HWA CHONG INSTITUTION
2025 C2 H2 CHEMISTRY PRELIMINARY EXAMINATION
MARK SCHEME / SUGGESTED SOLUTIONS

Paper 1

1	2	3	4	5	6	7	8	9	10
D	**D**	**D**	**C**	**A**	**B**	**A**	**A**	**B**	**A**
11	12	13	14	15	16	17	18	19	20
B	**D**	**D**	**C**	**B**	**C**	**B**	**A**	**C**	**A**
21	22	23	24	25	26	27	28	29	30
A	**A**	**B**	**D**	**D**	**C**	**A**	**B**	**C**	**B**

Comments

1 **D**

The largest difference in consecutive ionisation energies occurs between the 5th and 6th ionisation energies, implying that the 6th electron is removed from an inner quantum shell and element **X** has 5 valence electrons. Since element **X** belongs to Group 15, it is likely to form a chloride of the formula **X**C*l*$_5$.

2 **D**

Isotopes have the **same number of protons** but **different number of neutrons**.
The number of protons can be determined from the *number of electrons* and *charge*.
Once the number of protons are determined, the number of neutrons can be found from the nucleon number.
E.g., in **A**, H has 10 electrons and a charge of −2, so H has 8 protons. Thus, H has 10 neutrons.

	G		H	
	no. of protons	no. of neutrons	no. of protons	no. of neutrons
A	8	10	8	10
B	18	19	16	18
C	16	20	18	20
D	20	22	20	20

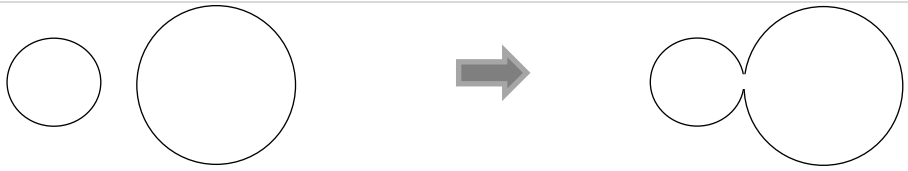
In **D**, G and H have the same number of protons (20) but different number of neutrons (22 and 20).
Note that **A** is incorrect as G and H have the same number of protons and neutrons.

3 **D**

The shape of a species depends on the **number of lone pairs and bond pairs of electrons** around the central atom. Refer to Topic 2 Chemical Bonding Sec. 6.1.

A	A*l*C*l*$_3$	PC*l*$_3$
	3 b.p. and 0 l.p. – trigonal planar	3 b.p. and 1 l.p. – trigonal pyramidal
B	BF_3	NH_3
	3 b.p. and 0 l.p. – trigonal planar	3 b.p. and 1 l.p. – trigonal pyramidal
C	SF_4	XeF_4
	4 b.p. and 1 l.p. – see saw (expanded octet)	4 b.p. and 2 l.p. – square pyramidal (expanded octet)
D	PH_4^+	BF_4^-
	4 b.p. and 0 l.p. – tetrahedral	4 b.p. and 0 l.p. – tetrahedral

4 **C**



n_s $V_s = 10\ m^3$ $P_s = 50\ kPa$ | n_b $V_b = 30\ m^3$ $P_b = 120\ kPa$ | $n_t = n_s + n_b$ $V_t = V_s + V_b$ $P_t = ??\ kPa$

Using $n_t = n_s + n_b$

Since T is constant, $P_tV_t = P_sV_s + P_bV_b$

After connection: $V_t = V_s + V_b$

$$P_t = \frac{(50)(10) + (120)(30)}{(10+30)} = 102.5\ kPa = 103\ kPa$$

5 **A**

This question tests the definition of relative masses found in Topic 1 & 4.

Option B is wrong as the relative atomic masses must take into account all the isotopes of the element, hence the term 'average mass' must be used.

Option C is wrong as the reference should be ^{12}C & not ^{1}H.

Option D is wrong as the reference should be to 1/12 the mass of one atom of ^{12}C.

