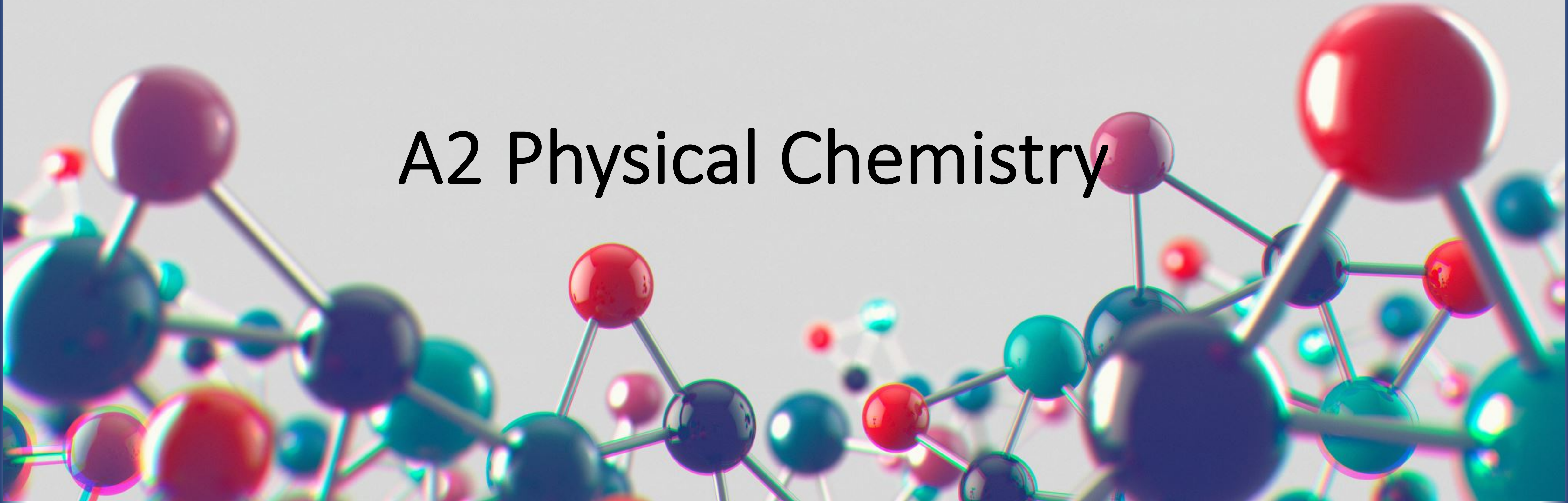

A2 Physical Chemistry

Equilibrium Constants and Le Chatelier’s Principle

Changing concentrations

Changing concentrations and Kc/Kp

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

Changing concentrations and Kc/Kp

$$2\,SO_2(g) \;+\; O_2(g) \rightrightarrows 2\,SO_3(g)$$

$$K_p = \frac{(P_{SO_{3(g)}})^2}{(P_{SO_{2(g)}})^2\,(P_{O_{2(g)}})}$$

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At a fixed temperature, this figure does not change

Changing concentrations and Kc/Kp

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

$$K_p = \frac{(5)^2}{(3)^2\ (4)}$$

At a fixed temperature, this figure does not change

Changing concentrations and Kc/Kp

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

$$K_p = \frac{(5)^2}{(3)^2\,(4)} = \frac{25}{36}$$

At a fixed temperature, this figure does not change

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

$$K_p = \frac{(5)^2}{(3)^2\,(4)} = \frac{25}{36} = 0.695\ atm^{-1}$$

At a fixed temperature, this figure does not change

Changing concentrations and Kc/Kp

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

$$K_p = \frac{(P_{SO_{3(g)}})^2}{(P_{SO_{2(g)}})^2\,(P_{O_{2(g)}})} = \frac{(5)^2}{(3)^2\,(4)} = 0.695\ atm^{-1}$$

At a fixed temperature, this figure does not change

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Additional $SO_{2(g)}$ added

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This increases P_{SO_2} to 6 atm

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This cannot change

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$$\frac{(5)^2}{(6)^2\,(4)} = 0.1736$$

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This increases P_{SO_2} to 6 atm

$$\frac{(5)^2}{(6)^2\,(4)} = 0.1736$$

The partial pressures of SO_2 and O_2 must decrease and the partial pressure of SO_3 increase i.e. the equilibrium moves to the right.

