30th International Chemistry Olympiad

Melbourne, Thursday July 9, 1998

Theoretical Examination

Example Answers and Marking Scheme

Official Version

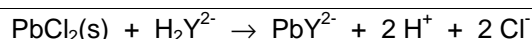## Problem 1   20 points

1-1. What is the lead compound that precipitates in Step 2?

PbCl$_2$ or any hydroxo species etc.

1 mark

1-2. Write a balanced ionic equation that explains the disappearance of the lead compound that precipitated in Step 3 (at pH 6).

PbCl$_2$(s) + H$_2$Y^{2-} → PbY^{2-} + 2 H$^+$ + 2 Cl$^-$ or similar

-1/2 mark for H$_4$Y or Y^{4-}

1 mark

1-3. What is the purpose of the hexamine in Step 5 of this analysis? Tick one.

|	
	It complexes the tin
3	It forms a pH buffer
	It reacts with oxides of nitrogen and chlorine
	It is a pH indicator

1 mark

1-4. What is the purpose of the Xylenol Orange in this analysis? Tick one.

|	
	It complexes the tin
	It acts as a pH buffer
3	It is a metallochromic indicator
	It is a pH indicator

1 mark

1-5. Write balanced ionic equations for the reactions that occur (i) during the titration and (ii) are responsible for the colour change at the endpoint in Step 6 of the analysis.

The standard lead solution is used to complex the excess EDTA from step 5. Some of the EDTA is already tied up as stable SnY and PbY^{2-} complexes. These species are not involved in the titration here. EDTA is mainly H$_2$Y^{2-} at pH 6, so in the following equations, H$_2$Y^{2-} must be used.

Pb^{2+} + H$_2$Y^{2-} → PbY^{2-} + 2 H$^+$ or similar
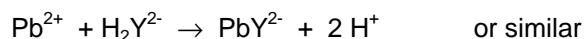
At the endpoint, a slight excess of Pb^{2+} forms a red complex with the xylenol orange indicator

Pb^{2+} + XO (yellow) → PbXO^{2+} (red) or similar
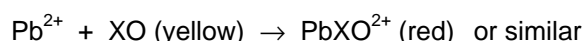
The titre here allows the calculation of excess EDTA, and therefore the total amounts of Sn+Pb to be determined.

2 marks

1-6. What is the role of the NaF in Step 7 of the analysis? Tick one.

3	It complexes the tin

	It acts as a pH buffer
	It complexes the lead
	It reacts with the Xylenol Orange

1 mark

1-7. Write a balanced ionic equation for the reaction that occurs in Step 7.

> From the graph of log K_{MY} vs pH, it can be seen that the fluoride forms a stable complex with Sn^{4+} but not with Pb^{2+} at pH 6, displacing EDTA:
>
> $SnY + n F^- + 2 H^+ \rightarrow SnF_n^{(n-4)-} + H_2Y^{2-}$ where n is typically 4-6.
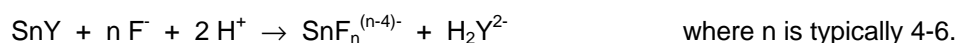
1 mark

1-8. Write a balanced ionic equation that explains why the colour changed from red to yellow in Step 7 of this analysis.

> The released EDTA destroys the small amount of red PbXO complex, producing free (yellow) XO. (Charge on XO ignored)
>
> $H_2Y^{2-} + PbXO^{2+} \rightarrow PbY^{2-} + XO \text{ (yellow)} + 2 H^+$ or similar

1 mark

1-9. Write a balanced ionic equation that explains why the lines on the graph of log K'_{MY} *vs* pH for Pb+EDTA and Pb+EDTA+F^- are coincident below pH 2.

> Below pH 2, F^- is protonated and does not compete effectively with Y for Pb^{2+}
>
> $H^+ + F^- \rightarrow HF$ or something similar.
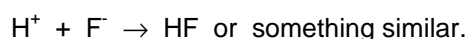
1 mark

1-10. Calculate the percentage by mass of Sn and Pb in the alloy.

> From step 6, calculate the amount of EDTA in excess from the amount of standard Pb^{2+} titrant: n(xs EDTA) = n(std. Pb^{2+})
>
> = (24.05 mL)(0.009970 mol/L)/ (1000 mL/L) = 2.398 x 10^{-4} mol
>
> Next, calculate the original amount of EDTA present in a 25.00 mL aliquot of the solution of dissolved alloy, n(init. EDTA)
> = (25.00 mL /250.0 mL)(25.00 mL)(0.2000 mol/L)/1000 mL/L = 5.000 x 10^{-4} mol
>
> Now calculate how much EDTA was consumed by the Pb^{2+} and Sn^{4+} in a 25 mL aliquot of the solution of dissolved alloy:
>
> n(EDTA consumed) = 5.000 x 10^{-4} - 2.398 x 10^{-4} mol
> = 2.602 x 10^{-4} mol   = n($Pb^{2+} + Sn^{4+}$) in a 25 mL aliquot
>
> From the titre in step 7, we calculate the amount of EDTA that is released from SnY by reaction with fluoride. (The fluoride is in large excess: 2.0 g NaF = 0.048 mol F^- or 0.3 M in the 160 mL solution)
> n(released EDTA) = n(std. Pb^{2+})
> = (15.00 mL)(0.009970 mol/L)/ (1000 mL/L)   = 1.496 x 10^{-4} mol
> = n(Sn^{4+}) in the 25 mL aliquot, so
> n(Pb^{2+}) in a 25 mL aliquot = (2.602 x 10^{-4} - 1.496 x 10^{-4}) mol = 1.106 x 10^{-4} mol
> So in the original 0.4062 g sample of alloy:
> m(Sn) = (250 mL/25.00 mL)(1.496 x 10^{-4} mol)(118.69 g/mol) = 0.1776 g and
> m(Pb) = (250 mL/25.00 mL)(1.106 x 10^{-4} mol)(207.19 g/mol) = 0.2292 g
>   -1/2 if sum of these masses used instead of sample mass
> The percentages of tin and lead:
> Sn: 100 x (0.1776/0.4062) = **43.7$_2$** % and Pb: 100 x (0.2292/0.4062) = **56.4$_2$** %

