1. (a)(i) $K_c = \frac{[NO_2(g)]^2}{[N_2O_4(g)]}$ [1]

(ii) $K_c = \frac{(0.0150)^2}{(0.0390)} = 5.77 \times 10^{-3}$ ✓ $mol\ dm^{-3}$ ✓ accept 5.76923 to 5.8×10^{-3}

If (i) is upside down: $\frac{[N_2O_4(g)]}{[NO_2(g)]^2}$, then ans = 173 ✓ $dm^3\ mol^{-1}$ ✓ accept 173.33333.....to 170

if no square in (i): $\frac{[NO_2(g)]}{[N_2O_4(g)]}$, then ans = 0.384615.. ✓ no units ✓ (must be stated)

if no square in (i) and inverse: $\frac{[N_2O_4(g)]}{[NO_2(g)]}$, 2.6 ✓ no units ✓ (must be stated)

[2]

(b) ΔH = (2 x 33) −(9) ✓ = (+)57 kJ mol^{-1} ✓

common errors: −57 ✓ × +24 ✓ × +75 ✓ × −24 × ×

[2]

(c) *change* more NO_2 / less N_2O_4 ✓

explanation equilibrium position ⟶ right or forwards / K_c increases ✓

reaction is endothermic ✓

THIS ANSWER IS CONSEQUENTIAL ON SIGN OF THE ANSWER TO (i)

BUT, a candidate interpreting a '+' enthalpy change as 'exothermic' (or vice versa) will lose the 3rd mark but the 2 'logic marks' before are still consequentially available.

[3]

(d) 1 mol N_2O_4 reacts with 2 mol NaOH ✓

amount of NaOH required = 0.00930 mol ✓

volume NaOH = 1000 x 0.0093/0.300 = 31.0 cm^3 / 0.0310 dm^3 ✓

Common errors

3.1 x 10^x (where x is incorrect) ✓ ✓ ×

15.5 cm^3 / 0.0155 dm^3 ✓ ✓ × *1.55 x 10^x (where x is incorrect)* ✓ × ×

62 cm^3 / 0.062 dm^3 ✓ ✓ × 6.2 x 10^x (where x is incorrect) ✓ × × [3]

[Total: 11]

2. (a) $k = \frac{\text{rate}}{[H_2(g)][NO(g)]^2}$ ✓

$k = 8.3 \times 10^4$ ✓ $dm^6\ mol^{-2}\ s^{-1}$ ✓ calculator value: 8.33333.... x 10^4

If [NO] is not squared: $\frac{\text{rate}}{[H_2(g)][NO(g)]}$ ×, ans = 250 ✓ units: $dm^3\ mol^{-1}\ s^{-1}$ ✓

If the expression is upside down: $\frac{[H_2(g)][NO(g)]^2}{\text{rate}}$ ×, ans = 1.2×10^{-5} ✓ units: mol^2 s dm^{-6} ✓

upside down and not squared: $\frac{[H_2(g)][NO(g)]}{\text{rate}}$ ××, ans = 0.004 mol s dm^{-3} ✓ [3]

(b)(i) *effect on rate* x 2 ✓

reason 1st order wrt $H_2(g)$ ✓ [2]

(ii) *effect on rate* x 1/4 ✓

reason 2nd order wrt NO(g) ✓

[2]

(iii) *effect on rate* x 27 ✓

[1]

(c)(i) slowest step ✓

[1]

(ii) step 1 (RDS) $H_2(g) + 2\,NO(g)$ ✓ $\longrightarrow N_2O(g) + H_2O(l)$

step 2 $H_2(g) + N_2O(g) \longrightarrow N_2(g) + H_2O(l)$ rest of equations ✓

[2]

(d)(i) NH_3, –3 ✓

NO, +2 ✓

HNO_3 +5 ✓ [3]

(ii) $4NH_3(g) + 5O_2(g) \longrightarrow 4NO(g) + 6H_2O(l)$

products + reactants ⟶ 1 mark; balancing ⟶ 1 mark ✓ ✓

[2]