Changing concentrations and Kc/Kp

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$$= \frac{(A)^2}{(B)^2\,(C)} = 0.1736$$

The partial pressures of SO_2 and O_2 must decrease and the partial pressure of SO_3 increase i.e. the equilibrium moves to the right.

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New conditions - not at equilibrium $\frac{(5)^2}{(6)^2 \ (4)}$

Equilibrium re-established

$$= \frac{(A)^2}{(4)^2 \ (C)}$$

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$$= \frac{(5.78)^2}{(4)^2 \ (3)}$$

$$K_p = \frac{(P_{SO_{3(g)}})^2}{(P_{SO_{2(g)}})^2\ (P_{O_{2(g)}})} = \frac{(5)^2}{(3)^2\ (4)} = 0.695\ atm^{-1}$$ **Original**

New conditions - not at equilibrium $\frac{(5)^2}{(6)^2\ (4)}$

Equilibrium re-established

$$= \frac{(5.78)^2}{(4)^2\ (3)}$$ **= 0.695 atm^{-1}**

Changing pressure

$$2\,SO_2(g) \quad + \quad O_2(g) \Rightarrow 2\,SO_3(g)$$

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

Total pressure – 4 atm

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Total pressure – 4 atm

$$K_p = \frac{(P_{SO_{3(g)}})^2}{(P_{so_{2(g)}})^2\,(P_{O_{2(g)}})}$$

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

Total pressure – 4 atm

$$K_p = \frac{(Y_{SO_{3(g)}} \times 4)^2}{(Y_{so_{2(g)}} \times 4)^2\ (Y_{O_{2(g)}} \times 4)}$$

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

Total pressure – 4 atm

$$K_p = \frac{(4Y_{SO_{3(g)}})^2}{(4Y_{SO_{2(g)}})^2\ (4Y_{O_{2(g)}})}$$

$$2\,SO_2(g) \;+\; O_2(g) \rightrightarrows 2\,SO_3(g)$$

Total pressure – 4 atm

$$K_p = \frac{16(Y_{SO_{3(g)}})^2}{16(Y_{SO_{2(g)}})^2 x\ 4(Y_{O_{2(g)}})}$$

$$2\,SO_2(g) \quad + \quad O_2(g) \rightrightarrows \; 2\,SO_3(g)$$

Total pressure – 4 atm

$$K_p = \frac{16(Y_{SO_{3(g)}})^2}{64[(Y_{so_{2(g)}})^2 \times (Y_{O_{2(g\,)}})]}$$

$$2\,SO_2(g) \quad + \quad O_2(g) \Rightarrow 2\,SO_3(g)$$

Total pressure – 4 atm $\quad K_p = \dfrac{16(Y_{SO_{3(g)}})^2}{64[(Y_{SO_{2(g)}})^2 \times (Y_{O_{2(g)}})]}$

$$2\,SO_2(g) \; + \; O_2(g) \Rightarrow 2\,SO_3(g)$$

Total pressure – 4 atm

$$K_p = \frac{16(Y_{SO_{3(g)}})^2}{64[(Y_{SO_{2(g)}})^2 \times (Y_{O_{2(g)}})]}$$

Pressure increased to 6 atm

$$2\ SO_2(g) \quad + \quad O_2(g) \Rightarrow 2\ SO_3(g)$$

Total pressure – 4 atm $\quad K_p = \dfrac{16(Y_{SO_{3(g)}})^2}{64[(Y_{SO_{2(g)}})^2 \times (Y_{O_{2(g)}})]}$

Pressure increased to 6 atm – the system is no longer at equilibrium if the mole fractions remain the same.

$$2\,SO_2(g) + O_2(g) \rightrightarrows 2\,SO_3(g)$$

Total pressure – 4 atm $K_p = \dfrac{16(Y_{SO_{3(g)}})^2}{64[(Y_{SO_{2(g)}})^2 \times (Y_{O_{2(g)}})]}$

Pressure increased to 6 atm – the system is no longer at equilibrium if the mole fractions remain the same.

$$\frac{(Y_{SO_{3(g)}} \times 6)^2}{(Y_{SO_{2(g)}} \times 6)^2\,(Y_{O_{2(g)}} \times 6)}$$

$$2\,SO_2(g) \quad + \quad O_2(g) \rightrightarrows 2\,SO_3(g)$$

Total pressure – 4 atm $\quad K_p = \dfrac{16(Y_{SO_{3(g)}})^2}{64[(Y_{SO_{2(g)}})^2 \times (Y_{O_{2(g)}})]}$