> Note the sum comes to 100.14% because of uncertainties in the titres. It is not correct to say %Sn = 100- %Pb or vice versa because there might have been other elements present in the alloy.
>
> -2 marks if only one metal calc and other calc. by difference from 100%
>
> -4 if only 1 calc.
>
> -1 for abuse of sig figs.

10 marks

Problem 2   20 points

2-1. In what year did Nathan Thompson plant the seeds?

Calculations:

Over a depth of 50 cm the apparent decay of Pb-210 was equal
to 356 - 178 - 89 - 44.5 - 22.5 - 11.25 - 5.63 - 2.81 - 1.39 = 8 half-lives

= 8 x 22 years = 176 years

2 marks

If 1995 was the year of coring then year of arrival was

1995 - 176 = 1819 (± 2)

1 mark

3 marks

2-2. Which step in the decay scheme explains how Pb-210 ends up in rainwater while its parent U-238 is only present in the earth's crust?

	U-238 – U-234
	U-234 – Th-230
	Th-230 – Ra-226
3	Ra-226 – Rn-222

1 mark

2-3. Use the distribution coefficients **D** given in Figures 1 and 2 and rank the following solvent systems for isolating Cu-64 and Co-55 by writing the numbers 1 to 4 in the boxes (1 is best).

	A	0.2 M HCl 96% methanol	to remove Ni-57 followed by
		2.0 M HCl 55% isopropyl alcohol	to remove Cu-64 followed by
		1.0 M HCl 55% isopropyl alcohol	to remove Co-55

	B	0.2 M HCl 96% methanol	to remove Ni-57 followed by
		2.0 M HCl 55% isopropyl alcohol	to remove Co-55 followed by
		1.0 M HCl 55% isopropyl alcohol	to remove Cu-64

	C	2.0 M HCl 55% isopropyl alcohol	to remove Co-55 followed by
		1.0 M HCl 55% isopropyl alcohol	to remove Cu-64

	D	0.2 M HCl 96% methanol	to remove Ni-57 followed by
		3.0 M HCl 55% isopropyl alcohol	to remove Co-55 followed by
		4.0 M HCl 55% isopropyl alcohol	to remove Cu-64

3 marks

A	B	C	D	Marks
4	1	2	3	3
3	1	2	4	2.5

4	2	1	3	2
3	2	1	4	1.5
All other combinations				0

2-4.   Having isolated relevant radionuclides, the presence of some long-lived radionuclides could interfere with medical use of Cu-64 or Co-55 or Ga-67. Indicate whether each of the following statements is true or false.

	True	False
Ni-57 may be present as a contaminant of Co-55.		3
Co-57 will interfere with the medical use of Co-55.	3	
Cu-67 will interfere with the medical use of Cu-64.	3	
Ga-66 will interfere with the medical use of Ga-67.		3
Ga-67 will interfere with the medical use of Cu-64.		3

5 marks

2-5.   If radionuclide contamination of Cu-64 or Co-55 or Ga-67 occurred which method would reduce the amount of radionuclide contaminant/s? Indicate whether each of the following statements is true or false.

	True	False
Remove Ni-57 before isolating Co-55.	3	
Separate the Ni-57 from the bombarded target material before isolating the Ga-67.	3	
Separate the radionuclides closer to the end of bombardment.	3	
Allow the Ni-57 to decay before isolating Co-55.		3

4 marks

2-6.   If zinc of natural isotopic abundance, instead of enriched Zn-68, was bombarded with high energy protons, indicate whether each of the following statements is true or false.

	True	False
Ga-67 would be produced at five fold higher yields.		3
Ga-67 would be produced at five fold lower yields	3	
Ga-67 would be produced at lower yields and contamination by Cu-64, Co-55, Co-57 and Ni-57 would increase.		3

Ga-67 would be produced at lower yields and contamination by Cu-64, Co-55, Co-57 and Ni-57 would remain the same.	3	

4 marks

Problem 3 **20 points**

3-1. What are the ∠(CCC) angles for each of these rings?

	polygon ∠(CCC) angle (degrees)
Dodecahedrane	108
Ovalene	120

2 marks

3-2. Which configuration do the above ∠(CCC) angles most closely match?

	Trigonal planar	Tetrahedral	Octahedral
Dodecahedrane		4	
Ovalene	4		

The ∠(CCC) angle for dodecahedrane is only slightly lower than the tetrahedral angle, but is much higher than the 90° required for octahedral coordination and is obviously too low for a trigonal planar arrangement. The corresponding angle for ovalene is identical to that for trigonal planar.

