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|  | **Titration**  In acid-base chemistry, we often use titration to determine the pH of a certain solution.  A setup for the titration of an acid with a base:  titsetup.gif  We use this instrumentation to calculate the amount of unknown acid in the receiving flask by measuring the amount of **base**, or **titrant**, it takes to **neutralize** the **acid**. There are two major ways to know when the solution has been neutralized. The first uses a pH meter in the receiving flask adding base slowly until the pH reads exactly 7. The second method uses an indicator. An indicator is an acid or base whose conjugate acid or conjugate base has a color different from that of the original compound. The color changes when the solution contains a 1:1 mixture of the differently colored forms of the indicator. Since we know the pH of the solution and the volume of titrant added, we can then deduce how much base was needed to neutralize the unknown sample.  **Titration Curves**  A titration curve is drawn by plotting data attained during a titration, titrant volume on the *x*-axis and pH on the *y*-axis. The titration curve serves to profile the unknown solution. In the shape of the curve lies much chemistry and an interesting summary of what we have learned so far about acids and bases.  The titration of a strong acid with a strong base produces the following titration curve:  http://img.sparknotes.com/figures/3/3a5994498f24d59f5d5d762b40844a2a/sasb.gif  ***Figure 1: Titration curve of a strong base titrating a strong acid***  Note the sharp transition region near the equivalence point on the Fig 1. Also remember that the equivalence point for a strong acid-strong base titration curve is exactly 7 .  **Titration Calculations**   * **You know how to calculate the molecular mass of a given chemical formula** * **You know how to calculate the number of moles**   * **You know how to manipulate the equations to get the form you require.**   When you are confronted by a Titration calculation the first rule is:    **DON’T PANIC!**    The Second rule is read through the question very carefully.  The Third rule is read through the question carefully again!  You biggest adversary is not your math skills; it’s the understanding of the question. Take your time, read it through and make a drawing if it helps. Don’t forget your units!!    We are now going to look at a question and hopefully guide the unbelievers (henceforth known as infidels) through a titration calculation. You should have laughed at that one… LOL…If you know how to do these, go straight to the questions at the end.  **The question:**  10.0 cm3 aka 10.0 ml of a solution of potassium hydroxide was titrated with a 0.10 M solution of hydrochloric acid. 13.5 cm3 of the acid was required for neutralization. Calculate the concentration of the potassium hydroxide solution.  **Step 1**  Write down everything you know. Placing the one you know most about on the left (you don’t have to do this, but it’s just a good idea ☺).    Hydrochloric Acid                                                      Potassium hydroxide  Volume used = 13.5 cm3                                          Volume used = 10.0 cm3  Concentration = 0.10 M                                            Concentration = TBD  **Step 2**  Write the equation or as much as you know about it.   HCl(aq) + NaOH(aq) → NaCl(aq) + H2O(l)   This is necessary to check out the ratios of reactants – in this case 1:1 so we don’t have to worry about any ratios. Remember to always balance your equations!!  **Step 3**  Calculate the Number of Moles used of the reactant you know most about. In this case the HCl(aq)    The rule here is Number of Moles = volume × concentration  http://www.webchem.net/images/Titrations1.png  **Step 3**  Work out how many moles of the unknown you have used, this is where you may need to multiply up or down the number of moles, so if 1 mole of HCl needed 2 mol of potassium hydroxide, then at this point you would multiply the number of moles of HCl by 2. In this case this is unnecessary.    Number of moles of HCl = 0.0014 mol    Number of moles KOH = 0.0014 mol – they react in a one to one ratio  **Step 4**    Work out the concentration of the potassium hydroxide.      Concentration = 0.14 M  **Q1 A solution of sodium hydroxide contained 0.25 mol dm-3. Using phenolphthalein indicator, titration of 25.0 cm3 of this solution required 22.5 cm3 of a hydrochloric acid solution for complete neutralisation.