# Equilibrium Design Moves

Connect a condition change to particle behavior and product formation.

**HS-PS1-6** "Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium..."

NAME ______________________ DATE ______________

## 1 READ AND MARK

Read it twice

**YOUR JOB** Underline each one-variable condition change in the passage. Circle the words that explain how particles respond, then number the resulting product changes 1, 2, and 3.

### Designing for More Product

1 Inside a sealed reaction vessel, reactant particles form products while product particles can also collide and form reactants. At equilibrium, both directions continue at equal rates, so the amounts stay constant, not necessarily equal. A chemical engineer can change one condition, then let the system reach a new equilibrium. The system responds to the change by favoring the direction that reduces its effect. This particle-level response explains a visible, macroscopic result: the measured amount of a chosen product can rise or fall. Equilibrium is dynamic, because particles still react even when the overall amounts no longer change.

2 Consider ammonia production: $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$. If an engineer adds nitrogen gas, only nitrogen is changed. The nitrogen concentration immediately increases. More collisions involving nitrogen and hydrogen occur, so the forward reaction is favored until a new equilibrium forms. The new mixture contains more ammonia than it did before the addition. Another one-variable design is to remove some ammonia once. Its concentration immediately drops. The reverse reaction then has less ammonia available for collisions, while the forward reaction forms additional ammonia. Removal must stop before a new equilibrium can be observed. After re-equilibration, forward and reverse rates match again.

3 Pressure offers a different single-variable option for gaseous reactions. In the ammonia equation, four moles of gas appear on the reactant side and two moles appear on the product side. Decreasing the vessel volume at constant temperature increases pressure. The system favors the side with fewer gas particles, so it shifts toward ammonia. Microscopically, particles are closer together after compression, and collisions occur more often. The reactions speed up at first, but the reverse reaction changes as the mixture changes. At the new equilibrium, forward and reverse rates are equal again. Changing volume is one variable, so do not combine it with adding nitrogen or removing ammonia in the same design decision.

## 2 ANSWER WITH EVIDENCE

Use the passage

1. Why can the amounts of reactants and products stay constant at equilibrium even though particles are still reacting?

2. An engineer adds nitrogen to the ammonia system. Describe the immediate change, the particle-level change, and the product result after a new equilibrium forms.

3. Why does the passage specify removing ammonia once instead of continuously? What must happen before the system can be called at equilibrium again?

4. For ammonia production, what one condition change increases the amount of ammonia by using pressure? Explain why the shift occurs.

## 3 YOUR TURN

Your own words

A reaction vessel contains $H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$, and the goal is to increase the amount of HI at equilibrium. Specify exactly one condition change, predict the shift, and explain the particle-level reason and the new equilibrium result.

ANSWER KEY

# Equilibrium Design Moves

HIGH SCHOOL · HS-PS1-6

## PART 1 · READ AND MARK

Underline each one-variable condition change in the passage. Circle the words that explain how particles respond, then number the resulting product changes 1, 2, and 3. Accept any marking that follows this job and points at the right text.

## PART 2 · ANSWERS

| # | QUESTION | ANSWER |
|---|---|---|
| 1 | Why can the amounts of reactants and products stay constant at equilibrium even though particles are still reacting? | **The forward and reverse reactions continue at equal rates, so there is no overall change in amount.** |
| 2 | An engineer adds nitrogen to the ammonia system. Describe the immediate change, the particle-level change, and the product result after a new equilibrium forms. | **Nitrogen concentration increases, collisions involving nitrogen and hydrogen increase, and the system shifts forward to produce more ammonia.** |
| 3 | Why does the passage specify removing ammonia once instead of continuously? What must happen before the system can be called at equilibrium again? | **Removal must stop so the system can re-equilibrate. At the new equilibrium, the forward and reverse rates match again.** |
| 4 | For ammonia production, what one condition change increases the amount of ammonia by using pressure? Explain why the shift occurs. | **Decrease the vessel volume at constant temperature. Pressure increases, and the system shifts to the product side because it has fewer moles of gas.** |

## PART 3 · YOUR TURN (SAMPLE ANSWER)

Add hydrogen gas only. The hydrogen concentration rises, so collisions between hydrogen and iodine particles occur more often and the forward reaction is favored. More HI forms until a new equilibrium is reached, where the forward and reverse reaction rates are equal again.

For Part 3, accept adding either $H_2$ or $I_2$ as the single changed variable if the student explains that the equilibrium shifts toward HI. Require a particle-level explanation and the statement that equal forward and reverse rates are restored at the new equilibrium.