

Chemistry Solutions (Physical)

Section A: Multiple Choice

1. **Answer:** 3/8

Working: $128 (\text{CH}_2\text{ClBr}) - 14 (\text{from CH}_2) = 114 (\text{Cl and Br})$
The only way to make 114 from the given masses of Cl and Br is
 $35 + 79$
Proportion of $^{35}\text{Cl} = 3/4$
Proportion of $^{79}\text{Br} = 1/2$
Proportion of both = $\frac{3}{4} * \frac{1}{2} = 3/8$

2. **Answer:** A

Working: Giant covalent structure \rightarrow high melting/boiling point and no
conduction of electricity (even when molten) \rightarrow A
(Other options: B is ionic, C is metallic, D is molecular covalent)

3. **Answer:** ClO_3^-

Working: CH_3^+ : 3 valence pairs, no lone pairs \rightarrow trigonal planar
 SO_3 : 3 bonding pairs (all double bonds) \rightarrow trigonal planar
 ClO_3^- : 4 valence pairs (3 bonding, 1 lone) \rightarrow trigonal pyramidal
 XeF_4 : 6 valence pairs (4 bonding, 2 lone) \rightarrow square planar
Only ClO_3^- is not planar

4. **Answer:** $+250 \text{ kJ mol}^{-1}$

Working: Sketching an energy profile for the reaction and marking on the
activation and heat (enthalpy change) energies,
Reverse activation energy = $-(-100) + 150 = 250$.

5. **Answer:** $6z > x + 3y$

Working: Bonds broken: 1 x $\text{N}\equiv\text{N}$ (x) and 3 x $\text{H}-\text{H}$ (3y)
Bonds formed: 6 x $\text{N}-\text{H}$ (6z)
Since overall change < 0 , energy released $>$ energy used
 \rightarrow bonds formed $>$ bonds broken
 $\rightarrow 6z > x + 3y$

6. **Answer:** the Cu^+ ion is acting as a reducing agent.

Working: Glass darkens when equilibrium shifted to the right
 Cu^+ becomes Cu^{2+} so it was oxidised (loss of electrons)
So Cu^+ was acting as the reducing agent
 Ag^+ becomes Ag so it was reduced (gain of electrons)
So Ag^+ was acting as the oxidising agent

7. **Answer:** $\text{rate} = k [\text{A}] [\text{Fe}(\text{CN})_6^{3-}]^2$

Working: Experiments 1 and 2: A x2, catalyst x3 \rightarrow rate x2
 \rightarrow zero order w.r.t. Catalyst, first order w.r.t. A
Experiments 2 and 4: A x2, iron... x3 \rightarrow rate x 18
 \rightarrow iron... x3 \rightarrow rate x 9 \rightarrow second order w.r.t. iron...
 $\rightarrow \text{rate} = k [\text{A}] [\text{Fe}(\text{CN})_6^{3-}]^2$

8. **Answer:** B

Working: Arrhenius equation: $k = A \exp(-E_a / RT)$
 \rightarrow approximate shape is $k = \exp(-1/T)$
[could use graphical calculator from here]
 $\rightarrow k = 1/\exp(1/T)$
 \rightarrow starts off increasing fast, then levels out (verify by building up sketches of the function)

9. **Answer:** 1 and 2 only

Working: 1: always true
2: true, since a change of state significantly increases entropy (disorderness of a gas > liquid)
3: Enthalpy of formation of water is more positive than steam
Enthalpy change = constant - larger value = smaller value
→ enthalpy change is more negative

10. **Answer:** 2

Working: 2 x Moles of ethanedioic acid = Moles of NaOH
 $2 \times \text{mass}/M_r = 0.0025$
 $\text{Mass} = 2.5 \times (15.8/250) = 0.158 \text{ g}$
 $0.158/M_r = 0.00125 \rightarrow M_r = 126.4$
 $n\text{H}_2\text{O} = 126.4 - (2 + 24 + 64) = 36.4$
 $18n = 36.4 \rightarrow n = 2.022 \rightarrow n = 2$

