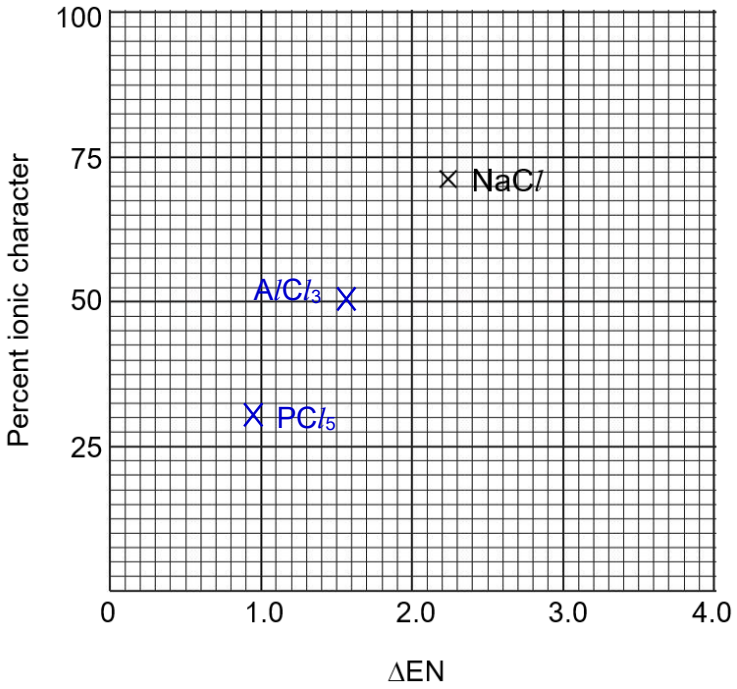
1(a)(i) Comparing sodium and chlorine, chlorine has a higher nuclear charge due to larger number of protons, Shielding effect remains approximately constant as electrons are added to the same electronic shell.

As there is stronger electrostatic attraction between the nucleus and the bonding electrons, chlorine has higher electronegativity, resulting in a larger EN value.

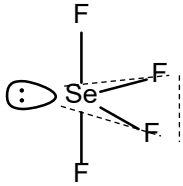
1(a)(ii) ΔEN for AlCl_3 = 3.16 – 1.61 = 1.55
ΔEN for PCl_5 = 3.16 – 2.19 = 0.970



1(a)(iii) Ionic bonds exist in NaCl due to large ΔEN (or large difference in electronegativities) between Na and Cl.
Covalent bonds exist in PCl_5 due to small ΔEN (or small difference in electronegativities) between P and Cl.

1(b)(i) SeF_4 > BrF_3

1(b)(ii) There are 4 bond pairs and 1 lone pair in the valence shell of Se atom. To minimise electrostatic repulsion, the shape of SeF_4 is see-saw.



Since lone pair – bond pair repulsion > bond pair – bond pair repulsion, the bond angles are 88° and 118° *(other acceptable bond angles < 90° and < 120°).*

2(a) By Le Chatelier's Principle, the position of equilibrium will shift right to decrease the concentration of Cl_2. The equilibrium mixture will contain more PCl_5, less PCl_3 and more Cl_2.

2(b)(i) $K_c = \frac{[PCl_5]}{[PCl_3][Cl_2]}$, $mol^{-1}dm^3$

2(b)(ii) $K_c = \frac{[PCl_5]}{[PCl_3][Cl_2]} = \frac{\left(\frac{1.2}{2}\right)}{\left(\frac{0.4}{2}\right)\left(\frac{0.25}{2}\right)} =$ 24.0 $mol^{-1}dm^3$

2(b)(iii)

	$PCl_3(g)$ +	$Cl_2(g)$ ⇌	$PCl_5(g)$
initial amount /mol	0.4	0.25 + x	1.2
change in amount /mol	–0.08	–0.08	+0.08
equilibrium amount /mol	0.4 – 0.08 = 0.32	0.25 + x – 0.08 = 0.17 + x	1.28

$K_c = \frac{[PCl_5]}{[PCl_3][Cl_2]} = \frac{\left(\frac{1.28}{2}\right)}{\left(\frac{0.32}{2}\right)\left(\frac{0.17+x}{2}\right)} = 24$

x = 0.163 mol

2(c) Na_2O reacts vigorously with water to give a strongly alkaline solution with a pH = 13–14.

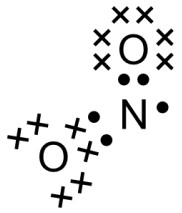
$Na_2O + H_2O \rightarrow 2NaOH$

P_4O_{10} reacts readily with water to give an acidic solution with a pH = 2.