6 **B**

Always check if the sum of the abundances of the isotopes add up to 100. In the case, they add up to 101.32.

$$\text{Ar (Ge)} = \left(\frac{19.01}{101.32}\times 70\right) + \left(\frac{24.96}{101.32}\times 72\right) + \left(\frac{7.76}{101.32}\times 73\right) + \left(\frac{41.0}{101.32}\times 74\right) + \left(\frac{8.59}{101.32}\times 76\right) = 72.8$$

7 **A**

Use the equation method to obtain the answer:

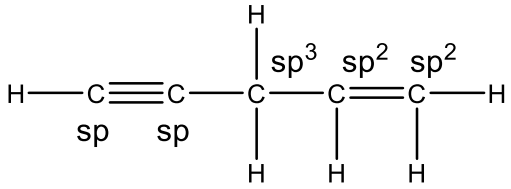
- Flip the first equation to get the MgO on the right side like in the combustion equation. Remember to flip the sign on its ΔH value.
- Half the third equation to ensure that the H_2 from the second equation and this third equation cancels off, and you get ½ O_2 as required in the combustion equation. Remember to halve its ΔH value.
- Add up all the equations to check that you get the combustion equation as given. And then add up all ΔH values to get the answer.

$MgCl_2(aq) + H_2O(l) \rightarrow MgO(s) + 2HCl(aq)$	+89
$Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$	– 435
$H_2(g) + ½O_2(g) \rightarrow H_2O(l)$	– 572 x ½ = – 286
$Mg(s) + ½O_2(g) \rightarrow MgO(s)$	– 632 kJ mol^{-1}

8	**A**	Option 1: ΔS increases as increasing the temperature at a fixed pressure increases the volume of the gas & increases the average kinetic energy of the gas particles and thus results in more ways to distribute the particles and energy. Option 2: ΔS increases as doubling the number of moles of non-interacting gas particles at a fixed pressure increases the volume of the gas results in more ways to distribute the particles and energy. Option 3: ΔS increases as doubling the number of moles of gas particles at a fixed pressure increases the volume of the gas results in more ways to distribute the particles and energy. Option4: ΔS decreases as the number of moles of gas particles at a fixed pressure drops from 1 to 0 on the right-hand side of the equation.
9	**B**	The rate equation can be written by inspecting the chemical equation of the slow step in the reaction mechanism. Hence it should look like: rate = $k[N_2O_2][H_2]$. Rate equations should contain only reactants or product terms but not intermediates. In this case, N_2O_2 is an intermediate. To replace it, we see that N_2O_2 is related to a reactant NO by the reversible reaction which can be expressed in the form of the chemical equilibrium constant. Thus $K=\frac{[N_2O_2]}{[NO]^2}$; rearranging gives $[N_2O_2] = K[NO]^2$. Substituting $[N_2O_2]$ in rate = $k[N_2O_2][H_2]$ gives rate = $kK[NO]^2[H_2]$ or rate = $k'[NO]^2[H_2]$. The units of the rate constant k' can be worked out as follows: rate = $k'[NO]^2[H_2]$ mol dm^{-3} s^{-1} = k' x (mol dm^{-3})^2 x (mol dm^{-3}) Simplifying gives k' = $mol^{-2}\,dm^6\,s^{-1}$
10	**A**	The area under the curve represent the total number of molecules. Thus this is represented by P + R. Since only the T is changed, the total number of molecule, P + R does not change. Thus the expression $\frac{R}{P+R}$ gives the fraction of molecules that have energy greater than the activation energy of the lower temperature. Note that the steeper curve represents the lower temperature while the shallower curve is for the higher temperature.
11	**B**	Option A is wrong as the correct temperature is 450 °C. Option C is wrong as the iron acts as an catalyst which speeds up the reaction but does not affect the yield. Option D is wrong as removing NH_3 shifts the position of the equilibrium to the right but does not affect the rate of reaction.

