ENTRANCE EXAMINATION AT THE UNIVERSITIES OF TECHNOLOGY IN FINLAND (HELSINKI, TAMPERE, LAPPEENRANTA, OULU, ÅBO)

Model Solutions (Chemistry Exam 26 May 2004)

1. a) formation of the deposit:

$$\mathbf{3\ CaCl_2\ (aq)\ +\ 2\ Na_3PO_4\ (aq)\ \rightarrow\ Ca_3(PO_4)_2\ (s)\ +\ 6\ NaCl\ (aq)}$$

1 p

b) acid-base reaction: $\mathbf{Mg(OH)_2\ (aq)\ +\ 2\ HClO_4\ (aq)\ \rightarrow\ Mg(ClO_4)_2\ (aq)\ +\ 2\ H_2O\ (l)}$

2 p

c) oxidation-reduction reaction:

$Cr_2O_7^{2-}$ (aq) + Cl^- (aq) + H^+ (aq) $\rightarrow$ Cr^{3+} (aq) + Cl_2 (g) + H_2O (l)

Chlorine is oxidized ($-1 \rightarrow 0$): 1) $2\ Cl^- \rightarrow Cl_2 + 2\ e^-$
Chromium is reduced ($+6 \rightarrow +3$): 2) $Cr_2O_7^{2-} + 6\ e^- + 14\ H^+ \rightarrow 2\ Cr^{3+} + 7\ H_2O$
The reaction of chlorine x 3: 3) $6\ Cl^- \rightarrow 3\ Cl_2 + 6\ e^-$

2) + 3):

$Cr_2O_7^{2-} + 6\ e^- + 14\ H^+ \rightarrow 2\ Cr^{3+} + 7\ H_2O$
$6\ Cl^- \rightarrow 3\ Cl_2 + 6\ e^-$

$$\mathbf{Cr_2O_7^{2-}\ (aq)\ +\ 6\ Cl^-\ (aq)\ +\ 14\ H^+\ \rightarrow\ 2\ Cr^{3+}\ (aq)\ +\ 3\ Cl_2\ (g)\ +\ 7\ H_2O\ (l)}$$

3 p
Σ 6 p

2. a) Silver chromate dissolves as follows:

	Ag_2CrO_4 (s)	$\Leftrightarrow$	2 Ag^+ (aq)	+	CrO_4^{2-} (aq)
At the beginning (mol/dm^3)	a		0		0
At equilibrium (mol/dm^3)	a–x		2 x		x

$$K_s = [Ag^+]^2\,[CrO_4^{2-}] = (2x)^2 \cdot x = 1.3 \cdot 10^{-12}\ mol^3/dm^9$$
$$4\,x^3 = 1.3 \cdot 10^{-12}\ mol^3/dm^9$$
$$x = 6.875 \cdot 10^{-5}\ mol/dm^3$$

$M(Ag_2CrO_4)$ = (2 · 107,90 + 52,00 + 4 · 16,00) g/mol = 331,8 g/mol

The solubility as milligrams in pure water:

$m(Ag_2CrO_4) = x \cdot M = 6.875 \cdot 10^{-5}\ mol/dm^3 \cdot 331.8\ g/mol = 2.281 \cdot 10^{-2}\ g/dm^3 =$ **23 mg/dm^3**

3 p

b) 0.010 mol/dm^3 $AgNO_3$ solution
$\Rightarrow [Ag^+] = [AgNO_3] = 0.010\ mol/dm^3$, limits the solubility of silver chromate

	Ag_2CrO_4 (s)	$\Leftrightarrow$	2 Ag^+ (aq)	+	CrO_4^{2-} (aq)
At the beginning (mol/dm^3)	a		0.010		0
At equilibrium (mol/dm^3)	a–x		0.010 + 2 x		x

$K_s = [Ag^+]^2 [CrO_4^{2-}] = (0.010 + 2x)^2\ x = 1.3 \cdot 10^{-12}\ mol^3/dm^9$

Approximation: 2x << 0,010 or x << 0,005

$\Rightarrow \quad 0.0001\ x = 1.3 \cdot 10^{-12}\ mol^3/dm^9$
$\Rightarrow \quad x = 1.3 \cdot 10^{-8}\ mol/dm^3$ the approximation is ok!