11. **Answer:** E_{mean} and E_{mp} are both dependent on T

Working: Mode < mean for the Maxwell-Boltzmann distribution
 E is dependent on T , and not p or n (essentially the same thing)

12. **Answer:** Tests **1** and **3** only

Working: Strong acid: fully dissociates → lots of ions
1: The strong acid would react faster since more H^+ ions in solution
2: Same moles of acid in each case so no difference in titre
3: The strong acid would conduct electricity better since more ions available/dissociated to carry charge

13. **Answer:** 1 only

Working: 1: Yes (to return any reagents splashed onto the side of the flask back in)
2: No (should rinse burette with what will go in it; HCl)

14. **Answer:** +6, +6, +4

Working: CrO_2F_2 : $\text{Cr} + 2(-2) + 2(-1) = 0 \rightarrow \text{Cr} = +6$
 $\text{K}_2\text{Mn}_2\text{O}_7$: $+2 + 2(\text{Mn}) + 7(-2) = 0 \rightarrow 2 \text{Mn} = 12 \rightarrow \text{Mn} = +6$
 BaTiO_3 : $+2 + \text{Ti} + 3(-2) = 0 \rightarrow \text{Ti} = +4$

15. **Answer:** $\Delta G^\circ = -RT \ln K_c$

Working: K_c expression: $K_c = [\text{C}]/[\text{A}]^2[\text{B}]$
Let forward and backward rate constants be k_1 and k_2
Using rate equations,
Rate (forward) = $k_1[\text{A}]^2[\text{B}]$, rate (back) = $k_2[\text{C}]$
Since at equilibrium, forward rate = backward rate:
 $k_1[\text{A}]^2[\text{B}] = k_2[\text{C}]$
Divide both sides by LHS $\rightarrow 1 = k_2[\text{C}]/k_1[\text{A}]^2[\text{B}]$
Replace K_c expression: $1 = k_2/k_1 * K_c \rightarrow K_c = k_1/k_2$
Using Arrhenius,
 $K_c = A \exp(-E_{\text{forward}}/RT) / A \exp(-E_{\text{backward}}/RT)$
 $K_c = \exp(E_{\text{backward}}/RT - E_{\text{forward}}/RT)$
 $RT \ln K_c = E_{\text{backward}} - E_{\text{forward}}$
 $-RT \ln K_c = E_{\text{forward}} - E_{\text{backward}}$
Considering the energy profile diagrams,
 $E_{\text{backward}} = E_{\text{forward}} - \Delta H$
 $-RT \ln K_c = E_{\text{forward}} - E_{\text{forward}} + \Delta H$
Equilibrium \rightarrow no net entropy change $\rightarrow \Delta G = \Delta H$
 $\rightarrow \Delta G = -RT \ln K_c$

Section B: Standard Questions

16.

- a. Sample of X is dissolved in a volatile solvent in a hypodermic needle connected to a **high voltage** supply and is ejected as a **fine mist/aerosol** [1 mark]
Each sample particle **gains a proton** as it leaves the needle [1 mark]
Ions accelerated by uniform electric field to **constant kinetic energy** [1 mark]
Ions drift / fly through the tube, **lighter ions reach the detector first** [1 mark]
Ions **gain an electron/discharge** at the detector, creating a current
The results are plotted on a **mass spectrum** [1 mark]
- b. Deduces that time is proportional to square root of mass
 $E_k = 1/2 mv^2$ and $v = d/t \rightarrow E_k = 1/2 m(d/t)^2 \rightarrow E_k = 1/2 md^2/t^2$
 $\rightarrow t^2 = m(d^2/2E_k)$ (since d, E_k are constants) $\rightarrow t = k\sqrt{m}$ [3 marks]
 $2.446 \times 10^{-4} = k\sqrt{(185 + 1)} \rightarrow k = 1.7935 \times 10^{-5}$ [1 mark]
Time = $1.7935 \times 10^{-5} * \sqrt{(187 + 1)} = \mathbf{2.459 \times 10^{-5} s}$ [2 marks]
- c. $A_r = (0.63 \times 187) + (0.37 \times 185) = 186.3$ [1 mark]
Closest match on periodic table is **rhenium (Re)** [1 mark]
- d. **Other isotopes of hydrogen** gained from the electrospray solvent [1 mark]