2 marks

3-3. What is the hybridization which most closely conforms to the geometric structure of these molecules?

	sp	sp^2	sp^3
Dodecahedrane			4
Ovalene		4	

As above, dodecahedrane conforms quite closely to a tetrahedral arrangement at each C atom, thus sp^3. Ovalene corresponds exactly to a trigonal planar arrangement, so sp^2.

2 marks

3-4. What is the value of the angle shown below for dodecahedrane (to the nearest 3 degrees), and for ovalene?
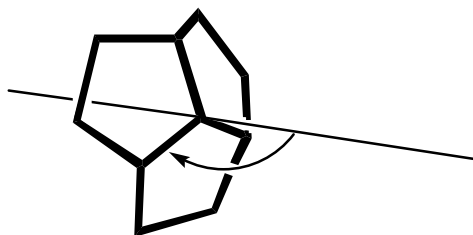
| dodecahedrane, $C_{20}H_{20}$ | 109-115 | degrees |
| ovalene, $C_{32}H_{14}$ | 90 | degrees |

For dodecahedrane, the three rings are not coplanar. Determination of the exact axis angle is complicated; but note that the $\angle$(CCC) angle for a C_5 ring is very close to the tetrahedral angle. Therefore distortion from a tetrahedral configuration at each carbon in dodecahedrane is slight: therefore the axis angle is about 109.5° (more probably ~112°). For ovalene, all rings are coplanar. The axis angle is clearly 90°.

2 marks

3-5. Which juncture is planar?

| | dodecahedrane, $C_{20}H_{20}$ |
| 3 | ovalene, $C_{32}H_{14}$ |

1 mark

3-6. For which C=C pair is H_2 addition <u>more</u> exothermic ?

| dodecahedrene | 3 |
| ovalene | |

1 mark

The C=C pair within the dodecahedrene skeleton is more suited to sp^3-hybridization than sp^2-hybridization: this favours dihydrogenation to yield dodecahedrane. For ovalene, sp^3-hybridization is disfavoured relative to sp^2-hybridization, so dihydrogenation at the indicated site is disfavoured on the grounds of angle strain. (This is quite apart from any reduction in ovalene's aromaticity, which is also likely to disfavour hydrogenation!)

3-7. For which of C_{60}, dodecahedrene, or ovalene is H_2 addition <u>most</u> exothermic?

C_{60}	
dodecahedrene	3
ovalene	

1 mark

The deviation from planarity, in a C_{60} juncture, is less than in dodecahedrene (which has very close to tetrahedral, ie sp^3, coordination at each carbon) but is clearly more than in ovalene (which is flat, i.e. ideal for sp^2 hybridization). Thus C_{60} is intermediate between dodecahedrene and ovalene in its preference for hydrogenated versus dehydrogenated structures. The junctures in dodecahedrene are all pentagons $[C_5,C_5,C_5]$. The junctures in

ovalene are all $[C_6, C_6, C_6]$. Those in C_{60} are $[C_5, C_6, C_6]$. The implication is that, the more pentagons are found in a juncture, the greater the deviation from planarity and hence the greater the relative stability of sp^3 hybridization, rather than sp^2, at the central carbon atom.]

3-8.   For which of C_{60}, dodecahedrene, or ovalene is H_2 addition <u>least</u> exothermic?

C_{60}	
dodecahedrene	
ovalene	3

1 mark

3-9.   Which juncture has the <u>least</u> deviation from planarity ?

A? [ ]   or **B**? [3]   or **C**? [ ]

1 mark

3-10. Which juncture has the <u>greatest</u> deviation from planarity ?

A? [ ]   or **B**? [ ]   or **C**? [3]

1 mark

> The juncture centred on atom '**A**' features two hexagons and a pentagon: this is the same pattern as that seen in the C_{60} junctures. For '**B**', the three surrounding rings are all hexagons, while for '**C**', the juncture contains two pentagons and a hexagon. The trend for increasing deviation from planarity with increasing number of pentagons in the juncture, indicates that the deviation from planarity will be most severe at '**C**', and least severe at '**B**'.

3-11. Of the above carbon-carbon bonds, numbered from 1 to 9, which represents the <u>most</u> favourable site for H_2 addition?

Bond number: [**9**]

2 marks

> Bonds 1, 2, 7, and 8 are each flanked by a pentagon and a hexagon. Bonds 3-6 are each 'sandwiched' between two hexagons. Bond 9 is between two adjacent pentagons. Of these configurations, bond 9 represents the geometry which is most distorted from planarity (preferred by sp^2 hybridization) and is closest to the dodecahedrane skeleton (for which the bond angles are almost ideal for sp^3 hybridization). Thus, bond 9 is the most favourable site for dihydrogenation.

3-12. Which has the larger average deviation from planarity at each juncture?

C_{60} ? [3]   or C_{180} ? [ ]

1 mark

> C_{180} obviously has a larger diameter than C_{60}, so its average deviation from planarity at a given juncture is less than that found for C_{60}. [To visualize this, it may help to note that the 'equator' of C_{180} will be defined by more atoms than are found along C_{60}'s 'equator'.]

3-13. Which of the following statements is correct, for $\Delta H°_f$ values in kJ g^{-1} units?

