SwissChO 2023 - Central Exam

SOLUTION KEY

PROBLEM 1 - PERIODIC TRENDS 12.0 POINTS

1.1a The first number shown below the electron shell diagram (1 pt)

1.1b pm - picometers (1 pt)

1.1c Answers will vary. The distance from the center of the atom (nucleus) to its outer electrons. (1 pt)

1.2 The atomic radius gets larger as you go down a group (column) in Model 1. Thus, Li is smaller than Na. (2 pts)

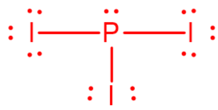
1.3 Atomic radii increase top to bottom because the number of energy levels increases, decreasing the "pull" on electrons from the protons in the nucleus and making the size of the atom larger. The highest occupied energy level has the greatest radius because as the number of electrons increase, new energy levels need to be added further away from the nucleus, making the size of the atom increase. (2 pts)

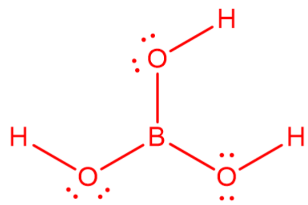
1.4 The atomic radius decreases from left to right across a period. Li is larger than F. (2 pts)

1.5 Atomic radii decrease left to right because the number of protons increases, which increases the attractive force on the electrons, and pulls the electrons in the same energy level closer to the nucleus. (1 pt)

Problem 2 - Chemical bonding 10 Points

2.1





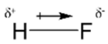
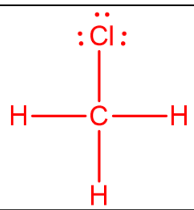
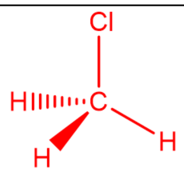
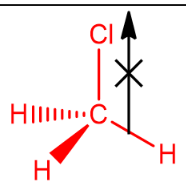
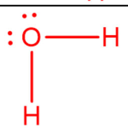
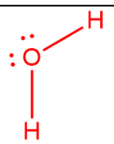
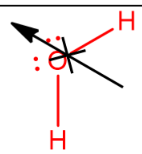
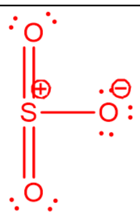
a) 1 pt

b) 1 pt

c) 1 pt

d) 1 pt

2.2 Fill in the table below appropriately. (6 pts)

Formula	Lewis structure	VSEPR (3D molecule)	Dipolar moment vectors Ex : 	Main intermolecular force
CH_3Cl				Dipole-dipole
H_2O				H-bond
SO_3			none	London dispersion forces

PROBLEM 3 - STOICHIOMETRY 10 POINTS

$CaCO_3$ (s) + 2 HCl (aq) $\longrightarrow$ $CaCl_2$ (aq) + CO_2 (g) + H_2O (l) (1 pt)

3.1 Mass of $CaCl_2$ in 400.0 L of solution
$m_{\text{CaCl}_2} = \rho * V * w_{\text{CaCl}_2} = 1.338 * 10^3 g/L * 400L * 0.350 = 1.875 * 10^5 g$ (1 pt)

Associated number of moles
$n_{\text{CaCl}_2} = \frac{m_{\text{CaCl}_2}}{M_{\text{CaCl}_2}} = \frac{1.873*10^5 g}{110.98 g/mol} = 1.688 * 10^3 mol$ (1 pt)

Number of moles + mass of necessary $CaCO_3$
$n_{\text{CaCO}_3} = n_{\text{CaCl}_2} = 1.688 * 10^3 mol$ (0.5 pt)

$m_{\text{CaCO}_3} = 1.688 * 10^3 mol * 100.09 g/mol = 1.690 * 10^5 g = 169 kg$
$massoflimestone = m_{\text{limestone}} = \frac{m_{\text{CaCO}_3}}{w_{\text{CaCO}_3}} = \frac{169.0 kg}{0.98} = 172 g$ (0.5 pt)

Necessary Volume of HCl:
Number of moles of HCl = $n_{\text{KCl}} = 2 * n_{\text{CaCl}_2} = 2 * 1.688 * 10^3 mol = 3.376 * 10^3 mol$ (1 pt)

