

Worksheet: Criteria for Equilibrium

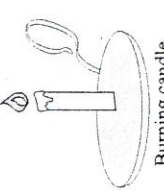
In the laboratory, Julie and Chris observe and then describe several experiments. Which of their descriptions corresponds to a system at equilibrium?


- A) The flame of a candle that is standing on the counter-top has a constant form. The size and colour of the flame remain the same for one hour.
- B) Water in a beaker is heated to the boiling point. The temperature remains at 100°C while the water is boiling.
- C) In a stoppered test-tube, at a constant temperature, the amount of reactants (mercury and oxygen) remains constant and the amount of products (mercuric oxide) remains constant.
- D) In a sealed container, a piece of zinc gets smaller as it reacts with hydrochloric acid. Gas bubbles are formed and the temperature increases.

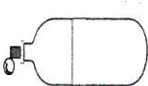
Among the following situations, which one represents a state of equilibrium?

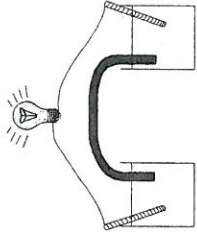
- A) The growth of algae at the bottom of a lake
- B) Wine in a sealed bottle
- C) An inflated tire
- D) The digestion of food

Which of the following represents a system at equilibrium?

A)  Burning candle

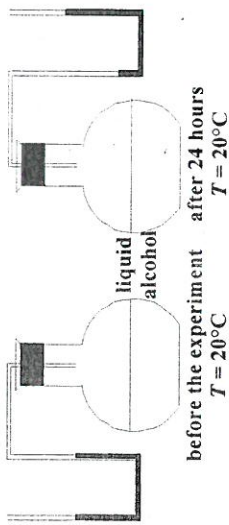
B)  Unopened soft drink bottle

C)  Scuba diver's air tank

D)  Electrochemical cell

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You introduce alcohol into a flask fitted with a manometer, as illustrated below. After 24 hours, you observe that the macroscopic properties of the system are constant.



Here are five explanations of the situation :

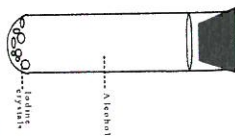
1. The evaporation of the alcohol has stopped because the volume of the liquid has remained constant.
2. The temperature remains constant; there is no more reaction.
3. The rate of evaporation is the same as the rate of condensation.
4. The condensation of alcohol vapour has stopped because the pressure has remained constant and the volume of liquid is constant.
5. All molecular activity has stopped because the macroscopic properties are constant.

Which explanations could explain the constant properties?

- A) 1, 2 and 4
- B) 3 and 5
- C) 3 alone
- D) 5 alone

Answers

- 5 In order to study the conditions in a system at equilibrium, some iodine crystals were placed in alcohol, as in the diagram below.



The iodine-alcohol solution quickly became reddish-colored. The color of the solution and the quantity of non-dissolved iodine crystals did not change over a period of a few days.

- Which analogy might best explain the **dynamics**, at the **microscopic** level, of this equilibrium system?
- A) A dam where the water level is constant. The amount of water leaving the dam is exactly the same as the water approaching the dam.
- B) A hockey game in which six players are on the ice at the same time. As one player leaves the bench to join the play, another player goes to the bench.
- C) A line-up at the cash in the cafeteria. As soon as a student pays, the length of the line-up decreases.
- D) A full dance club on a Saturday night. As soon as one customer leaves the club, the doorman lets in a new customer.

6 A student tried to neutralize 100 mL of 0.1 mol/L hydrochloric acid, HCl. Using a coloured indicator, she gradually added 100 mL of 0.01 mol/L sodium hydroxide, NaOH. She then put a stopper on the flask containing the resulting solution. After a while, she observed that the temperature and the intensity of the colour of the resulting solution remained the same.

The neutralization reaction for this system is represented by the following equation :



Which of the following statements describes this system at equilibrium?

- A) The chemical reaction stopped completely.
- B) The concentrations of $\text{H}^+_{(\text{aq})}$ and $\text{OH}^-_{(\text{aq})}$ are equal.
- C) The resulting solution contains no reactants.
- D) The rate of the forward reaction is equal to that of the reverse reaction.

