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Topic 4.6: Introduction to Titration

Worksheet · AP Chemistry

UNIT 4 · CHEMICAL REACTIONS

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How to Use This Worksheet

Work in order. Section A checks the ideas: the roles of the two solutions, the apparatus, and the difference between the endpoint and the equivalence point. Section B builds the calculation: 1 : 1 titrations, ratios that are not 1 : 1, averaging concordant titres, and a back titration. Section C combines everything in exam style, including judging laboratory errors by the direction they push the answer.

Every calculation follows the same three steps: moles of titrant from its concentration and the titre in litres, the mole ratio from the balanced equation, then the concentration or volume asked for. Carry unrounded values through and round only the final answer, to three significant figures. Molar masses you need: $CaCO_3$ 100.09 g/mol, CH_3COOH 60.05 g/mol.

Two habits protect your result. First, only concordant titres are ever averaged, and the rough run is never one of them. Second, whenever a procedure goes wrong, decide the direction of the error before its size: ask whether the recorded titre is larger or smaller than the truth, and follow the moles from there.

Do not look at the answer key until you have attempted every question.

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Section A: Recall and Concepts

A1. Define each term in one sentence. (a) Titrant. (b) Analyte. (c) Standard solution. (d) Equivalence point. (e) Endpoint. (f) Titre.

A2. Explain the reason for each piece of titration technique. (a) The burette is rinsed with the titrant before it is filled. (b) The pipette is rinsed with the analyte before use. (c) The flask is swirled throughout the titration. (d) Only two or three drops of indicator are added. (e) During the titration the sides of the flask are washed down with distilled water, and this does not change the result.

A3. A student records these burette readings for three accurate titrations of the same solutions: (1) initial 1.05 mL, final 25.30 mL; (2) initial 0.60 mL, final 24.75 mL; (3) initial 2.10 mL, final 26.30 mL. (a) Calculate the three titres. (b) State whether the titres are concordant, giving your reason. (c) Calculate the mean titre to use in the calculation.

A4. (a) State the difference between the equivalence point and the endpoint. (b) Sodium hydroxide is added from a burette to hydrochloric acid with phenolphthalein in the flask. Explain why the endpoint volume is always slightly larger than the equivalence volume. (c) A student adds titrant until the flask is a deep pink. State two separate problems with the result of that titration.

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A5. A titration curve is drawn for 25.0 mL of 0.100 M HCl in a flask with NaOH solution added from a burette. The curve starts near pH 1, rises slowly, then climbs steeply between 24.90 mL and 25.10 mL of added NaOH, crossing pH 7.0 at 25.00 mL, before levelling off near pH 13. (a) State what is plotted on each axis. (b) State the equivalence volume and how it is read from the curve. (c) State the pH at the equivalence point and explain why it has that value here. (d) Explain why one drop of NaOH added near 25.00 mL changes the pH far more than one drop added at the start.

Section B: Core Practice

B1. A 25.0 mL sample of NaOH solution is titrated with 0.150 M HCl, and the titre is 18.60 mL. The equation is $HCl + NaOH \rightarrow NaCl + H_2O$. (a) Calculate the moles of HCl delivered. (b) State the moles of NaOH in the flask. (c) Calculate the concentration of the NaOH solution.

B2. A flask holds 20.0 mL of 0.250 M HCl. It is titrated with 0.100 M NaOH. (a) Calculate the moles of HCl in the flask. (b) Calculate the moles of NaOH needed to neutralise it exactly. (c) Calculate the volume of the NaOH solution required.

B3. A 25.0 mL sample of H_2SO_4 is neutralised by 30.00 mL of 0.120 M NaOH. The equation is $H_2SO_4 + 2NaOH \rightarrow Na_2SO_4 + 2H_2O$. (a) Calculate the moles of NaOH delivered. (b) Calculate the moles of H_2SO_4 in the flask. (c) Calculate the concentration of the H_2SO_4. (d) State the ratio you used in part (b) and where it comes from.

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B4. The equation for sulfuric acid with potassium hydroxide is $H_2SO_4 + 2KOH \rightarrow K_2SO_4 + 2H_2O$. A flask holds 20.0 mL of 0.100 M H_2SO_4. (a) Calculate the moles of H_2SO_4 present. (b) Calculate the moles of KOH needed to neutralise it. (c) Calculate the volume of 0.250 M KOH required.

B5. A student titrates 25.0 mL of HCl with 0.100 M NaOH and records: rough run, 0.00 mL to 24.10 mL; run 1, 0.05 mL to 23.50 mL; run 2, 23.50 mL to 47.05 mL; run 3, 0.10 mL to 23.60 mL. (a) Calculate the titre of each run. (b) Identify the concordant titres and calculate their mean. (c) Use the mean titre to calculate the concentration of the HCl.

