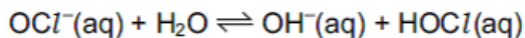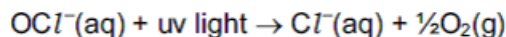# Worksheet: Le Chatelier's Principle

11 Swimming pool water can be kept free of harmful bacteria by adding aqueous sodium chlorate(I), NaOCl. This reacts with water to produce HOCl molecules which kill bacteria.

$$OCl^-(aq) + H_2O \rightleftharpoons OH^-(aq) + HOCl(aq)$$

In bright sunshine, the OCl^- ion is broken down by ultra-violet light.

$$OCl^-(aq) + uv\ light \rightarrow Cl^-(aq) + \tfrac{1}{2}O_2(g)$$
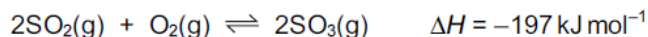
Which method would maintain the highest concentration of HOCl(aq)?

A acidify the pool water

B add a solution of chloride ions

C add a solution of hydroxide ions

D bubble air through the water

s/06/qp1

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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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33 Which statements about reversible reactions are correct?

1 An increase in concentration of a reactant always increases the concentration of the product.

2 An increase in temperature always increases the rate at which the equilibrium is established.

3 An increase in temperature always increases the concentration of the product at equilibrium.

s/16/qp12

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10 When vanadium(II) compounds are dissolved in water, the following equilibrium is established.

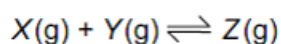$$V^{2+} + H_2O \rightleftharpoons V^{3+} + \frac{1}{2}H_2 + OH^-$$
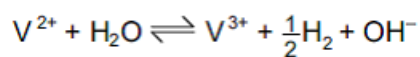
What would alter the composition of the equilibrium mixture in favour of the V^{2+} ions?

A   adding an acid

B   adding a reagent that selectively precipitates V^{3+} ions

C   allowing the hydrogen to escape as it forms

D   making the solution more alkaline

s/04/qp1

11 In an industrial process, two gases X and Y react together to form a single gaseous product Z.

$$X(g) + Y(g) \rightleftharpoons Z(g)$$

The percentage yield of product Z varies according to the pressure and the temperature as shown in the graphs.
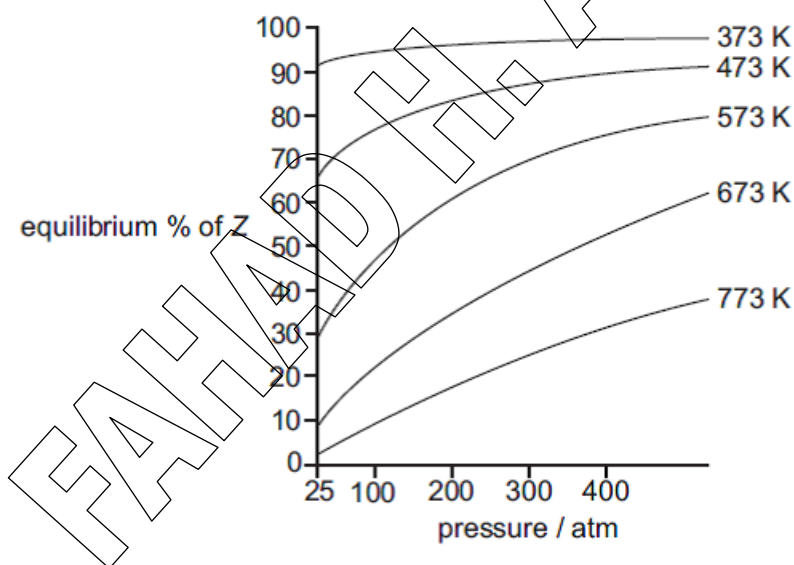
Which statement about this equilibrium reaction is correct?

A   Decreasing the temperature decreases the value of the equilibrium constant.

B   Decreasing the temperature increases the rate of this reaction.

C   Increasing the pressure increases the value of the equilibrium constant.

D   The reaction is exothermic in the forward direction.

s/04/qp1

10 The dissociation of dinitrogen tetraoxide into nitrogen dioxide is represented by the equation below.

$$N_2O_4(g) \rightleftharpoons 2NO_2(g); \qquad \Delta H^\ominus = +57\ kJ\,mol^{-1}$$

If the temperature of an equilibrium mixture of the gases is increased at constant pressure, will the volume of the mixture increase or decrease and why?

A   The volume will increase, but only because of a shift of equilibrium towards the right.

