

- 1 A mixture of N_2 and O_2 gases has a total pressure of 1.42 atm.
The mole fraction of N_2 is 0.700.

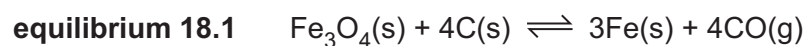
What is the partial pressure, in atm, of O_2 in the mixture?

- A** 0.211
B 0.426
C 0.493
D 0.994

Your answer

[1]

- 2(a)** Iron can be extracted from its ore Fe_3O_4 using carbon.
Several equilibria are involved including **equilibrium 18.1**, shown below.



- (i) Why is **equilibrium 18.1** a *heterogeneous* equilibrium?

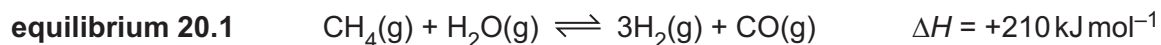
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- (ii) Write the expression for K_p for **equilibrium 18.1**.

3 This question is about equilibrium reactions.

- (a) Hydrogen gas is manufactured by the chemical industry using the reaction of methane and steam. This is a reversible reaction, shown in **equilibrium 20.1** below.



Explain, in terms of le Chatelier's principle, the conditions of pressure and temperature for a maximum yield of hydrogen from **equilibrium 20.1**, and explain why the operational conditions used by the chemical industry may be different.

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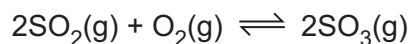
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- (b) A chemist investigates the equilibrium reaction between sulfur dioxide, oxygen, and sulfur trioxide, shown below.



- The chemist mixes together SO_2 and O_2 with a catalyst.
- The chemist compresses the gas mixture to a volume of 400 cm^3 .
- The mixture is heated to a constant temperature and is allowed to reach equilibrium without changing the total gas volume.

The equilibrium mixture contains 0.0540 mol SO_2 and 0.0270 mol O_2 .

At the temperature used, the numerical value for K_c is $3.045 \times 10^4\text{ dm}^3\text{ mol}^{-1}$.

- (i) Write the expression for K_c and the units of K_c for this equilibrium.

[2]

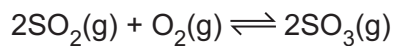
- (ii) Determine the amount, in mol, of SO_3 in the equilibrium mixture at this temperature.

Give your final answer to an **appropriate** number of significant figures.

Show all your working.

equilibrium amount of $\text{SO}_3 = \dots\dots\dots\text{ mol}$ [4]

- 4 The reversible reaction of sulfur dioxide and oxygen to form sulfur trioxide is shown below.



An equilibrium mixture contains 2.4 mol SO_2 , 1.2 mol O_2 and 0.4 mol SO_3 .
The total pressure is 250 atm.

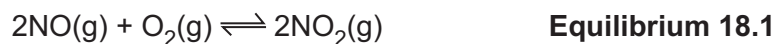
What is the partial pressure of SO_3 ?

- A 15 atm
- B 25 atm
- C 100 atm
- D 200 atm

Your answer

[1]

- 5 Nitrogen monoxide, NO, and oxygen, O₂, react to form nitrogen dioxide, NO₂, in the reversible reaction shown in **equilibrium 18.1**.



- (a) Write an expression for K_c for this equilibrium and state the units.

$K_c =$

Units = ... [2]

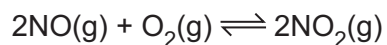
- (b) A chemist mixes together nitrogen and oxygen and pressurises the gases so that their total gas volume is 4.0 dm³.

- The mixture is allowed to reach equilibrium at constant temperature and volume.
- The equilibrium mixture contains 0.40 mol NO and 0.80 mol O₂.
- Under these conditions, the numerical value of K_c is 45.

Calculate the amount, in mol, of NO₂ in the equilibrium mixture.

amount of NO₂ = ... mol [4]

- (c) The values of K_p for **equilibrium 18.1** at 298 K and 1000 K are shown below.



Equilibrium 18.1

Temperature / K	K_p / atm^{-1}
298	$K_p = 2.19 \times 10^{12}$
1000	$K_p = 2.03 \times 10^{-1}$

- (i) Predict, with a reason, whether the forward reaction is exothermic or endothermic.