$P_4O_{10} + 6H_2O \rightarrow 4H_3PO_4$

Al_2O_3 does not dissolve in water (energy needed to break down the ionic lattice is more than the energy released on hydrating the ions). pH = 7

3(a)(i)



3(a)(ii) amount of manganate used = (44.8/1000) x 0.02 = 0.000896 mol
amount of iron(II) produced = 0.000896 x 5 = 0.00448 mol
amount of Fe^{2+} = amount of Fe^{3+}
amount of iron(III) reacted with hydroxylamine = 0.00448 mol

3(a)(iii) amount of hydroxylamine used = 0.074 / 33 = 0.00224 mol
Reduction: $Fe^{3+} + e^- \rightarrow Fe^{2+}$
amount of Fe^{3+} : amount of NH_2OH : amount of e^-
2 : 1 : 2

final oxidation state of nitrogen in product = – 1 + 2 = +1

N_2O

3(a)(iv) $Fe^{3+} + e^- \rightarrow Fe^{2+}$ (x4)
$2NH_2OH \rightarrow N_2O + H_2O + 4H^+ + 4e^-$ (x1)
$4Fe^{3+} + 2NH_2OH \rightarrow 4Fe^{2+} + N_2O + H_2O + 4H^+$

3(b)(i) The second ionisation energy of element F is the energy required to remove 1 mole of electrons from 1 mole of gaseous $\mathbf{F}^+$ ions to form 1 mole of gaseous $\mathbf{F}^{2+}$ ions.
$\mathbf{F}^+(g) \rightarrow \mathbf{F}^{2+}(g) + e^-$

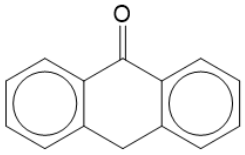
3(b)(ii) Large decrease in 2nd ionisation energy from **D** to **E** implies that the 2nd electron in **E** is removed from the outer electron shell.
E belongs to Group 2 and **B** belongs to group 17.
B is fluorine

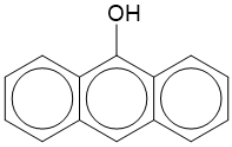
3(b)(iii) **A**: ns^2np^4 $\mathbf{A}^+$: ns^2np^3
B: ns^2np^5 $\mathbf{B}^+$: ns^2np^4
The 2nd electron removed in **B** is a paired electron which experiences greater electron-electron repulsion, so less energy is needed to remove the paired electron than the unpaired electron removed in **A**. Hence, the 2nd ionization energy of **B** is lower.

4(a)(i) The product of reduction of H_2O_2 is water which is clean / non-pollutant / environmentally friendly.

4(a)(ii) Reduction

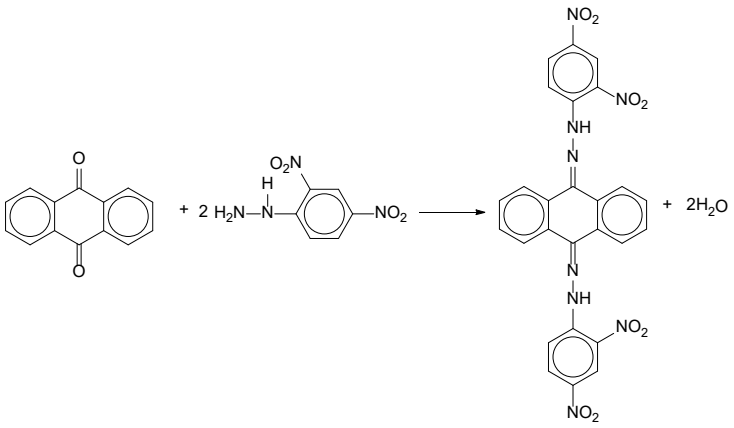
4(a)(iii) From $C_{14}H_8O_2$ to $C_{14}H_{10}O$, gain of 2 H and loss of 1 O = reduction



or


4(a)(iv)

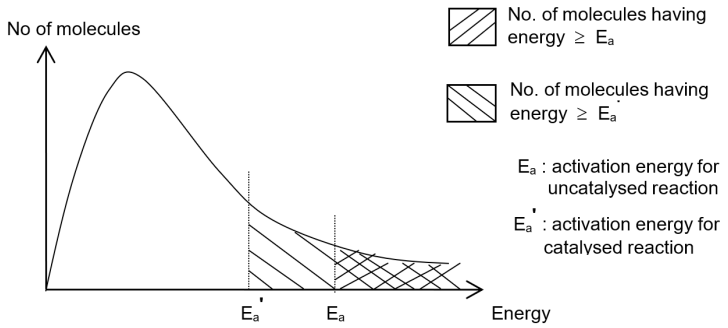
Add 2,4-DNPH.	
anthrahydroquinone	no orange ppt
anthraquinone	orange ppt formed



4(b) Sufficient energy is released from the formation of hydrogen bonds between water and H_2O_2 to overcome the hydrogen bonds between water molecules and hydrogen bonds between H_2O_2 molecules.
Insufficient energy is released from the formation of instantaneous dipole-induced dipole interactions between anthraquinone and water to overcome the hydrogen bonds between water molecules.
H_2O_2 dissolve in water / anthraquinone cannot dissolve in water.

