1 The Ostwald Process is a method for making nitric acid. The equation for the first stage of this process is

$$4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g) \qquad \Delta H = -905 \text{ kJ mol}^{-1}$$

(a) The equilibrium yield of nitrogen monoxide, NO, is **increased** by

(1)

☒ **A** increasing both the pressure and the temperature.

☒ **B** decreasing both the pressure and the temperature.

☒ **C** decreasing the pressure and increasing the temperature.

☒ **D** increasing the pressure and decreasing the temperature.

(b) For this stage of the process, the catalyst is an alloy of platinum and rhodium. A pressure of between 4 and 10 atm and a temperature of 1150 K are used. Unreacted reactants are recycled.

Which one of the following changes will affect the value of the equilibrium constant, K_p?

(1)

☒ **A** Changing the composition of the platinum-rhodium catalyst.

☒ **B** Increasing the pressure above 10 atm.

☒ **C** Decreasing the temperature below 1150 K.

☒ **D** Not recycling unreacted reactants.

(Total for Question = 2 marks)

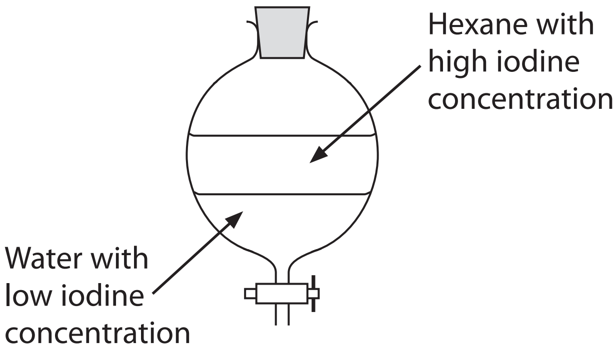
2 Iodine is soluble in both water and hexane. If iodine is added to a mixture of the two solvents, then the following equilibrium is set up.

$$I_2(aq) \rightleftharpoons I_2(hexane)$$

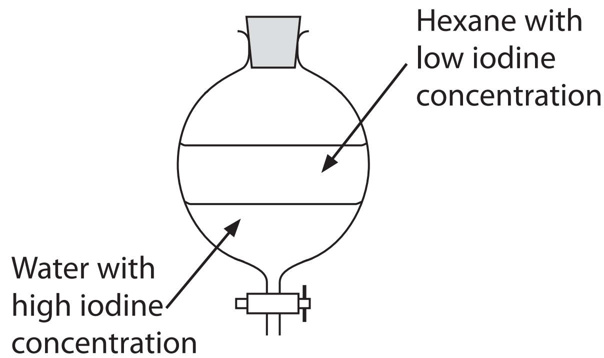
The equilibrium constant, known as the partition coefficient, is 85.

The density of hexane is 0.66 g cm^{-3}. The density of water is 1.00 g cm^{-3}.

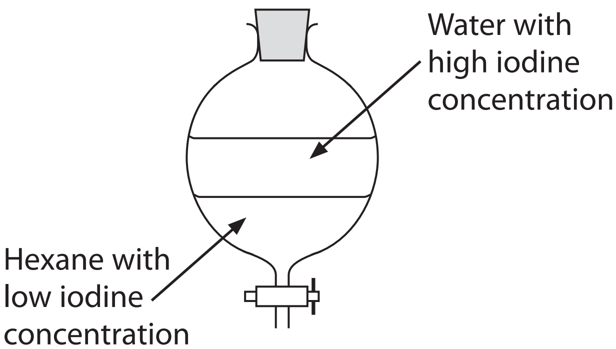
Which of the following diagrams is correct for this system at equilibrium?



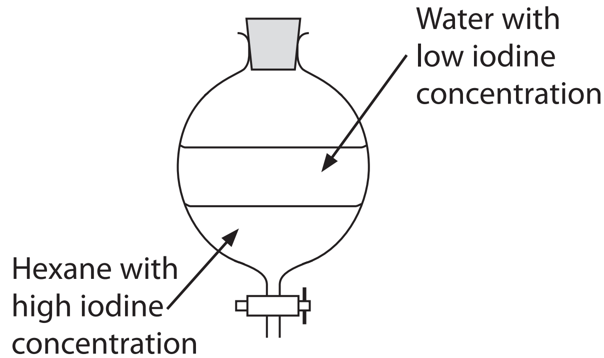
☒ **A**



☒ **B**



☒ **C**



☒ **D**

(Total for Question = 1 mark)

3 What are the units of the equilibrium constant (K_c) for the hypothetical reaction below?

$$2A(aq) + B(aq) \rightleftharpoons 4C(aq) + D(aq)$$

☒ **A** $mol^2\ dm^{-9}$

☒ **B** $mol^{-2}\ dm^9$

☒ **C** $mol^2\ dm^{-6}$

☒ **D** $mol^{-2}\ dm^6$

(Total for Question = 1 mark)

4 This question is about the reversible reaction below.

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

(a) A chemist investigating this reaction started with 10 moles of NO_2 and allowed the system to reach equilibrium. If 3 moles of N_2O_4 are formed, the number of moles of NO_2 at equilibrium is

(1)

☒ **A** 8.5

☒ **B** 7

☒ **C** 6

☒ **D** 4

(b) Under different conditions, 40% of the moles present at equilibrium is N_2O_4. If the total pressure of the system is 2.0 atm, the numerical value of the equilibrium constant, K_p is

(1)

☒ **A** 0.56

☒ **B** 0.67

☒ **C** 1.5

☒ **D** 1.8

(Total for Question = 2 marks)

5 Ammonium chloride decomposes on heating:

$$NH_4Cl(s) \rightleftharpoons NH_3(g) + HCl(g)$$

The equilibrium constant, K_p, for this reaction equals

☒ **A** $P_{NH_3} \times P_{HCl}$

☒ **B** $\dfrac{1}{P_{NH_3} \times P_{HCl}}$

☒ **C** $\dfrac{P_{NH_3} \times P_{HCl}}{P_{NH_4Cl}}$

☒ **D** $\dfrac{P_{NH_4Cl}}{P_{NH_3} \times P_{HCl}}$

(Total for Question = 1 mark)

6 Consider the equilibrium below.

$$CO(g) + Cl_2(g) \rightleftharpoons COCl_2(g)$$

(a) An increase in pressure by a factor of 2 will

(1)

☒ **A** quadruple K_p.

