RT · Redox titrations

Completed notes | Notes 1/3

Use titre, mole ratio and volume to find an unknown concentration or mass, and judge how an error changes the result.

1. The titration and its volumes

Two solutions, two jobs

A titration finds an unknown concentration. The **titrant** is the solution of known concentration in the buret, the tall tube with a tap. The **analyte** is the solution of unknown concentration in the flask.

We add titrant until the reaction is just complete. A **pipette** delivers a fixed volume of analyte into the flask more precisely than a graduated cylinder. A **buret** delivers the titrant and measures how much was used.

The titre is the volume of titrant delivered: titre = **final reading − initial reading**. A buret counts up from zero as liquid leaves. Read the meniscus, the curved surface, at eye level.

With initial 0.40 mL and final 18.90 mL, the titre is **18.50 mL**. Never assume the start is 0.00.

On the diploma: the readings are given, and a wrong option often uses the final reading without subtracting.

Watch: A titration has one known and one unknown (Alberta Chemistry Teacher, “Chemistry 30 - Redox titration example. Acidified chromium (II) ions with dichromate.”, 0:24)

Choose the trials

One trial may hold a mistake, so we repeat it and average only the trials that agree within the limit the question gives. Given 18.50 mL, 18.60 mL and 19.60 mL with a 0.20 mL limit, the agreeing trials are **18.50 and 18.60**.

Their average is **18.55 mL**. The 19.60 mL trial is left out because it **disagrees by more than the limit**, probably because too much titrant was added past the endpoint, which is the colour change that tells us to stop.

Watch: Average the volumes (Alberta Chemistry Teacher, “Chemistry 30 - Redox titration example. Acidified chromium (II) ions with dichromate.”, 8:31)

Watch: Leave out any trial more than 0.2 mL away (Alberta Chemistry Teacher, “Chemistry 30 - Redox titration example. Acidified chromium (II) ions with dichromate.”, 9:17)

Initial 0.40 mL; final 18.90 mL. Titre = 18.50 mL

Trials 18.50, 18.60, 19.60 mL (limit 0.20 mL). Average of agreeing trials = 18.55 mL

Chain: n(titrant) → mole ratio → n(analyte) → c(analyte)

Divide moles of analyte by the analyte (flask) volume.

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2. The equation and the endpoint

The equation gives the ratio

The balanced equation counts particles, so its coefficients also give mole ratios. Given $MnO_4^- + 8H^+ + 5Fe^{2+} \rightarrow Mn^{2+} + 4H_2O + 5Fe^{3+}$. One MnO_4^- reacts with **5** Fe^{2+}, so $n(Fe^{2+}) = \mathbf{5} \times n(MnO_4^-)$.

The reason is electrons, as in B3. Each MnO_4^- takes **5e⁻** (Mn +7 → +2) and each Fe^{2+} gives only **1e⁻** (+2 → +3). So five Fe^{2+} give the electrons for one MnO_4^-.

Reduction values from the data booklet: MnO_4^-/Mn^{2+} +1.51 V and Fe^{3+}/Fe^{2+} +0.77 V. The higher value is the oxidizing agent, so E° = 1.51 − 0.77 = **+0.74 V**. Acidified MnO_4^- or $Cr_2O_7^{2-}$ is usually the strongest oxidizing agent in a titration.

A positive value means the direction is spontaneous. It does not say the reaction is fast.

On the diploma: the mole ratio comes from the equation in the question, and wrong options often use a 1 : 1 ratio.

Watch: Start with a balanced redox equation (Alberta Chemistry Teacher, “Chemistry 30 - Redox titration example. Acidified chromium (II) ions with dichromate.”, 0:57)

Watch: Match the electrons, then write the equation (Alberta Chemistry Teacher, “Chemistry 30 - Redox titration example. Acidified chromium (II) ions with dichromate.”, 5:01)

Watch: Required over given: the coefficient ratio (Alberta Chemistry Teacher, “Chemistry 30 - Redox titration example. Acidified chromium (II) ions with dichromate.”, 13:42)

Endpoint and equivalence

MnO_4^- is **purple** and Mn^{2+} in dilute solution is almost **colourless**. While Fe^{2+} remains, each drop of purple turns colourless.