	$\Delta H°_f(C_{60}) < \Delta H°_f(C_{180}) < \Delta H°_f(\text{graphite})$
3	$\Delta H°_f(C_{60}) > \Delta H°_f(C_{180}) > \Delta H°_f(\text{graphite})$
	$\Delta H°_f(C_{60}) = \Delta H°_f(C_{180}) < \Delta H°_f(\text{graphite})$
	$\Delta H°_f(C_{60}) = \Delta H°_f(C_{180}) = \Delta H°_f(\text{graphite})$
	$\Delta H°_f(C_{60}) = \Delta H°_f(C_{180}) > \Delta H°_f(\text{graphite})$
	$\Delta H°_f(C_{180}) > \Delta H°_f(C_{60}) > \Delta H°_f(\text{graphite})$

2 marks

C_{60} has a larger average deviation from planarity than C_{180}, so sp^2 hybrization is less favourable for the smaller fullerene. However, both fullerenes are non-planar and therefore less amenable to sp^2 hybridization than graphite (which additionally gets stabilization from inter-layer electronic effects, although this last point does not have to be considered to attain the correct answer).

3-14. Which of graphs **a** to **e** best represents the dependence of potential energy upon reaction progress for the two processes:

$$\text{reactants} \quad \leftrightarrow \quad 3C_{60}$$

and

$$\text{reactants} \quad \leftrightarrow \quad C_{180}$$

a).

b).

c).

d).

e).
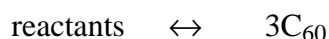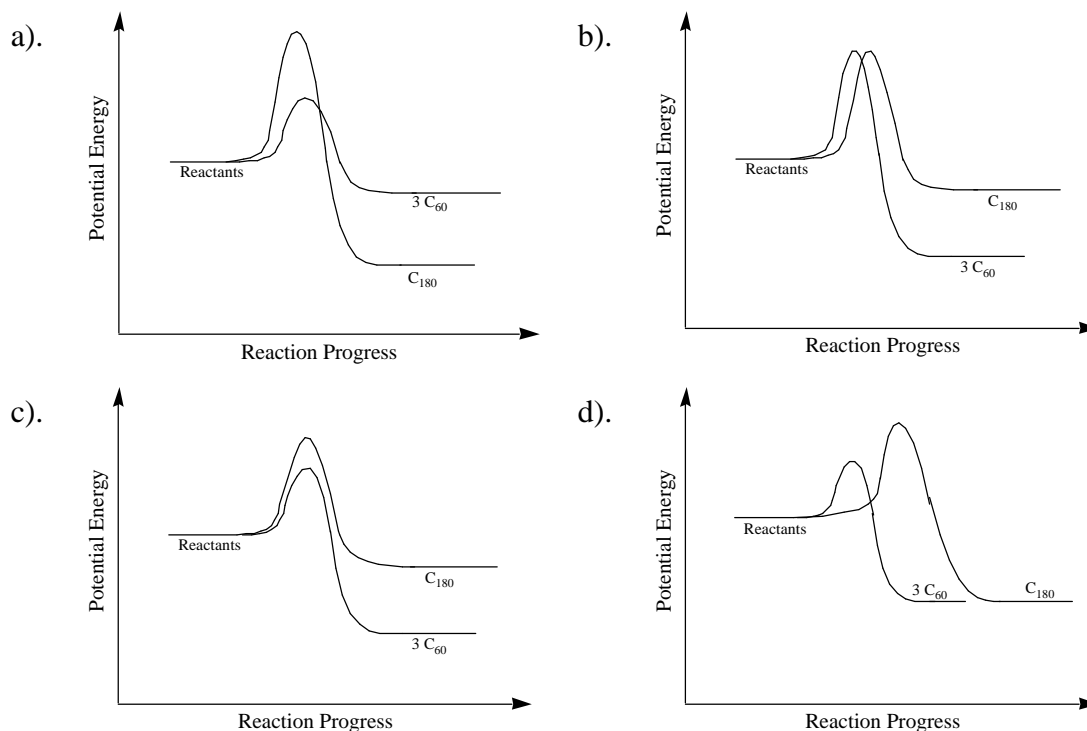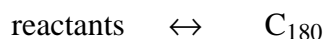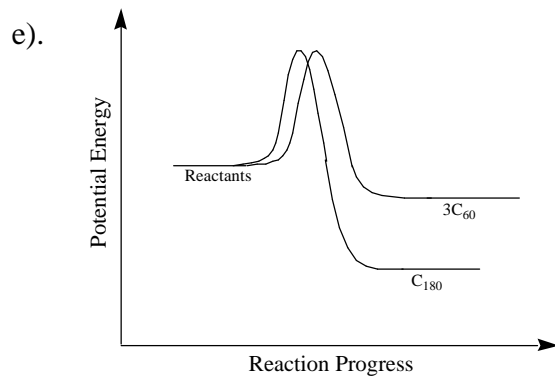
The best graph is: | **a)** |

| The equilibrium reaction |
| C_{180} ↔ reactants ↔ $3C_{60}$ |
| is characterized by a large positive energy change in going from left to middle, and a negative energy change of smaller magnitude in going from middle to right. Formation of C_{180} is thermodynamically favoured over three C_{60} molecules. However, C_{60} is found to predominate, implying that the reaction is under kinetic control and does not have sufficient time to reach equilibrium. |
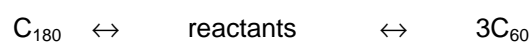
1 mark

Problem 4   **15 points**

4-1. On the next page of the answer sheet, construct the molecular orbitals arising from the separate interaction of the 2s, $2p_x$, $2p_y$, and $2p_z$ atomic orbitals and fill them in under the column labelled 'Molecular orbitals'. Remember to form the symmetric and anti-symmetric combinations of O_a and O_c first.