B6. A 0.500 g sample of limestone, mostly $CaCO_3$, is dissolved in 25.0 mL of 0.500 M HCl, an excess. The equation is $CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2O + CO_2$. The unreacted acid is then titrated with 0.250 M NaOH, and 18.75 mL is required. (a) Calculate the moles of HCl added at the start. (b) Calculate the moles of NaOH used, and hence the moles of HCl left unreacted. (c) Calculate the moles of HCl that reacted with the limestone. (d) Calculate the moles and the mass of $CaCO_3$ in the sample. (e) Calculate the percentage purity of the limestone.

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Section C: Exam Style

C1. Vinegar is a solution of ethanoic acid, CH_3COOH. A 25.0 mL sample of vinegar is titrated with 0.500 M NaOH, and the titre is 22.40 mL. The equation is $CH_3COOH + NaOH \rightarrow CH_3COONa + H_2O$. (a) Calculate the moles of NaOH delivered. (b) Calculate the moles of ethanoic acid in the sample. (c) Calculate the concentration of ethanoic acid in the vinegar. (d) Calculate the mass of ethanoic acid in 1.00 L of the vinegar. (e) The endpoint is taken as the first permanent pink from phenolphthalein. Explain what that colour tells you about which reactant is in excess at the endpoint.

C2. Four students describe what they did in a titration where a standard base in the burette was used to find the concentration of an acid in the flask. For each one, state the effect on the calculated concentration of the acid, too high, too low, or no effect, and explain your reasoning. (a) "I rinsed the burette with distilled water and filled it straight away. My titres were larger than expected, but the calculated concentration is unaffected because the extra volume cancels out." (b) "An air bubble in the burette tip escaped during my best run, so the liquid level fell further than usual." (c) "I rinsed the conical flask with the acid solution before pipetting the measured sample into it." (d) "Halfway through, I washed the inside walls of the flask down with distilled water so nothing was left unmixed."

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C3. A student titrates 25.0 mL of HCl of unknown concentration with 0.100 M NaOH, recording the pH as she goes. The steep section of her curve is centred on 25.00 mL of added NaOH. (a) State the volume of NaOH at the equivalence point. (b) Calculate the moles of NaOH added at the equivalence point. (c) Calculate the concentration of the HCl. (d) State the pH at the equivalence point and explain why. (e) Her partner stops the same titration at the indicator endpoint, 25.30 mL. Calculate the concentration he would report for the HCl and the percentage error in it, and state whether it is too high or too low.

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Answer Key

A1. (a) The solution of known concentration, delivered from the burette. (b) The solution of unknown concentration being analysed, a measured volume of which sits in the flask. (c) A solution whose concentration is known accurately, used as the titrant. (d) The point at which the reactants have been mixed in the exact mole ratio of the balanced equation, so neither is in excess. (e) The point at which the indicator changes colour and the titration is stopped. (f) The volume of titrant delivered, the final burette reading minus the initial reading.

A2. (a) Water left inside would dilute the titrant, so the delivered solution would be weaker than its stated concentration and the titre too large. (b) Any other liquid inside would contaminate or dilute the measured sample of analyte, changing the moles it contains. (c) Swirling mixes each addition through the whole flask so the reaction is complete everywhere; without it, a local excess of titrant near the jet could change the indicator's colour before the bulk has reacted. (d) The indicator is itself a weak acid or base and consumes titrant as it changes colour; a large amount would consume a measurable share and shift the endpoint. (e) The wash water adds no analyte and removes none; it changes the volume in the flask but not the moles of analyte, and the titration counts moles.

A3. (a) 25.30 − 1.05 = 24.25 mL; 24.75 − 0.60 = 24.15 mL; 26.30 − 2.10 = 24.20 mL. (b) Yes: the largest and smallest differ by only 0.10 mL, so all three lie within 0.10 mL of each other. (c) (24.25 + 24.15 + 24.20) ÷ 3 = 24.20 mL.

A4. (a) The equivalence point is where the reactants stand in the exact ratio of the balanced equation; the endpoint is where the indicator changes colour and addition stops. One belongs to the reaction, the other to the observation. (b) The colour change needs hydroxide in slight excess to appear: phenolphthalein only turns pink once a little NaOH remains unreacted. That extra fraction of a drop is delivered after the equivalence point, so the recorded volume is always a little larger. (c) Any two of: the volume recorded overshoots the equivalence point, so the calculated moles and concentration are too high; the deep colour means the excess is far more than the fraction of a drop the indicator needs, so the error is large rather than minimal; the run cannot be corrected by calculation and must be repeated.

A5. (a) pH on the vertical axis, volume of NaOH added on the horizontal axis. (b) 25.00 mL, read at the midpoint of the steep section of the curve. (c) 7.0. Equal moles of a strong acid and a strong base have reacted to give a neutral salt and water, with no excess of H^+ or OH^- left in solution. (d) At the start the flask holds a large excess of H^+, so one drop's OH^- neutralises only a tiny fraction of it and the pH barely moves. Near the equivalence point almost no excess remains, so the same drop removes a large fraction of what is left, or tips the mixture into excess OH^-, and the pH jumps by several units.