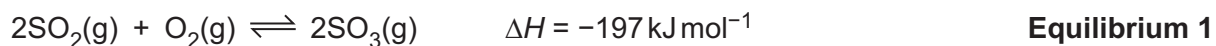
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- (ii) The chemist increases the pressure of the equilibrium mixture at the same temperature.

State, and explain in terms of K_p , how you would expect the equilibrium position to change.

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..... [3]

- 6(a)** The second step in the manufacture of sulfuric acid is the conversion of SO_2 into sulfur trioxide, SO_3 , using **Equilibrium 1**.



An industrial chemist carries out some research into **Equilibrium 1**.

- The chemist fills a 10.2 dm^3 container with $\text{SO}_2(\text{g})$ at RTP, and then adds 12.0 g of $\text{O}_2(\text{g})$.
- The chemist adds the vanadium(V) oxide catalyst, and heats the mixture. The mixture is allowed to reach equilibrium at a pressure of 2.50 atm and a temperature of 1000 K .
- A sample of the equilibrium mixture is analysed, and found to contain 0.350 mol of SO_3 .

- (i)** Write an expression for K_p for **Equilibrium 1**.

Include the units.

units = ... **[2]**

- (ii)** Determine the value of K_p for **Equilibrium 1** at 1000 K .

Show all your working.

Give your answer to **3** significant figures.

- (iii) The chemist repeats the experiment in **(b)** at a different temperature.

The chemist finds that the value of K_p is greater than the answer to **(b)(ii)**.

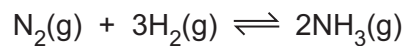
Explain whether the temperature in the second experiment is higher or lower than 1000 K.

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..... [2]

- (iv) Explain the significance of the expression: $K_p \gg 1$.

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..... [1]

- 7 The reversible reaction of nitrogen and hydrogen to form ammonia is shown below.



In the equilibrium mixture, the partial pressure of N_2 is 18.75 MPa and the partial pressure of H_2 is 2.50 MPa.

The total pressure is 25 MPa.

What is the value of K_p , in MPa^{-2} ?

- A 1.2×10^{-4}
- B 0.048
- C 0.075
- D 21

Your answer

[1]

8 Which statement(s) is/are correct when a catalyst is added to a system in dynamic equilibrium?

- 1 The rates of the forward and reverse reactions increase by the same amount.
- 2 The concentrations of the reactants and products do not change.
- 3 The value of K_c increases.

- A** 1, 2 and 3
- B** Only 1 and 2
- C** Only 2 and 3
- D** Only 1

Your answer

[1]

- 9 Methanol, CH_3OH , can be made industrially by the reaction of carbon monoxide with hydrogen, as shown in **equilibrium 1**.



- (a) Predict the conditions of pressure and temperature that would give the maximum equilibrium yield of CH_3OH in **equilibrium 1**.

Explain your answer.

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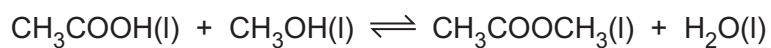
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..... [3]

- 10 A student investigates the reaction between ethanoic acid, $\text{CH}_3\text{COOH}(\text{l})$ and methanol, $\text{CH}_3\text{OH}(\text{l})$, in the presence of an acid catalyst. The equation is shown below.



- (a) The student carries out a second experiment to determine the value of K_c for this reaction.

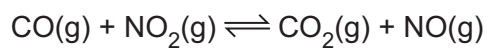
The student mixes 9.6 g of CH_3OH with 12.0 g of CH_3COOH and adds the acid catalyst.

When the mixture reaches equilibrium, 0.030 mol of CH_3COOH remains.

Calculate K_c for this equilibrium.

$K_c = \dots\dots\dots$ [4]

- 11 An equilibrium system is shown below.



Different amounts of CO, NO₂, CO₂ and NO are added to four containers, as shown below.

Container	CO/mol	NO ₂ /mol	CO ₂ /mol	NO/mol
A	1	1	0	0
B	1	0	1	1
C	1	1	1	0
D	0	1	1	1

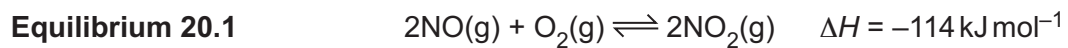
Which container would have the largest concentration of CO(g) at equilibrium?