Pressure increased to 6 atm – the system is no longer at equilibrium if the mole fractions remain the same.

$$\frac{36(Y_{SO_{3(g)}})^2}{216[(Y_{SO_{2(g)}})^2 \times (Y_{O_{2(g)}})]}$$

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

At equilibrium: $K_p = \dfrac{16(Y_{SO_{3(g)}})^2}{64[(Y_{SO_{2(g)}})^2 x\,(Y_{O_{2(g)}})]}$ = 0.25 x Mole fraction expression

Pressure increased to 6 atm – the system is no longer at equilibrium if the mole fractions remain the same.

$$\frac{36(Y_{SO_{3(g)}})^2}{216[(Y_{SO_{2(g)}})^2 x\,(Y_{O_{2(g)}})]}$$ = 0.167 x Mole fraction expression

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New conditions: $\dfrac{36(Y_{SO_{3(g)}})^2}{216[(Y_{SO_{2(g)}})^2 x\ (Y_{O_{2(g)}})]}$ = 0.167 x Mole fraction expression

Consider the change in pressure:

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

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Consider the change in pressure:

$$\frac{16}{64}$$

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Consider the change in pressure:

$$\frac{16}{64} \longrightarrow$$

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

At equilibrium: $$K_p = \frac{16(Y_{SO_{3(g)}})^2}{64[(Y_{SO_{2(g)}})^2 \times (Y_{O_{2(g)}})]} = 0.25 \times \text{Mole fraction expression}$$

New conditions: $$\frac{36(Y_{SO_{3(g)}})^2}{216[(Y_{SO_{2(g)}})^2 \times (Y_{O_{2(g)}})]} = 0.167 \times \text{Mole fraction expression}$$

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$$\frac{16}{64} \longrightarrow \frac{36}{216}$$

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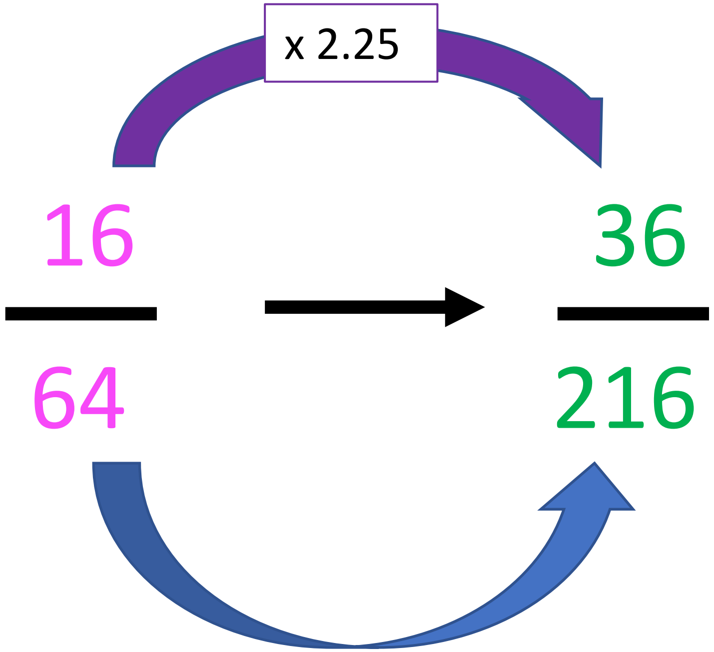
x 2.25