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B1. (a) Moles of HCl = 0.150 × 0.01860 = 0.00279 mol. (b) The ratio is 1 : 1, so moles of NaOH = 0.00279 mol. (c) Concentration = 0.00279 ÷ 0.0250 = 0.112 M.

B2. (a) Moles of HCl = 0.250 × 0.0200 = 0.00500 mol. (b) The ratio is 1 : 1, so 0.00500 mol of NaOH. (c) Volume = 0.00500 ÷ 0.100 = 0.0500 L = 50.0 mL.

B3. (a) Moles of NaOH = 0.120 × 0.03000 = 0.00360 mol. (b) The equation consumes 2 mol of NaOH per mole of H_2SO_4, so moles of acid = 0.00360 ÷ 2 = 0.00180 mol. (c) Concentration = 0.00180 ÷ 0.0250 = 0.0720 M. (d) 2 : 1, NaOH to H_2SO_4, taken from the coefficients of the balanced equation.

B4. (a) Moles of H_2SO_4 = 0.100 × 0.0200 = 0.00200 mol. (b) The ratio is 1 : 2, so moles of KOH = 2 × 0.00200 = 0.00400 mol. (c) Volume = 0.00400 ÷ 0.250 = 0.0160 L = 16.0 mL.

B5. (a) Rough: 24.10 − 0.00 = 24.10 mL. Run 1: 23.50 − 0.05 = 23.45 mL. Run 2: 47.05 − 23.50 = 23.55 mL. Run 3: 23.60 − 0.10 = 23.50 mL. (b) The rough titre is discarded. Runs 1 to 3 span 23.45 to 23.55 mL, within 0.10 mL, so all three are concordant. Mean = (23.45 + 23.55 + 23.50) ÷ 3 = 23.50 mL. (c) Moles of NaOH = 0.100 × 0.02350 = 0.00235 mol. The ratio is 1 : 1, so the flask held 0.00235 mol of HCl, and the concentration is 0.00235 ÷ 0.0250 = 0.0940 M.

B6. (a) Moles of HCl = 0.500 × 0.0250 = 0.0125 mol. (b) Moles of NaOH = 0.250 × 0.01875 = 0.00469 mol. Neutralisation is 1 : 1, so 0.00469 mol of HCl was left unreacted. (c) HCl reacted = 0.0125 − 0.00469 = 0.00781 mol. (d) The equation uses 2 mol of HCl per mole of $CaCO_3$, so moles of $CaCO_3$ = 0.00781 ÷ 2 = 0.00391 mol, with mass 0.00391 × 100.09 = 0.391 g. (e) Purity = 0.391 ÷ 0.500 × 100 = 78.2%.

C1. (a) Moles of NaOH = 0.500 × 0.02240 = 0.0112 mol. (b) The ratio is 1 : 1, so moles of ethanoic acid = 0.0112 mol. (c) Concentration = 0.0112 ÷ 0.0250 = 0.448 M. (d) Mass in 1.00 L = 0.448 × 60.05 = 26.9 g. (e) Phenolphthalein turns pink only when hydroxide ions remain unreacted in the flask. The first permanent pink therefore shows that NaOH is in slight excess and every ethanoic acid molecule has reacted: the endpoint sits just past the equivalence point, not before it.

C2. (a) Too high. The claim is wrong: the water dilutes the titrant, so a larger volume is needed to deliver the required moles, and nothing cancels. Worse, the moles are then calculated using the labelled concentration as if the titrant were undiluted, so too many moles are credited and the acid's concentration comes out too high. (b) Too high. The bubble's volume is counted in the burette reading difference but no titrant was delivered for that part of the fall, so the recorded titre exceeds the volume actually added, and the calculated concentration follows it up. (c) Too high. The rinse leaves extra acid in the flask beyond the measured 25.0 mL sample, so extra titrant is consumed and the extra moles are credited to the measured sample. (d) No effect. The added water changes the volume in the flask but not the moles of acid present, and the titration counts moles, so the titre and the result stand.

C3. (a) 25.00 mL, the midpoint of the steep section. (b) Moles of NaOH = 0.100 × 0.02500 = 0.00250 mol. (c) The ratio is 1 : 1, so the flask held 0.00250 mol of HCl, and its concentration is 0.00250 ÷ 0.0250 = 0.100 M. (d) pH 7.0: a strong acid and a strong base in exactly equal moles leave a neutral

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salt solution with no excess H^+ or OH^-. (e) Moles credited = 0.100 × 0.02530 = 0.00253 mol, giving a concentration of 0.00253 ÷ 0.0250 = 0.101 M. The error is (0.101 − 0.100) ÷ 0.100 × 100 = 1.20%, and the reported value is too high, because the endpoint volume is larger than the equivalence volume.

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