AP® Chemistry
2001 Sample Student Responses

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3A

3. Answer the following questions about acetylsalicylic acid, the active ingredient in aspirin.

(a) The amount of acetylsalicylic acid in a single aspirin tablet is 325 mg, yet the tablet has a mass of 2.00 g. Calculate the mass percent of acetylsalicylic acid in the tablet.

(b) The elements contained in acetylsalicylic acid are hydrogen, carbon, and oxygen. The combustion of 3.000 g of the pure compound yields 1.200 g of water and 3.72 L of dry carbon dioxide, measured at 750. mm Hg and 25°C. Calculate the mass, in g, of each element in the 3.000 g sample.

(c) A student dissolved 1.625 g of pure acetylsalicylic acid in distilled water and titrated the resulting solution to the equivalence point using 88.43 mL of 0.102 *M* NaOH(*aq*). Assuming that acetylsalicylic acid has only one ionizable hydrogen, calculate the molar mass of the acid.

(d) A 2.00×10^{-3} mole sample of pure acetylsalicylic acid was dissolved in 15.00 mL of water and then titrated with 0.100 *M* NaOH(*aq*). The equivalence point was reached after 20.00 mL of the NaOH solution had been added. Using the data from the titration, shown in the table below, determine

(i) the value of the acid dissociation constant, K_a, for acetylsalicylic acid and

(ii) the pH of the solution after a total volume of 25.00 mL of the NaOH solution had been added (assume that volumes are additive).

Volume of 0.100 *M* NaOH Added (mL)	pH
0.00	2.22
5.00	2.97
10.00	3.44
15.00	3.92
20.00	8.13
25.00	?

a. $\frac{\text{Acid}}{\text{Tablet}}$ $325\,mg = 0.325\,g$ $\frac{0.325\,g}{2.00\,g} \times 100\% = 16.3\%$

b. $HAc + O_2 \rightarrow CO_2 + H_2O$

$1.20\,g\ H_2O \times \frac{2.01588\,g\ H_2}{18.01528\,g\ mol} = 0.134\,g\ H$

$PV = nRT \qquad n = \frac{PV}{RT}$

$n = \frac{\frac{750}{760}\,atm \cdot 3.72\,L}{298\,K \cdot 0.0821\,L\,atm/mol\,K} = 0.150\,mol\ CO_2$

Next (ctd.)

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$0.150\ mol\ CO_2 \times \frac{44g\ CO_2}{1\ mol\ CO_2} \times \frac{12g\ C}{44g\ CO_2} = 1.8g\ C$

$3.00g\ H_xO_yC_2 - 1.80g\ C - 0.134g\ H = 1.066g\ O$

1.80g Carbon 0.134g Hydrogen 1.07g O

c. $88.43\cancel{mL} \times 0.102\frac{mol}{\cancel{L}} \times \frac{1\cancel{L}}{1000\cancel{mL}} = 0.00902\ mol\ NaOH$

1 mol NaOH neutralizes 1 mol acetylsalicylic acid

$MM = \frac{g}{mol} = \frac{1.625g}{0.00902mol} = \frac{180.2\ g}{mol}$

d. i. pH = pKa at $\frac{1}{2}$ the equivalence point

the equivalence point = 20.00 mL $\frac{1}{2}$ = 10.00 mL

pH at 10.00 mL = 3.44

$pH = 3.44 = pK_a \qquad pK_a = -\log K_a$

$K_a = 3.63 \times 10^{-4}$

ii. $25.00\cancel{mL} - 20.00\ mL = 5.00\ mL\ NaOH$ (to neutralize acetylsalicylic acid)

$5.00\ mL\ NaOH \times \frac{1L}{1000mL} \times \frac{0.100\ Mol}{L} = 5.00 \times 10^{-4}\ mol$

$\frac{5.00 \times 10^{-4}\ mol}{(25.00mL + 15.00mL)} \times \frac{1000mL}{1L} = 0.0125\ M\ NaOH = 0.0125\ M\ [OH^-]$

$pOH = 1.90 \qquad pH + pOH = 14$

$pH = 12.10$

3B,

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3. (a) $325\ mg\ acid \cdot \frac{1\ g}{1000\ mg} = 0.325\ g.$

$$\frac{\text{mass of acid}}{\text{total mass}} = \frac{0.325\ g}{2.00\ g} = 16.3\%$$

