A chemical reaction causes the chemical compositions of substances to change. **Reactants** are substances that enter into a chemical reaction, and **products** are substances produced by the reaction. This simulation will allow you to experiment with several factors that affect the rate at which reactants are transformed into products in a chemical reaction.

You will need blue, green, and orange markers or colored pencils for the first part of this activity.

* + - 1. Look at the key at the bottom of the simulation pane. In the space below, draw the two reactants and two products of this chemical reaction.

			Reactants: Products:
			2. Click Play  What do you see?

|  |  |  |
| --- | --- | --- |
| **Activity A: Temperature** | Get the Gizmo ready:* Click **Reset** ).
* Check that the **Reactant concentration** is set to

1.0 mol/L, the **Catalyst concentration** is set to0.00 mol/L, and the **Surface area** is **Minimum**. |  |

**How does temperature affect the rate of a chemical reaction?**

* + - 1. Observe: Select the **ANIMATION** tab. View the animation with **No Catalyst** selected. What do you see?

			When two reactant molecules meet, they form a temporary structure called an activated complex. The activated complex breaks up into the product molecules.

* + - 1. Observe: Return to the **CONTROLS** pane. Set the **temperature** to 0 °C and the **Simulation speed** to its maximum setting. Click **Play**.
				1. Describe the motions of the molecules.
				2. Now set the **Temperature** to 200 °C. How does increasing the temperature affect the motions of the molecules?
				3. What do you notice about the chemical reaction at the higher temperature?
			2. Interpret: Sleect the **GRAPH** tab. Click the **zoom out button** (--) until you can see the whole graph. What does this graph show?
			3. Predict: How do you think temperature will affect the rate of a chemical reaction?

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Trial** | **200 °C** | **150 °C** | **100 °C** | **50 °C** |
| 1 |  |  |  |  |
| 2 |  |  |  |  |
| **Mean half-life** |  |  |  |  |

* + - 1. Gather Data: Click **Reset**. A useful way to compare reaction rates is to record the time required for half of the reactants to react, called the **half-life** of the reaction. With the **Temperature** set to 200 °C, click **Play**. Click **Pause** when the number of reactant molecules is 10. Record the half-life time in the first space of the table below.

Repeat the experiment at different temperatures to complete the table.
(Note: to get exact times, you can refer to the TABLE tab)

* + - 1. Calculate: Calculate the mean (average) half-life for each temperature. Fill in these values above.

			*(Hint: To get an exact mean, first convert each “minute” time to seconds, then add this to the seconds portion of the measurement. To find the mean in seconds, add up the two times and divide by two. Convert the answer back to minutes and seconds.)*
			2. Analyze: What do your results indicate?
			3. Draw Conclusions: For two molecules to react, they must collide at just the right angle and with enough energy to break the original bonds and form new ones. Based on these facts, why does the reaction tend to go more quickly at higher temperatures?

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| **Activity B:****Surface area and concentration** | Get the Gizmo ready:* Click **Reset**.
* Check that the **Catalyst concentration** is set to

0.00 mol/L and the **Surface area** is **Minimum**.* Set the **Temperature** to 200 °C.
 |  |

**Introduction:** Reaction rates are also influenced by **surface area** and **concentration**. The surface area of a solid is a measure of how much of the solid is exposed to other substances. The concentration of a substance is a measure of how many molecules of that substance are present in a given volume.

# How do surface area and concentration affect reaction rates?

1. Observe: Change the **Surface area** from **Minimum** to **Maximum**. How does this change the amount of **Reactant B** molecules that are exposed to **Reactant A**?
2. Predict: How do you think increasing the surface area will affect the rate of the reaction?
3. Gather data: Set the **Reactant concentration** to 2.0 mol/L. Use the Gizmo to measure the half-life of the reaction for each surface area setting. (There will now be 20 reactant molecules left at the half-life.) Then, calculate the mean half-life for each setting.

|  |  |  |
| --- | --- | --- |
| **Trial** | **Minimum surface area** | **Maximum surface area** |
| 1 |  |  |
| 2 |  |  |
| **Mean half-life** |  |  |

1. Analyze: What do your results indicate?
2. Explain: Why does the reaction proceed more quickly when the surface area is increased?

