The 28th International Science Olympiad for Young Mathematicians, Physicists and Chemists
November 3, 2015
Chemistry - Form 12 (Solutions)

1. CAMPING GAS **(10 points)**

Molecular weight of butane and propane:

M_w(butane) = 4 x 12.00 + 10 x 1.008 = 58.08 g/mol **(1)**

M_w(propane) = 3 x 12.00 + 8 x 1.008 = 44.06 g/mol **(1)**

Energy needed to heat the water for tea:

$Q(tea) = c_p m\Delta T = 3 \times 0.2 \times 4.18 \times (100 - 5) = 238.26\ \text{kJ}$ **(1.5)**

Energy needed to heat the water in the ration packs:

$Q(food) = c_p m\Delta T = 3 \times 0.3 \times 4.18 \times (100 - 20) = 300.96\ \text{kJ}$ **(1.5)**

Total energy needed:

$Q(total) = Q(tea) + Q(food) = 539.22\ \text{kJ}$ **(1)**

Assuming 50% heat transfer efficiency, the heat emitted by the burner must be

$Q(gas) = \frac{Q(total)}{efficiency} = 1078.44\ \text{kJ}$ **(1)**

Let's assume we have *m* grams of gas in total. The total heat <u>emitted</u> by the gas in the burning process must be Q(gas):

$-Q(gas) = \frac{0.25m}{M_w(propane)}\Delta_C H(propane) + \frac{0.75m}{M_w(butane)}\Delta_C H(butane)$ **(2)**

$1078.44 = 12.494m + 37.157m \rightarrow m = 21.72\ \text{g} \approx \mathbf{21.7\ g}$ **(1)**

2. ACIDS **(11 points)**

Dissolving hydrofluoric acid:

$\mathrm{HF} \rightleftharpoons \mathrm{H^+} + \mathrm{F^-}$ **(0.5)**

The amount of protons is equal to the amount of fluoride anions:

$[H^+] = [F^-] = x$ **(1)**

Some of the acid has dissociated, some if it has not. In total, the amount of acid has to be 1 M:

$[F^-] + [HF] = 1 \rightarrow [HF] = 1 - x$ **(1)**

Hence we can rewrite the equation for the dissociation constant:

$K_a(HF) = \frac{[H^+][F^-]}{[HF]} = \frac{x^2}{1-x}$ **(1.5)**

Rearranging the equation, we can find x (since x has to be positive, there is only one solution):

$x^2 + 0.00072x - 0.00072 = 0 \rightarrow x = 0.026475$ **(0.5)**

And from which the pH of the HF solution is

$\mathrm{pH}(1M\ HF) = -\log[H^+] = -\log x = 1.577 \approx \mathbf{1.6}$ **(0.5)**

Similarly, for acetic acid:

$\mathrm{CH_3COOH} \rightleftharpoons \mathrm{H^+} + \mathrm{CH_3COO^-}$ **(0.5)**

$[H^+] = [CH_3COO^-] = y$ **(1)**

$[CH_3COO^-] + [CH_3COOH] = 1 \rightarrow [CH_3COOH] = 1 - y$ **(1)**

So the dissociation equation becomes

$K_a(CH_3COOH) = \frac{[H^+][CH_3^-COO^-]}{[CH_3COOH]} = \frac{y^2}{1-y}$ **(1.5)**

From which

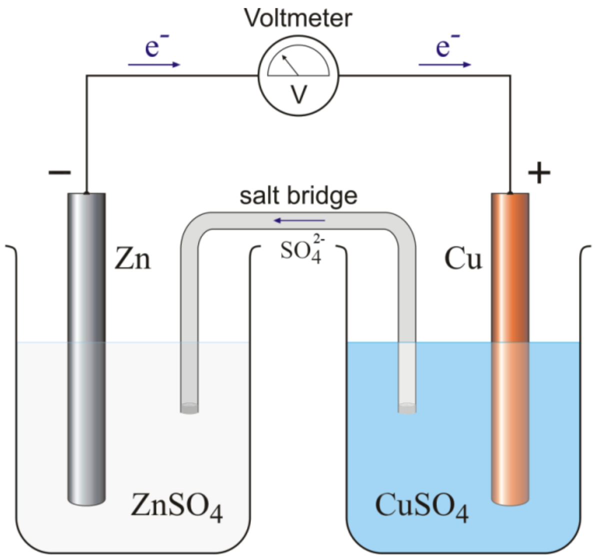
$y^2 + 0.0000176x - 0.0000176 = 0 \rightarrow y = 0.0041864$ **(0.5)**

And hence the pH of the solution is

$\mathrm{pH}(1M\ CH_3COOH) = -\log[H^+] = -\log y = 2.378 \approx \mathbf{2.4}$ **(0.5)**

HF is a stronger acid than CH_3COOH, because it gives a lower pH value when dissolved in water. **(1)**

3. BATTERY **(8 points)**



(3)

The **oxidation** reaction takes place on the **anode**:

$Zn - 2e^- \rightarrow Zn^{2+}$ **(1)**

The **reduction** reaction takes place on the **cathode**:

$Cu^{2+} + 2e^- \rightarrow Cu$ **(1)**

Thus the total reaction is

$Zn + CuSO_4 \rightarrow Cu + ZnSO_4$ **(1)**

Using the formula for the change in Gibbs free energy, we can find the electrochemical potential of one cell by knowing that z = 2 electrons take place in the reaction:

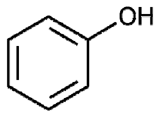
$$E = -\frac{\Delta G}{zF} = \frac{212\ 040}{2 \times 96485} = 1.0988\ \text{V}$$ **(1)**

Since the voltage needed is 12 V, the total number of cells must be

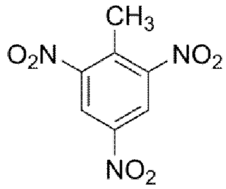
$$N = \frac{12}{E} = 10.92 \approx \boldsymbol{11\ cells}$$ **(1)**

4. BITS AND PIECES FROM ORGANIC CHEMISTRY **(11 points)**

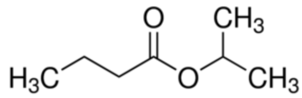
a)



phenol



trinitrotoluene (TNT)

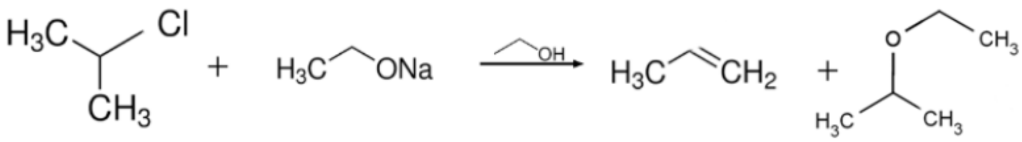


isopropylbutanoate or

1-methylethyl butanoate

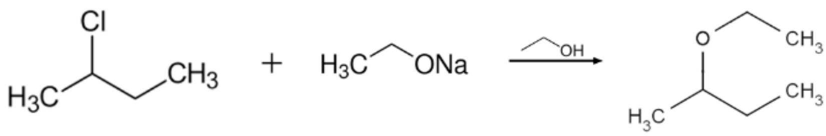
(3)

b) In this reaction there are E2 and S_N2 mechanisms competing with each other. E2 mechanism is dominating at higher temperatures; hence **A** is an elimination product propene. S_N2 mechanism is more dominant at lower temperatures, so **B** is the result of substitution (2-ethoxypropane).



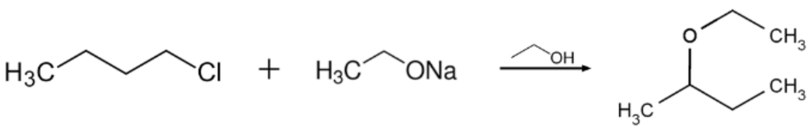
(0.5) **(0.5)** **A**, propene **(2)** **B**, 2-ethoxypropane **(2)**

For the first of the other reactions we have a substitution:



(1)

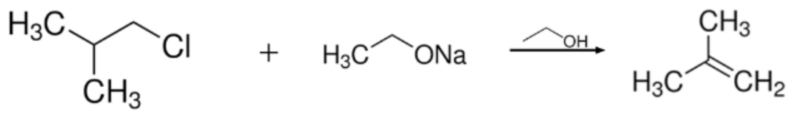
The second reaction also has a substitution, but there is a hydride shift as 2-ethoxybutane is more stable than butyl ethyl ether (which would be the product without the hydride shift):



(1)

0.5 points *for butyl ethyl ether.*

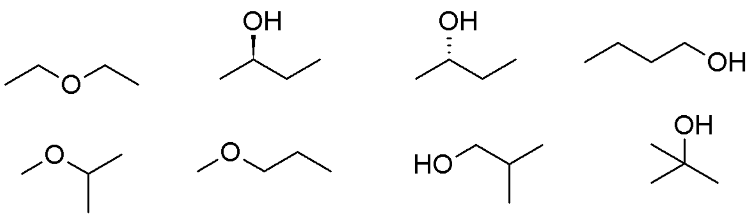
Access to the middle carbon is sterically hindered in the third reaction, so instead of substitution, we have elimination:



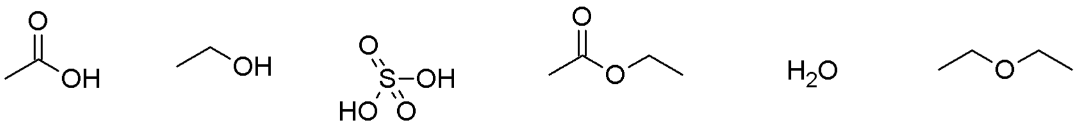
(1)

5. UNKNOWN LIQUIDS **(8 points)**

a) (**4 points**: **0.5 points** for each isomer)



b) (**3 points**: **0.5 points** for each formula)



A B C D E F

c) $C_2H_5OH \xrightarrow{>150 \text{ deg C,acid}} C_2H_4 + H_2O$ **(1)**