$$\frac{16}{64} \longrightarrow \frac{36}{216}$$

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



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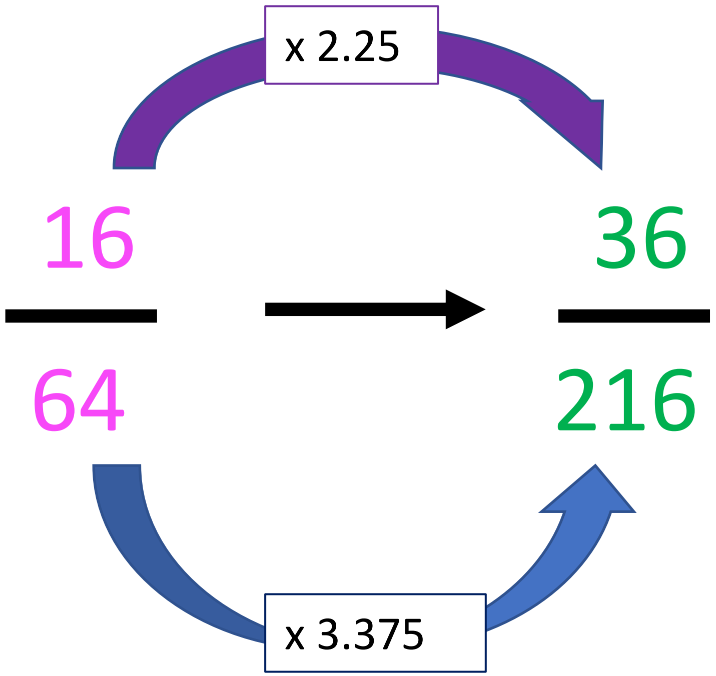
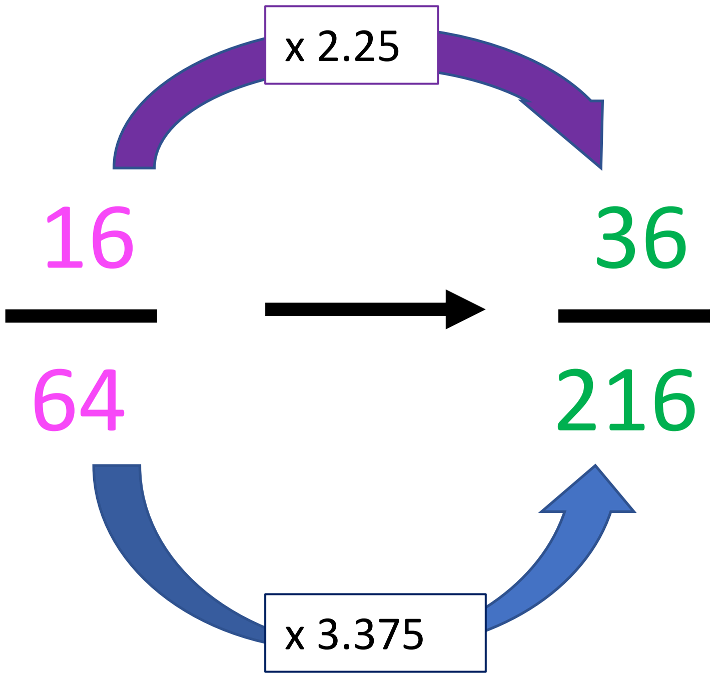


The change in pressure has affected the reactants more than the products.
Therefore in order to restore Kp and reach equilibrium again, the mole fractions of the reactants must decrease and the mole fraction of the product increase.

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



The equilibrium shifts to the right i.e. to side with the fewest number of gaseous moles

Changing temperature

$$2\,SO_2(g) + O_2(g) \Rightarrow 2\,SO_3(g)$$

ΔH -198.2 kJ/mol

Exothermic

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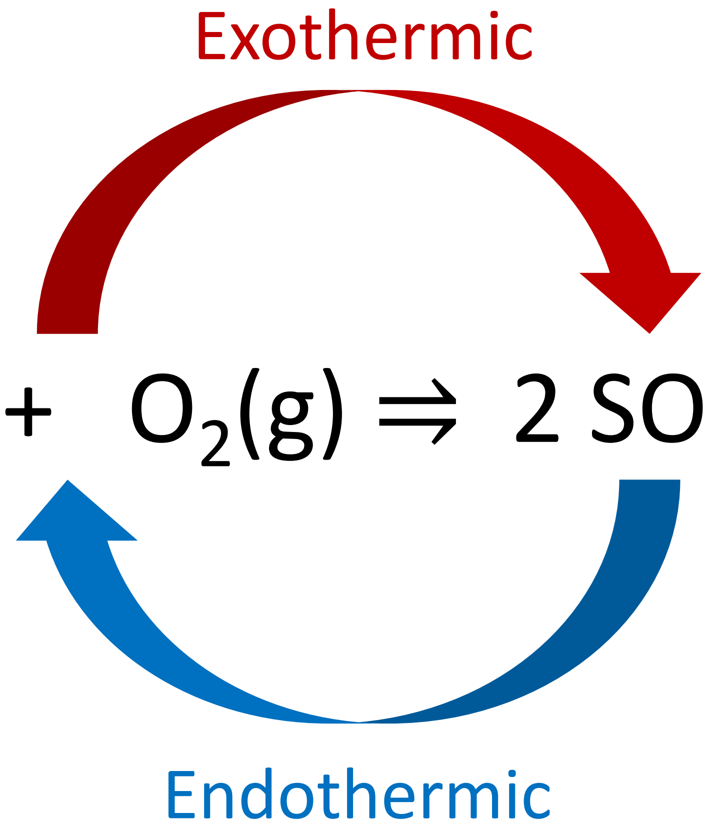