> 1 mark for each correct orbital, 0 otherwise.

9 marks

4-2. Why does the energy of the $6a_1$ orbital increase so rapidly as the bond angle changes from 90° to 180° ? (Choose one)

a)		Because the bonding character decreases	1 mark
b)		Because the anti-bonding character increases	1 mark
c)	3	Both (a) and (b)	2 marks
d)		Because the overlap decreases	0 marks

> The correct answer is c). The energy changes so rapidly because the overlap is bonding between all three atoms in the bent molecule, but becomes more and more anti-bonding as the molecule approaches linearity:
>
>
>
> linear molecule

2 marks

4-3. With reference to the Walsh diagram attached, write the symmetry label for the highest occupied orbital for each of the molecules BO_2, CO_2, NO_2 and FO_2, at a bond angle of 135°.

O_3	BO_2	CO_2	NO_2	FO_2
$6a_1$ (24e-)	$4b_2$ (21e-)	$4b_2$ (22e-)	$6a_1$ (23e-)	$2b_1$ (25e-)

> 0.5 marks for each correct label, 0 otherwise.

2 marks

4-4. Which of the following statements is predicted to be <u>true</u>? (Choose one)

a)		NO_2 is more bent than O_3, and FO_2 is more bent than O_3	1 mark
b)		NO_2 is more bent than O_3, and FO_2 is less bent than O_3	0 marks
c)		NO_2 is less bent than O_3, and FO_2 is less bent than O_3	1 mark
d)	3	NO_2 is less bent than O_3, and FO_2 is more bent than O_3	2 marks

> The correct answer is d). NO_2 is *less* bent than O_3
> NO_2 has 23 e⁻, one less than O_3, (24 e⁻) => $6a_1$ is singly occupied
>   => bending is less strong than in O_3 (experimental bond angle is actually 134°)
> FO_2 is *more* bent than O_3
> FO_2 has 25 e⁻ , one more than O_3, => $2b_1$ is singly occupied

=> this would favour smaller bond angle, but it is offset by a rise in energy of the $4b_2$ and $1a_2$ orbitals => predict slightly smaller bond angle, but not much change from O_3

2 marks

Atomic orbitals   Molecular orbitals   Marks

2p$_z$

2p$_y$

2p$_x$

2s

1s

z

x   y
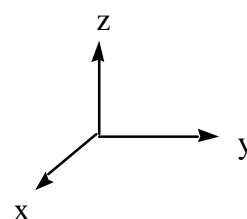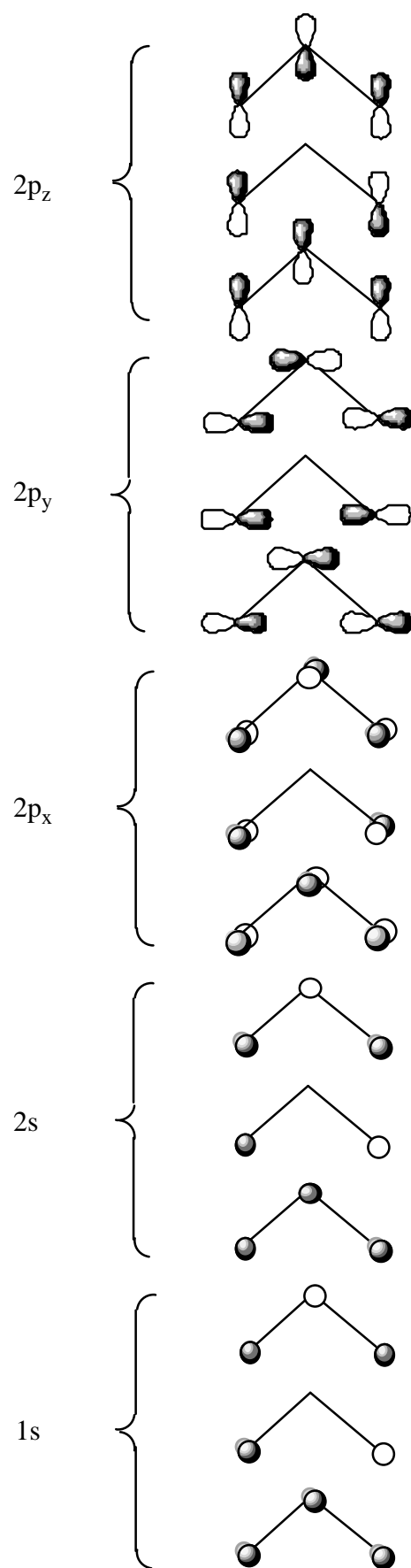
Problem 5   **15 points**

5-1. Write balanced ionic equations for the two reactions.

reaction 1:

$4Au + 8CN^- + O_2 + 2H_2O \rightarrow 4[Au(CN)_2]^- + 4OH^-$ 1.5 marks

reaction 2:

$Zn + 2[Au(CN)_2]^- \rightarrow [Zn(CN)_4]^{2-} + 2Au$ 1.5 marks
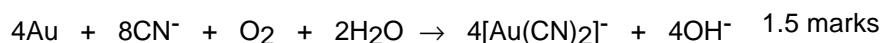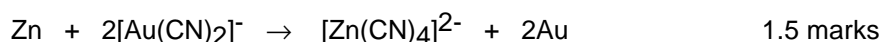
3 marks

5-2. Five hundred litres (500 L) of a solution 0.0100 M in $[Au(CN)_2]^-$ and 0.0030 M in $[Ag(CN)_2]^-$ was evaporated to one third of the original volume and was treated with zinc (40 g). Assuming that deviation from standard conditions is unimportant in this case and that all these redox reactions go essentially to completion, calculate the concentrations of $[Au(CN)_2]^-$ and of $[Ag(CN)_2]^-$ after reaction has ceased.

