Cambridge Chemistry Challenge Lower 6th

June 2018

Marking scheme for teachers

(please also read the additional instructions)

	p2	p3	p4	p5	p6	p7	p8	Total
mark	11	8	10	9	10	10	7	65

Mark

1(a) Percentage by mass of SiO_2 and Al_2O_3 in anorthosite: **[2]**

There is 1 mole of Al_2O_3 and 2 moles of SiO_2 per mole of anorthosite.

Mr $CaAl_2Si_2O_8$ = 40.08 + (2 x 26.98) + (2 x 28.09) + (8 x 16.00) = 278.22

Mr Al_2O_3 = (2 x 26.98) + (3 x 16.00) = 101.96

Mr SiO_2 = (1 x 28.09) + (2 x 16.00) = 60.09

Percentage Al_2O_3 = 101.96 / 278.22 x 100 = 36.6 % ✓

Percentage SiO_2 = (2 x 60.09) / 278.22 x 100 = 43.2% ✓

1(b)

(i) Maximum oxidation state of titanium: **[1]**

+4 or IV ✓

(ii) Formulae of two oxides in ilmenite: **[2]**

TiO_2 and FeO ✓✓

(iii) Equation for reaction between ilmenite and hydrogen: **[1]**

$FeTiO_3\ (s) + H_2\ (g) \longrightarrow Fe\ (s) + TiO_2\ (s) + H_2O\ (g)$ ✓

[Do not penalise lack of state symbols]

(iv) Tonnes of moon rock needed for one tonne of oxygen gas: **[4]**

Number of moles of O_2 (g) in 1 tonne = mass (g) / Mr (O_2)
= 1000000 / 32.00 = 31250 moles ✓

Each mole of ilmentite (and hence Ti) forms one mole of H_2O which on electrolysis gives half a mole of O_2 (g). The rock must contain 2 x 31250 = 62500 moles of Ti ✓

Mass of Ti needed = Number of moles of Ti x Ar (Ti) = 62500 x 47.90 = 2993750 g ✓

Mass of moon rock needed = 2993750 / 2.50 x 100 = 119750000 g
= 120 tonnes (3 sig. fig.) ✓

[Give full marks for a correct answer with no working; –1 for incorrect sig. fig penalise only once for the paper]

1(c) Equation for the reaction between ilmenite and methane: **[1]**

$FeTiO_3\ (s) + CH_4\ (g) \longrightarrow Fe\ (s) + TiO_2\ (s) + CO\ (g) + 2H_2\ (g)$ ✓

[Do not penalise lack of state symbols]

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Mark

1(d)

(i) Equation for regeneration of methane: [1]

$$CO\ (g) + 3H_2\ (g) \longrightarrow CH_4\ (g) + H_2O\ (g)$$

[Do not penalise lack of state symbols]

(ii) The sign of the standard entropy change plus reason: [2]

Negative. The reaction has four moles of gas reacting to form two moles of gas the products therefore have less disorder than the reactants.

(n.b. the sign will still be negative if the students have written water as a liquid).

[Credit should be given where students recognise that gases are more disorderd than other states and are the subject of interest in creating/reducing disortder.]

(iii) Standard enthalpy change at 298 K: [2]

$$\begin{tikzcd}
MgSiO_3\ (s) + 2CH_4\ (g) \arrow[rr] & & Si\ (s) + MgO\ (s) + 2CO\ (g) + 4H_2\ (g) \\
& Mg\ (s) + Si(s) + 2C\ (s) + 4H_2\ (g) + O_2\ (g) \arrow[ul, "\Delta_f H^o\ (MgSiO_3) + 2\Delta_f H^o\ (CH_4)"] \arrow[ur, "\Delta_f H^o\ (MgO) + 2\Delta_f H^o\ (CO)"'] &
\end{tikzcd}$$

$$\Delta_r H^o = 2 \times \Delta_f H^o\ (MgO) + 2\ \Delta_f H^o\ (CO) - (\Delta_f H^o\ (MgSiO_3) + 2\ \Delta_f H^o\ (CH_4)\ )$$
$$= (-601.6) + (2 \times -110.5) - ((-1549) + (2 \times -74.87))$$
$$= 876.1\ \text{kJ mol}^{-1}\ \text{(4 sig. fig.)}$$