After the last Fe^{2+} reacts, one extra drop leaves a faint **pink** that stays. Permanganate is its own indicator, so no extra indicator is needed.

Equivalence is the exact point where moles are in the **equation ratio**, and we calculate it. The endpoint is the colour change we **see**. A deep pink means too much titrant was added, so the titre is too **large**.

On the diploma: describe the endpoint as the first faint colour that stays, and keep equivalence (calculated) apart from endpoint (seen).

Watch: A redox titration: titrant and sample (Alberta Chemistry Teacher, “Chemistry 30 - Example: predicting redox reaction and observations of reactants and products”, 10:26)

Watch: Colours of ions on page 11 of the booklet (Alberta Chemistry Teacher, “Chemistry 30 - Example: predicting redox reaction and observations of reactants and products”, 10:47)

Watch: Orange fades to blue-green at the equivalence point (Alberta Chemistry Teacher, “Chemistry 30 - Example: predicting redox reaction and observations of reactants and products”, 11:45)

Watch: No indicator needed: use the colours of the reactants (Alberta Chemistry Teacher, “Chemistry 30 - Redox titration example. Acidified chromium (II) ions with dichromate.”, 17:01)

Watch: Permanganate: the purple tells you when to stop (Alberta Chemistry Teacher, “Chemistry 30 - Redox titration example. Acidified chromium (II) ions with dichromate.”, 18:21)

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3. The calculation chain and errors

Titrant moles to concentration

Concentration is moles per litre, so volumes go in litres. Given 25.00 mL of Fe^{2+} and an average titre of 18.50 mL of 0.0200 mol/L MnO_4^-. $n(MnO_4^-) = 0.0200 \times 0.01850 =$ **3.70×10^{-4} mol**.

Use the ratio, 5 Fe^{2+} for each MnO_4^-: $n(Fe^{2+}) = 5 \times 3.70 \times 10^{-4} =$ **1.85×10^{-3} mol**. Divide by the **flask volume** 0.02500 L to get **0.0740 mol/L**.

We do not divide by the **titre**. It is the volume of titrant, not the volume of the solution that held the iron(II).

On the diploma: forgetting to convert mL to L is a common wrong option, so convert first and write the unit beside each number.

Watch: The same three steps every time (Alberta Chemistry Teacher, “Chemistry 30 - Redox titration example. Acidified chromium (II) ions with dichromate.”, 10:45)

Watch: Step 1: moles of the known (Alberta Chemistry Teacher, “Chemistry 30 - Redox titration example. Acidified chromium (II) ions with dichromate.”, 12:02)

Watch: Step 3: concentration of the unknown (Alberta Chemistry Teacher, “Chemistry 30 - Redox titration example. Acidified chromium (II) ions with dichromate.”, 14:55)

Aliquots and errors

An aliquot is a measured part of a larger solution. If 20.00 mL is taken from 100.0 mL, the whole is 100.0 ÷ 20.00 = 5.000 times bigger, so multiply the aliquot moles by **5.000**.

Mass of iron = moles × **55.85 g/mol**. Mass percent = mass of iron ÷ mass of **sample** × 100.

The titre sets the moles of titrant, those set the moles of analyte, and those set the concentration. Adding too much titrant makes the titre too large, so all three come out too **high**.

On the diploma: to judge an error, follow the chain and mark each step larger, smaller or unchanged before you choose.