12	**D**	$MnO_4^-(aq) + 8\ H^+(aq) + 5\ e^- \rightarrow Mn^{2+}(aq) + 4\ H_2O(l)$ $SO_2(g) + 2\ H_2O(l) \rightarrow SO_4^{2-}(aq) + 4\ H^+(aq) + 2\ e^-$ Obtain the overall equation through multiplying the first half-equation by 2 and the second half-equation by 5 in order to eliminate the electrons: $2MnO_4^- + 5SO_2 + 2H_2O \rightarrow 2Mn^{2+} + 5SO_4^{2-} + 4H^+$ Notice that there is a net production of H^+ so $[H^+]$ increases as the reaction proceeds. Since pH = −lg $[H^+]$, pH decreases over time.
13	**D**	Titration Curve 1 = strong acid-weak base curve (equivalence pH is acidic) Titration Curve 2 = weak acid-weak base curve (no vertical portion in the curve) Option A is wrong as there are no suitable indicators for weak acid-weak base titrations. Option B is wrong as give above. Option C is wrong as Titration Curve 1 involves a strong acid as depicted by the flat smooth curve at pH between 0 & 2. A weak acid will give a sharper rise in pH before flattening out shortly after and then rising sharply again near the equivalence point (i.e. a buffer region).
14	**C**	The decomposition of H_2O_2 is usually written as $2H_2O_2 \rightarrow 2H_2O + O_2$. In basic medium, it may be written as $2HO_2^- \rightarrow 2OH^- + O_2$, where a proton is lost from both H_2O_2 & H_2O. Re-writing it to make clear that two ions of HO_2^- are reacting with each other in the decomposition process: **$HO_2^- + HO_2^- \rightarrow 2OH^- + O_2$**. Thus $HO_2^- \rightarrow 2OH^-$ (reduction) ➔ $HO_2^- + H_2O + 2e \rightarrow 3OH^-$ $E^\ominus = +0.88$ V And $HO_2^- \rightarrow O_2$ (oxidation) ➔ $HO_2^- + OH^- \rightarrow O_2 + H_2O + 2e$ $E^\ominus = -0.08$ V Thus E_{cell} = + 0.96 V The semi-permeable membrane allows ions to pass through to maintain electrical neutrality in both cells just like a salt bridge does.
15	**B**	The % composition of the alloy is a distractor and is not needed in the calculations. The total mass of metal deposited as the cathode represents the metal that was reduced. Use of the data booklet shows that both Cu & Ni may be both oxidized at the anode while the reduction potential for Cu^{2+} is positive and favorable while that for Ni^{2+} is negative and unfavorable, thus only Cu^{2+} is reduced at the cathode. Refer to the purification of copper in your notes for a similar analysis. Mass of Cu accumulated = 0.88 g No. of moles of Cu accumulated = 0.88 ÷ 63.5 = 0.013858 No. of moles of electrons passed through = 2 x 0.013858 = 0.027716 Q = It = nF 0.50 x 1.5 x 60 x 60 = 0.027716 x F F = 97416.654 F = Le 97416.654 = L x 1.6 x 10^{-19} L = 6.088 x 10^{23} or 6.09 x 10^{23}

16 **C**



Option A is correct as π bonds may be formed only side-on overlap of p orbitals. These bonds are found in the C≡C and C=C bonds.

Option B is correct as the H uses its 1s orbital to form the H–C bond in H–C≡

Option C is wrong as the sp C is bonded to a sp^3 C in ≡C–C

Option D is correct as the sp^3 C is bonded to a sp^2 C in C–C=

17 **B**

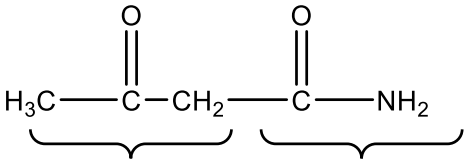
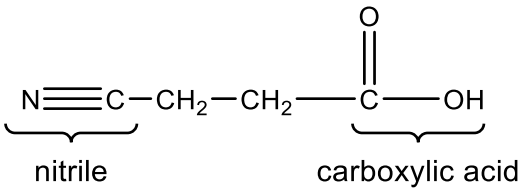
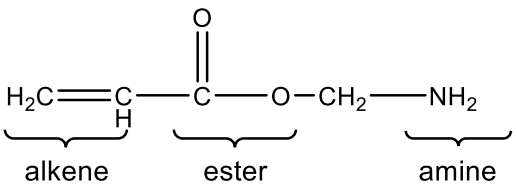
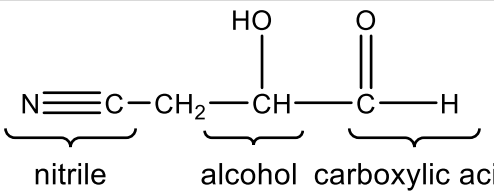
It is helpful to refer to the reaction mechanisms in the notes.