(b) $1.2\ g\ H_2O \cdot \frac{1\ mol}{18\ g} \cdot \frac{2\ mol\ H}{1\ mol\ H_2O} \cdot \frac{1.01\ g\ H}{1\ mol\ H} = 0.135\ g\ H$

$$3.72\ L.\ CO_2 \cdot \frac{1\ mol}{22.4\ L} \cdot \frac{1\ mol\ C}{1\ mol\ CO_2} \cdot \frac{12.01\ g\ C}{1\ mol\ C} = 2.00\ g.C$$

$$3.600 - 0.135 - 2.000 = 0.865\ g.\ O$$

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(c) Equivalence point means there are equal number of moles...

moles of NaOH = moles of acetylsalicylic acid

moles of NaOH = $0.08843 \cdot 0.102\ M = 9.02 \cdot 10^{-3}$ mol

1.625 g acid = $9.02 \cdot 10^{-3}$ mol

$\frac{1.625}{9.02 \cdot 10^{-3}} = MM$

molar mass = 180.2 g/mol

(d) (i) pKa = pH at equivalence point

pKa = 8.13

$Ka = 10^{-8.13} = 7.41 \cdot 10^{-9}$

(ii) After equivalence point, there is just excess NaOH

25.00 ml NaOH − 20.00 ml = 5.00 ml

5.00 ml · 0.1 M NaOH = $5.0 \cdot 10^{-4}$ mol OH^-

$\frac{5.0 \cdot 10^{-4}\ \text{mol}\ OH^-}{(25.00\text{ml} + 15.00\text{ml})} = 0.0125\ M\ OH^-$

$-\log(0.0125) = 1.90 = pOH$

$pH = 14.00 - 1.90 = 12.10$

3C,

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a) $\frac{325\text{mg}}{2\text{g}} \cdot \frac{1\text{g}}{1000\text{mg}} = 16.25\% \cdot 100\% = \boxed{16.25\%}$

b) $H_2C_2O_4 + O_2 \rightarrow ?H_2O + ?CO_2$

$1.2\text{g}\,H_2O \cdot \frac{1\text{mol}\,H_2O}{18\text{g}\,H_2O} \cdot \frac{2\text{mol}\,H}{1\text{mol}\,H_2O} \cdot \frac{1\text{g}\,H}{1\text{mol}\,H} = \boxed{.13\text{g}\,H}$

$3.72\text{L}\,CO_2 \cdot \frac{1\text{mol}\,CO_2}{22.4\text{L}\,CO_2} \cdot \frac{1\text{mol}\,C}{1\text{mol}\,CO_2} \cdot \frac{12\text{g}\,C}{1\text{mol}\,C} = 1.9\text{g} \; \boxed{2.0\text{g}\,C}$

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c) $\frac{.102\,mol}{1\,L} \cdot .08843\,L \cdot \frac{1\,mol\,H^+}{1\,mol\,NaOH^-} = 9.02\cdot10^{-3}\,mol\,H^+$

$9.02\cdot10^{-3}\,mol\,H^+ \cdot \frac{1\,mol\,HA}{1\,mol\,H^+} = 9.02\cdot10^{-3}\,mol\,HA$

$\frac{1.625\,g\,HA}{9.02\cdot10^{-3}\,mol\,HA} = \boxed{180.2\,g/mol}$

d) ii) $\frac{2.00\cdot10^{-3}\,mol}{.015\,L} = .133\,mol/L$

$[H^+] = \frac{1\,mol}{1\,L} \cdot .02\,L \cdot \frac{1\,mol\,H^+}{1\,mol\,OH^-} \cdot \frac{1}{.015\,L} = .133\,mol/L$ $.133\,mol/L \cdot .015\,L = 2.0\cdot10^{-3}$

$HA \rightleftharpoons H^+ + A^-$

$2.00\cdot10^{-3}$ 0 0

$1.0\cdot10^{-3}$ $2.0\cdot10^{-3}$

$3.44 = pKa$

$10^{-3.44} = Ka$

$\boxed{Ka = 3.63\cdot10^{-4}}$

20ml is the equivalence point

↓

10ml is the half-point, where $pH = pKa$

ii) $pH = pKa + \log\left(\frac{A^-}{HA}\right)$