Worksheet: Equilibrium Constant Kp

34 Sulfur dioxide and oxygen react in the gas phase.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \qquad \Delta H = -197\,kJ\,mol^{-1}$$

Which statements are correct?

1 Increasing the pressure increases the equilibrium yield of SO_3.

2 Increasing the temperature lowers the value of the equilibrium constant K_p.

3 The presence of a vanadium(V) oxide catalyst increases the equilibrium yield of SO_3.

m/17/qp12

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10 At a total pressure of 1.0 atm, dinitrogen tetraoxide is 50 % dissociated at a temperature of 60 °C, according to the following equation.

$$N_2O_4 \rightleftharpoons 2NO_2$$

What is the value of the equilibrium constant, K_p, for this reaction at 60 °C?

A $^1/_3$ atm **B** $^2/_3$ atm **C** $^4/_3$ atm **D** 2 atm

s/06/qp1

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10 At high temperatures, steam decomposes into its elements according to the following equation.

$$2H_2O(g) \rightleftharpoons 2H_2(g) + O_2(g)$$

In one experiment at 1 atm pressure, it was found that 20 % of the steam had been converted into hydrogen and oxygen.

What are the values of the equilibrium partial pressures, in atm, of the components of this equilibrium?

	partial pressure of steam	partial pressure of hydrogen	partial pressure of oxygen
A	$\frac{0.80 \times 1}{1.0}$	$\frac{0.10 \times 1}{1.0}$	$\frac{0.10 \times 1}{1.0}$
B	$\frac{0.80 \times 1}{1.0}$	$\frac{0.133 \times 1}{1.0}$	$\frac{0.067 \times 1}{1.0}$
C	$\frac{0.80 \times 1}{1.0}$	$\frac{0.20 \times 1}{1.0}$	$\frac{0.10 \times 1}{1.0}$
D	$\frac{0.80 \times 1}{1.1}$	$\frac{0.20 \times 1}{1.1}$	$\frac{0.10 \times 1}{1.1}$

w/04/qp1

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11 Dinitrogen tetroxide dissociates into nitrogen dioxide on heating.

$$N_2O_4(g) \rightleftharpoons 2NO_2(g)$$

In an experiment the partial pressures of the gases at equilibrium were found to be NO_2, 0.33 atm; N_2O_4, 0.67 atm.

What is the numerical value of K_p at the temperature of the experiment?

A 0.16 **B** 0.49 **C** 0.65 **D** 2.03

w/08/qp1

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10 For the equilibrium $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$, what will change the value of K_p?

A adding a catalyst

B adding more O_2

C increasing the pressure

D increasing the temperature

w/08/qp1

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8 The equilibrium

$$N_2(g) + O_2(g) \rightleftharpoons 2NO(g) \qquad \Delta H = +180\,kJ\ mol^{-1}$$

contributes to a series of reactions producing photochemical smog.

Which factors would affect the value of K_p of the above equilibrium?

	change in pressure	change in temperature	presence or absence of a catalyst
A	✓	✓	✗
B	✓	✗	✓
C	✗	✓	✓
D	✗	✓	✗

w/09/qp11

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36 The table describes some of the chemistry and thermodynamic properties of the halogens.

process	name and symbol of quantity
$2HX(g) \rightarrow H_2(g) + X_2(g)$	enthalpy change of reaction, $\Delta H^{\ominus}$
$H_2(g) + X_2(g) \rightleftharpoons 2HX(g)$	equilibrium constant, K_p
$X(g) \rightarrow X^+(g) + e^-$	ionisation energy, $\Delta H_i^{\ominus}$

Which statements about the relative values of these quantities are correct?

1 $\Delta H^{\ominus}$ for HC*l* > $\Delta H^{\ominus}$ for HBr

2 K_p for HBr > K_p for HI

3 $\Delta H_i^{\ominus}$ for I > $\Delta H_i^{\ominus}$ for C*l*

w/12/qp13

3 Nitrogen dioxide, NO_2, can enter the atmosphere in a variety of ways.

(a) (i) State one natural and one man-made source of atmospheric NO_2.

natural .....

man-made .....

[1]

(ii) Write an equation to show how NO_2 leads to the formation of nitric acid in acid rain.

..... [1]

(iii) Use equations to illustrate the catalytic role of NO_2 in the formation of sulfuric acid in acid rain.

.....

.....

..... [3]

(b) Nitrogen dioxide exists in equilibrium with dinitrogen tetroxide, N_2O_4.

$$2NO_2(g) \rightleftharpoons N_2O_4(g)$$

2.00 mol of dinitrogen tetroxide was sealed in a container at 350 K. After equilibrium had been established the total pressure was 140 kPa and the mixture of gases contained 1.84 mol of dinitrogen tetroxide.

(i) Give the expression for the equilibrium constant, K_p, for this equilibrium.

$K_p =$

[1]

(ii) Calculate the number of moles of NO_2 present at equilibrium.

[1]

(iii) Calculate the total number of moles of gas present at equilibrium and hence the mole fraction of each gas present at equilibrium.

[2]

(iv) Calculate the partial pressure of each gas present at equilibrium.