The solubility as milligrams in 0.010 M $AgNO_3$ solution:

$m(Ag_2CrO_4) = x \cdot M = 1.3 \cdot 10^{-8}\ mol/dm^3 \cdot 331.8\ g/mol = 4.313 \cdot 10^{-6}\ g/dm^3 = \underline{\mathbf{0.0043\ mg/dm^3}}$

3 p
Σ 6 p

3. a) 0.01 mol/dm^3 NaOH: $[NaOH] = [OH^-] = 0.01$

pOH = –log [OH] = – log 0.01 = 2.0

pH = 14 – pOH = **<u>12</u>**

1 p

b) 0.01 mol/dm^3 CH_3COOH

	CH_3COOH	+	H_2O	$\Leftrightarrow$	CH_3COO^-	+	H_3O^+
At the beginning (mol/dm^3)	0.01				0		0
At equilibrium (mol/dm^3)	0.01–x				x		x

$$K_a = \frac{[CH_3COO^-]\,[H_3O^+]}{[CH_3COOH]} = \frac{x^2}{0{,}01 - x} = 1{,}8 \cdot 10^{-5}\ mol/dm^3$$

Approximation: x << 0,01 $\Rightarrow$ $x^2 = 1.8 \cdot 10^{-7}$
$x = 4.24 \cdot 10^{-4}$ the approximation is ok!

pH = $-\log [H_3O^+] = -\log 4.24 \cdot 10^{-4}$ = **<u>3.4</u>**

2 p

c) 0.01 mol/dm^3 CH_3COONa $\Rightarrow$ $[CH_3COO^-] = 0.01\ mol/dm^3$

	CH_3COO^-	+	H_2O	$\Leftrightarrow$	CH_3COOH	+	OH^-
At the beginning (mol/dm^3)	0.01				0		0
At equilibrium (mol/dm^3)	0.01–x				x		x

$$K_b(CH_3COO^-) = \frac{K_w}{K_a} = \frac{10^{-14}}{1.8 \bullet 10^{-5}} = \frac{x^2}{0.01 - x} = 5.55 \cdot 10^{-10}$$

Approximation: $x << 0.01 \Rightarrow$ $x^2 = 5.55 \cdot 10^{-12}$

$x = 2.357 \cdot 10^{-6}$ the approximation is ok!

$pOH = -\log [OH] = -\log 2.357 \cdot 10^{-6} = 5.6$

pH $= 14 - pOH = 14 - 5.6 =$ **<u>8.4</u>**

3 p

Σ 6 p

4. a) $CH_4\ (g) + 2\ O_2\ (g) \rightarrow CO_2\ (g) + 2\ H_2O\ (g)$

1 p

b) $pV = nRT$

$$n(CH_4)_{introduced} = \frac{pV}{RT} = \frac{152\ kPa \bullet 200\ dm^3 / min}{8.314\ J/(Kmol) \bullet 298.15\ K} = 12.26\ mol/min$$

$n(O_2)_{theoretical} = 2 \cdot n(CH_4)_{introduced} = 24.52$ mol/min

$$n(air)_{theoretical} = \frac{n(O_2)_{theoretical}}{0.21} = \frac{24.52}{0.21} mol/min = 116{,}76\ mol/min$$

$$V(air)_{theoretical} = \frac{n(air)_{theor.}RT}{p} = \frac{116.76\ mol/min \bullet 8.314\ J/(Kmol) \bullet 298.15\ K}{101\ kPa}$$

$= 2.866\ m^3/min = 2866\ dm^3/min$

n(air)$_{introduced}$ $= 3 \cdot 2866\ dm^3/min =$ **<u>8598 dm³/min</u>**

2 p

c) The composition of the exhaust gas mixture:

$n(O_2) = n(O_2)_{introd.} - n(O_2)_{theor.} = 3 \cdot 24.52\ mol/min - 24.52\ mol/min = 49.04\ mol/min$

$$n(N_2) = \frac{79}{21} \cdot n(O_2)_{introduced} = 276.73\ mol/min$$

$n(CO_2) = n(CH_4)_{introduced} = 12.26$ mol/min

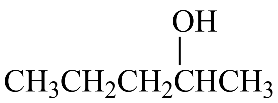
$n(H_2O) = 2 \cdot n(CH_4)_{introduced} = 24.52$ mol/min

