# Shift the Balance

Read a reactor design, then refine an equilibrium system.

**CH.PS1.6** "Refine the design of a chemical system by specifying a change in conditions that would affect the amounts of reactants or products at equilibrium.*"

NAME _____ DATE _____

## 1 READ AND MARK

Read it twice

**YOUR JOB** Underline each change to reactor conditions, circle the clue that predicts which side it favors, and number the design limits the engineers must consider.

### Designing a Sulfur Trioxide Reactor

1. At a plant that makes sulfur trioxide, operators guide the reversible reaction $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$ + heat. Sulfur trioxide is used to make sulfuric acid for fertilizers and other products. In a sealed reactor, the forward and reverse reactions continue even when the measured amounts stop changing. This balance is equilibrium, not a stopped reaction. A design change can disturb the balance, and the mixture settles at a new equilibrium. The goal is not merely to make a reaction faster. Operators want a greater fraction of the mixture to be useful product while keeping the equipment practical.

2. Consider the reactor's adjustable volume and temperature. Squeezing a gas mixture into less space raises its pressure. At equilibrium, this favors the side with fewer gas molecules: the sulfur trioxide side has two for every three on the reactant side. Heating favors the direction that absorbs heat, while cooling favors the direction that releases it. Because heat appears on the product side of this reaction, a lower temperature favors sulfur trioxide. These changes affect the amounts present after equilibrium returns, not just the speed at which molecules collide.

3. A product outlet can draw sulfur trioxide away as it forms. With less product in the reaction mixture, the system shifts toward making more of it. Similarly, adding a reactant can favor products. A catalyst helps both directions proceed faster but does not change the amounts at equilibrium. Real design choices have costs: extreme compression requires sturdy equipment, and strong cooling can make reactions too slow for useful production. Engineers compare a proposed change with an unchanged reactor at the same starting conditions, measuring product amounts only after each system has reached equilibrium again.

## 2 ANSWER WITH EVIDENCE

Use the passage

1. A reactor makes ammonia: $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ + heat. If its temperature must stay fixed, how could you change its volume to increase the amount of ammonia at equilibrium? Explain.

2. A sealed container holds $N_2O_4(g)$ + heat $\rightleftharpoons 2NO_2(g)$. Its volume must stay fixed. What temperature change would increase the amount of $NO_2$ at equilibrium? Explain.

3. A reactor uses $CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g)$ + heat. Its temperature and volume cannot change. Which product could an outlet remove to increase the amount of $H_2$ formed at equilibrium? Explain.

4. A sealed reactor holds $H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$ + heat. An engineer suggests adding a catalyst to increase the amount of HI at equilibrium. Would that work? Specify a different condition change that would work.

## 3 YOUR TURN

Your own words

A reactor uses $CH_4(g) + H_2O(g)$ + heat $\rightleftharpoons CO(g) + 3H_2(g)$. You cannot add or remove gases. In four sentences, propose two condition changes to increase $H_2$ at equilibrium, explain why each works, and describe a fair comparison that would test your design.

# Shift the Balance



## PART 1 · READ AND MARK

Underline each change to reactor conditions, circle the clue that predicts which side it favors, and number the design limits the engineers must consider. Accept any marking that follows this job and points at the right text.

## PART 2 · ANSWERS

| # | QUESTION | ANSWER |
|---|---|---|
| 1 | A reactor makes ammonia: $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ + heat. If its temperature must stay fixed, how could you change its volume to increase the amount of ammonia at equilibrium? Explain. | **Decrease the volume. The higher pressure favors the product side, which has two gas molecules rather than four.** |
| 2 | A sealed container holds $N_2O_4(g)$ + heat $\rightleftharpoons 2NO_2(g)$. Its volume must stay fixed. What temperature change would increase the amount of $NO_2$ at equilibrium? Explain. | **Raise the temperature. Heating favors the product direction because it absorbs heat.** |
| 3 | A reactor uses $CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g)$ + heat. Its temperature and volume cannot change. Which product could an outlet remove to increase the amount of $H_2$ formed at equilibrium? Explain. | **Remove $CO_2$. Removing a product favors the direction that makes more products, including $H_2$.** |
| 4 | A sealed reactor holds $H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$ + heat. An engineer suggests adding a catalyst to increase the amount of HI at equilibrium. Would that work? Specify a different condition change that would work. | **No. A catalyst does not change equilibrium amounts. Lowering the temperature favors the heat-releasing product direction.** |

## PART 3 · YOUR TURN (SAMPLE ANSWER)

I would heat the mixture and expand the reactor to produce more $H_2$. Heating favors the product direction because it absorbs heat. Expanding lowers pressure, favoring the product side with four gas molecules rather than the reactant side with two. I would compare its $H_2$ amount with that of an unchanged reactor started with the same mixture, measuring both after equilibrium is reached.

Accept equivalent changes with correct equilibrium reasoning. For Your Turn, the comparison should use the same starting mixture and measure amounts after equilibrium, not just reaction speed.