(iv) Standard entropy change at 298 K: [1]

$$\Delta_r S^o = S^o(Si) + S^o(MgO) + 2 \times S^o(CO) + 4 \times S^o(H_2) - (\ S^o(MgSiO_3) + 2 \times S^o(CH_4)\ )$$
$$= 18.81 + 26.95 + (2 \times 197.7) + (4 \times 130.7) - (67.76 + (2 \times 188.7))$$
$$= 518.8\ \text{J mol}^{-1}\ \text{K}^{-1}\ \text{(4 sig. fig.)}$$

1(e)

(i) Standard Gibbs energy for the reaction at 298.0 K: [2]

$$\Delta_r G^o = \Delta_r H^o - T\Delta_r S^o = 876.1 - (298.0 \times 518.8 / 1000)$$
$$= 721.5\ \text{kJ mol}^{-1}\ \text{(4 sig. fig.)}$$

The reactants are favoured.

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Mark

1(e)
(ii) Minimum temperature at which products will be favoured: **[3]**

The equation shows that as T increases $\Delta_r G^o$ decreases. The products will be favoured at all temperatures above that at which is $\Delta_r G^o$ is zero.

When $\Delta_r G^o = 0$, T = $\Delta_r H^o / \Delta_r S^o$ ✓

= 876.1 / (518.8 / 1000)

= 1689 K (4 sig. fig.) ✓

The products will be favoured at all temperatures above 1689 K. ✓

1(f) Elements in order of first ionisation energy, easiest first: **[2]**

Na < Al < Mg < Si < O ✓✓

[1 mark is awarded for correctly identifying O as the highest, with an additional 1 mark for Na<Al<Mg<Si or an additonal 1/2 mark for Na<Al<Si<Mg]

1(g)
(i) Units of constant *C*: $K^{-5/2}$ ✓ **[1]**

The fraction a must be dimensionless. The exponential terms are dimensionless, therefore *C* must have the same units as the *T* term: $K^{-5/2}$.

1(g)
(ii) Percentage of oxygen atoms ionized: **[4]**

$C = 6.58 \times 10^{-7}\ K^{-5/2}$; $R = 8.314\ J\ K^{-1}\ mol^{-1}$ $T = 10000\ K$;
$Ei = 1314\ kJ\ mol^{-1} = 1314000\ J\ mol^{-1}$ ✓

$$\alpha = \sqrt{\frac{(6.58 \times 10^{-7} \times e^{(-1314000 / (8.314 \times 10000)})}{10000^{-5/2} + (6.58 \times 10^{-7} \times e^{(-1314000 / (8.314 \times 10000)})}}$$ ✓

$\alpha = 0.02999$ ✓

The percentage of oxygen ionised is 3.00 % (3 sig. figs). ✓

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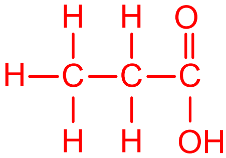
Mark

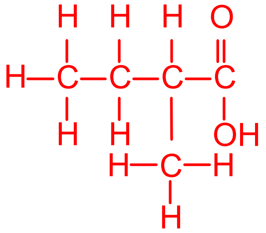
2(a)

(i) Structure of propanoic acid: [1]



or CH_3CH_2COOH ✓

(ii) 2–methyl butanoic acid: [1]



or $CH_3CH_2CH(CH_3)COOH$ ✓

2(b) General formula for a carboxylic acid: [1]

$C_nH_{2n+1}COOH$ ✓

2(c)

(i) Percentage by mass of metal ion **M** in **salt A**: [1]

100.0 – (12.66 + 3.16 + 29.54) = 54.64% ✓

(ii) Empirical formula of **salt A** using **M** for the metal ion: [2]

Element	Ar	%	%/Ar	Divide by smallest	Whole numbers
C	12.011	12.66	1.05403	1	4
H	1.008	3.16	3.13492	2.9742126	12
O	15.999	29.54	1.84637	1.7517136	7

✓

$MC_4H_{12}O_7$ ✓

(iii) Identify the metal that forms ion **M**: [1]

Mr ($C_4H_{12}O_7$) = 172.14. This corresponds to 45.35% of the total mass.