Option 1 is correct as the C*l*$_2$ acts as the electrophile in the first step of the electrophilic addition reaction mechanism.

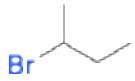
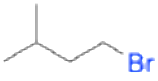
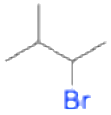
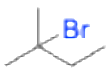
Option 2 is wrong as the C*l*$_2$ acts as the electrophile while H_2O acts as the nucleophile in the second step of the electrophilic addition reaction mechanism.

Option 3 is correct as the C*l*$_2$ undergoes homolytic cleavage to form C*l*• radicals in uv light in the first step of the free radical substitution reaction mechanism.

18 **A**

Option 1		The molecular formula is $C_4H_7O_2N$.
Option 2		The molecular formula is $C_4H_5O_2N$.
Option 3		The molecular formula is $C_4H_7O_2N$.
Option 4		The molecular formula is $C_4H_5O_2N$.

19 **C**

mono-brominated product				
no. of H atoms which can be substituted (probability)	6	3	2	1

20 **A**

Recall what a catalytic converter does. A catalytic converter in cars reduces harmful emissions and its overall aim is to reduce CO, hydrocarbons, and oxides of nitrogen.

Option A is wrong as it shows CO_2 being reduced to CO, while the converter is meant to oxidise CO to CO_2.

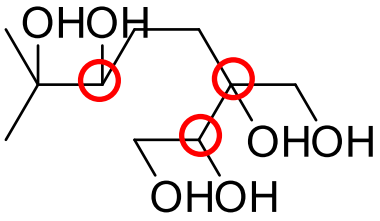
Option B is correct as CO is oxidized, and NO is reduced.

Option C is correct as it shows the complete combustion of hydrocarbons.

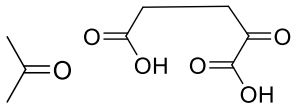
Option D is correct as hydrocarbons react with NO, reducing NO to N_2.

21 **A**

A The mild oxidation product is shown below with the chiral centres circled.

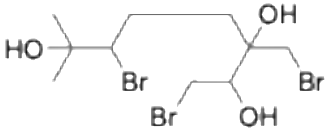


B Only two oxidative cleavage organic products:



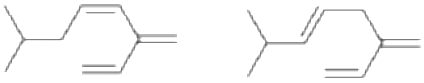
CO_2 is <u>not</u> an organic product.

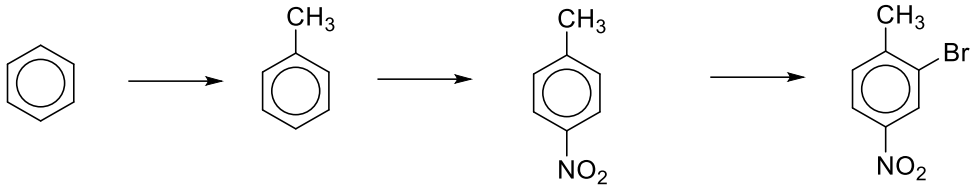
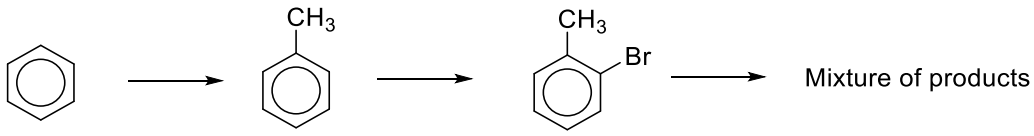
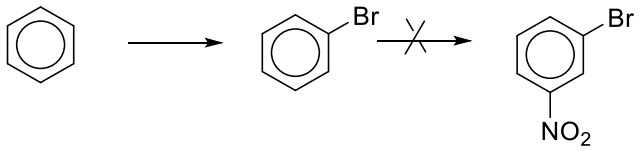
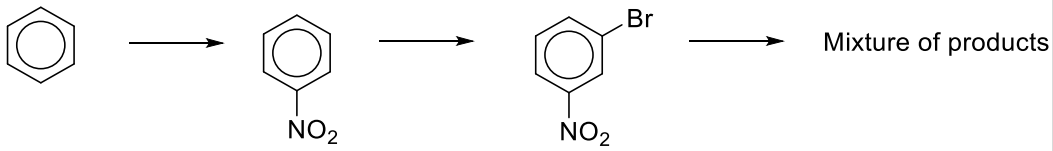
C Alkene C=C undergoes electrophilic addition with Br_2 or Cl_2 (halogens), and would react with aqueous Br_2 in a similar manner.