Your answer

[1]

- 12 This question is about chemical equilibrium.

Nitrogen monoxide, NO, and oxygen, O₂, react to form nitrogen dioxide, NO₂, in the reversible reaction shown in **Equilibrium 20.1**.



- (a) A dynamic equilibrium exists in a closed system.

State **one** other feature of a dynamic equilibrium.

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- (b) A chemist investigates the equilibrium shown in **Equilibrium 20.1**.

The chemist mixes together 1.60 mol of NO(g) and 1.50 mol of O₂(g) in a container and the mixture is allowed to reach equilibrium.

At equilibrium:

- 75% of the NO(g) has been converted to NO₂(g)
- the total pressure is 1.21 MPa.

- (i) Calculate K_p , in MPa⁻¹, for **Equilibrium 20.1**.

Give your answer to **3** significant figures.

$$K_p = \dots\dots\dots \text{MPa}^{-1} \quad [4]$$

- (ii) The chemist then repeats the experiment three times. In each experiment, the chemist makes **one** change but uses the same initial amounts of NO and O₂.

Complete the table to show the predicted effect of each change compared with the original experiment.

Only use the words **greater**, **smaller** or **same**.

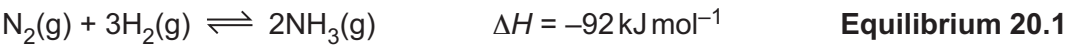
Change	K_p	Equilibrium amount of NO ₂ (g)	Initial rate
Temperature increase			
Pressure increase			
Catalyst added			

[3]

13 This question is about equilibria involving hydrogen.

(a)* Hydrogen is used industrially to manufacture ammonia.

The equilibrium is shown below.



1.20 mol $\text{N}_2(\text{g})$ is mixed with 3.60 mol $\text{H}_2(\text{g})$ in a 8.00 dm^3 container.

The mixture is heated to 550°C with an iron catalyst and allowed to reach equilibrium.

The equilibrium mixture contains 0.160 mol of NH_3 .

Determine the equilibrium constant K_c for **Equilibrium 20.1**, and explain why the operational conditions used by industry may be different from those required for a maximum equilibrium yield of ammonia. **[6]**

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Additional answer space if required.

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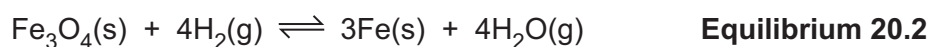
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- (b) In industry, hydrogen is also used to reduce the iron oxide Fe_3O_4 as shown in **Equilibrium 20.2**.

The reaction is carried out at 500°C .



- (i) When the temperature is decreased, the value of K_p decreases.

Determine whether the forward reaction is exothermic or endothermic.
Explain your answer.

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..... [1]

- (ii) Two students are discussing the effect of pressure on the equilibrium position of **Equilibrium 20.2**.

Student 1 says:

“There are more moles of products than reactants, so increasing the pressure will shift the equilibrium to the left hand side.”

Student 2 disagrees.

Determine which student is correct. Justify your answer.

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..... [1]

14 This question is about oxides of nitrogen.

(a) An investigation is carried out on the equilibrium system shown below.



- (i)** A sealed flask containing 6.00 moles of $\text{NO}_2(\text{g})$ is heated to a constant temperature and allowed to reach equilibrium.

The equilibrium mixture contains 5.40 mol of $\text{NO}_2(\text{g})$, and the total pressure is 5.00 atm.

Determine the value of K_p and give your answer to **3** significant figures.

Include an expression for K_p and the units of K_p in your answer.

$K_p = \dots\dots\dots$ units $\dots\dots\dots$ **[5]**

- (ii) The sealed flask in (a)(i) is then heated to a higher temperature at an increased pressure. The system is allowed to reach equilibrium again.

Explain why it is difficult to predict how these changes in reaction conditions affect the amount of $\text{N}_2\text{O}_4(\text{g})$ formed at equilibrium.