Watch: Buret and pipette: what is in each (Alberta Chemistry Teacher, “Chemistry 30 - Redox titration example. Acidified chromium (II) ions with dichromate.”, 8:11)

Watch: Pipette precision and significant figures (Alberta Chemistry Teacher, “Chemistry 30 - Redox titration example. Acidified chromium (II) ions with dichromate.”, 15:45)

RT · Worked practice

Redox titrations | Questions 1-2 of 12

State symbols: (s) solid, (aq) dissolved in water, (l) liquid, (g) gas. Use the supplied reaction and conditions. B4 values name the Alberta Chemistry 30 Data Booklet table where used.

RT-P01 · Easy · Buret readings: initial 3.05 mL, final 24.55 mL. Find the titre.

1. Titre = final − initial = 24.55 − 3.05 = 21.50 mL.

2. The readings increase as liquid leaves the buret, so the final reading is larger. Do not assume the initial reading is 0.00.

RT-P02 · Easy · Trials: 20.10 mL, 20.20 mL, 21.30 mL. The limit is 0.20 mL. Which trials are averaged, and what is the average?

1. The first two trials differ by 0.10 mL, within the limit. The third differs by more than 1 mL, so it is left out.

2. The average is (20.10 + 20.20) ÷ 2 = 20.15 mL.

RT · Worked practice

RT-P03 · Easy · Given $MnO_4^- + 8H^+ + 5Fe^{2+} \rightarrow Mn^{2+} + 4H_2O + 5Fe^{3+}$. How many moles of Fe^{2+} react with 2.0×10^{-4} mol of MnO_4^-? Explain the ratio using electrons.

1. $n(Fe^{2+}) = 5 \times 2.0 \times 10^{-4} = 1.0 \times 10^{-3}$ mol.

2. Each MnO_4^- takes 5 electrons (Mn +7 → +2) and each Fe^{2+} gives 1 electron, so five Fe^{2+} are needed for each MnO_4^-.

RT-P04 · Easy · Use +1.51 V for MnO_4^-/Mn^{2+} and +0.77 V for Fe^{3+}/Fe^{2+}. Which reactant is the oxidizing agent, and what is E°cell?

1. MnO_4^- is the oxidizing agent because +1.51 V is the higher reduction value. Fe^{2+} is the reducing agent.

2. E°cell = 1.51 − 0.77 = +0.74 V. The positive value says the direction is spontaneous; it does not say how fast the reaction is.

RT · Worked practice

Redox titrations | Questions 5-6 of 12

RT-P05 · Medium · Given $MnO_4^- + 8H^+ + 5Fe^{2+} \rightarrow Mn^{2+} + 4H_2O + 5Fe^{3+}$. A 25.00 mL sample of $Fe^{2+}(aq)$ needs 22.40 mL of 0.0150 mol/L $MnO_4^-(aq)$. Find $c(Fe^{2+})$ in mol/L.

1. $n(MnO_4^-) = 0.0150 \times 0.02240 = 3.36 \times 10^{-4}$ mol.

2. $n(Fe^{2+}) = 5 \times 3.36 \times 10^{-4} = 1.68 \times 10^{-3}$ mol.

3. $c(Fe^{2+}) = 1.68 \times 10^{-3} \div 0.02500 = 0.0672$ mol/L.

RT-P06 · Medium · Explain why a permanganate titration of iron(II) needs no added indicator. Describe the colour before and at the endpoint.

1. MnO_4^- is purple and is reduced to almost colourless Mn^{2+} while Fe^{2+} remains, so each drop turns colourless.

2. After the last Fe^{2+} reacts, one extra drop of MnO_4^- leaves a faint pink-purple that stays. The titrant is its own indicator.

RT · Worked practice

Redox titrations | Questions 7-8 of 12

RT-P07 · Medium · Given $5H_2C_2O_4 + 2MnO_4^- + 6H^+ \rightarrow 10CO_2 + 2Mn^{2+} + 8H_2O$. A 10.00 mL sample of $H_2C_2O_4(aq)$ needs 12.60 mL of 0.0200 mol/L $MnO_4^-(aq)$. Find $c(H_2C_2O_4)$ in mol/L.