17.

a. i) KMnO_4 [1 mark]

ii) Reduction of manganate ions: $\text{MnO}_4^- + 8 \text{H}^+ + 5 \text{e}^- \rightarrow \text{Mn}^{2+} + 4 \text{H}_2\text{O}$

Oxidation of ethanedioate ions: $\text{C}_2\text{O}_4^{2-} \rightarrow 2 \text{CO}_2 + 2 \text{e}^-$

Overall: $2 \text{MnO}_4^- + 5 \text{C}_2\text{O}_4^{2-} + 16 \text{H}^+ \rightarrow 2 \text{Mn}^{2+} + 8 \text{H}_2\text{O} + 10 \text{CO}_2$

b. Deduces an acid-base reaction [1 mark]

$\text{H}_2\text{C}_2\text{O}_4 + 2 \text{OH}^- \rightarrow \text{C}_2\text{O}_4^{2-} + 2 \text{H}_2\text{O}$ [1 mark]

c. Moles of $\text{MnO}_4^- = 26.5 \times 0.02 / 1000 = 5.3 \times 10^{-4}$ [1 mark]

Moles in 25 cm^3 sample / pipette $\text{C}_2\text{O}_4^{2-}$ (from acid and salt):

$5.3 \times 10^{-4} \times 5/2 = 1.325 \times 10^{-3}$ [1 mark]

Moles of $\text{NaOH} = 10.45 \times 0.1 / 1000 = 1.045 \times 10^{-3}$ [1 mark]

So moles of $\text{C}_2\text{O}_4^{2-}$ from acid in 25 cm^3 / pipette is

$1.045 \times 10^{-3} / 2 = 5.225 \times 10^{-4}$ [1 mark]

So the moles of $\text{C}_2\text{O}_4^{2-}$ in sodium ethanedioate in 25 cm^3 is

$(1.325 \times 10^{-3}) - (5.225 \times 10^{-4}) = 8.025 \times 10^{-4}$ [1 mark]

So in the original sample of sodium ethanedioate,

$= 8.025 \times 10^{-4} \times 10 = 8.025 \times 10^{-3}$ [1 mark]

Mass of $\text{Na}_2\text{C}_2\text{O}_4 = 8.025 \times 10^{-3} \times 134 = 1.0754$ [1 mark]

Percentage $= 1.0754 / 1.9 \times 100 = \mathbf{56.6\%}$ (3 s.f.) [1 mark]

18.

a. i) $\text{Na}_2\text{S}_2\text{O}_3 (\text{aq}) + 2 \text{HCl} (\text{aq}) \rightarrow 2 \text{NaCl} (\text{aq}) + \text{S} (\text{s}) + \text{SO}_2 (\text{g}) + \text{H}_2\text{O} (\text{l})$
[1 mark for identifying NaCl and S , 1 mark for SO_2]

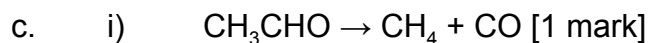
ii) Place the reaction flask on a marked X

The X will become obscured by the precipitate [1 mark]

- b. Any 6 points from:
1. Measure 10 cm³ of hydrochloric acid and 10 cm³ of sodium thiosulfate in separate clean measuring cylinders. (Volumes may differ but must be sensible)
 2. Put the solutions in separate test tubes / boiling tubes
 3. Incubate the boiling tubes in a water bath at a particular temperature (e.g. 60 °C)
 4. Place conical flask on the centre of the large marked cross
 5. Add the thiosulfate solution first followed by the acid
 6. Start the stopwatch and swirl the conical flask
 7. Stop the stopwatch when the cross is no longer visible through the flask and record the time taken
 8. Repeat at different temperatures / wait for reagents to cool to a lower temperature
 9. Plot a graph of rate (1/time) against temperature