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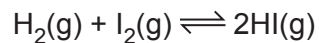
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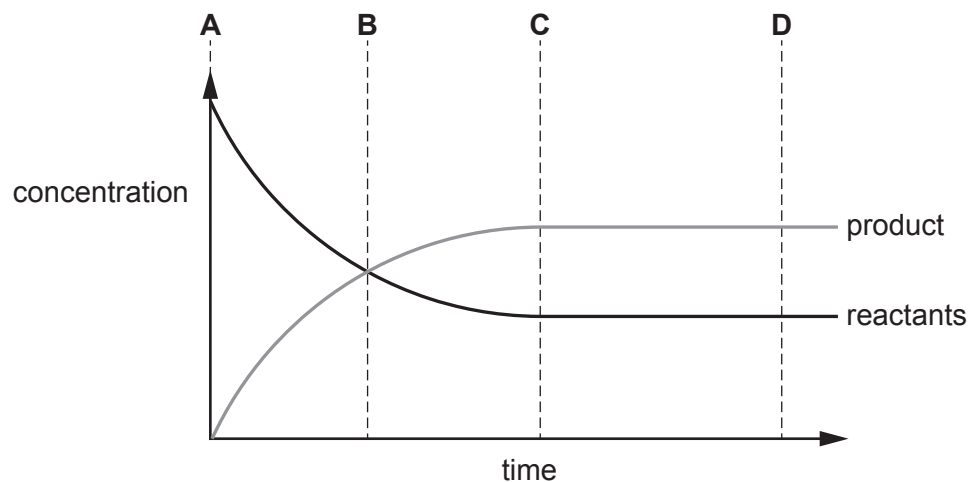
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- 15 The reversible reaction between hydrogen and iodine to form hydrogen iodide is



The graph shows how the concentrations of the reactants and product change as the reaction reaches a dynamic equilibrium.

At which point on the graph is the equilibrium reached?

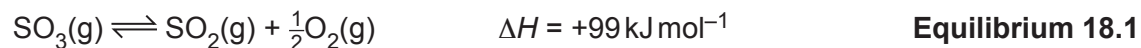


Your answer

[1]

16 This question is about two oxides of sulfur: sulfur dioxide, SO_2 , and sulfur trioxide, SO_3 .

(a) SO_3 decomposes to form SO_2 and O_2 , as shown in **Equilibrium 18.1**.



(i) 2.25 moles of SO_3 is heated to 550°C in the presence of a catalyst and the resulting mixture allowed to reach equilibrium.

The equilibrium mixture contains 0.900 mol of SO_2 and the total pressure is 2.80 atm.

Calculate the numerical value for K_p for **Equilibrium 18.1** under these conditions and state the units of K_p .

Give your answer to **3** significant figures.

$K = \dots\dots\dots$

(ii) The numerical values of K_p for **Equilibrium 18.1** at temperatures T_1 and T_2 are shown below.

Temperature	K_p
T_1	3.3×10^{-5}
T_2	7.7×10^{-2}

Explain why T_2 is a higher temperature than T_1 .

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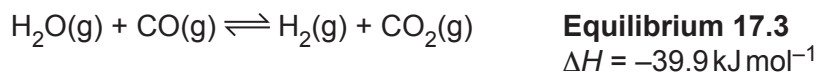
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(iii) Suggest how the value of K_p would change if the reaction was repeated with no catalyst added and the pressure of the system increased.

Tick (✓) one box in each row.

Change	Decrease	No change	Increase
No catalyst			
Increased pressure			

17(a) Steam can be reduced by carbon monoxide in a reversible reaction.



At 700 K the value of K_p is 8.13.

(i) Explain why K_p for **Equilibrium 17.3** has no units.

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..... **[1]**

(ii) An equal number of moles of steam and carbon monoxide are left at 700 K in a sealed container until equilibrium is reached.

At equilibrium, both H_2 and CO_2 have a partial pressure of 211 kPa.

Calculate the partial pressures of H_2O and CO at equilibrium.

Partial pressure of H_2O = ... kPa

Partial pressure of CO = ... kPa
[3]

(iii) At a second temperature the value of K_p for **Equilibrium 17.3** is 129.

Explain whether the second temperature is higher or lower than 700 K.

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