$E^\circ_{Ag/Zn} = -0.31 - (-1.26) = 0.95$ V

$E^\circ_{Au/Zn} = -0.60 - (-1.26) = 0.66$ V

$E^\circ_{Ag/Zn} > E^\circ_{Au/Zn}$ Therefore the Ag(I) complex will be reduced first.

(i)   mol Ag(I) in 500 L = 500 x 0.0030 = 1.5 mol
(ii)   mol Au(I) in 500 L = 500 x 0.010 = 5.0 mol
(iii) mol Zn in 40 g   = 40 / 65.38   = 0.61 mol

1 mol zinc reacts with 2 mol of Ag(I) or Au(I)

Therefore 0.61 mol Zn will consume 1.2 mol $[Ag(CN)_2]^-$

$[Ag(CN)_2]^-$ remaining = 1.5 - 1.2 = 0.3 mol

$[Au(CN)_2]^-$ will not be reduced.

Concentration of $[Au(CN)_2]^-$ when reaction has ceased = 0.010 x 3 = 0.030 M

Concentration of $[Ag(CN)_2]^-$ when reaction has ceased = 0.3 x 3/500 = 0.002 M

$[Au(CN)_2]^- =$ **0.030 M**   **$[Ag(CN)_2]^- =$**   **0.002 M**

5 marks

$[Zn(CN)_4]^{2-} + 2e- \rightarrow Zn + 4CN^-$ $E^\circ = -1.26$ V

$[Au(CN)_2]^- + e- \rightarrow Au + 2CN^-$ $E^\circ = -0.60$ V

$[Ag(CN)_2]^- + e- \rightarrow Ag + 2CN^- \qquad E° = -0.31 \text{ V}$

$[Ag(CN)_2]^- + e- \rightarrow Ag + 2CN^- \qquad E° = -0.31 \text{ V}$
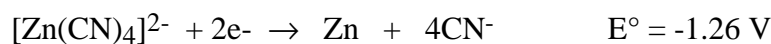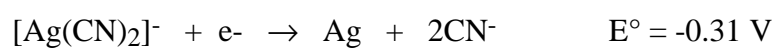
5-3. $[Au(CN)_2]^-$ is a very stable complex under certain conditions. What concentration of cyanide ion is required to keep 99 mol% of the gold in solution in the form of the cyanide complex ? $\{[Au(CN)_2]^- : K_f = 4 \times 10^{28}\}$

$$Au^+ + 2CN^- \rightleftharpoons [Au(CN)_2]^- \quad K_f = 4 \times 10^{28}$$
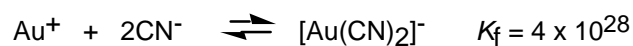
99 mol% $[Au(CN)_2]^-$ $\quad K_f = [Au(CN)_2^-] / \{[Au^+] [CN^-]^2 \}$

$[Au(CN)_2^-] / \{[Au^+] + [Au(CN)_2^-]\} = 99/100$

so $100[Au(CN)_2^-] = 99[Au^+] + 99[Au(CN)_2^-]$

therefore $[Au^+] = [Au(CN)_2^-] / 99$

Substituting into K_f:

$4 \times 10^{28} = 99 / [CN^-]^2 \quad\quad [CN^-] = 5 \times 10^{-14}$ M

6 marks

5-4. There have been several efforts to develop alternative gold extraction processes which could replace this one. This is because:

	sodium cyanide solutions corrode mining machinery
3	sodium cyanide escapes into ground water and produces hydrogen cyanide which is toxic to many animals.
	gold obtained by this process is not pure.

1 mark

Problem 6   **20 points**

6-1.   Draw two alternative structures showing possible geometries for $SnCl_4$
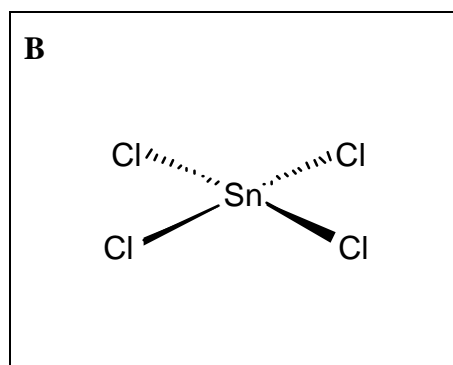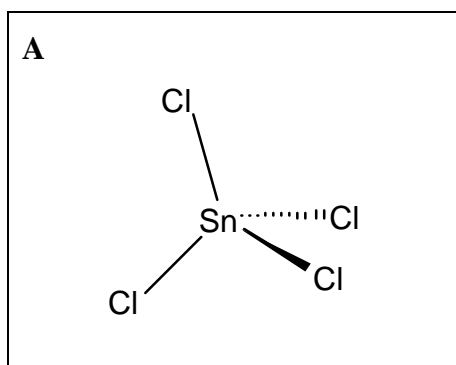
1 mark