**  **(a) write the equation for the titration reaction.**  **(b) what apparatus would you use to measure out (i) the sodium hydroxide solution? (ii) the hydrochloric acid solution?**  **(c) what would you rinse your apparatus out with before doing the titration ?**  **(d) what is the indicator colour change at the end-point?**  **(e) calculate the moles of sodium hydroxide neutralised.**  **(f) calculate the moles of hydrochloric acid neutralised.**  **(g) calculate the concentration of the hydrochloric acid in mol/dm3 (molarity).**    **Q2 A solution made from pure barium hydroxide contained 2.74 g in exactly 100 cm3 of water. Using phenolphthalein indicator, titration of 20.0 cm3 of this solution required 18.7 cm3 of a hydrochloric acid solution for complete neutralisation. [atomic masses: Ba = 137, O = 16, H = 1)**  **(a) write the equation for the titration reaction.**  **(b) calculate the molarity of the barium hydroxide solution.**  **(c) calculate the moles of barium hydroxide neutralised.**  **(d) calculate the moles of hydrochloric acid neutralised.**  **(e) calculate the molarity of the hydrochloric acid**  **Q3 4.90g of pure sulphuric acid was dissolved in water, the resulting total volume was 200 cm3. 20.7 cm3 of this solution was found on titration, to completely neutralise 10.0 cm3 of a sodium hydroxide solution. [atomic masses: S = 32, O = 16, H = 1)**  **(a) write the equation for the titration reaction.**  **(b) calculate the molarity of the sulphuric acid solution.**  **(c) calculate the moles of sulphuric acid neutralised.**  **(d) calculate the moles of sodium hydroxide neutralised.**  **(e) calculate the concentration of the sodium hydroxide in mol dm-3 (molarity).**  **Q4 100 cm3 of a magnesium hydroxide solution required 4.5 cm3 of sulphuric acid (of concentration 0.1 mol dm-3) for complete neutralisation. [atomic masses: Mg = 24.3, O = 16, H = 1)**  **(a) give the equation for the neutralisation reaction.**  **(b) calculate the moles of sulphuric acid neutralised.**  **(c) calculate the moles of magnesium hydroxide neutralised.**  **(d) calculate the concentration of the magnesium hydroxide in mol dm-3 (molarity).**  **(e) calculate the concentration of the magnesium hydroxide in g cm-3.**  **Q5 Magnesium oxide is not very soluble in water, and is difficult to titrate directly. Its purity can be determined by use of a 'back titration' method. 4.06 g of impure magnesium oxide was completely dissolved in 100 cm3 of hydrochloric acid, of concentration 2.0 mol dm-3 (in excess). The excess acid required 19.7 cm3 of sodium hydroxide (0.20 mol dm-3) for neutralisation. This 2nd titration is called a 'back-titration', and is used to determine the unreacted acid. [atomic masses: Mg = 24.3, O = 16)**  **(a) write equations for the two neutralisation reactions.**  **(b) calculate the moles of hydrochloric acid added to the magnesium oxide.**  **(c) calculate the moles of excess hydrochloric acid titrated.**  **(d) calculate the moles of hydrochloric acid reacting with the magnesium oxide.**  **(e) calculate the moles and mass of magnesium oxide that reacted with the initial hydrochloric acid.**  **(f) hence the % purity of the magnesium oxide.**  **(g) what compounds could be present in the magnesium oxide that could lead to a false value of its purity ? explain.**  **Q6 2 dm3 of concentrated hydrochloric acid (10 M) was spilt onto a laboratory floor. It can be neutralised with limestone powder. [atomic masses: Ca = 40, C = 12, O = 16)**  **(a) give the equation for the reaction between limestone and hydrochloric acid.**  **(b) how many moles of hydrochloric acid was spilt?**  **(c) how many moles of calcium carbonate will neutralise the acid?**  **(d) what minimum mass of limestone powder is needed to neutralise the acid?**  **(e) 1000 dm3 of sulphuric acid, of concentration 2 mol dm-3, leaked from a tank.**  **Q7 A 50.0 cm3 sample of sulphuric acid was diluted to 1.00 dm3. A sample of the diluted sulphuric acid was analysed by titrating with aqueous sodium hydroxide. In the titration, 25.00 cm3 of 1.00 mol dm-3 aqueous sodium hydroxide required 20.0 cm3 of the diluted sulphuric acid for neutralisation.**  **(a) give the equation for the full neutralisation of sulphuric acid by sodium hydroxide.**  **(b) calculate how many moles of sodium hydroxide were used in the titration?