B   The volume will increase, both because of a shift of equilibrium towards the right and also because of thermal expansion.

C   The volume will stay the same, because any thermal expansion could be exactly counteracted by a shift of equilibrium towards the left.

D   The volume will decrease, because a shift of equilibrium towards the left would more than counteract any thermal expansion.

s/05/qp1

34 Two bulbs **R** and **S**, connected by a mercury manometer, are held in a thermostat, as shown. The volume of **R** is twice that of **S**. **R** contains gas, X, at the same pressure as the nitrogen in **S**.
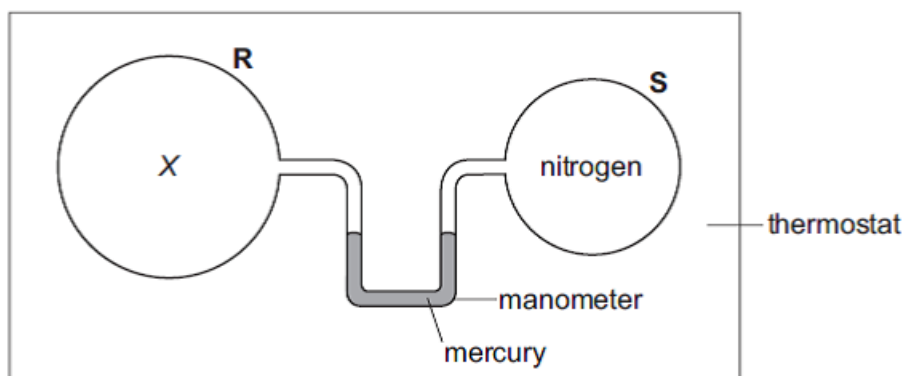

When the temperature is increased, which gases in bulb **R** would cause the mercury level in the right-hand limb of the manometer to rise?

1   an equilibrium mixture $N_2F_4(g) \rightleftharpoons 2NF_2(g)$; ΔH positive

2   an equilibrium mixture $CH_3NC(g) \rightleftharpoons CH_3CN(g)$; ΔH negative

3   nitrogen

s/07/qp1

32 Catalysts are used in many reversible reactions in the chemical industry. Vanadium(V) oxide is used in this way in the Contact process for the formation of SO_3.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$
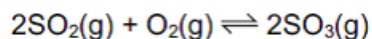
What effect does vanadium(V) oxide have on this equilibrium?

1 It speeds up the forward reaction.

2 It increases the value of K_p.

3 It increases the value of E_a for the reverse reaction.

s/08/qp1

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15 The percentage of ammonia obtainable, if equilibrium were established during the Haber process, is plotted against the operating pressure for two temperatures, 400 °C and 500 °C.

Which diagram correctly represents the two graphs?
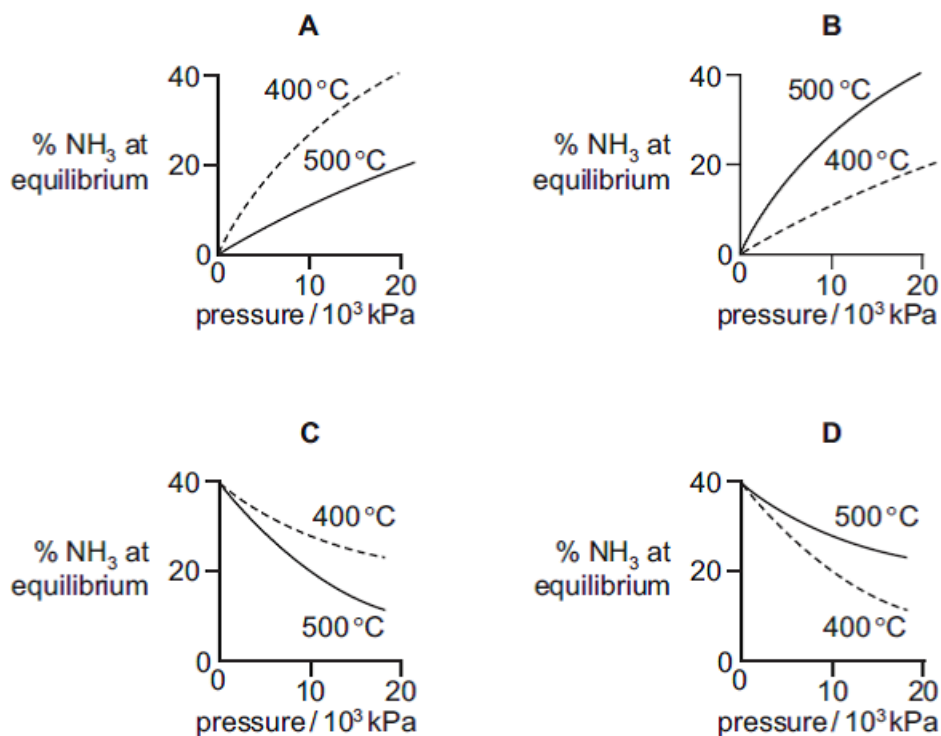
s/10/qp11