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Endothermic

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$$K_p = \frac{(P_{SO_{3(g)}})^2}{(P_{SO_{2(g)}})^2\,(P_{O_{2(g)}})}$$

Exothermic

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

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Any increase in temperature shifts the equilibrium in the endothermic direction

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In this reaction the number of moles and partial pressures of SO_2 and O_2 increases

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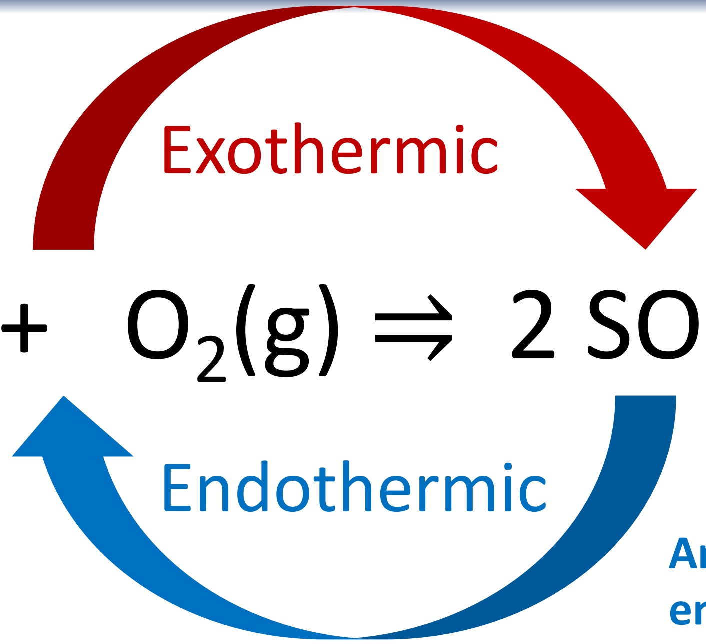

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$$K_p = \frac{(P_{SO_{3(g)}})^2}{(P_{SO_{2(g)}})^2\,(P_{O_{2(g)}})}$$

Kp decreases

Exothermic

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

ΔH -198.2 kJ/mol

Endothermic

Any decrease in temperature shifts the equilibrium in the exothermic direction

$$K_p = \frac{(P_{SO_{3(g)}})^2}{(P_{SO_{2(g)}})^2\,(P_{O_{2(g)}})}$$

Exothermic

$$2\,SO_2(g) + O_2(g) \rightleftharpoons 2\,SO_3(g) \qquad \Delta H = -198.2\ \text{kJ/mol}$$

Endothermic

Any decrease in temperature shifts the equilibrium in the exothermic direction

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$$K_p = \frac{(P_{SO_{3(g)}})^2}{(P_{SO_{2(g)}})^2\,(P_{O_{2(g)}})}$$

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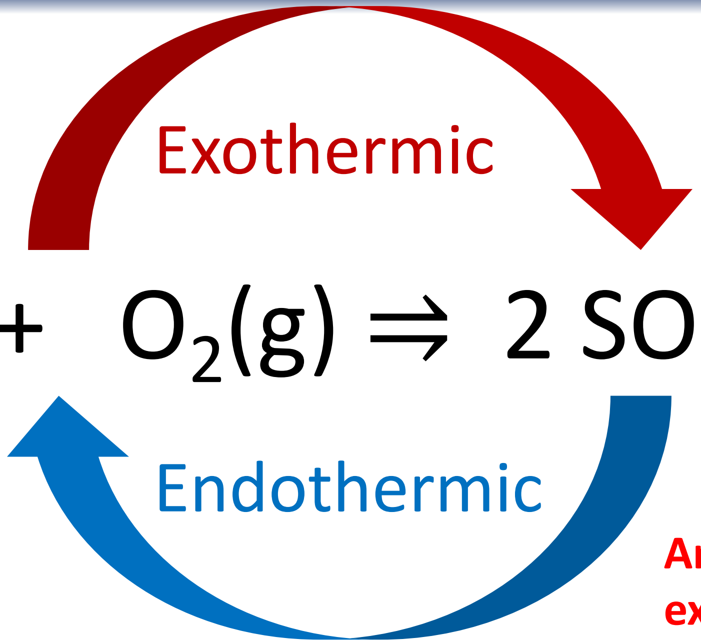