**  **(c) calculate the concentration of the diluted acid.**  **(d) calculate the concentration of the original concentrated sulphuric acid solution.**  **Calculate the minimum mass of magnesium oxide required to neutralise it.**  **Solutions**  **Q1 (a) NaOH(aq) + HCl(aq) ==> NaCl(aq) + H2O(l)**  **(b) (i) pipette (ii) burette**  **(c) everything with distilled water, then pipette with a little of the NaOH(aq) and the burette with a little of the HCl(aq)**  **(d) pink to colourless, the first drop of excess acid removes the pink alkaline colour of phenolphthalein**  **(e) moles sodium hydroxide neutralised: 0.25 x 25/1000 = 0.00625 mol NaOH**  (remember: **moles = molarity x volume in dm3** and its two rearrangements and 1 dm3 = 1000 cm3)  **(f) moles HCl = moles NaOH (equation) = 0.00625 mol HCl (in 22.5 cm3)**  **(g) concentration hydrochloric acid = 0.0062 x 1000 ÷ 22.5 = 0.278 mol dm-3**  (scaling up to 1 dm3 = 1000 cm3 to get the molarity)    **Q2 (a) Ba(OH)2(aq) + 2HCl(aq) ==> BaCl2(aq) + 2H2O(l)**  **(b) formula mass of Ba(OH)2 = 171, moles = 2.74 ÷ 171 = 0.016 mol in 100 cm3,**  **therefore 0.16 mol in 1000 cm3, so molarity of Ba(OH)2 is 0.16 mol dm-3**  **(c) moles Ba(OH)2 used in titration = 0.16 x 20/1000 = 0.0032 mol**  **(d) moles HCl titrated = 2 x moles of Ba(OH)2 used (2 : 1 in equation)**  **= 0.0064 mol HCl in 18.7 cm3 of the acid solution, 18.7 cm3 = 0.0187 dm3**  **(e) therefore molarity of HCl(aq) = 0.0064/0.0187 = 0.342 mol dm-3**    **Q3 (a) 2NaOH(aq) + H2SO4(aq) ==> Na2SO4(aq) + 2H2O(l)**  **(b) moles H2SO4 = 4.90 ÷ 98 = 0.05 mol in 200cm3**  **scaling up to get molarity of the sulphuric acid solution, 0.05 x 1000 ÷ 200 = 0.25 mol dm-3**  **(c) moles of sulphuric acid neutralised = 0.25 x 20.7/1000 = 0.005175 mol**  **(d) moles of sodium hydroxide neutralised = 2 x 0.005175 = 0.01035 mol** (2 : 1 in equation)  **(e) concentration of the sodium hydroxide = 0.01035 x 1000 ÷ 10 = 1.035 mol dm-3** (molarity 1.04, 3sf)    **Q4 (a) Mg(OH)2(aq) + H2SO4(aq) ==> MgSO4(aq) + 2H2O(l)**  **(b) moles of sulphuric acid neutralised = 0.1 x 4.5/1000 = 0.00045 mol**  **(c) moles of magnesium hydroxide neutralised also = 0.00045 (1:1 in equation) in 100 cm3**  **(d) concentration of the magnesium hydroxide in mol dm-3 = 0.00045 x 1000 ÷ 100 = 0.0045**  (scaling up to 1000cm3=1dm3,  to get molarity)  **(e) molar mass of Mg(OH)2 = 58.3**  **so concentration of the magnesium hydroxide = 0.0045 x 58.3 = 0.26 g dm-3 (= g per 1000 cm3),**  **so concentration = 0.26 ÷ 1000 = 0.00026 g cm-3**    **Q5 (a)(i) MgO(s) + 2HCl(aq) ==> MgCl2(aq) + H2O(l)**  **(a)(ii) NaOH(aq) + HCl(aq) ==> NaCl(aq) + H2O(l)**  **(b) moles of hydrochloric acid added to the magnesium oxide = 2 x 100/1000 = 0.20 mol HCl**  **(c) moles of excess hydrochloric acid titrated = 19.7 ÷ 1000 x 0.2 = 0.00394 mol HCl**  {mole ratio NaOH:HCl is 1:1 from equation (ii)}  **(d) moles of hydrochloric acid reacting with the magnesium oxide = 0.20 - 0.00394 = 0.196 mol HCl**  **(e) mole MgO reacted = 0.196 ÷ 2 = 0.098** {1: 2 in equation (i)}  **the formula mass of MgO = 40.3**  **therefore mass of MgO reacting with acid = 0.098 x 40.3 = 3.95 g**  **(f) % purity = 3.95 ÷ 4.06 x 100 = 97.3% MgO**  **(g) Mg(OH)2 from MgO + H2O, MgCO3 from the original mineral source, both of these compounds react with acid and would lead to a false titration value.**      **Q6 (a) CaCO3(s) + 2HCl(aq) ==> CaCl2(aq) + H2O(l) + CO2(g)**  **(b) moles of hydrochloric acid was spilt = 2 x 10 = 20 mol HCl**  **(c) moles of calcium carbonate to neutralise the acid = 20 ÷ 2 = 10 mol CaCO3** (1:2 in equation)  **(d) formula mass of CaCO3 = 100,**  **so mass of limestone powder needed to neutralise the acid = 100 x 10 = 1000g CaCO3**  **(e) the neutralisation reaction is MgO + H2SO4 ==> MgSO4 + H2O,**  **moles H2SO4 = 1000 x 2 = 2000 mol acid, 2000 mol MgO needed** (1:1 in equation),  **mass MgO needed = 2000 x 40.3 = 80600 g** or **80.6 kg**    **Q7 (a) 2NaOH(aq) + H2SO4(aq) ==> Na2SO4(aq) + 2H2O(l)**  **(b) moles of sodium hydroxide used in the titration = 25 x 1/1000 = 0.025 mol NaOH**  **(c) mol H2SO4 = mol NaOH ÷ 2 = 0.0125 mol in 20 cm3,**  **so scaling up to 1000 cm3 to get molarity of diluted acid = 0.0125 x 1000 ÷ 20 = 0.625 mol dm-3**  (or molarity = 0.0125 mol/0.02 dm3 = 0.625 mol dm-3)  **(d) scaling up from 50 to 1000 cm3, gives the concentration of the original concentrated sulphuric acid solution,**  **= 0.625 x 1000 ÷ 50 = 12.5 mol dm-3** |