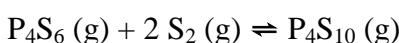


**Important:** Bubble in **A**, **B** or **C** as the test form code at the top right of your answer sheet.  
Useful information is provided at the end.

## VERSION A

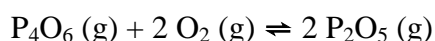
1. The reaction  $A(aq) + 2 B(aq) \rightleftharpoons 2C(aq) + D(aq)$  has  $K_c = 14$ . At a particular moment in time,  $[A] = 0.4 \text{ M}$ ,  $[B] = 0.5 \text{ M}$ ,  $[C] = 1.1 \text{ M}$ , and  $[D] = 1.4 \text{ M}$ . Which of the following statements is true?
- $Q < K$  and the reaction is proceeding to the right.
  - $Q < K$  and the reaction is proceeding to the left.
  - $Q > K$  and the reaction is proceeding to the left.**
  - $Q > K$  and the reaction is proceeding to the right.
  - The reaction is at equilibrium.

2. In the following reaction at 600 K, which has  $K_c = 6.2 \times 10^3$  and  $\Delta H^\circ = -254 \text{ kJ}$ , 1.0 mol of each substance is introduced into a 1.0 L vessel in the presence of a catalyst and allowed to reach equilibrium at 600 K.



If the volume of the vessel is then doubled, what will happen?

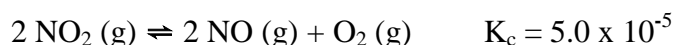
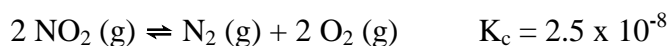
- the concentrations will all decrease, and the reaction will then shift left-to-right.
  - the concentrations will all increase, and the reaction will then shift right-to-left.
  - the concentrations will all increase, and the reaction will then shift left-to-right.
  - the concentrations will all decrease, but the reaction will then not shift.
  - the concentrations will all decrease, and the reaction will then shift right-to-left.**
3. Consider the reaction



At a particular moment in time,  $p_{O_2}$  is found to be increasing. Which of the following statements is true?

- $Q_p < K_p$
- $Q_p > K_p$**
- $Q_p = K_p$
- $Q_p < 0$
- cannot decide without knowing  $K_c$

4. At a particular temperature,



Use the above information to calculate the  $K_c$  for the reaction below at that temperature.



- $2.0 \times 10^3$**
  - $5.0 \times 10^{-4}$
  - impossible to determine
  - $1.3 \times 10^{-12}$
  - $2.5 \times 10^{-5}$
5. What is  $K_c$  for the following reaction, whose  $K_p = 8.2 \times 10^2$  at 500 K?



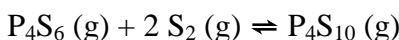
- 20**
- 0.050
- $3.4 \times 10^4$
- $8.2 \times 10^2$
- impossible to determine.