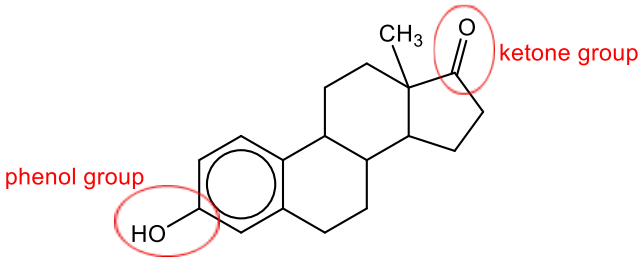
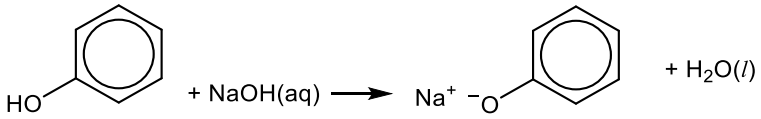
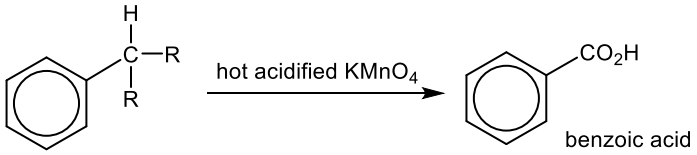
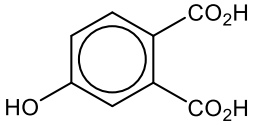


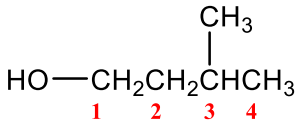
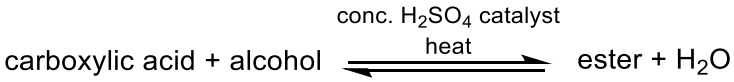
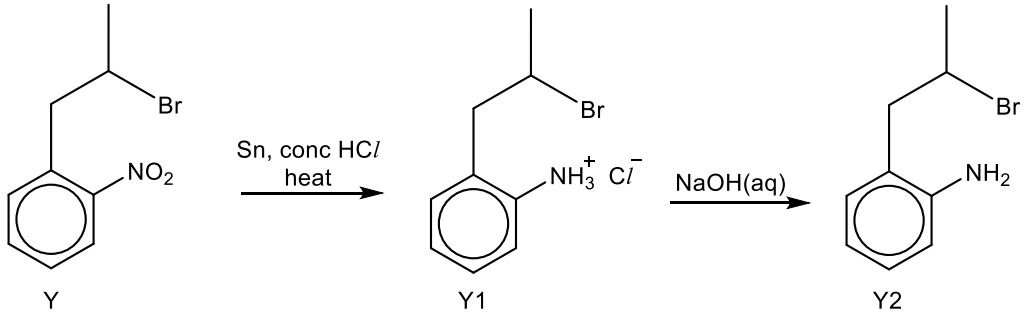
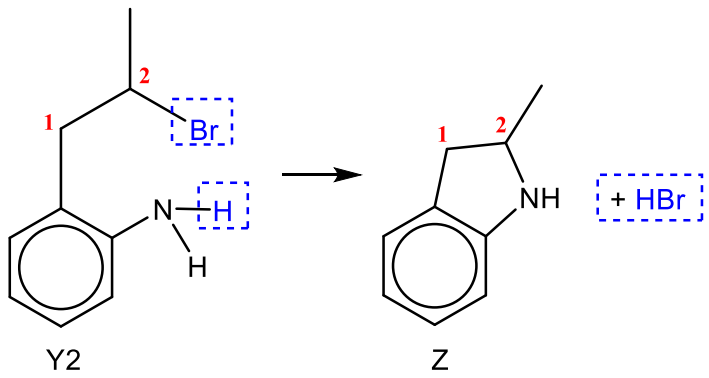
Major product contains one secondary alcohol and two tertiary alcohol functional groups.

