Key

Problem Set B: Applying Le Châtelier's Principle

The oxidation of ammonia is a reversible exothermic reaction that proceeds as follows:

$$4\,NH_{3\,(g)} + 5\,O_{2\,(g)} \rightleftharpoons 4\,NO_{(g)} + 6\,H_2O_{(g)} + \text{heat}$$

9 mol gas 10 mol gas

For each situation described in the table, indicate an increase or decrease in overall concentration from the initial equilibrium conditions to the newly re-established equilibrium conditions.

Component	**Stress**	**Equilibrium Concentrations**			
		$[NH_3]$	$[O_2]$	$[NO]$	$[H_2O]$
NH_3	addition	↑	↓	↑	↑
	removal	↓	↑	↓	↓
O_2	addition	↓	↑	↑	↑
	removal	↑	↓	↓	↓
NO	addition	↑	↑	↑	↓
	removal	↓	↓	↓	↑
H_2O	addition	↑	↑	↓	↑
	removal	↓	↓	↑	↓

	$[NH_3]$	$[O_2]$	$[NO]$	$[H_2O]$
Increase in temperature	↑	↑	↓	↓
Decrease in temperature	↓	↓	↑	↑
Increase in pressure	↑	↑	↑	↑
Decrease in pressure	↓	↓	↓	↓
Addition of a catalyst	—	—	—	—
An inert gas is added	—	—	—	—

Problem Set C: Le Châtelier's Principle

State the ***direction*** in which each of the following equilibrium systems would be shifted upon the application of the following stresses.

1.	$2\ SO_{2\,(g)} + O_{2\,(g)} \rightleftarrows 2\ SO_{3\,(g)} + \text{energy}$	decreased temperature	Right
2.	$C_{(s)} + CO_{2\,(g)} + \text{energy} \rightleftarrows 2\ CO_{(g)}$	increased temperature	Right
3.	$N_2O_{4\,(g)} \rightleftarrows 2\ NO_{2\,(g)}$	increased total pressure	Left
4.	$CO_{(g)} + H_2O_{(g)} \rightleftarrows CO_{2\,(g)} + H_{2\,(g)}$	decreased total pressure	No shift
5.	$2\ NOBr_{(g)} \rightleftarrows 2\ NO_{(g)} + Br_{2\,(g)}$	decreased total pressure	Right
6.	$3\ Fe_{(s)} + 4\ H_2O_{(g)} \rightleftarrows Fe_3O_{4\,(s)} + 4\ H_{2\,(g)}$	addition of $Fe_{(s)}$	No shift
7.	$2\ SO_{2\,(g)} + O_{2\,(g)} \rightleftarrows 2\ SO_{3\,(g)}$	addition of catalyst	No shift
8.	$CaCO_{3\,(s)} \rightleftarrows CaO_{(s)} + CO_{2\,(g)}$	removal of $CO_{2\,(g)}$	Right
9.	$N_{2\,(g)} + 3\ H_{2\,(g)} \rightleftarrows 2\ NH_{3\,(g)}$	addition of He	No shift

Consider the following equilibrium system for questions #10-16:

$$3\ H_{2\,(g)} + N_{2\,(g)} \rightleftarrows 2\ NH_{3\,(g)} + \text{Heat}.$$

State the effect each of the following will have on the equilibrium system:

10.	More N_2 is added to the system	right
11.	Some NH_3 is removed from the system	right
12.	The temperature is increased	left
13.	The volume of the vessel is increased	Left
14.	A catalyst was added	no shift
15.	An inert gas was added at constant pressure	no shift

16 (a) A catalyst is added to the above reaction and equilibrium is allowed to re-establish. Compare the rates of the forward and reverse reactions of the new equilibrium system to that of the original equilibrium system.

Forward Rate has ↑ Reverse Rate has ↑

(b) If the temperature was increased in the above reaction and a new equilibrium was established. Compare the rates of the forward and reverse reactions of the new equilibrium system to that of the original equilibrium system.

Forward Rate has ↑ Reverse Rate has ↑

(c) The volume of the container was increased in the above reaction and a new equilibrium was established. Compare the rates of the forward and reverse reactions of the new equilibrium system to that of the original equilibrium system.

Forward Rate has ↓ Reverse Rate has ↓

Consider the following equilibrium system

$$H_{2\,(g)} + I_{2\,(g)} \rightleftarrows 2\,HI_{\,(g)}$$

Predict the shift, if any, observed when each of the following stresses are applied to the system.

17. The volume of the vessel is increased — None
18. The pressure is increased — None
19. A catalyst is added — None

Consider the following equilibrium system:

$$3\,Fe_{\,(s)} + 4\,H_2O_{\,(g)} \rightleftarrows Fe_3O_{4\,(s)} + 4\,H_{2\,(g)}$$

Predict the shift, if any, observed when each of the following stresses are applied to the system.

20. The volume of the vessel is decreased — None
21. The pressure is decreased — None
22. More Fe is added to the system — None
23. Some Fe_3O_4 is removed from the system — None
24. A catalyst is added to the system — None

Consider the following equilibrium:

$$2\,NO_{\,(g)} + Br_{2\,(g)} + \text{energy} \rightleftarrows 2\,NOBr_{\,(g)}$$

Predict the shift, if any, observed when each of the following stresses are applied to the system.

25. The volume of the vessel is increased — Left
26. The pressure is decreased — Left
27. More Br_2 is added to the system — Right
28. Some NO is removed from the system — Left
29. A catalyst is added to the system — None

Some CO was added to the equilibrium below and a new equilibrium was established.

$$2\,CO_{\,(g)} + O_{2\,(g)} \rightleftarrows 2\,CO_{2\,(g)} + \text{energy}$$

30. Compare the rates of the forward and reverse reactions of the new equilibrium system to that of the original equilibrium system.

Forward Rate has ↑ Reverse Rate has ↑

31. Compared to the original concentrations, after the shift, have the new concentrations increased or decreased?

[CO] ↑ [O_2] ↓ [CO_2] ↑

32. Did the equilibrium shift favour the formation of reactants or products?

products

A catalyst was added to the equilibrium below and a new equilibrium was established.

$$2\,CO_{(g)} + O_{2\,(g)} \rightleftarrows 2\,CO_{2\,(g)} + \text{energy}$$

33. Compared to the original system, the rates of the forward and reverse reactions of the new equilibrium.

Forward Rate has ↑ Reverse Rate has ↑

34. Compared to the original concentrations, after the shift, have the new concentrations increased or decreased?

[CO] / [O_2] / [CO_2] /

35. Did the equilibrium ***shift*** favour the formation of reactants or products?

No

The volume of the container was decreased and a new equilibrium was established.

$$2\,CO_{(g)} + O_{2\,(g)} \rightleftarrows 2\,CO_{2\,(g)} + \text{energy}$$

36. Compare to the original system, the rates of the forward and reverse reactions of the new equilibrium.

Forward Rate has ↑ Reverse Rate has ↑

37. Compared to the original concentrations, after the shift, have the new concentrations increased or decreased? [CO] ↑ [O_2] ↑ [CO_2] ↑

38. Did the equilibrium shift favor the formation of reactants or products? products