6. At a particular temperature, the  $p_{\text{Ne}}$  in the following reaction is  $2.9 \times 10^2$  atm at equilibrium, and the moles of  $\text{IF}_3$ ,  $\text{I}_2$  and  $\text{NeF}_2$  are equal. What is  $K_p$ ?
- $$2 \text{IF}_3 (\text{s}) + 3 \text{Ne} (\text{g}) \rightleftharpoons \text{I}_2 (\text{s}) + 3 \text{NeF}_2 (\text{s})$$
- $2.4 \times 10^7$
  - $4.1 \times 10^{-8}$
  - $3.4 \times 10^{-3}$
  - $2.9 \times 10^2$
  - cannot be determined without the temperature
7. Once the reaction  $2 \text{A} + 2 \text{B} \rightleftharpoons \text{C} + \text{D}$  has reached equilibrium, which of the following statements must be true?
- the forward rate constant is equal to the backward rate constant.
  - $K_c < 1$
  - $[\text{A}] = 2[\text{C}]$
  - $K_c < 1$
  - the backward reaction rate is equal to the forward reaction rate.
8. The reaction  $2 \text{PH}_3 (\text{g}) \rightleftharpoons \text{P}_2 (\text{g}) + 3 \text{H}_2 (\text{g})$  has  $K_c = 8.0$  at a particular temperature. At equilibrium,  $[\text{H}_2] = 0.24 \text{ M}$  and  $[\text{P}_2] = 0.20 \text{ M}$ . What is  $[\text{PH}_3]$  at equilibrium?
- $1.5 \times 10^{-2} \text{ M}$
  - $3.5 \times 10^{-4} \text{ M}$
  - $1.9 \times 10^{-2} \text{ M}$
  - $2.4 \times 10^{-4} \text{ M}$
  - cannot be determined without the temperature.
9. 
$$2 \text{SO}_2 (\text{g}) + \text{O}_2 (\text{g}) \rightleftharpoons 2 \text{SO}_3 (\text{g})$$
 1.000 atm of  $\text{SO}_2$  and 1.000 atm of  $\text{O}_2$  were placed in a container, and the reaction allowed to reach equilibrium. At equilibrium,  $p_{\text{O}_2} = 0.612 \text{ atm}$ . What is  $K_p$ ?
- 19.6
  - 4.39
  - 9.80
  - 11.4
  - impossible to determine
10. A  $3.6 \times 10^{-3} \text{ M}$  solution of one of the following acids has  $\text{pOH} = 11.56$ . Identify the acid.  
HF,  $\text{HNO}_2$ , HI,  $\text{HClO}$ , HCN
- HF
  - HI
  - $\text{HNO}_2$
  - $\text{HClO}_3$
  - HCN
11. Consider the reaction  $2 \text{KClO}_3 (\text{s}) \rightleftharpoons 2 \text{KCl} (\text{s}) + 3 \text{O}_2 (\text{g})$  at 500 K. At equilibrium,  $p_{\text{O}_2} = 0.20 \text{ atm}$ . What is  $K_c$ ?
- $8.0 \times 10^{-3}$
  - 550
  - $1.2 \times 10^{-7}$
  - 125
  - impossible to determine.
12. 
$$\text{CO} (\text{g}) + \text{H}_2\text{O} (\text{g}) \rightleftharpoons \text{CO}_2 (\text{g}) + \text{H}_2 (\text{g})$$
 2.00 M  $\text{CO}$  and 1.00 M  $\text{H}_2\text{O}$  were placed in a flask and allowed to reach equilibrium at a particular temperature where  $K_c = 1.56$ . What is the  $[\text{CO}]$  at equilibrium?
- 0.27 M
  - 0.73 M
  - 1.27 M
  - 1.73 M
  - none of the other answers

13.  $2 \text{CO}_2 (\text{g}) \rightleftharpoons 2 \text{CO} (\text{g}) + \text{O}_2 (\text{g})$   
 2.000 atm of  $\text{CO}_2$  are added to a vessel and heated to 100 K. At equilibrium, the  $p_{\text{CO}}$  was found to be double the  $p_{\text{O}_2}$ . What is the  $K_c$  for this reaction at 500K?
- 2.00
  - $5.3 \times 10^{-2}$
  - $2.1 \times 10^3$
  - $6.8 \times 10^{-4}$
  - impossible to determine

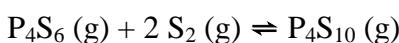
14. The reaction  $\text{A} \rightleftharpoons \text{B}$  has an equilibrium constant  $K = 1.0 \times 10^4$  at a certain temperature. Which of the following is true at equilibrium?
- $[\text{A}] = (1.0 \times 10^{-4})[\text{B}]$
  - The reaction lies far to the left-hand side.
  - The forward rate constant = the backward rate constant.
  - $[\text{A}] = [\text{B}]$
  - The  $K$  for  $2\text{B} \rightleftharpoons 2\text{A}$  is  $2.0 \times 10^4$ .

15. In the following reaction at 600 K, which has  $K_c = 6.2 \times 10^3$  and  $\Delta H^\circ = -254 \text{ kJ}$ , 1.0 mol of each substance is introduced into a 1.0 L vessel in the presence of a catalyst and allowed to reach equilibrium at 600 K.



If nitrogen gas,  $\text{N}_2(\text{g})$ , is now added to the vessel, what will happen?

- $[\text{S}_2]$  will decrease and  $[\text{P}_4\text{S}_{10}]$  will increase.
  - the equilibrium concentrations will stay the same.
  - $[\text{S}_2]$  will increase and  $[\text{P}_4\text{S}_{10}]$  will decrease.
  - all concentrations will increase.
  - the value of  $K_c$  will increase
16. In the following reaction at 600 K, which has  $K_c = 6.2 \times 10^3$  and  $\Delta H^\circ = -254 \text{ kJ}$ , 1.0 mol of each substance is introduced into a 1.0 L vessel in the presence of a catalyst and allowed to reach equilibrium at 600 K.



If more  $\text{S}_2$  is now added to the flask, what will happen?