M accounts for 54.65 % of the mass. Ar (M) = 172.14 / 45.35 x 54.65.

= 207.4

the metal is therefore lead/Pb ✓

2(d)

(i) Empirical formula of **salt B:** [2]

Element	Ar	%	%/Ar	Divide by smallest	Whole numbers
C	12.011	14.76	1.22887	1	4
H	1.008	1.85	1.83532	1.4934958	6
O	15.999	19.68	1.23008	1.0009792	4

✓

$MC_4H_6O_4$ or $PbC_4H_6O_4$ ✓

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Mark

2(d)

(ii) Equation for formation of **salt B** from hydrated **salt A**: **[1]**

$PbC_4H_{12}O_7$ (s) $\longrightarrow$ $PbC_4H_6O_4$ (s) + $3H_2O$ (g)

or $Pb(C_2H_3O_2)_2.3H_2O$ (s) $\longrightarrow$ $Pb(C_2H_3O_2)_2$ (s) + $3H_2O$ (g) ✓

or $Pb(CH_3COO)_2.3H_2O$ (s) $\longrightarrow$ $Pb(CH_3COO)_2$ (s) + $3H_2O$ (g)

[Do not penalise lack of state symbols; accept any correct formula for salt B]

(iii) The oxidation state of metal ion **M** in **salt B**: **[1]**

Pb(II) or +2 (note error in paper / answerbooklet: accept +2 for **A** or **B**) ✓

(iv) The carboxylic acid whose anion is present in **salt B**: **[1]**

Ethanoic acid ✓

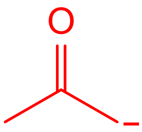
2(e) Equation for the formation of **salt B**: **[1]**

Pb (s) + $2CH_3COOH$ (aq) + H_2O_2 (aq) $\longrightarrow$ $Pb(CH_3COO)_2$ (aq) + 2 H_2O (l) ✓

[Do not penalise lack of state symbols; accept any correct formula for salt B]

2(f)

(i) Structure of anion formed by removing one proton from **ketone C**: **[1]**



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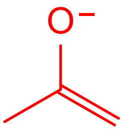
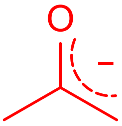


or



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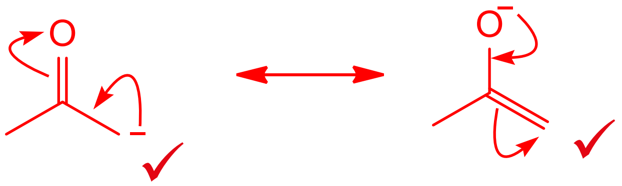
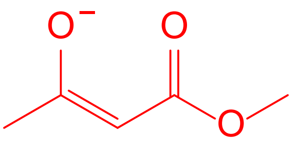
(ii) Delocalisation of charge on the anion of **ketone C**: **[2]**



2(g) Representations of the anion of **methyl 3-oxobutanoate**: **[2]**

Representation I



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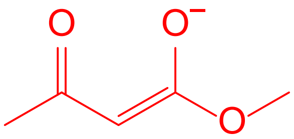
Representation II



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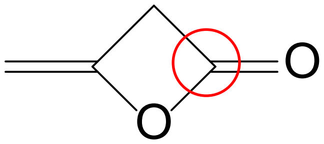
2(h) Circle the atom in **diketene** attacked by a nucleophile: **[1]**



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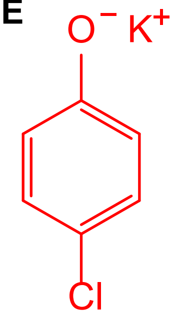
Mark

