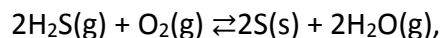


1a) For the following reaction at equilibrium, which of the following disturbances will increase product yield?



$$\Delta H^\circ_{\text{rxn}} = +30 \text{ kJ}$$

$$K_p = 2.6 \times 10^{-9} \text{ at } 25^\circ\text{C}$$

I: Increase temperature

II: Increase volume

III: decreasing moles of  $\text{O}_2$

- A) I only
- B) II only
- C) I and III
- D) II and III
- E) I, II, and III

1b) Fill in the blank

The principle used in part 1a to determine the shift in an equilibrium reaction is called \_\_\_\_\_

Answer: Le Chatelier's

2) Consider the following overall reaction and its rate law:  $2\text{A} + \text{B} \rightarrow 2\text{C}$ ,  $\text{Rate} = k[\text{A}][\text{B}]$ . Which of the following mechanisms can be considered a possible mechanism for the reaction?

I:  $2\text{A} + \text{B} \rightarrow 2\text{C}$  (one step)

II:  $\text{A} + \text{B} \rightleftharpoons \text{M}$  (slow)

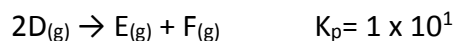
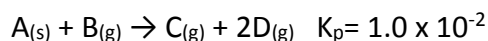
III:  $\text{A} + \text{B} \rightleftharpoons \text{M}$  (fast)

$\text{M} + \text{A} \rightarrow 2\text{C}$  (fast)

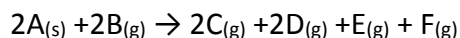
$\text{M} + \text{A} \rightarrow 2\text{C}$  (slow)

- A) Only I
- B) Only II
- C) I and III
- D) II and III
- E) I, II, and III

Use the following two reactions for questions 3-4:



3) What is the  $K_p$  of the following reaction? Be sure to show all your work to be eligible for partial credit.



$$K_p = 1.0 \times 10^{-3}$$

4) If excess A and 10.0 atm of B react according to reaction 1, what would be the predicted partial pressure of D at equilibrium?

A) 0.37 atm

B) 0.58 atm

C) 0.29 atm

D) 0.16 atm

E) 0.32 atm

5) Which of the following statements is *false*? Then, correct the false statement.

A) Increasing the temperature increases the rate of a reaction

B) Increasing the temperature increases the rate constant of a reaction

C) The activation energy is the energy difference between reactants and products

D) Lowering the activation energy increases the rate of a reaction.

C is false because  $\Delta H$  is the difference between the reactants and products

6) The decomposition of  $\text{N}_2\text{O}_4$  into  $\text{NO}_2$  has  $K_p = 2$ . Some  $\text{N}_2\text{O}_4$  is placed into an empty container, and the partial pressure of  $\text{NO}_2$  at equilibrium is measured to be 0.2 atm. What was the initial pressure in the container prior to decomposition?

A) 0.12 atm

B) 0.10 atm

C) 0.20 atm

D) 0.22 atm

E) 0.30 atm

Consider the following reactions when answering questions 7-8.

Reaction 1:  $2\text{NO}(\text{g}) + \text{Br}_2(\text{g}) \rightleftharpoons 2\text{NOBr}(\text{g})$      $\Delta H^\circ_{\text{rxn}} = -16 \text{ kJ}$      $K_p = 27$  at  $25^\circ\text{C}$

Reaction 2:  $\text{CO}_2(\text{g}) \rightleftharpoons \text{C}(\text{s}) + \text{O}_2(\text{g})$      $\Delta H^\circ_{\text{rxn}} = +100 \text{ kJ}$      $K_p = 2.6 \times 10^{-9}$  at  $25^\circ\text{C}$

7) For which reaction(s) above would an increase in reaction vessel volume at constant temperature result in an increase in product yield?

A) Neither Reaction

B) Reaction 1 only

C) Reaction 2 only

D) Both reactions

8) For which reaction(s) above would an increase in temperature at constant volume result in an increase in product yield?

A) Neither Reaction

B) Reaction 1 only

**C) Reaction 2 only**

D) Both reactions

9) The equilibrium constant  $K_c$  is found to be 1.05 for the decomposition of phosphorus pentachloride to phosphorus trichloride and molecular chlorine at 250 °C. If the initial concentrations of  $\text{PCl}_5$ ,  $\text{PCl}_3$ , and  $\text{Cl}_2$  are 0 M, 3 M, and 4 M, respectively, what is the equilibrium concentration of  $\text{PCl}_3$  at 250 °C?  $\text{PCl}_{5(g)} \rightleftharpoons \text{PCl}_{3(g)} + \text{Cl}_{2(g)}$ . Show your work.