D Hot ethanolic sodium hydroxide causes an elimination reaction, in which a halogenoalkane loses HX to form an alkene. Some possible products (which doesn't match the question context):



22	**A**	**A**  In the nitration step, $-CH_3$ directs $-NO_2$ to the 4-position since $-CH_3$ is 2,4-directing. In the bromination step, both methyl and nitro substituents direct the bromo group to the desired position (i.e. the directing effects mutually reinforce one another). **B**  The methyl and bromo substituents are both 2,4-directing and hence in the nitration step, they direct the nitro group to different positions (i.e. the directing effects do <u>not</u> mutually reinforce one another). Thus, a mixture of products will be formed resulting in very low yield of the desired product. **C**  The nitration step will not produce the desired product as the major product since bromine is 2,4-directing yet we need $-NO_2$ to be directed to the 3-position relative to Br. **D**  The nitro substituent is 3-directing and the bromo substituent is 2,4-directing and hence in the alkylation step, they direct the methyl group to different positions (i.e. the directing effects do <u>not</u> mutually reinforce one another). Thus, a mixture of products will be formed resulting in very low yield of the desired product.
23	**B**	Bromoalkanes and acyl bromides undergo hydrolysis by nucleophilic substitution, in which the C–Br bond breaks heterolytically to release Br^- ions. (Bromoarenes do not hydrolyse because the C–Br bond is strengthened by delocalisation of lone pair on Br into the benzene ring.) The Br^- ions formed can be identified by silver nitrate, which produces a cream precipitate of AgBr. K does not give any ppt, L gives 0.2 mol of ppt and M gives 0.3 mol of ppt.

24	**D**	V W X all react with Na to give H_2 ⇒ V W X contain alcohol &/or carboxylic acid &/or phenol group. ∴ A is **incorrect** ∵ the 2nd compound doesn't give such a reaction. Only 1 of V W X reacts with Fehling's reagent. ∴ only one of them has aliphatic aldehyde group (i.e. an aldehyde but not benzaldehyde). B is **incorrect** ∵ the 2nd and 3rd compounds have aliphatic aldehyde groups. C is **incorrect** ∵ the 1st and 3rd compounds have aliphatic aldehyde groups. D is **correct**, only the 2nd compound has aliphatic aldehyde group.
25	**D**	The compound (oestrone) has a ketone group and a phenol group.  A is **correct**. The ketone group gives orange ppt with 2,4-DNPH. B is **correct**. The phenol group gives an (ionic) salt with aq. NaOH, reaction illustrated below using phenol.  C is **correct**. Compounds with the following structure (e.g. methylbenzene) react with hot acidified $KMnO_4$ to give benzoic acid (side-chain oxidation for alkylbenzenes).  For oestrone (study its "side-chain" carefully), it indeed gives a dicarboxylic acid:  D is **incorrect**. Only alcohols and carboxylic acids give white (HC*l*) fumes with PCl_5.