1. Observe: Click **Reset**. Move the **reactant concentration** slider back and forth. What do you notice?
2. Predict: How will increasing the reactant concentration affect the rate of the reaction? Why?

1. Gather data: Make sure the **Temperature** is 200 °C and the **Surface area** is **Maximum**. Use the Gizmo to measure the half-life for each given reactant concentration. (Note that the number of reactant molecules changes with each concentration.) Calculate the means.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Trial** | **0.4 mol/L** | **0.8 mol/L** | **1.2 mol/L** | **1.6 mol/L** | **2.0 mol/L** |
| 1 |  |  |  |  |  |
| 2 |  |  |  |  |  |
| **Mean half-life** |  |  |  |  |  |

1. Compare: If possible, find the mean times for each concentration for your entire class. What is the mean class time for a concentration of 0.4 mol/L? How about for 2.0 mol/L?

Mean for 0.4 mol/L: Mean for 2.0 mol/L:

1. Analyze: What do these results indicate?
2. Apply: Hydrochloric acid reacts with the mineral calcite to produce carbon dioxide gas, water, and calcium chloride. Based on what you have learned in activity A and activity B, what are *three* things you could do to make the reaction occur more quickly?

|  |  |  |
| --- | --- | --- |
| **Activity C: Catalysts** | Get the Gizmo ready:* Click **Reset** ).
 |  |

**Introduction:** A **catalyst** is a substance that helps a chemical reaction to proceed. The catalyst molecules are not changed by the reaction and can be reused over and over again.

#  How do catalysts affect the rate of a chemical reaction?

1. Observe: Select the ANIMATION tab. Select **With catalyst**, and observe. What do you see?

Why do you think the shape of a catalyst is important?

1. Predict: How do you think catalysts will affect the rate of a chemical reaction?
2. Gather data: On the CONTROLS pane, set the **Reactant concentration** to 2.0 mol/L, the **Surface area** to **Maximum**, and the **Temperature** to 50 °C. Measure the half-life for each given catalyst concentration. Calculate the means.

|  |  |
| --- | --- |
| **Trial** | **Catalyst concentration** |
| **0.00 mol/L** | **0.05 mol/L** | **0.10 mol/L** | **0.15 mol/L** |
| 1 |  |  |  |  |
| 2 |  |  |  |  |
| **Mean half-life** |  |  |  |  |

1. Analyze: What do your results indicate?
2. Explore: Set the **Catalyst concentration** to 0.00 mol/L and the **Temperature** to 0 °C.
 Click **Play**, wait for 10 minutes of **simulated** time, and click **Pause**.

What happens?

Click **Reset**, set the **Catalyst concentration** to 0.25 mol/L, and click **Play**. After 10 simulated minutes, click **Pause**.

What happens now?

Why do you think the catalysts allowed the chemical reaction to take place at 0 °C?
3. Draw conclusions: What is the usefulness of catalysts?
4. Apply: Most of the chemical reactions inside your body rely on protein catalysts called **enzymes** to take place. For example, the enzyme pepsin helps to break down protein molecules in your stomach. What might happen if your stomach stopped producing pepsin?

**Notes on Potential Energy Diagrams Draw both diagrams for Endothermic and Exothermic reactions. Label every part of the graph and include definitions Potential Energy, Activation Energy, Activated Complex, Enthalpy (**ΔH) **and Transition State.**

**Use the Potential Energy Diagram below to answer the questions that follow.**

* + - 1. Is the overall reaction as show endothermic or exothermic?
			2. What is the activation energy for the **forward** reaction?
			3. What is the activation energy for the **reverse** reaction?
			4. What is the enthalpy change of the **forward** reaction?
			5. What is the ΔH for the **reverse** reaction?
			6. Is the reverse reaction endothermic or exothermic?
			7. What is the chemical species of the activated complex?
			8. What is the chemical species that has the highest **potential** energy?
			9. What is the species that has the highest **kinetic** energy?
			10. What do you think would be faster, the **forward** or **reverse** reaction? **Why?**