5   Ammonia is manufactured on a large scale by the Haber process.

In a particular plant, conditions of 400 °C and 250 atm in the presence of an iron catalyst are used.
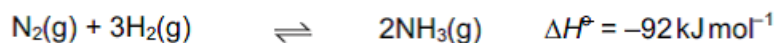
$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H^\ominus = -92\,kJ\,mol^{-1}$$

What could contribute most to increasing the equilibrium yield of ammonia?

A   adding more catalyst

B   increasing the pressure to 400 atm

C   increasing the temperature to 1000 °C

D   using air rather than nitrogen

s/11/qp12

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36 In the manufacture of sulfuric acid the reaction $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$ usually takes place at 400 °C and 1 atm pressure. In one industrial plant, it is decided to change the pressure to 20 atm.

What will be the consequences of this change?

1   increased running costs

2   an increased percentage of sulfur trioxide in the equilibrium mixture

3   the rate of the backward reaction increases

s/12/qp11

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9   Methanol is manufactured by reacting carbon dioxide and hydrogen.

$$CO_2(g) + 3H_2(g) \rightleftharpoons CH_3OH(g) + H_2O(g) \qquad \Delta H = -49\,kJ\,mol^{-1}$$
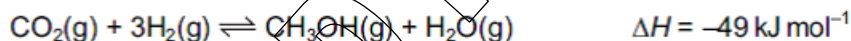
What would increase the equilibrium yield of methanol in this process?

A   adding a catalyst

B   adding an excess of steam

C   increasing the pressure

D   increasing the temperature

s/12/qp12

36 Which statements are true about the Haber process for the manufacture of ammonia?

1   At higher temperatures, the yield goes down but the rate of production of ammonia is faster.

2   At higher pressures, the yield goes down but the rate of production of ammonia is faster.

3   In the presence of a catalyst, the yield goes down but the rate of production of ammonia is faster.

s/12/qp12

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32 One explanation of the explosion at the Chernobyl nuclear power plant in 1986 is that the graphite reactor overheated and reacted with the cooling water according to the following equation.

$$C(s) + H_2O(g) \rightleftharpoons H_2(g) + CO(g) \qquad \Delta H = +131\,kJ\,mol^{-1}$$
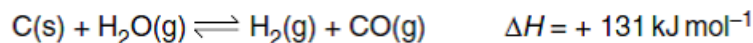
What are possible reasons why the forward reaction is more likely to occur at high temperature?

1   Hydrogen and carbon monoxide do not react at high temperature.

2   At lower temperature, the position of equilibrium lies too far to the left.

3   The energy of activation is high.

w/03/qp1

11 Which statement concerning the equilibrium reaction below is true?

$$2CrO_4^{2-}(aq) + 2H^+(aq) \rightleftharpoons Cr_2O_7^{2-}(aq) + H_2O(l)$$
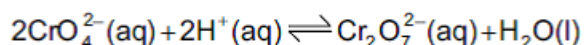
A   An increase in acid concentration will result in an increase in the concentration of $Cr_2O_7^{2-}(aq)$.

B   A redox reaction is taking place.

C   The addition of a catalyst will result in an increase in the concentration of $Cr_2O_7^{2-}(aq)$.

D   The equilibrium constant, K_c, has no units.

w/04/qp1

32 Ammonia is produced commercially by the Haber process in which nitrogen and hydrogen react as shown.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)\;;\; \Delta H = -92\,kJ\,mol^{-1}$$
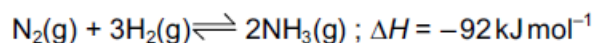
Which statements are true of the commercial process?

1   A temperature of 1000 °C is used.

2   A pressure of 100 - 200 atm is used.

3   The yield of ammonia is less than 20 %.

w/04/qp1

19 In the Contact process for the production of sulphuric acid, sulphur dioxide is mixed with air and passed over a vanadium(V) oxide catalyst at about 450 °C and a pressure slightly above atmospheric pressure.
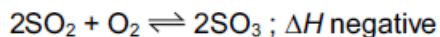
$$2SO_2 + O_2 \rightleftharpoons 2SO_3 \; ; \; \Delta H \text{ negative}$$

What affects the choice of conditions for this reaction?