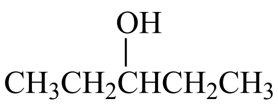
n(O_2)	49.04 mol	**13.53 mol-%**
n(N_2)	276.73 mol	**76.33 mol-%**
n(CO_2)	12.26 mol	**3.38 mol-%**
n(H_2O)	24.52 mol	**6.76 mol-%**
	∑ 362.55 mol	100.00 mol-%

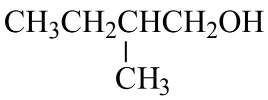
3 p
∑ 6 p

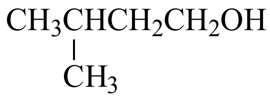
5.a)

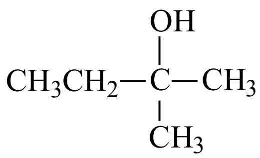
$CH_3CH_2CH_2CH_2CH_2OH$ 1-pentanol

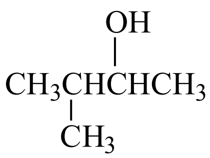

2-pentanol

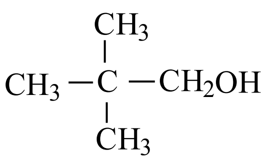

3-pentanol


2-methyl-1-butanol


3-methyl-1-butanol

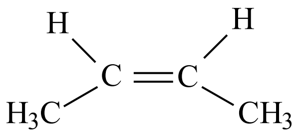

2-methyl-2-butanol


3-methyl-2-butanol


2,2-dimethyl-1-propanol

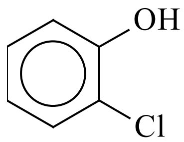
½ p / structural formula = 4 p

b)



1 p

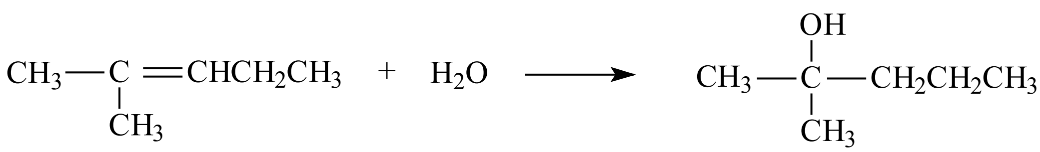
c)



1 p

Σ 6 p

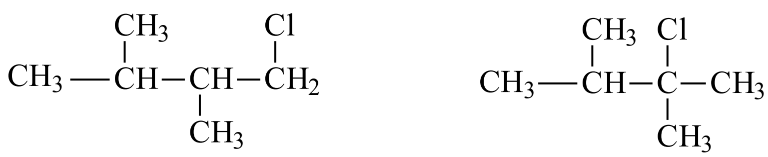
6. a)



2-methyl-2-pentanol

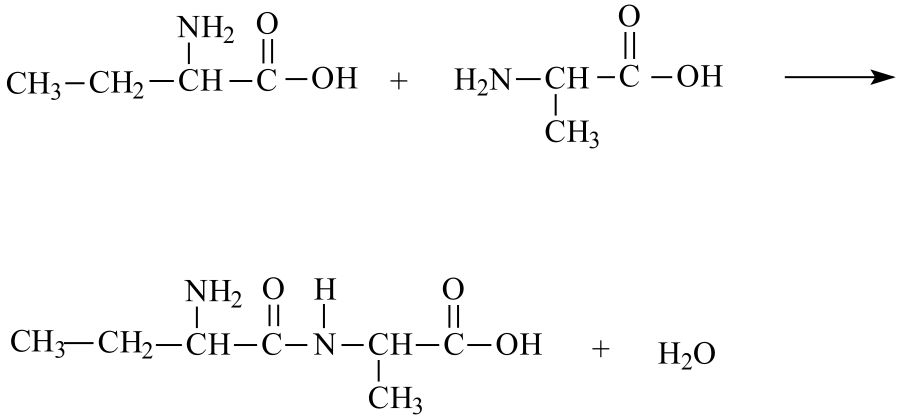
2 p

b)



2 p

c)



2 p

Σ 6 p