2(i) The role of **compound E** in the synthesis of **Sweetener D**:

electrophile radical initiator base [✓ nucleophile] ✓ **[1]**

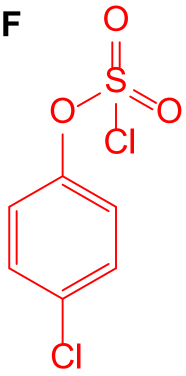
2(j) Structures:

Compound E



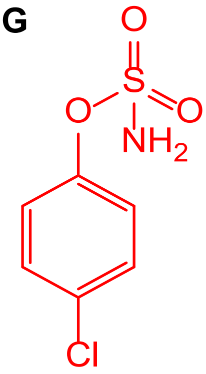
✓

Compound F



✓

Compound G



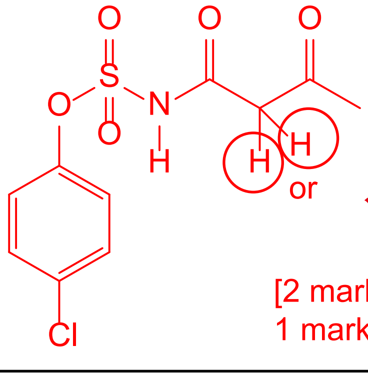
✓

[3]

2(k)

(i & ii) Structure of **Compound H** with most acidic proton circled:

Compound H



✓✓

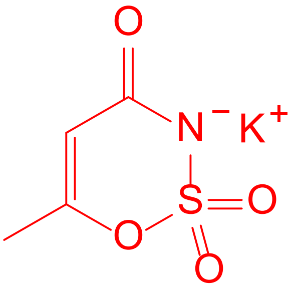
✓

[2 marks for the structure;
1 mark for correct proton indicatated]

[3]

(iii) Structure:

Sweetener D



✓✓✓

[3]

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Mark

2(l) Concentration of **Sweetener D** in city water (ng dm^{-3}): **[1]**

concentration (ng dm^{-3}) = concentration (nmol dm^{-3}) x Mr(Sweetener D)

= 0.0426 x 201.244

= 8.57 ng dm^{-3} (3 sig. fig) ✓

[-1 for incorrect sig. fig - penalise once only for paper]

2(m) Concentration of **Sweetener D** in pool water (ng dm^{-3}): **[1]**

Using the calibration line y = mx + c, with y peak area ratio, m = 0.098, x [Sweetener d] and c = – 0.015:

[Sweetner D in sample] (ng dm^{-3}) = (Peak Area Ratio + 0.015)/0.098

= 7.806 ng dm^{-3}

The sample was diluted 20-fold, therefore the concentration in the pool water = 7.806 x 20 = 156 dm^{-3} (3 sig. fig.) ✓

2(n) Concentration of **Sweetener D** in urine (ng dm^{-3}): **[1]**

[Sweetner D in sample] (dm^{-3}) = (Peak Area Ratio + 0.015)/0.098

= 24.74 ng dm^{-3}

The sample was diluted 100000-fold, therefore the concentration in the urine = 24.74 x 100000 = 2470000 ng dm^{-3} (3 sig. fig.) ✓

2(o) Volume of urine in the pool (dm^3): **[4]**

[Sweetener D]from_urine = [Sweetener D]pool – [Sweetener D]city_water

= 156.1... – 8.572... = 147.5... ng dm^{-3} ✓

Pool volume (dm^3) = pool volume (m^3) * 1000 = 840000 ✓

Mass Sweetener D from urine = [Sweetener D]from_urine * pool volume

= 147.5... x 840000 = 1.239... x10^8 ng ✓

volume of urine = Mass Sweetener D from urine/[Sweetener D] urine

= 1.239... x10^8 / 2.474... x10^6 = 50 .1 dm^3 (3 sig. fig.) ✓

[An answer of 53.0/52.99 dm^3 indicates that the student has forgotten to account for Sweetener D in the city water and should be given 3 marks.]

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