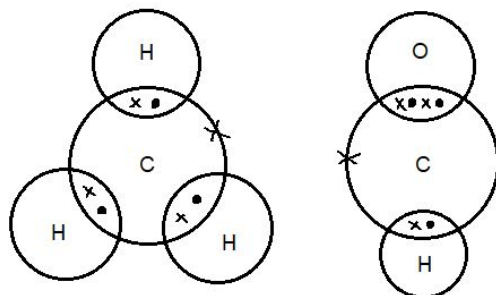
19.

- a. At $T = 273 + 25 = 298$: $k = A \exp(-50000/8.31 \cdot 298) = A \exp(-20.19)$
 $= 1.7 \times 10^{-9} A$ [2 marks]
 At $T = 273 + 35 = 308$: $k = A \exp(-50000/8.31 \cdot 308) = A \exp(-19.54)$
 $= 3.3 \times 10^{-9} A$ [1 mark]
 Ratio $= (3.3 \times 10^{-9} A) / (1.7 \times 10^{-9} A) = 1.94$ (approximately 2 / doubles) [1 mark]
- b. At temperature T : $k = A \exp(-50000/8.31 \cdot T) = A \exp(-6017/T)$ [1 mark]
 At temperature $T+10$: $k = A \exp(-50000/8.31(T+10)) = A \exp(-6017/(T+10))$
 [1 mark]
 Set ratio to 1.5: $\exp(-6017/(T+10)) / \exp(-6017/T) = 1.5$ [1 mark]
 $\exp(6017/T - 6017/(T+10)) = 1.5$
 $6017/T - 6017/(T+10) = 0.4055 \rightarrow 6017(1/T - 1/(T+10)) = 0.4055$
 $\rightarrow 1/T - 1/(T+10) = 6.738 \times 10^{-5} \rightarrow 10 = 6.738 \times 10^{-5} T(T+10)$
 $\rightarrow (6.738 \times 10^{-5}) T^2 + (6.738 \times 10^{-4}) T - 10 = 0$
 $\rightarrow T = -390$ or $T = 380$
 Since T is in Kelvin, $T > 0 \rightarrow \mathbf{T = 380 K}$ or $107 \text{ } ^\circ\text{C}$ [4 marks for solving correct equation by any valid method]

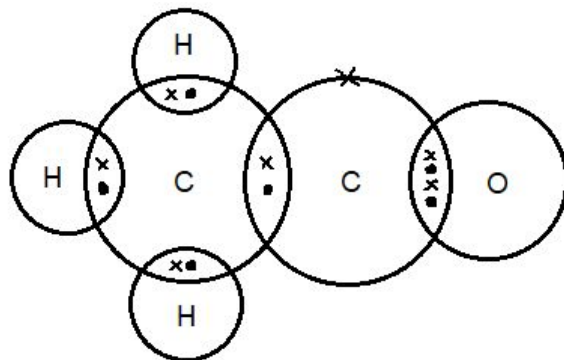
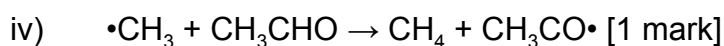


ii) $\text{rate} = k[\text{CH}_3\text{CHO}]^{1.5}$ [1 mark]

iii)

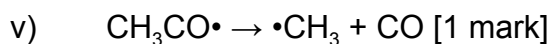


[1 mark for correct CH_3 , 1 mark for correct CHO . Accurate molecular geometry not required]



[1 mark]

[Dots and crosses may be allocated in any consistent arrangement]



d. i) Single step reactions \rightarrow reaction order = number of molecules

Initiation step: $\text{rate} = k_i [\text{CH}_3\text{CHO}]$ [1 mark]

Termination step: $\text{rate} = k_t [\bullet\text{CH}_3]^2$ [1 mark]