26	**C**	This question asks about making the ester, 3-methylbutyl ethanoate. The "3-methylbutyl" part of this ester (look at the first part of its name) is derived from the alcohol: 3-methylbutan-1-ol:  To make an ester of an alcohol, there are two methods:   The "ethanoate" part of this ester (look at the last part of its name) is derived from ethanoic acid, CH_3CO_2H, or ethanoyl chloride, CH_3COCl. ∴ A and B are **incorrect**. Between C vs. D, C has the correct alcohol. (The alcohol in D is 2-methylbutan-1-ol.)
27	**A**	The reaction described in the question should give compound Y2.  However, for the four given options, one H "disappeared" from the NH_2 group (in Y2), Br also "disappeared", and a new ring is formed. We therefore deduce that the NH_2 and Br (in Y2) must have reacted together (while the mixture is still hot). We then deduce that this bromoalkane group (in Y2) has undergone nucleophilic substitution with the NH_2 group (in Y2) to give compound Z —— similar to the reaction between a halogenoalkane and NH_3. 

28 **B**

A Statement is **in**correct. Melting point of group 2 elements generally **de**creases down the group as less energy is required to overcome weaker metallic bonding between metal cations and sea of delocalised electrons. While the number of valence electrons contributed per metal atom remains as 2 and the charge of each metal cation remains as +2, the ionic radius increases down group 2 hence charge density of cation decreases resulting in weaker metallic bonding.

B Statement is correct. Down group 2 from Mg to Ba, reduction potential becomes more negative, increases tendency for group 2 elements to be oxidised, reducing power of group 2 elements increases as group 2 elements have higher tendency to reduce others when themselves undergo oxidation. From Data Booklet:

	$E^{\ominus}$ / V
$Mg^{2+} + 2e^- \rightleftharpoons Mg$	−2.38
$Ca^{2+} + 2e^- \rightleftharpoons Ca$	−2.87
$Ba^{2+} + 2e^- \rightleftharpoons Ba$	−2.90

C Statement is **in**correct. Volatility of group 17 elements **de**creases (becomes less volatile) down the group as more energy is needed to overcome stronger dispersion forces between halogen molecules as size of electron cloud increases.

D Statement is **in**correct. Down group 17 from F_2 to I_2, reduction potential becomes less positive, decreases tendency for group 17 elements to be reduced, oxidising power of group 17 elements **de**creases as group 17 elements have lower tendency to oxidise others when themselves undergo reduction. From Data Booklet:

	$E^{\ominus}$ / V
$F_2 + 2e^- \rightleftharpoons 2F^-$	+2.87
$Cl_2 + 2e^- \rightleftharpoons 2Cl^-$	+1.36
$Br_2 + 2e^- \rightleftharpoons 2Br^-$	+1.07
$I_2 + 2e^- \rightleftharpoons 2I^-$	+0.54

29 **C**

Students are expected to know that the density of vanadium is higher that of calcium. Density is defined as mass per unit volume. Both metals are in the same period.

1 Statement is correct. Vanadium (50.9) has a higher relative atomic mass than calcium (40.1), with heavier atoms per unit volume, the density of vanadium is higher.

2 Statement is **in**correct. A stronger shielding effect would result in weaker effective nuclear charge and larger atomic radius. Vanadium has a smaller atomic radius and a higher relative atomic mass compared to calcium which enables more and heavier atoms per unit volume. Hence, the density of vanadium is higher that of calcium.

3 Statement is correct. Vanadium (0.135 nm) has a smaller atomic radius compared to calcium (0.197 nm) because the outer shell electrons of vanadium experience greater attraction to the nucleus. The smaller atomic radius enables more efficient close packing of vanadium atoms, resulting in a greater number of atoms per unit volume. Hence, the density of vanadium is higher that of calcium.

30 **B**

In reactant platinum(IV) chloride and the product platinum(IV) compound, each platinum has an oxidation number of +4.

Since the central platinum ion in X^{2+} has an oxidation state of +4, there must be two Cl^- ions acting as ligands, so that the overall charge on the complex cation can be +2. The other four ligands, to make up the co-ordination number of 6, must therefore be ammonia that has no charge. Hence complex cation X^{2+} is $[Pt(NH_3)_4Cl_2]^{2+}$, containing a total of 4 ammonia molecules as ligands.