

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 ≥ 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.