6.2 Reversible reactions and equilibrium

Name: _____ Class: _____ Date: _____ **Total: 41 marks**

KEY WORDS dynamic equilibrium • Le Chatelier principle

Objective

Represent reversible reactions, define equilibrium and (HT) apply Le Chatelier's principle. Original questions for spec statements 4.6.2.1–4.6.2.7.

1 Key knowledge and worked examples

Reversible reactions use the ⇌ arrow: A + B ⇌ C + D. Exothermic in one direction transfers the **same energy** endothermically in the other.

Dynamic equilibrium: in a **closed system**, reached when the **forward and reverse rates are equal** – concentrations constant, both reactions still happening.

(HT) Le Chatelier – the system **counteracts** a change:

Change	Position shifts
reactant concentration ↑	toward products
product concentration ↓	toward products
pressure ↑ (gases)	toward the side with **fewer gas molecules**
temperature ↑	toward the **endothermic** direction
catalyst added	**no shift** – equilibrium reached sooner

Worked example (3 marks, HT). $N_2(g) + 3\ H_2(g) \rightleftharpoons 2\ NH_3(g)$ (exothermic forward). Predict the effect of raising the pressure and of raising the temperature.

Four gas molecules on the left, two on the right – higher pressure shifts toward ammonia; higher temperature shifts the position in the endothermic direction – the reverse – so the ammonia yield falls; a catalyst would not change the yield, only the speed.

2 Practice

2.1 What arrow shows a reversible reaction? [1]

2.2 What is equal at equilibrium? [1]

2.3 *(HT)* $2\ SO_2(g) + O_2(g) \rightleftharpoons 2\ SO_3(g)$ – which side has fewer gas molecules? [1]

3 Exam-style questions

3.1 Explain what is meant by dynamic equilibrium in a closed system. [4]

3.2 *(HT)* For a hypothetical $A(g) + B(g) \rightleftharpoons C(g)$ reaction with an endothermic forward direction, predict and explain the effect of (a) adding more A at fixed volume; (b) cooling the mixture. [4]

3.3 *(HT)* Why do industries sometimes use a moderate temperature rather than a low one for an exothermic equilibrium process? [3]

3.4 Heating blue hydrated copper sulfate forms white anhydrous copper sulfate and water, taking in 72 kJ for a stated amount. Describe the reverse change and its energy transfer for the corresponding amount. Also write the reversible word equation for ammonium chloride forming ammonia and hydrogen chloride; state which direction heating favours. [4]

3.5 In a sealed vessel, forward/reverse rates at 0, 10, 20 and 30 minutes are respectively 0.8/0.0, 0.5/0.2, 0.3/0.3 and 0.3/0.3 in the same units. The reactant and product amounts at 20 minutes are 0.60 and 0.20 mol. Identify the first recorded equilibrium time, explain why the unequal amounts are allowed, and evaluate: "Both reactions have stopped." [4]

3.6 *(HT)* $A(g) + B(g) \rightleftharpoons C(g)$ is at equilibrium in a fixed-volume vessel. More C is added. Distinguish the immediate concentration change from the subsequent reaction and explain what happens until a new equilibrium is reached. Must C return exactly to its original concentration? [4]

3.7 *(HT)* Predict and explain the effect of compression at fixed temperature on (a) $PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$; (b) $H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$; (c) $C(s) + CO_2(g) \rightleftharpoons 2CO(g)$. For (a), also predict expansion. [6]

3.8 *(HT)* A forward reaction is exothermic. At 300 °C it gives 80% equilibrium yield and production rate 2 units; at 400 °C it gives 55% and rate 8 units. A plant needs at least 50% yield and rate 5 units. Choose a temperature and justify it. Explain the yield trend, and predict how heating would affect yield for a different endothermic forward reaction. [5]

3.9 *(HT)* Without a catalyst, a closed system reaches equilibrium in 20 minutes with reactant concentration 0.60 mol/dm^3 and product concentration 0.20 mol/dm^3. A suitable catalyst gives the same final concentrations in 4 minutes at the same temperature, with the same starting amounts. Explain its effects on forward/reverse rates and position, and evaluate: "A faster reaction always has a larger equilibrium yield." [4]

Solutions

2.1 The equilibrium ($\rightleftharpoons$) arrow.

2.2 The rates of the forward and reverse reactions.

2.3 The right-hand side – 2 molecules of SO_3 against 3 of reactants.

3.1 A closed system prevents reactants or products escaping; both forward and reverse reactions continue to occur; their rates become exactly equal; so the concentrations of all substances remain constant – equilibrium is dynamic, not static.

3.2 (a) The system counteracts the added A by using it up – the position shifts right, more C forms until equilibrium is restored. (b) The forward reaction is endothermic, so cooling shifts the position in the exothermic direction – to the left, less C; because the system releases energy to counteract the fall in temperature.

3.3 A low temperature favours the exothermic forward direction and the yield; but rate falls steeply with temperature, so production would be too slow; a moderate temperature compromises yield against rate, keeping the process economic.

3.4 Add water to white anhydrous copper sulfate to form blue hydrated copper sulfate; the reverse is exothermic and releases 72 kJ for the same corresponding amount. Ammonium chloride $\rightleftharpoons$ ammonia + hydrogen chloride; heating favours the rightward decomposition and cooling the reverse formation. Equal energy magnitude is for reversed changes of matching amounts, not arbitrary quantities.

3.5 The first recorded equilibrium time is 20 minutes, when the rates are equal. The sealed vessel prevents escape. Equilibrium requires equal rates, not equal amounts or concentrations, so 0.60 and 0.20 mol are compatible. Both reactions continue at non-zero rate 0.3; they have not stopped. The observations do not locate the exact onset between recorded readings.

3.6 Adding C immediately increases its concentration. The reverse reaction then exceeds the forward rate, consuming some C and forming A/B. Concentrations change until forward/reverse rates become equal again. C need not return exactly to its original concentration; the principle predicts a response opposing the addition, not complete cancellation of it. Do not keep rates equal during the adjustment.

3.7 (a) One gas molecule on the left versus two on the right; compression shifts left to fewer gas molecules, expansion right to more. (b) Two gaseous molecules each side, so no predicted position shift. (c) Count only gases: one CO_2 versus two CO, excluding solid carbon; compression shifts left. Count coefficients, not the number of different formulae. These predictions concern volume changes at fixed temperature.

3.8 Choose 400 °C: 55% meets the $\geq$50% yield requirement and rate 8 meets the $\geq$5 requirement, whereas 300 °C fails the rate target. Heating favours the endothermic reverse direction, lowering equilibrium product yield for the exothermic forward reaction. For an endothermic forward reaction, heating favours products and raises their equilibrium amount. The data justify this target-based choice, not a claim that 400 °C is cheapest without energy/equipment cost information.

3.9 A catalyst speeds both forward and reverse reactions, through a lower-activation-energy pathway, so equilibrium is reached sooner. Final position/yield is unchanged at the same conditions, as the same concentrations demonstrate; therefore "always larger yield" is false. Concentrations are constant at equilibrium but not equal to one another. The comparison assumes the same starting quantities and closed-system conditions.