- 7 In which one of the following systems can equilibrium be achieved?

- A) An alcohol thermometer reads 25°C.
- B) A glass of water fizzes after you add an antacid.
- C) A river is saturated with oxygen.
- D) The air around an oil-fired thermal power station is saturated with sulfur dioxide.

- 8 Examine the list of open and closed systems below.

- 1) A capped bottle of pop
- 2) The water level in the lake
- 3) A corked test tube of water
- 4) A saturated solution
- 5) An alcohol thermometer reading 25°C
- 6) The volume of water in a swimming pool

Which examples from the list above represent a closed system?

- A) 1, 2, 3 and 4
- B) 1, 2, 5 and 6
- C) 1, 3, 4 and 5
- D) 3, 4, 5 and 6

- 9 Which situation represents a dynamic equilibrium?

- A) An abandoned car rusting
- B) A burning candle emitting a constant flame
- C) KCl precipitate at the bottom of a fixed volume of a saturated solution
- D) A rock and a brick with identical mass balancing on opposite sides of a scale

- 10 Which of the following is an example of a system in a state of dynamic equilibrium?

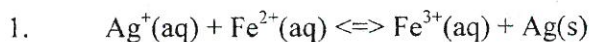
- A) A 200-mL beaker containing 100 mL of alcohol_(l) at STP
- B) The constant water level in the reservoir of the LG2 dam
- C) A sealed bottle containing 125 g of sugar, C₁₂H₂₂O_{11(s)}
- D) A 250-mL beaker containing 100 mL of a saturated salt solution with excess salt at the bottom



Chem 534

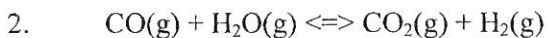
More Le Chatelier(from <http://www.mynewschool.co.uk/le-chateliers2a.htm>)

Assume that dynamic equilibrium has been reached. A stress is then applied. Shade the appropriate circle to show how this stress affects the equilibrium.



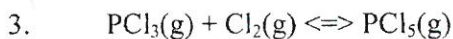
Fe^{3+} is added.

Shifts to Left, meaning that you'll get more Ag^+ and Fe^{2+} Shifts to Right No Change



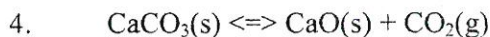
CO is added.

Shifts to Left Shifts to Right No Change



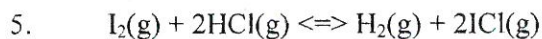
Cl_2 is added.

Shifts to Left Shifts to Right No Change



$\text{CO}_2(\text{g})$ is removed.

Shifts to Left Shifts to Right No Change



The pressure is decreased.

Shifts to Left Shifts to Right No Change

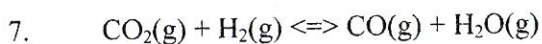
Same number of moles on either side



The pressure is increased.

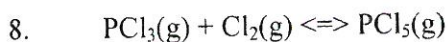
Shifts to Left Shifts to Right No Change

Shifts to side with least number of moles.



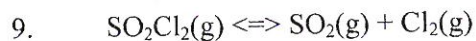
H₂ is removed.

Shifts to Left Shifts to Right No Change



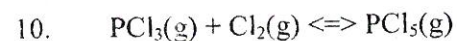
A catalyst is added.

Shifts to Left Shifts to Right No Change



The pressure is decreased.

Shifts to Left Shifts to Right No Change



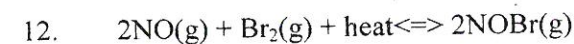
The pressure is decreased.

Shifts to Left Shifts to Right No Change



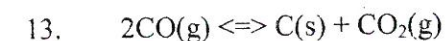
NO is removed.

Shifts to Left Shifts to Right No Change



The temperature is increased.

Shifts to Left Shifts to Right No Change



The pressure is decreased.

