The 28th International Science Olympiad for Young Mathematicians, Physicists and Chemists
November 3, 2015
Chemistry - Form 11 (Solutions)

1. FIREWORKS **(10 points)**

1) $2Na + O_2 \rightarrow Na_2O_2$ Sodium peroxide – Sodium – **B**: gives yellow colour **(1)**

$2Cu + O_2 \rightarrow 2CuO$ copper(II) oxide – Copper – **C**: gives blue colour **(1)**

$4Li + O_2 \rightarrow 2Li_2O$ lithium oxide – Lithium – **A**: gives red colour **(1)**

Alternative solution:

$2Na + O_2 \rightarrow Na_2O_2$ sodium peroxide – Sodium – **B**: gives yellow colour **(1)**

$2Sr + O_2 \rightarrow 2SrO$ strontium(II) oxide – Strontium – **C**: gives red colour **(0.5)**

$4Cu + O_2 \rightarrow 2Cu_2O$ copper(I) oxide – Copper – **A**: gives blue colour **(0.5)**

2) a)

$$x_C = \frac{\frac{2\text{ g}}{12\text{ g/mol}}}{\frac{2\text{ g}}{12\text{ g/mol}}+\frac{2\text{ g}}{32\text{ g/mol}}+\frac{21\text{ g}}{101\text{ g/mol}}} = 0.381 \quad \textbf{(1)}$$

$$x_S = \frac{\frac{2\text{ g}}{32\text{g/mol}}}{\frac{2\text{ g}}{12\text{ g/mol}}+\frac{2\text{ g}}{32\text{ g/mol}}+\frac{21\text{ g}}{101\text{ g/mol}}} = 0.143 \quad \textbf{(1)}$$

$$x_{KNO3} = \frac{\frac{21\text{ g}}{101\text{ g/mol}}}{\frac{2\text{ g}}{12\text{ g/mol}}+\frac{2\text{ g}}{32\text{ g/mol}}+\frac{21\text{ g}}{101\text{ g/mol}}} = 0.476 \quad \textbf{(1)}$$

b) D – K_2CO_3 **(0.5)**

E– K_2SO_4 **(0.5)**

F – CO_2 **(0.5)**

G – N_2 **(0.5)**

$10KNO_3 + 3S + 8C = 2K_2CO_3 + 3K_2SO_4 + 6CO_2 + 5N_2$ **(2)**

The 28th International Science Olympiad for Young Mathematicians, Physicists and Chemists
November 3, 2015
Chemistry - Form 11 (Solutions)

2. ACID RAIN **(10 points)**

1) a) CO_2 **(0.5)**

$CO_2 + H_2O \rightarrow H_2CO_3$ **(0.25)**

$H_2CO_3 + H_2O \rightleftharpoons H_3O^+ + HCO_3^-$ **(0.25)**

b) A – SO_3, sulphur trioxide **(0.5)**

B – NO_2, nitrogen dioxide **(0.5)**

$SO_3 + H_2O \rightarrow H_2SO_4$ **(0.5)**

$2NO_2 + H_2O \rightarrow HNO_2 + HNO_3$ **(0.5)**

c) $2H^+ + CaCO_3 \rightarrow H_2O + Ca^{2+} + CO_2\uparrow$ **(1)**

d) $2NO_3^- + 8H^+ + 3Cu \rightarrow 3Cu^{2+} + 2NO\uparrow + 4H_2O$ **(1)**

$4Sn + 10H^+ + NO_3^- \rightarrow NH_4^+ + 4Sn^{2+} + 3H_2O$ **(1)**

Reducing nitrogen to oxidation states 0, 1 and 2 can also be considered right, reducing nitrogen to oxidation state 4 resulting in NO_2 being a product is not correct since acid rain is not concentrated HNO_3.

2)

$$M(SO_2) = 32\frac{\text{g}}{\text{mol}} + 2 * 16\frac{\text{g}}{\text{mol}} = 64\frac{\text{g}}{\text{mol}}$$

$SO_2 + H_2O \rightarrow H_2SO_3$

$$n(H_2SO_3) = n(SO_2) = \frac{m(SO_2)}{M(SO_2)} = \frac{2.5*10^{10}\text{g}}{64\frac{\text{g}}{\text{mol}}} = 3.9 * 10^8 \text{ mol}$$ **(1)**

$$c(H_2SO_3) = \frac{n(H_2SO_3)}{V} = \frac{3.9*10^8\text{mol}}{2.4*10^{10}\text{l}} = 1.6 * 10^{-2} \text{ M}$$ **(1)**

$Ka1 = \frac{[H^+][HSO_3^-]}{[H_2SO_3]}$ (equation 1)

Assume that pH is low enough that 2nd order dissociation can be ignored.