$\rho_{\text{solution}} = d * \rho_{\text{H}_2\text{O, k°C}} = 1.18 * 1.00 * 10^3 g/L = 1.18 * 10^3 g/L$ (0.5 pt)

$\gamma_{\text{HCl}} = 1.18 * 10^3 g/L * 0.360 = 424.8 g/L$ (0.5 pt)

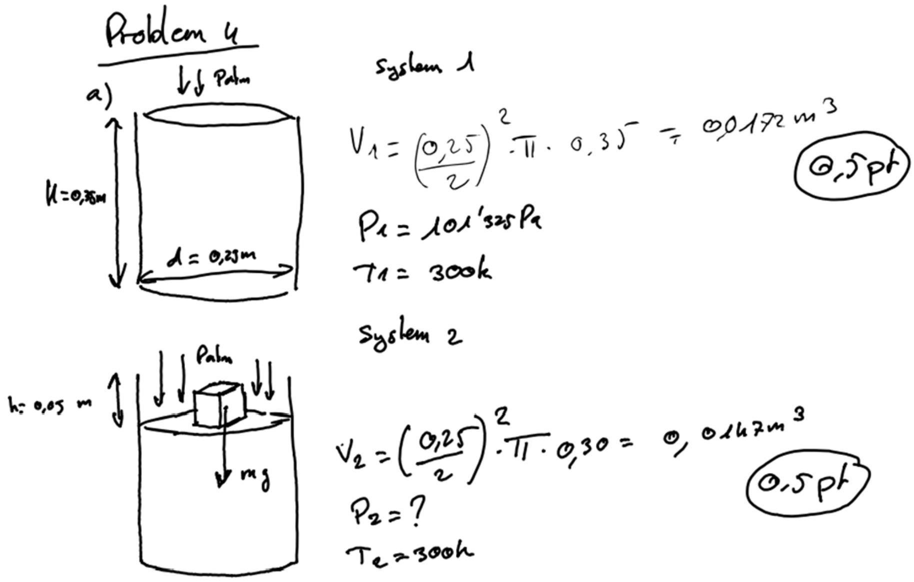
$c_{\text{HCl}} = \frac{\gamma_{\text{HCl}}}{M_{\text{HCl}}} = \frac{424.8 g/L}{86.46 g/mol} = 11.65 mol/L$ (1 pt)

$V_{\text{HCl}} = \frac{n_{\text{HCl}}}{c_{\text{HCl}}} = \frac{3.376*10^3 mol}{11.68 mol/L} = 290L$ (1 pt)

3.2 Volume of CO_2 formed
$n_{\text{CO}_2} = n_{\text{CaCl}_2} = 1.688 * 10^3 mol$ (1 pt)

We consider CO_2 as an ideal gas:
$V_{\text{CO}_2} = \frac{n_{\text{CO}_2} RT}{p} = \frac{1.688*10^3 mol*8.3145 J/mol*k*293,1K}{1.00*10^5 Pa} = 41.1 m^3$ (1 pt)

PROBLEM 4 - GASES **10 POINTS**



4.1 $P_1V_1 = P_2V_2$
$P_2 = \frac{P_2V_1}{V_2} = \frac{101325*0.0172}{0.0147} = 118557,14Pa$ (2 pts)
$\Delta P = P_2 - P_{atm} = 17232,143Pa$ (1 pt)
$P = \frac{F}{s}$
$F = P * s = 17232.14 * (\frac{0.25}{2})^2 * \pi = 848.88N$ (1 pt)
$F = m * g$
$m = \frac{F}{g} = \frac{846.88}{9.81} = 86.23kg$ (1 pt)

4.2 $V_3 = V_1$ (1 pt)
$\frac{V_1}{T_3} = \frac{V_2}{T_2}$
$T_3 = \frac{V_1*T_2}{V_2} = \frac{0.0172*300}{0.0147} = 351.02K$ (2 pts)
$T_3 = 351.02 - 273 = 78C$ (1 pt)