A A lower temperature would not raise the concentration of SO_3 at equilibrium.

B At a lower temperature of 300 °C the V_2O_5 catalyst would not be effective.

C At 450 °C nitrogen and oxygen from the air combine to form nitrogen oxides which are needed as additional catalysts.

D The heat generated by the reaction raises the temperature of the catalyst bed to 600 °C at which temperature the reaction begins to take place.

w/06/qp1

33 Phosphorus pentachloride is introduced into an empty gas syringe which has a movable, tightly-fitting plunger. The gas is allowed to expand until equilibrium is reached at a temperature at which the phosphorus pentachloride partially dissociates.

$$PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$$
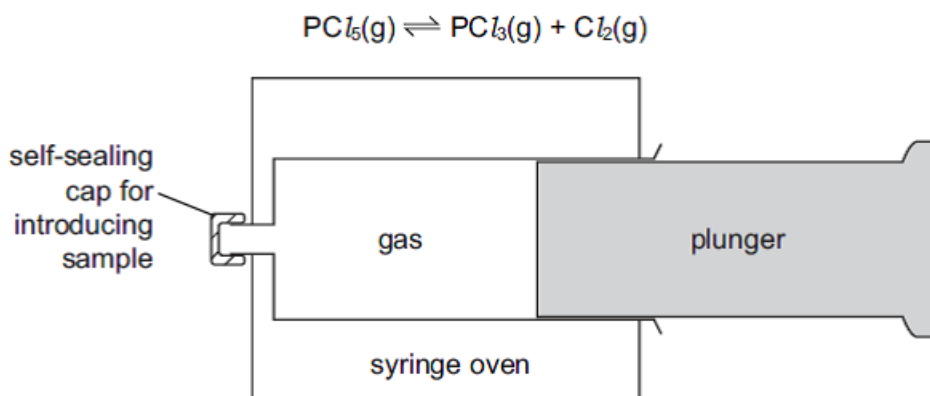
Which statements are correct?

1 The equilibrium pressure inside the syringe will be greater than atmospheric pressure.

2 When the plunger is pushed in the equilibrium adjusts to produce more $PCl_5(g)$.

3 The volume of gas in the syringe at equilibrium will be greater than if no dissociation had occurred.

w/07/qp1

36 Which statements about the Haber process for the industrial production of ammonia are correct?

1 The equilibrium constant K_p increases with pressure.

2 As the temperature increases, the equilibrium constant for the forward reaction becomes smaller.

3 The process is usually carried out at between 450 °C and 550 °C at a pressure of at least 150 atm.

w/08/qp1

9 PCl_5 dissociates as follows.

$$PCl_5(g) \rightarrow PCl_3(g) + Cl_2(g)$$
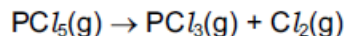
The extent of dissociation is 13 % at 160 °C and 100 % at 300 °C.

Which pair of statements about this formation of PCl_3 is correct?

	shape of PCl_3 molecule	the reaction is
A	pyramidal	endothermic
B	pyramidal	exothermic
C	trigonal	endothermic
D	trigonal	exothermic

w/09/qp11

31 Ethanol is manufactured by reacting ethene gas and steam in the presence of phosphoric(V) acid.

$$C_2H_4(g) + H_2O(g) \rightleftharpoons C_2H_5OH(g) \qquad \Delta H = -45\,kJ\,mol^{-1}$$
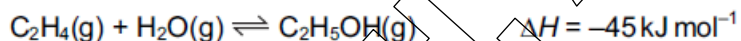
The reaction is carried out at 570 K and 60 atm.

What would be the consequences of carrying out the reaction at the same temperature but at a pressure of 200 atm?

1 The manufacturing costs would increase.

2 The maximum yield at equilibrium would be higher.

3 The reaction would proceed at a faster rate.

w/10/qp11

10 When gaseous iodine is heated with hydrogen at 450 °C, an equilibrium is established.

$$H_2(g) \ + \ I_2(g) \ \rightleftharpoons \ 2HI(g) \qquad \Delta H = +53\,kJ\,mol^{-1}$$

colourless   purple   colourless
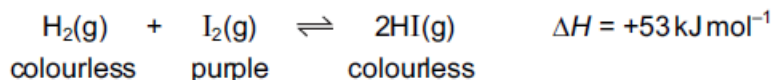
Which change of conditions will cause the purple colour of the equilibrium mixture to become paler?