4(c)(i) A heterogeneous catalyst is a catalyst which is not in the same phase as the reactants.

4(c)(ii)



The reactant molecules are adsorbed onto the surface of the solid catalyst. The adsorption weakens the covalent bonds within the reactant molecules, thereby lowering the activation energy for the reaction. The adsorption increases the concentration of reactant molecules at the catalyst surface and allows the reactant molecules to come into close contact with proper orientation for reaction.

The catalyst provided an alternative reaction pathway of lower activation energy. As such, significantly more reactant molecules have energy greater than or equal to the activation energy for the catalysed reaction. Frequency of effective collisions increases and an increase in the rate of the reaction. Rate constant also increases.

After the reaction, desorption of product molecules occurs and the product molecules eventually diffuse away from the catalyst surface.

4(d)(i) Finely dividing the palladium into nanoparticles increases its surface area to volume ratio, providing more active sites for adsorption of reactants.

4(d)(ii) Due to their small size, nanoparticles can enter human body through pores on skin, breathing/respiratory system, or ingestion (by digestive system).
These particles can travel around the body via the circulatory system, get deposited in body tissues / cells / organs and cause the latter to be damaged / inflamed / develop cancer / cause immune response.

4(d)(iii) Gold particles are larger and the deposition of the nanoparticles decreases the chances / prevents them from being inhaled or ingested.

5(a) Across the period, nuclear charge increases due to increasing number of protons.
As electrons are added to the 3d subshell, the increase in the number of inner 3d electrons provide more shielding between the nucleus and the outer 4s electrons.
The increase in shielding effect offsets the increase in nuclear charge. Hence, the electrostatic attraction between the nucleus and outer 4s electrons increases minimally. The first IE remains almost constant/ relatively invariant.

5(b)(i) Atoms with the same proton number but different nucleon numbers (i.e. same number of protons but different number of neutrons)

5(b)(ii) A_r of copper = [5(63)+2(65)]/7 = 63.5714

5(b)(iii)

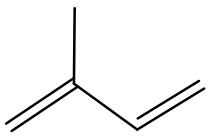
atomic mass unit of 114	$^{79}Br^{35}Cl$
atomic mass unit of 116	$^{79}Br^{37}Cl$ and $^{81}Br^{35}Cl$
atomic mass unit of 118	$^{81}Br^{37}Cl$

5(b)(iv) percentage of sample with $^{79}Br^{35}Cl$ = (1/2)(3/4) = 3/8 = 0.375 = 37.5%
percentage of sample with $^{81}Br^{37}Cl$ = (1/2)(1/4) = 1/8 = 0.125 = 12.5%
percentage of sample with $^{79}Br^{37}Cl$ and $^{81}Br^{35}Cl$ = (1/2)(1/4) + (1/2)(3/4) = 4/8 = 50%

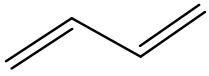
5(c)(i) **Oxidising** agent. Oxidation state nitrogen decreases from **+5 in HNO_3** to **+4 in NO_2**.

5(c)(ii) Sulfur precipitate: $4 - y = \frac{64.2}{32.1}$ $\therefore y = 2$
NO_2 gas: $13 - (3 + 2x) = \frac{182}{22.7}$ $\therefore x = 1$

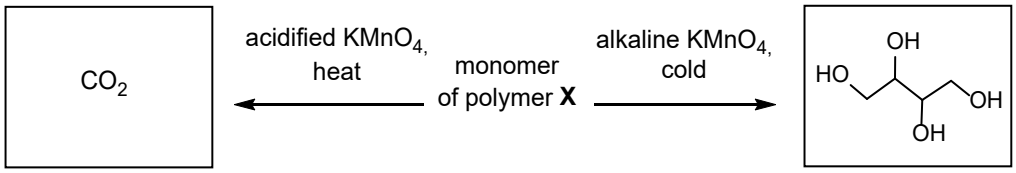
6(a)



6(b)(i) buta-1,3-diene or butadiene

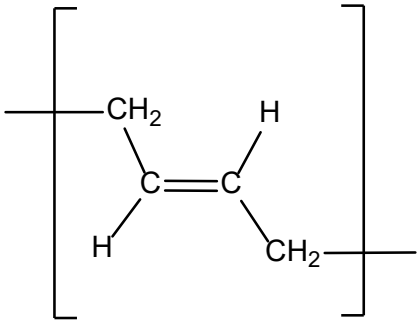


6(b)(ii)



6(c)(i) Cis-trans isomerism.
There is restricted rotation about the C=C bond and each carbon of the C=C bond is bonded to two different groups.