- the reaction shifts from right-to-left, and  $K_c$  stays unchanged.
  - the reaction shifts from right-to-left, and  $K_c$  decreases.
  - the reaction shifts from left-to-right, and  $K_c$  decreases.
  - the reaction shifts from left-to-right, and  $K_c$  stays unchanged.
  - the reaction shifts from left-to-right, and  $K_c$  increases.
17. Which of the following is an Arrhenius base?
- $\text{NH}_3$
  - $\text{CH}_3\text{COOH}$
  - $\text{H}_3\text{O}^+$  (aq)
  - $\text{F}^-$
  - KOH**

18. What is  $Q_c$  for the following reaction?  $2 \text{CH}_4 (\text{g}) \rightleftharpoons \text{C}_2\text{H}_2 (\text{g}) + 3 \text{H}_2 (\text{g})$

- |   |  |
|---|--|
| a. $Q_c = \frac{[\text{H}_2]^3[\text{C}_2\text{H}_2]}{[\text{CH}_4]^2}$ | d. $Q_c = \frac{[\text{C}_2\text{H}_2] + [\text{H}_2]^3}{[\text{CH}_4]^2}$ |
| b. $Q_c = \frac{[\text{C}_2\text{H}_2][\text{H}_2]}{[\text{CH}_4]}$     | e. $Q_c = \frac{[\text{C}_2\text{H}_2][\text{H}_2]^3}{[\text{CH}_4]}$      |
| c. $Q_c = \frac{3[\text{H}_2][\text{C}_2\text{H}_2]}{2[\text{CH}_4]}$   |  |

19. Which of the following is not a conjugate acid/base pair?
- $\text{H}_2\text{SO}_4 / \text{HSO}_4^-$
  - $\text{F}^- / \text{HF}$
  - $\text{Cl}^- / \text{HCN}$
  - $\text{HNO}_2 / \text{NO}_2^-$
  - $\text{HPO}_3^- / \text{H}_2\text{PO}_3$
20. Some  $\text{HCl}$  (g) is dissolved in pure water to give a final concentration of  $4.0 \times 10^{-12}$  M. What is the pH of this solution of  $\text{HCl}$  (aq) to one decimal place?
- 11.4
  - 1.4
  - 4.0
  - 8.2
  - 7.0
21. Which of the following is not a Bronsted base?  $\text{NH}_3$ ,  $\text{F}^-$ ,  $\text{OH}^-$ ,  $\text{CH}_3\text{COO}^-$ .
- $\text{OH}^-$
  - $\text{F}^-$
  - $\text{NH}_3$
  - $\text{CH}_3\text{COO}^-$
  - they are all Bronsted bases.
22. In the following reaction at 600 K, which has  $K_c = 6.2 \times 10^3$  and  $\Delta H^\circ = -254$  kJ, 1.0 mol of each substance is introduced into a 1.0 L vessel in the presence of a catalyst and allowed to reach equilibrium at 600 K.
- $$\text{P}_4\text{S}_6 (\text{g}) + 2 \text{S}_2 (\text{g}) \rightleftharpoons \text{P}_4\text{S}_{10} (\text{g})$$
- If the temperature is now lowered, what will happen to the equilibrium concentrations?
- $[\text{P}_4\text{S}_6]$  will decrease and  $[\text{P}_4\text{S}_{10}]$  will increase.
  - the concentrations will stay the same.
  - $[\text{S}_2]$  will increase and  $[\text{P}_4\text{S}_{10}]$  will decrease.
  - all concentrations will increase.
  - $[\text{P}_4\text{S}_6]$  will increase and  $[\text{P}_4\text{S}_{10}]$  will decrease.
23. Which of the following is not a strong acid:  $\text{HI}$ ,  $\text{HNO}_3$ ,  $\text{HBr}$ ,  $\text{HSO}_4^-$
- $\text{HI}$
  - $\text{HBr}$
  - $\text{HNO}_3$
  - $\text{HSO}_4^-$
  - they are all strong acids
24. Which of the statements is true about the equilibrium below?
- $$\text{HCOOH} (\text{aq}) + \text{CN}^- (\text{aq}) \rightleftharpoons \text{HCOO}^- (\text{aq}) + \text{HCN} (\text{aq})$$
- $\text{HCOO}^-$  is the stronger base, and  $K_c < 1$
  - $\text{CN}^-$  is the stronger base, and  $K_c > 1$
  - $\text{CN}^-$  is the weaker base, and  $K_c > 1$ .
  - $\text{HCOOH}$  is the stronger acid, and  $K_c < 1$ .
  - $\text{HCN}$  is the stronger acid, and  $K_c < 1$ .
25.  $K_c = 0.10$  for the reaction below at a particular temperature.
- $$2 \text{SeO}_2 (\text{g}) + \text{O}_2 (\text{g}) \rightleftharpoons 2 \text{SeO}_3 (\text{g})$$
- What is  $K_c$  for the following reaction at the same temperature?
- $$4 \text{SeO}_3 (\text{g}) \rightleftharpoons 4 \text{SeO}_2 (\text{g}) + 2 \text{O}_2 (\text{g})$$
- 3.2
  - 100
  - 0.01
  - 20
  - 0.02