Shifts to Left Shifts to Right No Change

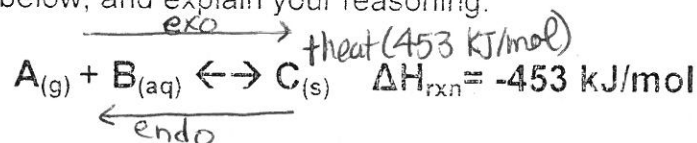


Temperature is lowered

Shifts to Left Shifts to Right No Change

Le Châtelier's Principle

Explain how the following changes in reaction conditions will affect the position of the equilibrium below, and explain your reasoning.

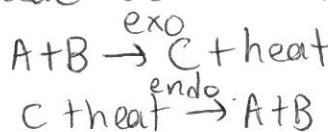


- 1) The pressure of A in the reaction chamber is increased.

Shift right → more product are made because increasing the pressure of A will lead to more effective collisions.

- 2) The temperature of the reaction is increased by 20° C.

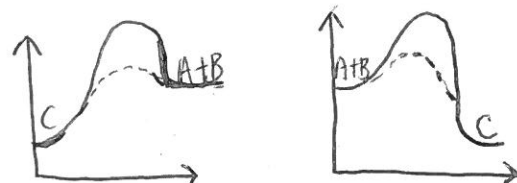
Shift left → more reactant made because reaction wants to absorb excess heat.



- 3) A catalyst is added to the system.

No effect
→ lowers barrier for forward and reverse

→ reaches equilibrium faster.



- 4) As the reaction progresses, more of compound B is steadily added to the reaction chamber.

↑ [B]

Shifts right → more product.

↑ [B] leads to more effective collisions

- 5) An inhibitor is added to the reaction chamber.

No effect.

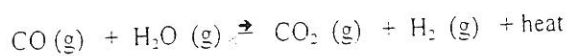
- 6) Argon gas is added to the reaction chamber, doubling the pressure.

↓

Inert gas - No effect because the collisions with Argon gas don't lead to the formation of products (not effective)

For each of the following indicate the direction the equilibrium would shift and what would happen to the concentrations of each substance in the equilibrium

7 The following equilibrium reaction may be established with carbon dioxide and steam



What would be the effect of each of the following on the equilibrium:

(a) The addition of more H_2O ?

Shift right - $\uparrow [\text{CO}_2]$ and $[\text{H}_2]$
- $\downarrow [\text{CO}]$ and $[\text{H}_2\text{O}]$

(b) The removal of some H_2 ?

Shift right

$\underbrace{\hspace{10em}}$
same.

(c) Raising the temperature?

Shift left

$\downarrow [\text{CO}_2]$ $[\text{H}_2]$
 $\uparrow [\text{CO}]$ $[\text{H}_2\text{O}]$

(d) Increasing the pressure?

no shift - equal number of moles.

(e) Addition of a catalyst?

no shift - system reaches equilibrium faster without favouring forward or reverse.

8 What would be the effect on each of the following on the equilibrium involving the synthesis of methanol?



(a) The removal of CH_3OH .

Shift right -

$\uparrow [\text{CH}_3\text{OH}]$
 $\downarrow [\text{CO}]$ and $[\text{H}_2]$

(b) an increase in pressure

Shift right

$\underbrace{\hspace{10em}}$
same.

(c) lowering the concentration of H_2 .

Shift left

$\downarrow [\text{CH}_3\text{OH}]$
 $\uparrow [\text{CO}]$ and $[\text{H}_2]$

9 What would be the effect of each of the following on the equilibrium involving the reaction of coke, C (s), with steam to give CO and H_2 ?



(a) The addition of steam?

Shift right -

$\uparrow [\text{CO}]$ and $[\text{H}_2]$
 $\downarrow [\text{H}_2\text{O}]$

(b) An increase in pressure?

Shift left -

$\downarrow [\text{CO}]$ and $[\text{H}_2]$
 $\uparrow [\text{H}_2\text{O}]$

(c) The removal of H_2 as it is produced?

Shift right $\uparrow [\text{CO}]$ and $[\text{H}_2]$, $\downarrow [\text{H}_2\text{O}]$

Le Chatelier's Principle

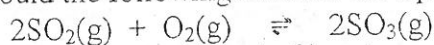
1. What 3 factors alter the equilibrium position in chemical reactions?