1. $n(MnO_4^-) = 0.0200 \times 0.01260 = 2.52 \times 10^{-4}$ mol.

2. The ratio from this equation is 5 $H_2C_2O_4$ for every 2 MnO_4^-: $n(H_2C_2O_4) = 2.52 \times 10^{-4} \times 5/2 = 6.30 \times 10^{-4}$ mol.

3. $c(H_2C_2O_4) = 6.30 \times 10^{-4} \div 0.01000 = 0.0630$ mol/L.

RT-P08 · Medium · A student divides the moles of Fe^{2+} by the titre instead of by the 25.00 mL flask volume. Explain the error and name the volume to divide by.

1. The concentration of the analyte is its moles divided by the volume of the analyte solution that held them.

2. The titre is the volume of titrant. Divide by the flask (pipetted) volume, 25.00 mL = 0.02500 L.

RT · Worked practice

Redox titrations | Questions 9-10 of 12

RT-P09 · Challenging · Given $MnO_4^- + 8H^+ + 5Fe^{2+} \rightarrow Mn^{2+} + 4H_2O + 5Fe^{3+}$. A 10.00 mL aliquot from a 250.0 mL flask of $Fe^{2+}(aq)$ needs 15.60 mL of 0.0100 mol/L $MnO_4^-(aq)$. Find the mass of iron in the whole flask (Fe: 55.85 g/mol, Alberta Chemistry 30 Data Booklet).

1. $n(MnO_4^-) = 0.0100 \times 0.01560 = 1.56 \times 10^{-4}$ mol. $n(Fe^{2+})$ in the aliquot = $5 \times 1.56 \times 10^{-4} = 7.80 \times 10^{-4}$ mol.

2. The whole flask holds $250.0 \div 10.00 = 25.00$ times as much: 1.95×10^{-2} mol.

3. Mass = $1.95 \times 10^{-2} \times 55.85 = 1.09$ g.

RT-P10 · Challenging · A student rinses the buret with distilled water, not with the permanganate solution, before filling it. Is the calculated $c(Fe^{2+})$ too high, too low or unchanged? Explain with the chain of calculation.

1. The water makes the titrant weaker, so more volume is needed to reach the endpoint. The titre is larger than it should be.

2. The calculation still uses the given concentration, so $n(MnO_4^-)$, $n(Fe^{2+})$ and $c(Fe^{2+})$ are all too high.

RT · Worked practice

Redox titrations | Questions 11-12 of 12

RT-P11 · Challenging · An iron tablet of mass 0.800 g is dissolved and made up to 100.0 mL. A 20.00 mL aliquot needs 14.10 mL of 0.0200 mol/L MnO_4^-(aq). Find the mass percent of iron in the tablet ($MnO_4^- + 8H^+ + 5Fe^{2+} \rightarrow Mn^{2+} + 4H_2O + 5Fe^{3+}$; Fe: 55.85 g/mol).

1. $n(MnO_4^-) = 0.0200 \times 0.01410 = 2.82 \times 10^{-4}$ mol. $n(Fe^{2+})$ in the aliquot = $5 \times 2.82 \times 10^{-4} = 1.41 \times 10^{-3}$ mol.

2. The whole is 100.0 ÷ 20.00 = 5.000 times the aliquot: 7.05×10^{-3} mol. Mass of iron = $7.05 \times 10^{-3} \times 55.85 = 0.3937$ g.

3. Mass percent = 0.3937 ÷ 0.800 × 100 = 49.2 %.

RT-P12 · Challenging · A bubble sits in the buret tip at the start and leaves during a titration. The recorded titre is larger than the liquid delivered to the flask. Is the calculated analyte concentration too high, too low or unchanged? Explain.

1. The bubble volume is counted as titrant delivered although it did not enter the flask, so the titre is too large.

2. Following the chain, n(titrant), n(analyte) and the calculated concentration are all too high.