Rates are equal $\rightarrow k_i [\text{CH}_3\text{CHO}] = k_t [\bullet\text{CH}_3]^2$ [1 mark]

$\rightarrow k_i [\text{CH}_3\text{CHO}] - k_t [\bullet\text{CH}_3]^2 = 0$ [1 mark]

ii) $k_i [\text{CH}_3\text{CHO}] = k_t [\bullet\text{CH}_3]^2$

Square root of both sides $\rightarrow k_i^{1/2} [\text{CH}_3\text{CHO}]^{1/2} = k_t^{1/2} [\bullet\text{CH}_3]$ [1 mark]

$[\bullet\text{CH}_3] = (k_i^{1/2} / k_t^{1/2}) [\text{CH}_3\text{CHO}]^{1/2}$

k are constants so $[\bullet\text{CH}_3]$ is proportional to $[\text{CH}_3\text{CHO}]^{1/2}$ [1 mark]

- iii) From first propagation step, $\bullet\text{CH}_3 + \text{CH}_3\text{CHO} \rightarrow \text{CH}_4 + \text{CH}_3\text{CO}\bullet$
 Rate = $k_p [\bullet\text{CH}_3][\text{CH}_3\text{CHO}]$ [1 mark]
 Since $[\bullet\text{CH}_3]$ is proportional to $[\text{CH}_3\text{CHO}]^{1/2}$,
 Rate = $k[\text{CH}_3\text{CHO}]^{1/2} [\text{CH}_3\text{CHO}] = k[\text{CH}_3\text{CHO}]^{3/2}$ [2 marks]
 \rightarrow order = $3/2 = 1.5$ [1 mark]

20.

- a. i) Either
 $\text{NaOH (aq)} + \text{CO}_2 \text{ (g)} \rightarrow \text{NaHCO}_3 \text{ (aq)}$
 or
 $\text{NaOH (aq)} + \text{CO}_2 \text{ (g)} \rightarrow \text{NaHCO}_3 \text{ (s)}$
 or
 $\text{NaOH (s)} + \text{CO}_2 \text{ (g)} \rightarrow \text{NaHCO}_3 \text{ (s)}$ [1 mark]
 [cannot have NaOH (s) and NaHCO₃ (aq)]
- ii) The gaseous carbon dioxide is removed from the products [1 mark]
- b. Balanced equation:
 $\text{C}_x\text{H}_y \text{ (g)} + (x + y/4) \text{ O}_2 \text{ (g)} \rightarrow x \text{ CO}_2 \text{ (g)} + (y/2) \text{ H}_2\text{O (g)}$ [1 mark]
 NaOH removes $\text{CO}_2 \rightarrow$ volume of $\text{CO}_2 = 30 \text{ cm}^3$ (from contraction) [1 mark]
 $pV = nRT \rightarrow 0.000030 = (\text{moles CO}_2) \cdot 8.31 \cdot T/p$
 Moles $\text{CO}_2 = (3.608 \times 10^{-6}) p/T$ [1 mark]
 Moles $\text{C}_x\text{H}_y = pV/RT = p \cdot 0.000010 / 8.31 \cdot T = 1.203 \times 10^{-6} p/T$ [1 mark]
 Ratio = $x = [(3.608 \times 10^{-6}) p/T] / [1.203 \times 10^{-6} p/T] = 3$ [1 mark]
 Volume of C_xH_y consumed = 10 cm^3
 Volume of oxygen consumed = $10(x + y/4) = 10(3 + y/4) = 30 + 5y/2 \text{ cm}^3$ [1 mark]
 Volume of water vapour formed = $5y \text{ cm}^3$ [1 mark]
 Volume of products = 5 + volume of reactants (from expansion)
 $30 + 5y = 5 + 10 + 30 + 5y/2$ [1 mark] $\rightarrow 5y = 15 + 5y/2 \rightarrow 5y/2 = 15 \rightarrow y = 6$
 \rightarrow hydrocarbon is C_3H_6 [1 mark]