(iii) molar masses NH_3 = 17; HNO_3 = 63 ✓

mass = 700 000 x 17/63 = 1.89×10^5 tonnes ✓ calc value 1.888888.... x 10^5

ans: mark could be consequential on incorrect molar masses. [2]

[Total: 18]

3. (a) Empirical formula = C : H : O = 40.0/12 : 6.7/1 : 53.3/16 = 3.33 : 6.7 : 3.33 ✓

= CH_2O ✓

mass CH_2O = 30; M_r = 90 ∴ molecular formula = $C_3H_6O_3$ ✓ [3]

(b)

$$K_a = \frac{[H^+(aq)]\,[A^-(aq)]}{[HA(aq)]} \;/\; \frac{[H^+(aq)]^2}{[HA(aq)]}$$ ✓

$$\therefore 1.2 \times 10^{-5} = \frac{[H^+(aq)]^2}{1.5}$$

$[H^+(aq)] = \sqrt{\{(1.2 \times 10^{-5}) \times (1.5)\}} = 4.2 \times 10^{-3}$ mol dm^{-3} ✓

pH = $-\log[H^+(aq)]$ ✓ = $-\log 4.2 \times 10^{-3}$ = 2.4 / 2.37 ✓

***4 marks**:* K_a expression✓;

$[H^+]$✓;

pH expression✓;

calculation of pH from $[H^+]$ (ecf) ✓

***Common error**:* Without square root, answer is 4.7/ 4.7447... ✓✓✓x

[4]

(c)(i) A solution that minimises changes/resists change in pH after addition of acid/alkali ✓
NOT 'maintains constant pH' or 'cancel out' [1]

(ii) $CH_3COOH \rightleftharpoons H^+ + CH_3COO^-$ / $CH_3COOH + H_2O \rightleftharpoons H_3O^+ + CH_3COO^-$ [1]

(iii) The weak acid or CH_3COOH reacts with added alkali / added alkali reacts with H^+ ✓

The base or CH_3COO^- reacts with added acid ✓
Direction of movement indicated for one change / indication of the products formed for one change ✓ [3]

(d) *effect on pH* increases ✓

explanation equilibrium ⟶ left ✓

H^+ removed by CH_3COO^- ✓ [3]

[Total: 15]

4. (a) ***Pressure: 3 marks***

high pressure ✓ fewer gaseous moles on right ✓

Compromise: pressure used but too much is requires too much energy/high costs/causes safety issues/thick pipes ✓

Temperature: 4 marks

low temperature ✓ reaction is exothermic ✓

Increased temperature needed to increase the rate/low temperature gives a slow rate ✓

Compromise: idea of a compromise between rate and equilibrium amount ✓

7 marking points ⟶ 6 max

Clear, well-organised, using specialist terms ✓

[7]

(b)(i)

what citric acid does: citric acid dissociates ✓

H^+ released / H_2O accepts H^+/behaves as a base ✓

equation: $H_3A + 3H_2O \longrightarrow 3H_3O^+ + A^{3-}$

or $H_3A \longrightarrow 3H^+ + A^{3-}$

or $H_3A + H_2O \longrightarrow H_3O^+ + H_2A^-$

or $H_3A \longrightarrow H^+ + H_2A^-$ ✓ (or other intermediate dissociation)

The equation alone will also score the 2 'what citric acid does' marks.

how H⁺ reacts: H^+ now reacts with HCO_3^- ions/$NaHCO_3$ ✓

equation: $H^+ + HCO_3^- \longrightarrow H_2O + CO_2$ ✓

The equation alone will also score the 'how H^+ reacts' mark.

5 marks ⟶[4] max

(ii) Molar mass of $NaHCO_3$ = 84.0 ✓

amount of $NaHCO_3$ = 0.5/84.0 = 5.95×10^{-3} mol ✓

3 mol $NaHCO_3$ reacts with 1 mol citric acid ✓

amount of citric acid = $5.95 \times 10^{-3}/3 = 1.98 \times 10^{-3}$ mol ✓

mass of citric acid required = $1.98 \times 10^{-3} \times 192 = 0.380$ g ✓

(allow 0.4 g)

Answer of 0.127g / 0.12698 g from dividing by 3 twice ⟶ ✓✓✓✓✗

[5]

[Total: 16]