**$\text{PCl}_3 = 1.02 \text{ M}$**

10) Sodium-24 is a radioactive isotope that decays via first order kinetics and has a half-life of 15 hours. What fraction of an original sample of sodium-24 will decompose in 3 days?

A) 4%

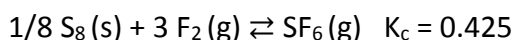
B) 13%

C) 50%

D) 87%

E) **96%**

11) For the following reaction, given that a 1L flask initially contains 2 moles  $\text{S}_8$ , 2 moles  $\text{SF}_6$ , and 2 moles  $\text{F}_2$ , will  $Q$  or  $K$  be larger? Will the reaction shift towards the products or the reactants? Show your work.



**Answer:  $K > Q$ , reaction will make more products**

12) Given the overall reaction  $2\text{H}_2 + 2\text{NO} \rightarrow 2\text{H}_2\text{O} + \text{N}_2$  and the following mechanism:

Step 1:  $\text{NO} + \text{NO} \rightleftharpoons \text{N}_2\text{O}_2$  (fast)

Step 2:  $\text{N}_2\text{O}_2 + \text{H}_2 \rightarrow \text{H}_2\text{O} + \text{N}_2\text{O}$  (slow)

Step 3:  $\text{N}_2\text{O} + \text{H}_2 \rightarrow \text{N}_2 + \text{H}_2\text{O}$  (fast)

Which of the following is/are true?

I: The rate law for the overall reaction is  $\text{Rate} = k[\text{N}_2\text{O}_2][\text{H}_2]$

II: The absolute value of the rate of change of  $\text{H}_2$  is  $\frac{1}{2}$  the rate of change of  $\text{N}_2$

III: The rate of the reaction is equal to the rate of  $\text{H}_2$

A) Only I

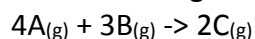
B) Only II

C) Only III

D) I, II, and III

**E) None**

13) Given the following experimental data, find the rate law and the rate constant. Show all work to be eligible for partial credit.



| Experiment | Initial [A] (M) | Initial [B] (M) | Initial Rate (M/min) |
|------------|-----------------|-----------------|----------------------|
| 1          | 0.100           | 0.100           | 5.00                 |
| 2          | 0.300           | 0.100           | 45.0                 |
| 3          | 0.100           | 0.200           | 10.0                 |
| 4          | 0.300           | 0.200           | 90.0                 |

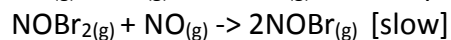
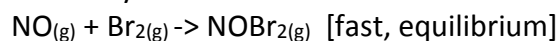
$$\text{Rate} = k[A]^2[B]$$

$$K = 5000 \text{ M}^{-2}\text{min}^{-1}$$

14) The rate constant of a reaction is  $4.7 \times 10^{-3} \text{ s}^{-1}$  at  $25^\circ\text{C}$ , and the activation energy is  $33.6 \text{ kJ/mol}$ . What is  $k$  at  $75^\circ\text{C}$ ?

$$K_2 = 3.29 \times 10^{-2}$$

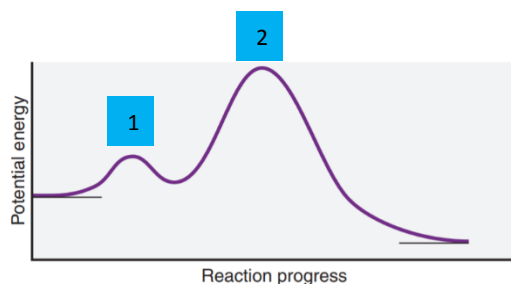
15) In a study of nitrosyl halides, a chemist proposes the following mechanism for the synthesis of nitrosyl bromide:



If the rate law is  $\text{rate} = k[\text{NO}]^2[\text{Br}_2]$ , is the proposed mechanism valid? Show all your work.

Yes, the proposed mechanism is valid

16)



a) Free response: How many elementary steps are in the reaction mechanism? 2

b) Which step is rate limiting? 1 or 2

c) Is the overall reaction exothermic or endothermic?

Exothermic/Endothermic

17) What is the  $K_b$  of a conjugate base if the  $K_a$  of the acid is  $7.1 \times 10^{-4}$ ? Show your work.

$$K_b = 1.41 \times 10^{-11}$$