PROBLEM 5 - CHEMICAL EQUILIBRIUM 10 POINTS

5.1

	$2\,NO_2$	⇄	N_2O_4	
Situation initiale	-		0.0670 M (3.35/50)	(1pt)
Equation	2X		0.067-X = 0.0643 M	(1pt)
Equilibre	0.0054 M		0.0643	(1pt)

$$Kc = \frac{[N_2O_4]}{[NO_2]^2} \quad (1pt)$$

$$Kc = \frac{0.0643}{(0.0054)^2} = 2'205.075 \quad (1pt)$$

5.2

$$\Delta H_r = \Delta H_{f(N_2O_4)} - 2\Delta H_{f(NO_2)} = 9{,}16\ ^{kJ}/_{mol} - 2\left(33{,}18\ ^{kJ}/_{mol}\right) = -57{,}2\ ^{kJ}/_{mol} \rightarrow$$
réaction exothermique

(1pt)

1) Travailler à basse température (1pt)
2) Travailler à haute pression car 2 mol à gauche et 1 seule mol à droite (1pt)
3) Travailler avec une concentration élevée de NO_2 ou retirer le N_2O_4 au fur et à mesure qu'il est formé pour en diminuer sa concentration (1pt)

5.3

$$N_2O_4\,_{(g)} \rightleftarrows 2\,NO_2\,_{(g)}$$

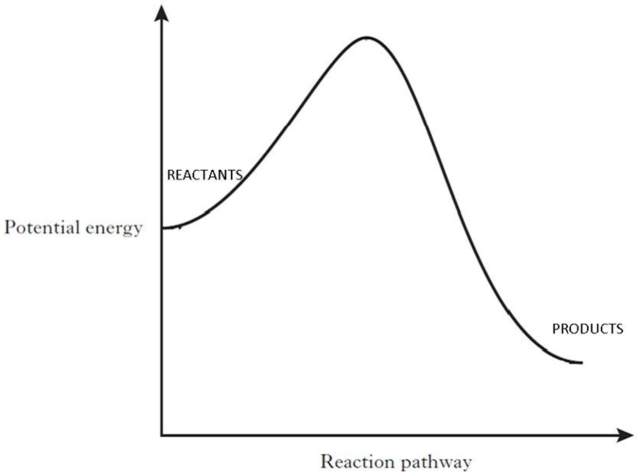
$$K_{c\,indirect} = \frac{1}{K_{c\,direct}} = \frac{1}{2205.075} = 4.535 \cdot 10^{-4} \text{ (1pt)}$$

PROBLEM 6 - THERMOCHEMISTRY 10 POINTS

6.1 $2\,Al + Fe_2O_3 \longrightarrow 2\,Fe + Al_2O_3$ (1pt)

6.2 (2 pts)

ΔHr = ΔHf (Al_2O_3) - ΔHf (Fe_2O_3) = -1675.7 – (-824.2) = -851.5 <0 → exothermic



6.3 $\Delta Gr = \Delta Hr * TSr = (-851.5) * 298.15 * (-36.5) = -840.6 < 0$ -> spontaneous (3 pts)

6.4 $\Delta Gr = 0 - T = \Delta Hr/Sr = 23.328K$ (2 pts)