$[H^+] = [HSO_3^-]$ (equation 2)

$[H_2SO_3] = c(H_2SO_3) - [HSO_3^-]$ (equation 3)

Replace [HSO_3^-] and [H_2SO_3] from equations 2 and 3 to equation 1 and solve the quadratic equation for [H^+].

$$[H^+]^2 + K_a1 * [H^+] - K_a1 * c = 0$$

The positive solution for this equation is [H^+] = 1.0*10^{-2} M and pH = 2.00. **(2)**

3. QUANTITATIVE RELATIONS IN CHEMISTRY **(8 points)**

a) $2NH_3 + NaOCl = N_2H_4 + NaCl + H_2O$ **(1)**

$2NH_3 + H_2O_2 = N_2H_4 + 2H_2O$ **(1)**

$(NH_2)_2CO + NaOCl + 2NaOH = N_2H_4 + NaCl + Na_2CO_3 + H_2O$ **(1)**

b) $M(N_2H_4)$ = 32 g/mol, $M(NH_3)$ = 17 g/mol

m = 34 g / (2·17 g/mol)·32 g/mol = **32 g** **(1)**

c) M(NaOCl) = 74.5 g/mol, M(NaOH) = 40 g/mol, $M((NH_2)_2CO)$ = 60 g/mol

EA(Olin Raschig) = 32 g/mol / (74.5 g/mol + 2·17 g/mol) = 29% **(1)**

EA(peroxide) = 32 g/mol / (34 g/mol + 2·17 g/mol) = 47% **(1)**

EA(urea) = 32 g/mol / (60 g/mol + 74.5 g/mol + 40 g/mol) = 18% **(1)**

d) Peroxide process is the greenest in terms of atom economy and because by-products (waste) such as sodium chloride are not produced. **(1)**

4. CONDUCTOMETRY **(10 points)**

1) a) point A – $H^+ < Na^+ = OH^-$ **(0.5)**

point B – $H^+ = OH^- < Na^+ = Cl^-$ **(0.5)**

point C – $OH^- < H^+ = Na^+ < Cl^-$ **(0.5)**

b) 5 ml **(0.5)**

c) $c = \frac{\kappa}{\lambda_{Na^+} + \lambda_{Cl^-}} = \frac{0.125 \frac{1}{\Omega * m}}{5.01 \frac{1}{\Omega * m * M} + 7.64 \frac{1}{\Omega * m * M}}$=0.01 M **(3)**

d) c(NaOH, original) = c(NaCl, pH=7)=0.01M $pOH = -\log(c(NaOH)) = -\log(0.01) = 2$

$pH = 14 - pOH = 14 - 2 = 12$ **(2)**

2) (**0.5 points** for each correct cell that was not filled in before)

Volume of HCl added	Conductance of the solution	pH of the solution
7 ml	$3*10^{-4}/(\Omega*m)$	2.4
8 ml	*$4*10^{-4}/(\Omega*m)$*	2.2
~5 ml	$1.25*10^{-4}/(\Omega*m)$	*9*

5. OXIDATION AND REDUCTION **(10 points)**

1) $3Br_2 + 4O_3 = 6BrO_2$ **(1)**

$2Br_2 + 5O_2 = 2Br_2O_5$ **(1)**

$2SBr_2 = Br_2 + S_2Br_2$ **(1)**

$S + O_2 = SO_2$ **(1)**

$2SO_2 + O_2 = 2SO_3$ **(1)**

2) $2BrO_2 + H_2O = HBrO_2 + HBrO_3$ **(1)**

$Br_2O_5 + H_2O = 2HBrO_3$ **(1)**

$2SBr_2 + 3H_2O = 4HBr + H_2SO_3 + S$ **(1)**

$4S_2Br_2 + 12H_2O = 8HBr + 3H_2SO_4 + 5H_2S$ **(1)**

$SO_2 + H_2O = H_2SO_3$ **(0.5)**

$SO_3 + H_2O = H_2SO_4$ **(0.5)**