6-2.   Draw three alternative structures showing possible geometries for $SnCl_5^-$.
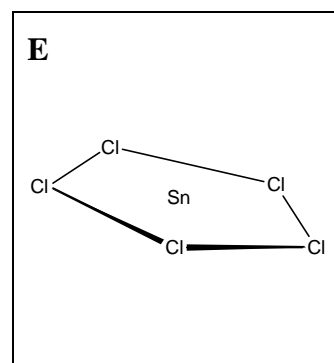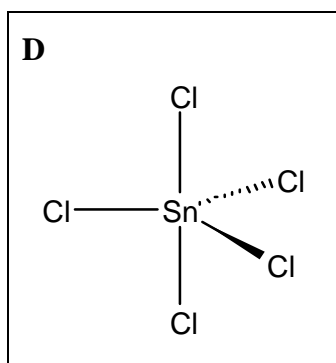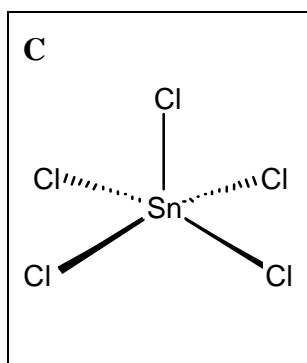
1.5 marks

6-3.   Use Valence Shell Electron Pair Repulsion (VSEPR) theory to predict which of geometries **C**, **D**, or **E** is likely to be preferred for $SnCl_5^-$.

C? [   ]   or **D?** [3   ]   or **E?** [   ]

0.5 marks

6-4.   Draw three alternative possible geometries for $SnCl_6^{2-}$.

Cl, Cl, Cl, Sn, Cl, Cl, Cl (octahedral drawing)	Cl, Cl, Cl, Sn, Cl, Cl, Cl (planar drawing)	(blank)
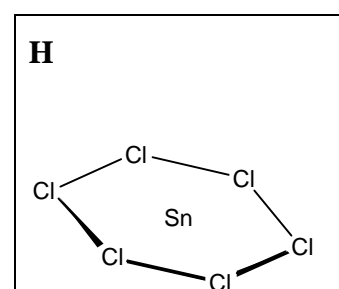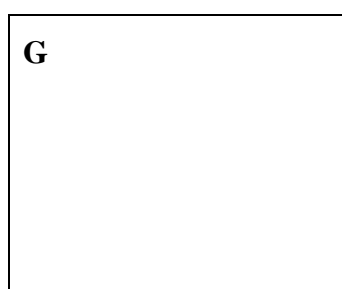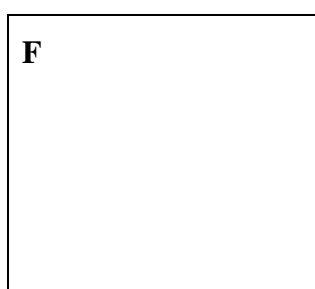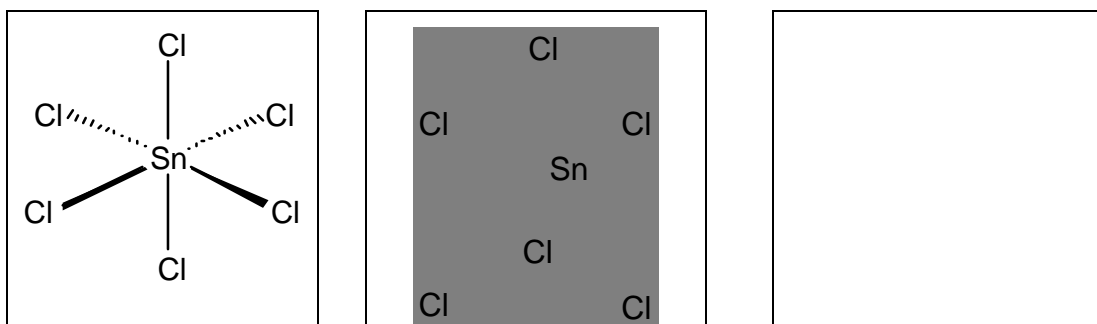
1.5 marks

6-5. Use Valence Shell Electron Pair Repulsion (VSEPR) theory to predict which geometry of **F**, **G** and **H** is likely to be preferred for $SnCl_6^{2-}$

F? 3   or **G**?   or **H**?

0.5 marks

6-6. Write the empirical formula for the tin-containing species in a solution containing $SnCl_6^{2-}$ (as the tetrabutylammonium salt) detected by negative ion ESMS.

$SnCl_5^-$
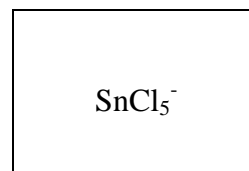
1 mark

6-7. Write the empirical formula for the tin-containing species in a solution containing $SnBr_6^{2-}$ (as the tetrabutylammonium salt) detected by negative ion ESMS.