**Use the Potential Energy Diagram below to answer the questions that follow.**

**Potential Energy (kJ/mol)**

1. What is the activation energy for the **forward** reaction?
2. What is the activation energy for the **reverse** reaction?
3. What is the ΔH of the **forward** reaction?
4. What is the ΔH for the **reverse** reaction?
5. Is the **forward** reaction endothermic or exothermic?
6. Is the **reverse** reaction endothermic or exothermic?
7. What is the chemical species of the activated complex?
8. What species or set of species has the lowest potential energy?
9. Which bon is stronger, A—B or B—C? **Give reasons for your answer!**
10. What chemical species or set of species is moving the fastest? **Give reasons for your answer!**

**Notes on Dynamic Equilibrium**

**Equilibrium**

* Will a reaction occur? We use two things to determine this:
	+ 1. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
		2. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
* How fast will the reaction be? We learned that reactions could be sorted into two categories:
	+ 1. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
		2. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

FIVE factors that affect the rate of the reaction:

1. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
2. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
3. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
4. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
5. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
* How far will the reaction go?
	+ \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_: The condition in which the **\_\_\_\_\_\_\_** of the forward reaction equals the **\_\_\_\_\_\_\_\_** of the reverse reaction.

		- * When ­­­­­­­­­­­­­­\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ is reached, the concentrations of the reactants and products no longer change.
			* This **DOES NOT** mean that the \_\_\_\_\_\_\_\_\_\_\_\_\_\_ of reactant and products are equal.

**LeChatlier’s Principle Overview:**

* Definition of LeChatlier’s Principle
* LeChatlier’s Principle discusses things that will change the \_\_\_\_\_\_\_\_\_\_\_\_ of reactions.
* Three types of things that will be of interest to us that affect the rates of reactions:
	+ 1. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
		2. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
		3. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Change in Concentration:**

Example: H2 (g) + Cl2 (g) $⇌$ 2HCl (g) ΔH = -184.60 kJ

* If we added more H2 to the reaction, which direction would it shift towards?
* If we added more HCl to the reaction, which direction would it shift towards?
* If we remove Cl2 from the reaction, which direction would it shift towards?

SOLIDS have \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Change in Temperature:**

Example: H2 (g) + Cl2 (g) $⇌$ 2HCl (g) ΔH = -184.60 kJ

* Is the reaction endothermic or exothermic?
* If we put the reaction in ice water, which direction will it shift towards?
* If we put the reaction in hot water, which direction will it shift towards?

 **Change in Pressure:**

* Pressure is special because it only affects \_\_\_\_\_\_\_\_\_\_\_\_\_\_. If there is an \_\_\_\_\_\_\_\_ in pressure, the equilibrium will shift to the side of the reaction with \_\_\_\_\_\_\_\_\_\_\_\_\_ moles of gas.

Example: N2 (g) + 3H2 (g) $⇌$ 2NH3 (g) ΔH = -92.22 kJ

* + Which side has more moles of gas?
	+ If we change the pressure from 1.00 atm to 0.25 atm, which direction will the reaction shift?
	+ If we change the pressure from 0.70 atm to 1.50 atm, which direction will the reaction shift?

**Student Exploration: Equilibrium and Concentration**

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**1st Block: FFVD9NNMTH 3rd Block: T9V7C5XRLH 4th Block: NDBZCBRFHT**

**Gizmo Warm-up**

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 NO2** to 8 and **Moles N2O4** to 0.

1. Click **Play** () and observe the colliding molecules. Click **Bar Chart** in the upper right-hand corner. What do you notice?
2. Click **Reset** (), and set **Moles NO2** to 0 and **Moles N2O4** to 8. Click **Play**. Click **Bar Chart**

What do you notice now?

1. When a reaction can proceed in either direction, it is a **reversible reaction**. Based on what you have observed, is the synthesis of NO2 into N2O4 a reversible reaction? Explain.

|  |  |  |
| --- | --- | --- |
| **Activity A:** **Reversible reactions** | Get the Gizmo ready: * Click **Reset**. **Reaction 1** should be selected.
* Set **Moles NO2** to 8 and **Moles N2O4** to 0.
* Move the **Sim. speed** slider all the way to the right.
 |  |

1. Predict: Suppose you began with 8 moles of NO2 in the chamber. What do you think will happen if you let the reaction go for a long time?
2. Test: Click **Play**. Select the BAR CHARTtab 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 NO2 and moles N2O4?
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**.