6.5 Thermite (1 pt)

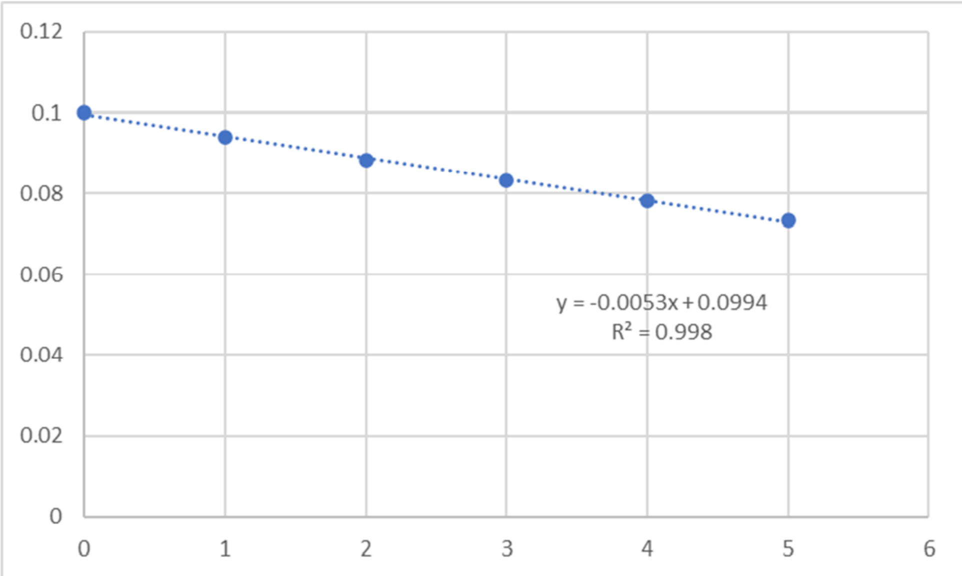
6.6 For soldering railway tracks together (1 pt)

Problem 7 - Chemical kinetics 10 Points

7.1a B, E and F since they are all ran at the same temperature with different concentrations or areas to react. (3 pts)

7.1b D will have the greatest rate, since it has the highest temperature, concentration as well as the best ability to mix. (2 pts)

7.2 (5 pts)



The concentration vs time graphe is constant, hence the reaction is of zero order.

v= k meaning you need the slope of the curve. K= 0.0053

Problem 8 - Acid Base **10 Points**

8a (6 pts)

a) Pka1 = 1.9, pka2 = 7.4
By comparing with the table below, → H_3PO_4

8b (2 pts) $H_3PO_3 + NaOH \longrightarrow NaH_2PO_3 + H_2O$
$NaH_2PO_3 + NaOH \longrightarrow Na_2HPO_3 + H_2O$

8c (2 pts) A mixture of xylene cyanol and themolphtalein. It starts off purple, transits to green and then turns blue.

PROBLEM 9 - REDOX 10 POINTS

9.1 $Fe^{2+} \longrightarrow Fe^{3+} + e^-$ (1 pt)

9.2 $MnO_4^- + 8\,H^+ + 5\,e^- \longrightarrow Mn^{2+} + 4\,H_2O$ (2 pts)

9.3 $5\,Fe^{2+} + MnO_4^- + 8\,H^+ \longrightarrow 5\,Fe^{3+} + Mn^{2+} + 4\,H_2O$ (2 pts)

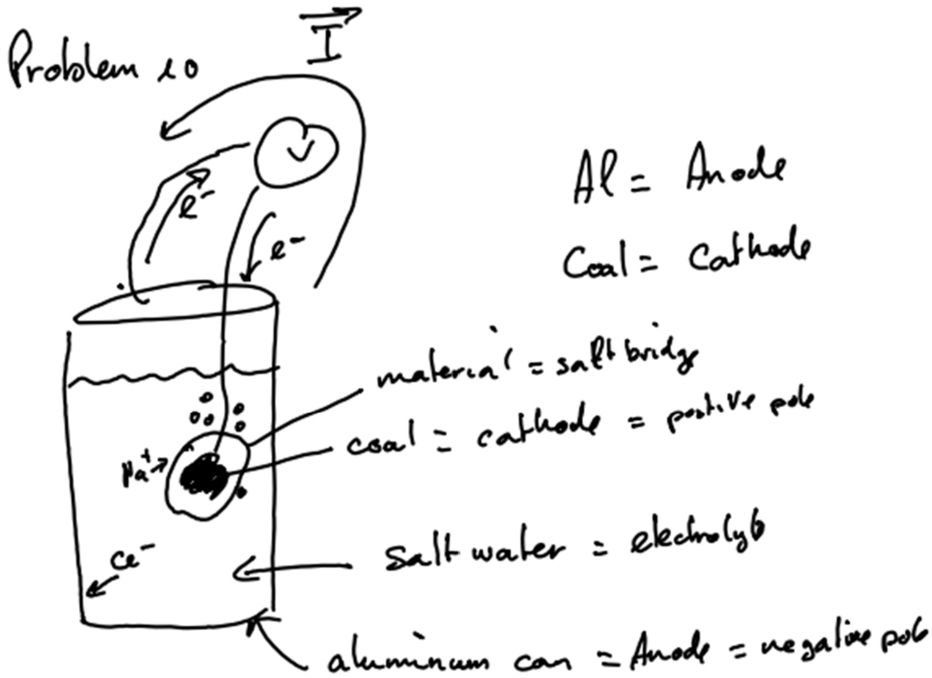
9.4 (4 pts)