- Concentration
- Pressure
- Temperature

2. Given the reaction, $\text{H}_2(\text{g}) + \text{I}_2(\text{g}) \rightleftharpoons 2\text{HI}(\text{g})$, How would you go about maximizing the amount of HI produced?

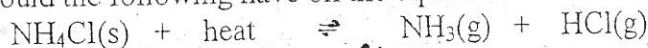
↑ [Reactants] or ↓ [Product]

3. What effect would the following have on the equilibrium shift for the reaction:



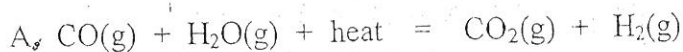
- a. O_2 is added to the reaction Right
- b. SO_3 is removed from the reaction Right
- c. SO_3 is added to the reaction Left
- d. The pressure is decreased Left

4. What effect would the following have on the equilibrium shift for the reaction?"



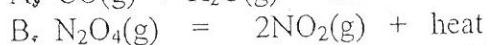
- a. The temperature is decreased Left
- b. The pressure is increased Left
- c. HCl is removed Right
- d. Volume of the closed container is increased ~~Left~~ Right

5. Predict the effect upon the following reaction equilibria of: (a) increased temperature, (b) increased pressure.



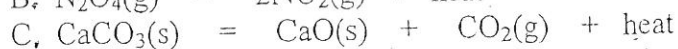
a. Right

b. No shift



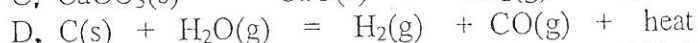
a. Left

b. Left



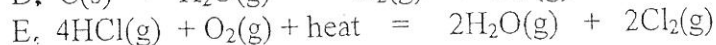
a. Left

b. Left



a. Left

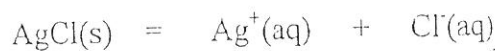
b. Left



a. ~~Left~~ Right

b. Right

6. If HCl(aq) is added to the following solution, what will happen to the amount of the solid AgCl? (Hint: What ions are formed when HCl molecules dissolve in water?)



Shift left, more solid AgCl precipitates out.

7. What methods are used in the Haber process to increase the production of ammonia?



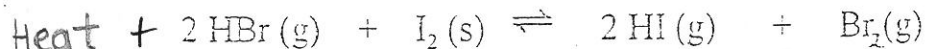
↑ Pressure by ↓ volume.

↓ Heat

↑ [N₂] OR [H₂] or Remove NH₃

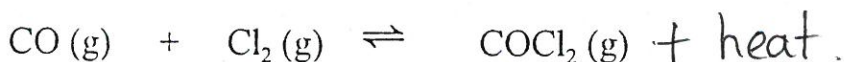
8.

For the system below at equilibrium :