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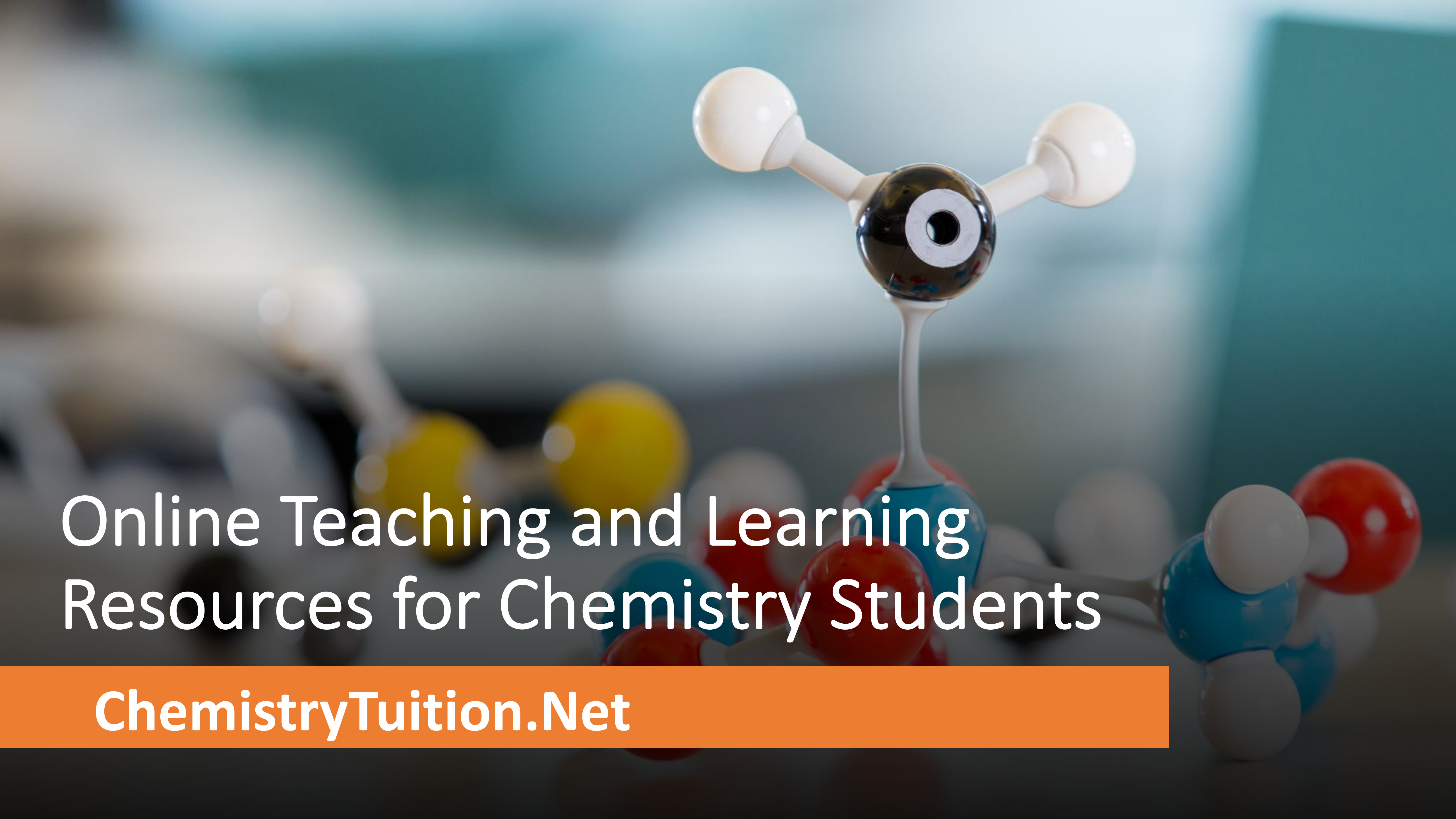
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