	$5Fe^{2+}$	+	MnO_4^-	+	$8H^+$	$\longrightarrow$	$5Fe^{3+}$	+	Mn^{2+}	+	$4H_2O$
C :			0.025 M								
V :			0.0245 L								
n :	0.00306 mol (1pt)		0.0006125 mol (1pt)								
MM :	151,908 g/mol (1pt)										
m :	0.465 g (1pt)										

9.5 $Teneurmassique = \frac{0.465}{1} * 100 = 46.5\%$ (1 pt)

PROBLEM 10 - ELECTROCHEMISTRY 10 POINTS

10.1 (6 pts)



10.2 (2 pts)
$O_2 + 4\,H^+ + 4\,e^- \longrightarrow H_2O$ 3 E = 1.23 V
$Al^{3+} + 3\,e^- \longrightarrow Al$ 4 E = 1.66 V
$3\,O_2 + 4\,Al + 12\,H^+ \longrightarrow 6\,H_2O + 4\,Al^{3+}$

10.3 (2 pts)
$\Delta E = 1.23 - (-1.66) = 2.89V$

Figure 1: for 12 Volts you need at least 5 systems wired up in series

PROBLEM 11 - SOLUBILITY 10 POINTS

11.1 (1 pt)
$CaC_2O_4 \longleftrightarrow Ca^{2+}$ (aq) + $C_2O_4{}^{2-}$ (aq)
$K_s = [\mathrm{Ca}^{2+}] * [\mathrm{C_2O_4}^{2-}] = 2.3 * 10^{-9} M^2$

11.2 (6 pts)
$m = 0.768 g M(x) = 128.102 g/mol$ (1 pt)
$n = \frac{m}{M(x)} = 6.00 * 10^{-3}$ (1 pt)
$S = [\mathrm{Ca}^{2+}] = [\mathrm{C_2O_4}^{2-}] -> K_s = S^2$ (1 pt)
$S = K_{\mathrm{s}}{}^{0.5} = 4.8 * 10^{-5} mol/L$ (1 pt)
$S = \frac{n}{V} -> V = \frac{n}{S} = \frac{0.006 mol}{4.80 M * 10^{-5} M} = 125 L$ (2 pts)

11.3 (3 pts)
$\Pi = [2.5 * 10^{-6} M] * [5.0 * 10^{-4} M] = 1.00 * 10^{-9} M^2$ (1 pt)
if $\Pi < K_s$ (1 pt)
No precipitation (1 pt)

PROBLEM 12 - ORGANIC CHEMISTRY **10 POINTS**

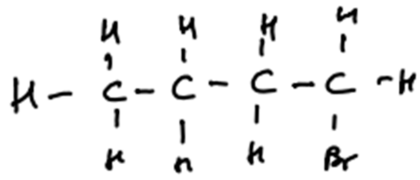
12.1a Step W = reduction, so $LiAlH_4$ or $NaBH_4$ (1pt)

12.1b Step Y = Addition, so HBr (1 pt)

12.2a Step x = dehydration (1 pt)

12.2b Step Z = Oxydation (1 pt)

12.3 1- Brombutane (1 pt)



12.4 Tollens reagent $AgNO_3$ + NaOH. The aldehyde will be oxydized and not the ketone. (1 pt)

12.5 Because the double bon dis on a terminal carbon and there are no assymetric carbons. (1 pt)

12.6 D and E each have an assymetric carbon. (2 pts)

12.7 Butan-1-ol (1 pt)