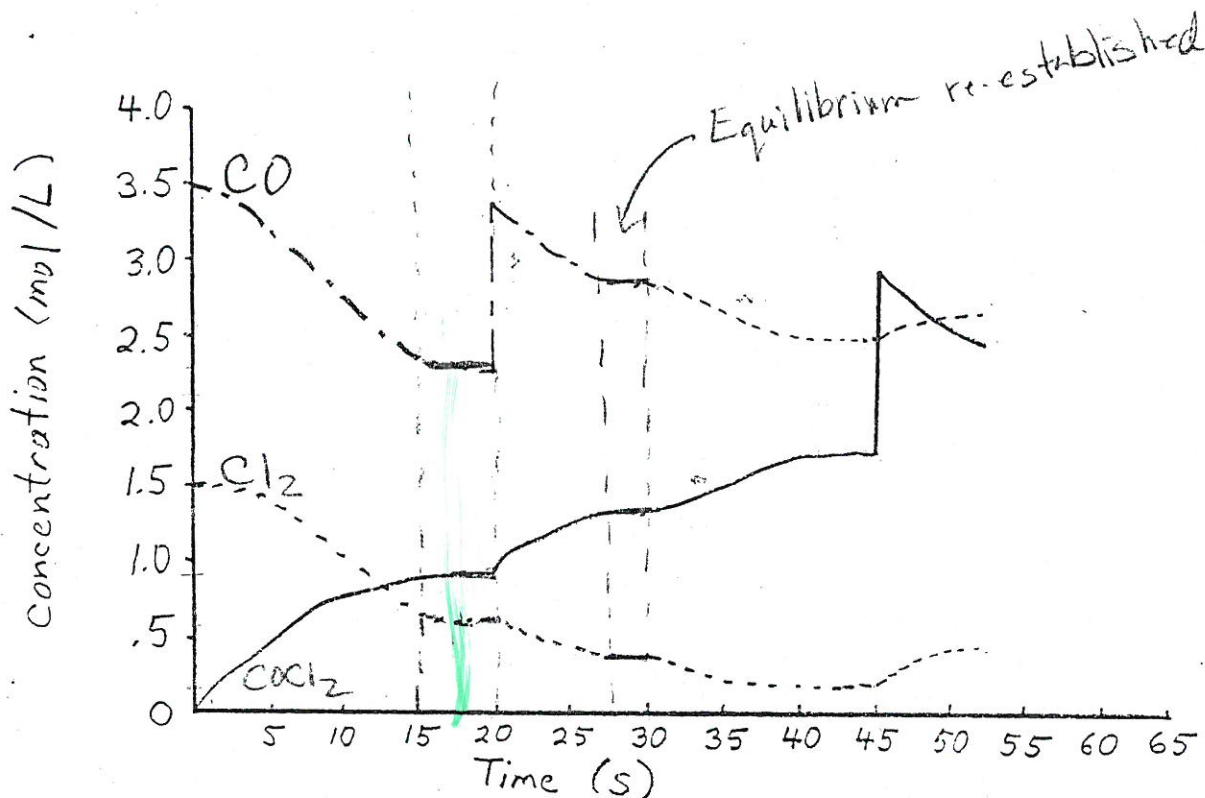


indicate what effect each of the changes below would have, and explain each in terms of the Collision Theory of Reaction Kinetics.

- a) decreasing the volume of the reaction vessel $\rightarrow \downarrow V \uparrow P \therefore$ Shifts to Side with least number of moles, left.
- b) adding more HI. $\uparrow [\text{HI}]$ will cause an increase in effective collisions which will favour the reverse reaction and cause the reaction to shift left.
- c) adding a catalyst no effect on equilibrium, will lower activation energy for forward and reverse reaction, reaches equilibrium faster.
- d) adding some neon gas no effect, inert gas will increase pressure in system but will not lead to more effective collisions.
- e) removing some I_2 no effect, ~~solid~~ adding or removing a solid has no change in concentration.
- f) increasing the temperature
Increasing heat in the system will cause the system to absorb excess heat through the endothermic reaction. This leads to a shift right.



the graph below shows the concentration of all three species plotted against time.



- a) How much time was required for the system to reach equilibrium?
(1 mark) **17s.**
- b) Approximate the value for K_c at $t = 17 \text{ s}$. (1 mark) **$K_c = 0.652$** $K_c = \frac{[0.9]}{[2.3][0.6]}$
- c) Explain what changes occurred at the 20 s mark. (2 marks)
[CO] increased causing equilibrium to shift right and produce COCl_2
[Cl₂] will decrease
- d) What change in conditions might have been imposed on the system at the 30 s mark. Explain. (3 marks)
~~reactants decreased and products increased. This can be explained by decrease in temperature or an increase in pressure (volume decrease)~~
- e) Are any events taking place between the 15 s and 20 s mark? Explain (3 marks) **dynamic equilibrium where the concentration of all the reactants/products are constant.**
- f) What change may have taken place at $t = 45 \text{ s}$? (1 mark)
 COCl_2 was added so reaction shifts left where the concentration of CO and Cl_2 are increasing.
- g) What differences would you have noted if a catalyst had been present during the entire course of the reaction? (2 marks)
rates are increased
- h) List the changes you might impose on the system if you wanted to maximize the yield of COCl_2 . (3 marks)
 → ↑ [] of reacting substances
 → ↓ volume of container
 → reaction exo. so decrease temperature.