[2]

(v) Calculate the value of the equilibrium constant, K_p, at 350 K.
Give your answer to **three** significant figures and include the units.

K_p = ...

units = ...

[2]

[Total: 13]

s/14/qp23

2 Ammonium nitrate fertiliser is manufactured from ammonia. The first reaction in the manufacture of the fertiliser is the catalytic oxidation of ammonia to form nitrogen monoxide, NO. This is carried out at about 1×10^3 kPa (10 atmospheres) pressure and a temperature of 700 to 850 °C.

$$4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g) \qquad \Delta H^{\ominus} = -906\,kJ\,mol^{-1}$$

(a) Write the expression for the equilibrium constant, K_p, stating the units.

K_p =

units ..... [2]

(b) What will be the effect on the yield of NO of **each** of the following?
In each case, explain your answer.

(i) increasing the temperature

.....

.....

.....

(ii) decreasing the applied pressure

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.....

.....

[4]

s/13/qp21

(d) The conversion of sulfur dioxide into sulfur trioxide is carried out at a temperature of 400 °C.

(i) With reference to Le Chatelier's Principle and reaction kinetics, state and explain one advantage and one disadvantage of using a higher temperature.

.....

.....

.....

.....

.....

..... [4]

(ii) State the expression for the equilibrium constant, K_p, for the formation of sulfur trioxide from sulfur dioxide.

K_p =

[1]

(iii) 2.00 moles of sulfur dioxide and 2.00 moles of oxygen were put in a flask and left to reach equilibrium.
At equilibrium, the pressure in the flask was 2.00×10^5 Pa and the mixture contained 1.80 moles of sulfur trioxide.

Calculate K_p. Include the units.

K_p = ...

units = ...
[5]

w/14/qp21

(d) The Haber process is typically carried out at a temperature of 400 °C.

(i) With reference to Le Chatelier's Principle and reaction kinetics, state and explain one advantage and one disadvantage of using a higher temperature.

.....

.....

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.....

.....

..... [4]

(ii) State the expression for the equilibrium constant, K_p, for the formation of ammonia from nitrogen and hydrogen in the Haber process.

K_p =

[1]

(iii) 2.00 moles of nitrogen and 3.00 moles of hydrogen were put in a vessel and left to reach equilibrium.

At equilibrium, the pressure was 2.00×10^7 Pa and the mixture contained 1.60 moles of ammonia.

Calculate K_p. Include the units.

K_p = ...

units = ...

[5]

w/14/qp23

(c) At temperatures above 1500 K, HC*l* will decompose.

A sample of 0.300 mol of HC*l* decomposed in a sealed container.

The resulting equilibrium mixture was found to contain 1.50×10^{-2} mol of Cl_2.

(i) Calculate the amounts, in mol, of H_2 and HC*l* present in the equilibrium mixture.

H_2 = ... mol

HC*l* = ... mol
[2]

(ii) Calculate the mole fraction of each gas in the equilibrium mixture.

mole fraction of HC*l* = ...

mole fraction of H_2 = ...

mole fraction of Cl_2 = ...
[1]

(d) In another experiment under different conditions, an equilibrium mixture was produced with mole fractions for each species as shown.

species	mole fraction
HC*l*	0.88
H_2	0.06
Cl_2	0.06

(i) Write the expression for the equilibrium constant, K_p, for the decomposition of HC*l*.

$$2HCl(g) \rightleftharpoons H_2(g) + Cl_2(g)$$

K_p =

[1]

(ii) Explain why the total pressure of the system does **not** need to be known for K_p to be calculated for this experiment.

.....

..... [1]

(iii) Calculate the value of K_p for this experiment.

K_p = ... [1]

s/17/qp22

(c) At a pressure of 1.50×10^5 Pa, 1.00 mol of sulfur dioxide gas, SO_2, was mixed with 1.00 mol of oxygen gas, O_2. The final equilibrium mixture formed was found to contain 0.505 mol of O_2.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$

(i) Calculate the amount, in mol, of SO_2 and SO_3 in the equilibrium mixture.

SO_2 = ... mol

SO_3 = ... mol
[1]

(ii) Calculate the partial pressure of oxygen gas, pO_2, in the equilibrium mixture.

pO_2 = ... Pa [2]

(d) In another equilibrium mixture formed from different starting amounts of SO_2 and O_2, the partial pressures of SO_2, O_2 and SO_3 were as shown.

$pSO_2 = 8.42 \times 10^2$ Pa

$pO_2 = 6.00 \times 10^4$ Pa

$pSO_3 = 9.10 \times 10^4$ Pa

(i) Write the expression for the equilibrium constant, K_p, for the production of SO_3 from SO_2 and O_2.

K_p =

[1]

(ii) Calculate the value of K_p for this reaction and state the units.

K_p = ...

units = ...

[2]

s/17/qp23

(d) Under certain conditions the equilibrium pressures of the three gases are

nitrogen	44.8 atm,
hydrogen	105.6 atm,
ammonia	37.2 atm.

(i) Write an expression for the equilibrium constant, K_p, for the Haber Process.

(ii) Calculate K_p from these data, giving the units.

[4]

s/03/qp2