26.  $K_c$  for the reaction  $\text{Al (s)} + \text{Cl}_2 \text{ (g)} \rightleftharpoons \text{AlCl}_3 \text{ (s)}$  is given by
- $K_c = 1 / [\text{Cl}_2]$
  - $K_c = [\text{AlCl}_3] / [\text{Al}][\text{Cl}_2]$
  - $K_c = [\text{Cl}_2]$
  - $K_c = 1 / [\text{Al}][\text{Cl}_2]$
  - none of the other answers
27. A  $2.4 \times 10^{-2} \text{ M}$  solution of  $\text{NaOH}$  has a volume of  $0.10 \text{ L}$ . If  $0.20 \text{ L}$  of pure water is added, what is the  $[\text{OH}^-]$  in the final solution?
- $1.2 \times 10^{-2} \text{ M}$
  - $2.4 \times 10^{-2} \text{ M}$
  - $0.8 \times 10^{-2} \text{ M}$
  - $3.6 \times 10^{-2} \text{ M}$
  - cannot be determined without  $K_c$
28. In the reaction below, the  $\text{H}_2\text{O (l)}$  is acting as a what?
- $$\text{NH}_3 \text{ (g)} + \text{H}_2\text{O (l)} \rightleftharpoons \text{NH}_4^+ \text{ (aq)} + \text{OH}^- \text{ (aq)}$$
- Bronsted acid
  - Bronsted base
  - both a Bronsted acid and a Bronsted base
  - neither a Bronsted acid nor a Bronsted base
  - cannot be determined
29. The reaction  $\text{H}_3\text{O}^+ \text{ (aq)} + \text{OH}^- \text{ (aq)} \rightarrow 2 \text{H}_2\text{O (l)}$  is what kind of reaction?
- self-ionization of water
  - weak acid dissociation
  - weak base dissociation
  - neutralization
  - auto-ionization of water
30. Consider the reaction  $\text{I}_2 \text{ (g)} \rightleftharpoons 2\text{I (g)}$  at  $500 \text{ K}$ . The initial  $[\text{I}_2] = 0.45 \text{ M}$  and initial  $[\text{I}] = 0$ . What is  $[\text{I}]$  at equilibrium?  $K_c = 5.6 \times 10^{-12}$  at  $500\text{K}$ .
- $2.5 \times 10^{-5} \text{ M}$
  - $6.4 \times 10^{-6} \text{ M}$
  - $1.6 \times 10^{-6} \text{ M}$
  - $5.0 \times 10^{-4} \text{ M}$
  - impossible to determine

### Version Check

31. This question will not be graded. Bubble in your answer as question 31 so that we can check your exam version, if we think something is wrong,
- Version A
  - Version B
  - Version C

### Useful Information

Acid  $K_a$  values

$\text{HIO}_3$	$1.6 \times 10^{-1}$
$\text{HClO}_2$	$1.12 \times 10^{-2}$
$\text{HNO}_2$	$7.1 \times 10^{-4}$
$\text{HF}$	$6.8 \times 10^{-4}$
$\text{HCOOH}$	$1.8 \times 10^{-4}$
$\text{C}_6\text{H}_5\text{COOH}$	$6.3 \times 10^{-5}$
$\text{CH}_3\text{COOH}$	$1.8 \times 10^{-5}$
$\text{CH}_3\text{CH}_2\text{COOH}$	$1.3 \times 10^{-5}$
$\text{HClO}$	$2.9 \times 10^{-8}$
$\text{HBrO}$	$2.3 \times 10^{-9}$
$\text{HCN}$	$6.2 \times 10^{-10}$
$\text{HIO}$	$2.3 \times 10^{-11}$

$$K_p = K_c (RT)^{\Delta n}$$

$$R = 0.082 \text{ L}\cdot\text{atm}/\text{mol}\cdot\text{K}$$