Unit 8 · Chemical Equilibrium

ANSWER KEY · FOR TEACHERS

Full marks 33

Give the marks for the points in the marking scheme; an answer in other words that says the same is right.

1 Key words

K · 4

i. ✓ **True**
ii. ✗ **False**: At equilibrium the concentrations stay constant, but they are not usually equal.
iii. ✗ **False**: A catalyst speeds up the forward and backward reactions equally: equilibrium is reached sooner, but its position doesn't change.
iv. ✓ **True**
v. ✗ **False**: A large equilibrium constant means the reaction goes far towards the products; it says nothing about speed.
vi. ✓ **True**
vii. ✗ **False**: A pure solid (or pure liquid) has an active mass of 1 and is left out of K_c.
viii. ✓ **True**

Each carries 0.5 mark.

2 Label the diagram

K · 2

1. deposition
2. condensation
3. sublimation
4. melting

Each carries 0.5 mark.

3 Multiple choice

i. **a.** $I_2(s) \rightleftharpoons I_2(g)$ — K · 1

In $I_2(s) \rightleftharpoons I_2(g)$ the substance only changes its state (solid–vapor equilibrium); no new substance forms. The other three are chemical equilibria.

ii. **d.** nothing to the amounts at equilibrium — U · 1

A catalyst speeds up the forward and backward reactions by the same factor, so K and the equilibrium amounts stay the same. It only helps a mixture **reach** equilibrium sooner.

iii. **c.** 1/K — U · 1

The backward reaction's constant is the reciprocal of the forward one's: $\frac{[NO_2]^2}{[N_2O_4]} = \frac{1}{K}$.

iv. **a.** mol L^{-1} — A · 1

$K_c = \frac{[PCl_3][Cl_2]}{[PCl_5]}$: $(\text{mol L}^{-1})(\text{mol L}^{-1}) \div (\text{mol L}^{-1}) = \textbf{mol L}^{-1}$.

v. **c.** the position doesn't change — A · 1

Two moles of gas on each side ($\Delta n = 0$): neither direction lowers the number of molecules, so pressure doesn't shift this equilibrium.

4 Short answers

a. MARKING SCHEME — U · 2

✓ CO_2 escapes from the open kiln.
✓ Removing a product shifts the equilibrium to the right until all the $CaCO_3$ is used (no equilibrium in an open system).

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b. MARKING SCHEME A · 2

- ✓ The K_p expression.
- ✓ $\Delta n = -1$, so $K_p = K_c/RT$, less than K_c.

c. MARKING SCHEME A · 3

- ✓ Raised temperature: more CO (endothermic forward).
- ✓ Raised pressure: no change (equal moles of gas).
- ✓ Water removed: more CO.

5 Long answer

ANSWER U · 4

Law of mass action: at a constant temperature, the rate of a reaction is proportional to the product of the active masses (molar concentrations) of the reactants, each raised to the power of its coefficient in the balanced equation.

$K_c = \dfrac{[SO_3]^2}{[SO_2]^2[O_2]}$.

A **very large** K (10^3 or more): the equilibrium mixture is mostly products; the reaction goes almost to completion. A **very small** K (10^{-3} or less): mostly reactants; the forward reaction hardly happens.

Halving the equation takes the **square root** of K: $K_c' = \dfrac{[SO_3]}{[SO_2][O_2]^{1/2}} = \sqrt{K_c}$.

MARKING SCHEME

- ✓ The law of mass action stated.
- ✓ The K_c expression.
- ✓ Large K: mostly products; small K: mostly reactants.
- ✓ The halved equation's K is $\sqrt{K_c}$.

6 Numerical problems

a. ANSWER A · 4

i. Dissociated: $0.40 \times 2.0 = 0.80$ mol, giving 0.80 mol each of PCl_3 and Cl_2; 1.20 mol of PCl_5 left. In 2.0 L: $[PCl_5]$ = **0.60 mol/L**, $[PCl_3] = [Cl_2]$ = **0.40 mol/L**.

ii. $K_c = \dfrac{0.40 \times 0.40}{0.60}$ = **0.27 mol/L**.

iii. $\Delta n = 2 - 1 = +1$, T = 523 K: $K_p = K_c\,RT = 0.267 \times 0.0821 \times 523$ = **11.5 atm**.

MARKING SCHEME

- ✓ Moles at equilibrium: 1.20, 0.80, 0.80.
- ✓ Concentrations 0.60, 0.40, 0.40 mol/L.
- ✓ K_c = 0.27 mol/L.
- ✓ K_p = 11.5 atm ($\Delta n = 1$).

b. ANSWER A · 4

i. Let x mol/L of H_2 react: $[H_2] = [I_2] = 1.0 - x$, $[HI] = 2x$.

$\dfrac{(2x)^2}{(1.0-x)^2} = 64$, so $\dfrac{2x}{1.0-x} = 8$, $2x = 8 - 8x$, x = **0.80**.

$[H_2] = [I_2]$ = **0.20 mol/L**, [HI] = **1.60 mol/L**. (Check: $1.6^2 \div 0.2^2 = 64$.)

ii. The backward reaction: $K_c' = \dfrac{1}{64}$ = **0.0156**.

MARKING SCHEME

- ✓ The equilibrium amounts in terms of x.
- ✓ x = 0.80 from the square root.
- ✓ $[H_2] = [I_2] = 0.20$, [HI] = 1.60 mol/L.
- ✓ $K_c' = 1/64 = 0.0156$.

7 Think

ANSWER

Heating speeds up both reactions, but **not equally**: the endothermic direction, here the forward one, speeds up more. So for a while the forward reaction runs faster than the backward one, and the mixture shifts **to the right** until the rates are equal again, with more brown NO_2 and less N_2O_4.

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This is Le Chatelier's principle: the equilibrium shifts to take in the added heat. Since the new mixture has more product, the equilibrium constant itself **increases**: temperature is the one condition that changes K.

MARKING SCHEME

- ✓ Heating speeds up the endothermic (forward) reaction more than the backward one.
- ✓ The equilibrium shifts right: more NO_2 (Le Chatelier: heat is taken in).
- ✓ K itself changes (increases) with temperature.

8 Activity: Equilibrium with two glasses

(not marked)

WHAT STUDENTS SHOULD FIND

At first B gains water fast, because A is full and B nearly empty. As A falls and B rises, the strawful from A gets smaller and the one from B bigger, until both straws carry the **same amount**: the levels then stop changing, though water is still moved both ways each turn. That is a **dynamic equilibrium**, like a reaction's: the forward and backward rates are equal and the amounts stay constant, but are **not equal** (the levels settle where the two straws carry the same, which depends on their widths).

Marks by level	Knowledge	Understanding	Application	Higher ability	Total
Marks	7	8	15	3	**33**

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