6(c)(ii)



Structure of polymer **Y** (trans isomer)

6(c)(iii) polymer **Z** (cis isomer)

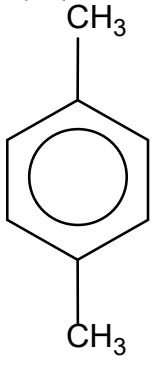
6(d) Carbon-carbon bonds are non-polar / too strong / not attacked by nucleophiles / cannot by hydrolysed.

6(e)(i) Reactions with a high percentage atom economy are more efficient and less wasteful/maximises the use of resources/reduce by-products.

6(e)(ii) The percentage atom economy of the reaction to form PET is lower than that to form polymer **X** as H_2O / another molecule is also formed during the condensation while all the monomers are used to form polymer **X**.

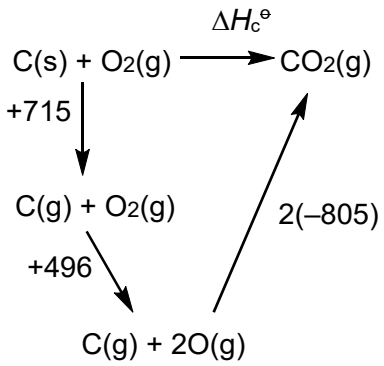
6(f) step I : CH_3Cl, $AlCl_3$
step II : $KMnO_4$(aq), H_2SO_4(aq), heat

Intermediate:



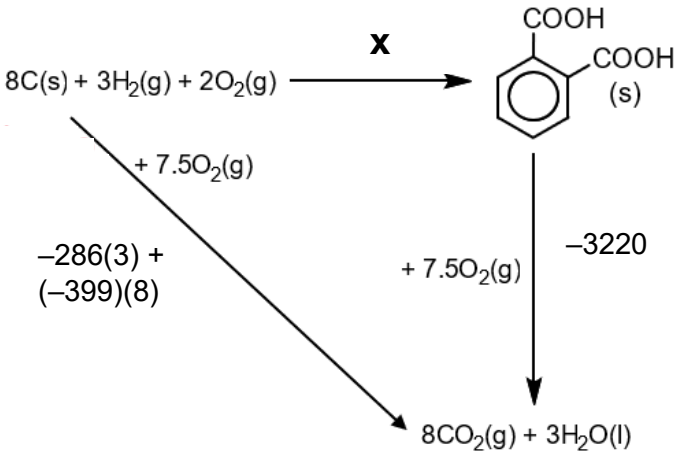
6(g)(i) Benzene-1,4-dicarboxylic acid is more energetically stable as it has a less exothermic standard enthalpy change of combustion.

6(g)(ii)



$\Delta H_c^{\ominus}$ = 715 + 496 + 2(–805) = – 399 kJ mol^{-1}

6(g)(iii)



x = (–286 x 3) + (–399 x 8) – (–3220)
= – 830 kJ mol^{-1}

6(h)(i) The *standard enthalpy change of neutralisation, ΔH_n°*, is the enthalpy change when an acid and a base react to form one mole of water at 298 K and 1 bar.

6(h)(ii) After adding NaOH(aq) to solid potassium hydrogen phthalate, the buffer contains A^{2-} and HA^-.

$$5.0 = 5.40 + \lg\left(\frac{[A^{2-}]}{[HA^-]}\right)$$

$\frac{[A^{2-}]}{[HA^-]} = 0.398$ (1)

$[A^{2-}] + [HA^-] = 0.1$ (2)

Solving (1) and (2), $[HA^-] = 0.07153$ mol dm^{-3}

$[A^{2-}] = 0.1\text{-}0.07153 = 0.02847$ mol dm^{-3}

$HA^- + OH^- \rightarrow A^{2-} + H_2O$

Amount of NaOH needed = amount of $A^{2-} = 0.02847 \times \frac{250}{1000} = 0.007118$ mol

Volume of NaOH needed = $\frac{0.007118}{0.1} \times 1000 = 71.2\ cm^3$