☒ **B** double K_p.

☒ **C** have no effect on K_p.

☒ **D** halve K_p.

(b) The units of K_p are

(1)

☒ **A** atm^{-2}

☒ **B** atm^{-1}

☒ **C** atm

☒ **D** atm^2

(Total for Question 2 marks)

7 Methanol is produced in the equilibrium reaction

$$2H_2(g) + CO(g) \rightleftharpoons CH_3OH(g) \qquad \Delta H \qquad 18.3\ \text{kJ mol}^{-1}$$

Addition of more hydrogen to the equilibrium mixture at constant temperature

- ☒ **A** increases the equilibrium yield of methanol.
- ☒ **B** decreases the equilibrium yield of methanol.
- ☒ **C** increases the value of K_p.
- ☒ **D** decreases the value of K_p.

(Total for Question 1 mark)

8 The equation for the equilibrium between $NO_2(g)$ and $N_2O_4(g)$ can be written in two ways.

$$2NO_2(g) \rightleftharpoons N_2O_4(g) \quad \text{Equilibrium constant} \quad K_c$$

or

$$NO_2(g) \rightleftharpoons \tfrac{1}{2}N_2O_4(g) \quad \text{Equilibrium constant} \quad K'_c$$

Which expression is correct?

- ☒ **A** $K_c \quad K'_c$
- ☒ **B** $K_c \quad (K'_c)^2$
- ☒ **C** $K_c \quad 2(K'_c)$
- ☒ **D** $K_c \quad \tfrac{1}{2}K'_c$

(Total for Question 1 mark)

9 4.0 mol of methanoic acid are reacted with 6.0 mol of ethanol.

$$HCOOH(l) + C_2H_5OH(l) \rightleftharpoons HCOOC_2H_5(l) + H_2O(l)$$

The equilibrium mixture contains 3.0 mol of $HCOOC_2H_5$.

The equilibrium constant, K_c, for the reaction is

☒ **A** 0.33

☒ **B** 1.0

☒ **C** 3.0

☒ **D** 4.0

(Total for Question 1 mark)

10 This question is about the equilibrium reaction

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H = -92\ \text{kJ mol}^{-1}$$

Which statement is **not** correct?

☒ **A** The units of K_p are atm^{-2}.

☒ **B** K_p increases as temperature is decreased.

☒ **C** K_p increases when the pressure increases.

☒ **D** K_p increases when the total entropy change, ΔS_{total}, increases.

(Total for Question = 1 mark)

11 The equation for the synthesis of methanol is

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$$

At equilibrium, when the temperature is 340 K, the total pressure is 20 atm. The moles of each component present at equilibrium are shown in the table below.

Formula	Equilibrium moles / mol	Mole fraction
CO	0.15	0.23
H_2	0.32	
CH_3OH	0.18	0.28

(a) The mole fraction of hydrogen in the equilibrium mixture is

(1)

☒ **A** 0.23

☒ **B** 0.46

☒ **C** 0.49

☒ **D** 0.92

(b) The numerical value for the equilibrium partial pressure of the carbon monoxide, in atmospheres, is

(1)

☒ **A** 3.0

☒ **B** 4.6

☒ **C** 5.0

☒ **D** 9.2

(c) Units for the equilibrium constant, K_p, for this reaction are

(1)

☒ **A** no units

☒ **B** atm

☒ **C** atm^{-1}

☒ **D** atm^{-2}

(Total for Question = 3 marks)

12 What are the units of $\boldsymbol{K_c}$ for the following equilibrium?

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

☒ **A** atm

☒ **B** atm ^{1}

☒ **C** dm^{3} mol ^{1}

☒ **D** mol dm ^{3}

(Total for Question 1 mark)

13 Consider the equilibrium

$$Cl_2(g) + PCl_3(g) \rightleftharpoons PCl_5(g)$$

Which of the following is true when the total pressure of the system is increased at constant temperature?

		Value of K_p	Mole fraction of $PCl_5(g)$
☒	**A**	decreases	decreases
☒	**B**	unaltered	increases
☒	**C**	decreases	increases
☒	**D**	unaltered	unaltered

(Total for Question = 1 mark)

14 Iron and steam at high temperature react in a closed vessel to give an equilibrium mixture

$$3Fe(s) + 4H_2O(g) \rightleftharpoons Fe_3O_4(s) + 4H_2(g)$$

Which of the following is the correct expression for K_p?

☒ **A** $K_p = \dfrac{P_{H_2}}{P_{H_2O}}$

☒ **B** $K_p = \dfrac{P_{Fe_3O_4} P_{H_2}^4}{P_{Fe}^3 \, P_{H_2O}^4}$

☒ **C** $K_p = \dfrac{P_{H_2}^4}{P_{H_2O}^4}$

☒ **D** $K_p = P_{H_2}^4$

(Total for Question = 1 mark)