$SnBr_5^-$
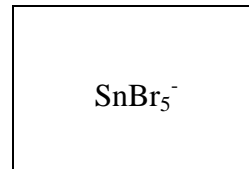
1 mark

6-8. Write the empirical formula for each of the four new species.

m/z=339

$SnCl_4Br^-$

m/z=383

$SnCl_3Br_2^-$

m/z=427

$SnCl_2Br_3^-$

m/z=471

$SnClBr_4^-$
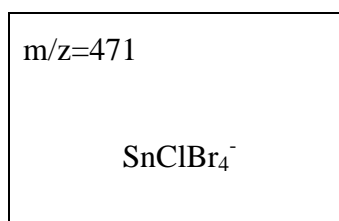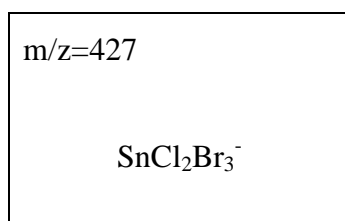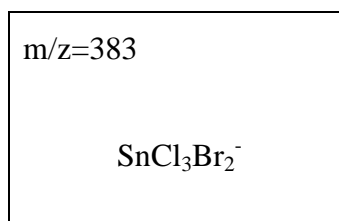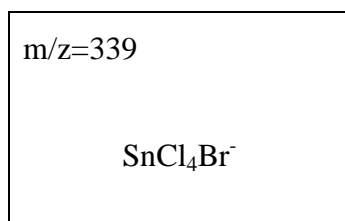
4 marks

6-9. Write the empirical formula for the tin-containing species in this mixture that give rise to the peaks listed below:

-912 ppm	-1117 ppm
$SnCl_5Br^{2-}$	$SnCl_4Br_2^{2-}$
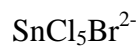
-1322 ppm	-1554 ppm	-1800 ppm
$SnCl_3Br_3^{2-}$	$SnCl_2Br_4^{2-}$	$SnClBr_5^{2-}$

5 marks

6-10. Draw the geometry for the four tin-containing species present in the solution at -30 °C that give rise to the peaks listed below:

-1092 ppm   and   -1115 ppm (2 compounds)
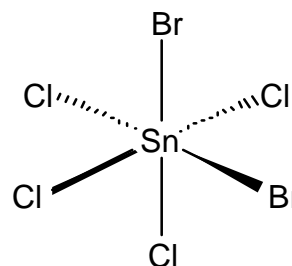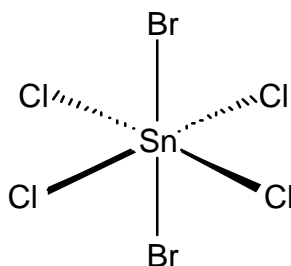
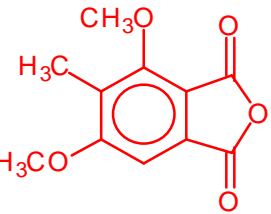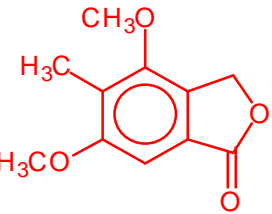-1322 ppm   and   -1336 ppm (2 compounds)
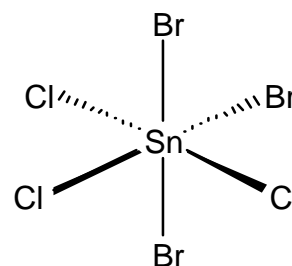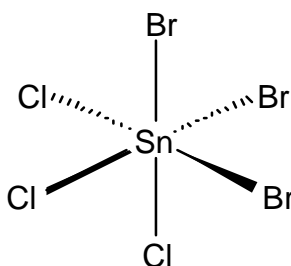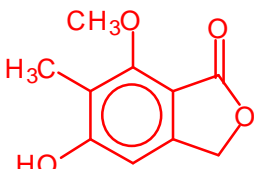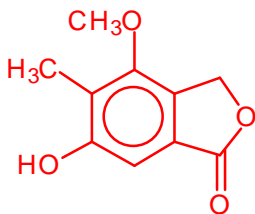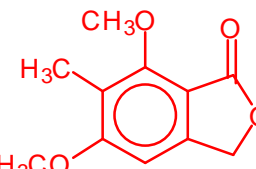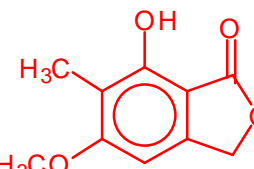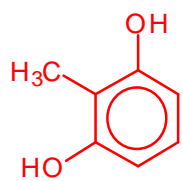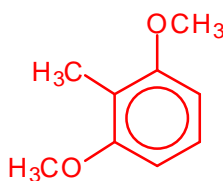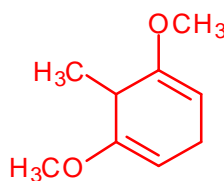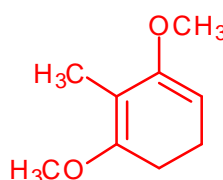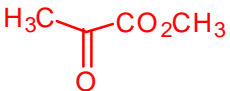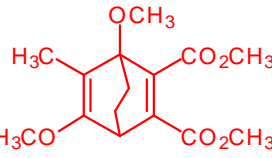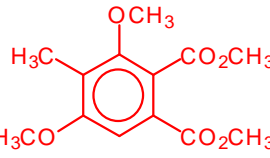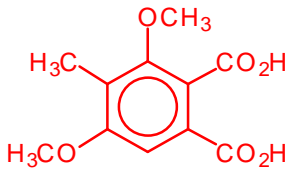
4 marks

Note: The structure/ppm assignments for cis/trans and fac/mer can be reversed without any penalty

Problem 7   **21 points**

7-1.   On the answer template below, fill in the structures of compounds **A** to **O**.

A	**B**	**C**	**D**
E	**F**	**G**	**H**
I	**J**	**K**	**L**
M	**N**	**O**	Other structure for **B**

1.5 marks for each correct structure