A decrease in pressure

B decrease in temperature

C increase in pressure

D increase in temperature

w/11/qp11

7   The Contact process is used in the manufacture of sulfuric acid. The equation for the main reaction is shown below.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \qquad \Delta H = -196\,kJ\,mol^{-1}$$

Which statement about this reaction is **incorrect**?

A   Increased pressure gives a higher yield of SO_3.

B   Increased temperature gives a higher yield of SO_3.

C   In the forward reaction the oxidation state of sulfur changes from +4 to +6.
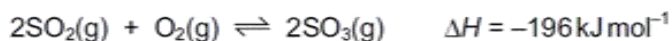
D   Vanadium(V) oxide is used as a catalyst.

s/14/qp11

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18   Sulfur trioxide is manufactured from sulfur dioxide and oxygen, using the Contact process.

Which condition affects the value of the equilibrium constant, K_c?

A   adjusting the temperature

B   increasing the pressure

C   removing SO_3 from the equilibrium mixture

D   using a catalyst

s/13/qp11

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8   The reaction between sulfur dioxide and oxygen is a dynamic equilibrium.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$
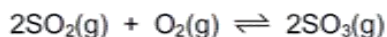
What happens when the pressure of the system is increased?

A   The rate of reaction will decrease and the position of the equilibrium will move to the left.

B   The rate of reaction will decrease and the position of the equilibrium will move to the right.

C   The rate of reaction will increase and the position of the equilibrium will move to the left.

D   The rate of reaction will increase and the position of the equilibrium will move to the right.

s/13/qp12

34 The following equilibrium is an exothermic reaction in the forward direction.

$$2CrO_4^{2-}(aq) + 2H^+(aq) \rightleftharpoons Cr_2O_7^{2-}(aq) + H_2O(l)$$
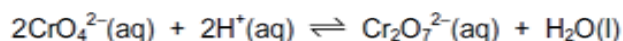
What happens when the concentration of CrO_4^{2-} ions **increases and** the temperature **decreases**?

1　The concentration of $Cr_2O_7^{2-}$ ions increases.

2　The equilibrium constant increases.

3　The activation energy decreases.

w/13/qp13

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34 If N_2O_4 gas is placed in a sealed vessel the following equilibrium is established.

$$N_2O_4(g) \rightleftharpoons 2NO_2(g)$$
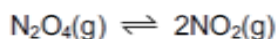
The forward reaction is endothermic.

What happens when the temperature is increased?

1　The equilibrium constant increases.

2　The partial pressure of NO_2 increases.

3　The activation energy is unchanged.

w/13/qp11

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33 What are necessary properties of a dynamic equilibrium?

1　Equal amounts of reactants and products are present.

2　Concentrations of reactants and products remain constant.

3　The rate of the forward reaction is the same as the rate of the reverse reaction.

w/13/qp11

$$CO_2(g) + 3H_2(g) \rightleftharpoons CH_3OH(g) + H_2O(g)$$

(c) The synthesis of methanol is carried out at about 500 K with a pressure of between 40 and 100 atmospheres (between 4×10^6 Pa and 10×10^7 Pa) and using a catalyst. The use of such conditions will affect both the rate of reaction and the equilibrium yield.

In the spaces below, explain the effects of higher temperature, higher pressure, and the use of a catalyst on the **equilibrium yield** of methanol.
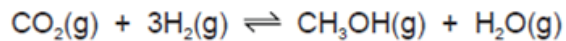
higher temperature

effect ....

explanation ....

....

higher pressure

effect ....

explanation ....

....

use of catalyst

effect ....

explanation ....

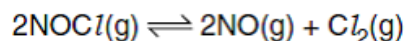...

[6]

s/12/qp21

NO is also formed when nitrosyl chloride, NOCl, dissociates according to the following equation.

$$2NOCl(g) \rightleftharpoons 2NO(g) + Cl_2(g)$$

Different amounts of the three gases were placed in a closed container and allowed to come to equilibrium at 230 °C. The experiment was repeated at 465 °C.

The equilibrium concentrations of the three gases at each temperature are given in the table below.

temperature / °C	concentration / mol dm^{-3}		
	NOCl	NO	Cl$_2$
230	2.33×10^{-3}	1.46×10^{-3}	1.15×10^{-2}
465	3.68×10^{-4}	7.63×10^{-3}	2.14×10^{-4}

(iii)   Is the forward reaction endothermic or exothermic? Explain your answer.

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[5]

s/08/qp2