1. Record: On the BAR CHARTtab, turn on **Show data values**. How many moles of NO2 and N2O4 are there right now? Moles NO2 \_\_\_\_\_\_\_\_\_\_ Moles N2O4 \_\_\_\_\_\_\_\_\_\_
2. Calculate: Suppose all the NO2 molecules were synthesized into N2O4. Given the equation 2NO2 ⇄ N2O4, how many moles of N2O4 would be produced? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
3. Experiment: Click **Reset** (). On the INITIAL SETTINGStab, set **Moles NO2** to 0 and **Moles N2O4** to 4. Click **Play**. Click **Pause** when the bars of the bar chartstop moving very much.
4. List the current amounts of each substance: Moles NO2 \_\_\_\_\_\_ Moles N2O4 \_\_\_\_\_\_
5. How do these results compare to starting with 8 moles of NO2?
6. 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?

1. Set up the Gizmo: Click **Reset** () and select the EXPERIMENTtab on the left. On the INITIAL SETTINGStab on the right, select **Reaction 2**. Set **Moles NO** to 5, **Moles NO2** to 5, and **Moles N2O3** to 0. What are the reactants and product of this reaction?

Reactants: \_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_ Product: \_\_\_\_\_\_\_\_\_\_

(Note: In this reaction, some of the NO2 reactants combine to form N2O4, as in reaction 1.)

1. 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**.
2. At first, do you notice more blue flashes or red flashes?
3. What do you notice about the frequency of blue and red flashes as time goes by?
4. Click **Reset**. This time, start the experiment with 0 moles of NO and NO2 and 5 moles of N2O3. Click **Play**. What do you notice about the red and blue flashes now?
5. Explain: Think about how the numbers of blue and red flashes reflect the rates of the forward (reactants 🡪 products) and reverse (products 🡪 reactants) reactions.
6. What happens to the rate of the forward reaction as the reactants are consumed?
7. What happens to the rate of the reverse reaction as the products are produced?
8. Why do reversible reactions *always* result in chemical equilibria?

**LeChatlier’s Principle Practice with Equilibrium**

**1) Sulfuryl chloride, SO2Cl2, is a highly reactive gaseous compound. When heated, it decomposes as follows
 SO2Cl2 (g) ↔ SO2 (g) + Cl2 (g). This decomposition is endothermic. Explain how the concentrations of each compound will change if the following occurs.**

A) There is an increase in chlorine gas: [SO2Cl2] [SO2] [Cl2]

B) The volume of the container increases: [SO2Cl2] [SO2] [Cl2]

C) The pressure of the container increases: [SO2Cl2] [SO2] [Cl2]

D) The reaction is heated and temperature increases: [SO2Cl2] [SO2] [Cl2]

 **2) For each situation, indicate how the given reactions will respond to the change in equilibrium:**
 I) N2(g) + 3 H2(g) ↔ 2 NH3(g)  II) N2(g) +2 O2(g) ↔ 2 NO2(g) III) N2O4(g) ↔ 2 NO2(g)

A) If the pressure increased, indicate which of the reactions would shift to the left?

B) If the concentration of NO­2 increased, which of the reactions would shift to the left?

**3) Predict the shift in equilibrium when the following reactions decrease their temperatures:**
A) H2 + Cl2 ↔ 2 HCl + Heat B) CO(g) + H2O(g) ↔ CO2(g) + H2(g) ∆H = 37.2 kJ/mol

**4) 2 HI(g) + Cl2(g) ↔ 2 HCl(g) + I2(g) + heat
Describe how equilibrium changes in response to each of these statements:**
A) Increasing the volume of the container:

B) Decreasing the pressure inside the container:

C) Increasing the temperature at a constant volume:

D) Increasing the concentration of chlorine gas: