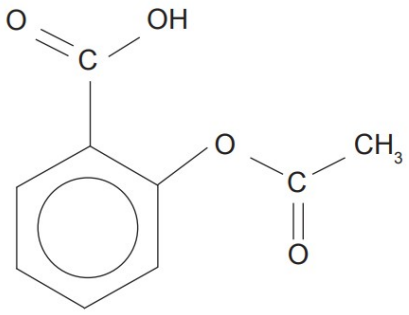
Aspirin is one of the most popular and readily available pain-relieving drugs. The structure of aspirin is given below:



Aspirin contains two functional groups.

(a) (i) On the diagram of aspirin above, circle the **two** functional groups. Label them **A** and **B**. (2 marks)

(ii) Name each functional group. (2 marks)

Functional group **A**: _____

Functional group **B**: _____

(b) In one commercial brand of aspirin, each '300 mg tablet' is claimed to contain 100% aspirin. To determine the actual percentage by mass of aspirin in an aspirin tablet, the following procedure, involving a back titration, was used.

Step 1: Three aspirin tablets, each with a mass of 300.0 mg, were crushed and dissolved in excess sodium hydroxide solution. Exactly 100.0 mL of 0.204 mol L^{-1} solution of sodium hydroxide was used. The mixture was boiled to ensure complete reaction.

Step 2: The excess sodium hydroxide solution was titrated with hydrochloric acid as follows: 20.0 mL of the solution from step 1 was pipetted into a conical flask and 0.125 mol L^{-1} hydrochloric acid was placed in the burette. The indicator, phenolphthalein, was used and an average titre of 17.89 mL of hydrochloric acid was required to reach the end-point.

Notes:

- Assume that any other chemicals present in an aspirin tablet are inert and will not react with either NaOH(aq) or HCℓ(aq).
- Phenolphthalein is colourless at a pH less than 8.3 and pink at a pH greater than 10.0.

(i) This is a titration between a strong acid and strong base. Strong acid–strong base titrations typically result in an equivalence point with a pH close to 7. Phenolphthalein was chosen as the indicator for this titration. Considering all of the species present in the solution at the equivalence point, explain why phenolphthalein is a suitable indicator to show the end-point. Support your answer with a suitable equation. (3 marks)

(ii) Calculate how many moles of hydroxide ions reacted with the aspirin. (5 marks)

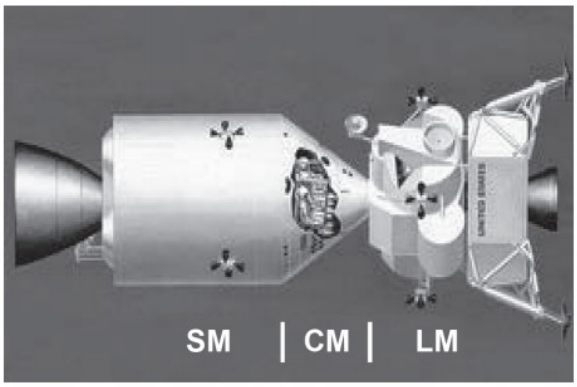
(iii) Each aspirin molecule requires two hydroxide ions for complete reaction. Calculate the percentage by mass of aspirin in one aspirin tablet. (The molar mass of aspirin is 180.154 g mol^{-1}.) (4 marks)

An important procedure in volumetric analysis is the washing of equipment with the appropriate solution prior to the titration in order to minimise experimental error.

(c) Before performing the experiment, the glassware was washed with the solutions given in the table. Complete the table below by stating the effect of the washing. (4 marks)

Washing procedure	**Effect on the volume of hydrochloric acid used**	**Effect on the % of aspirin calculated**
The conical flask was washed with distilled water.		
The burette was washed with distilled water.		

In 1971, the seventh manned Apollo mission, Apollo 13, was launched and expected to land on the moon. Two days into the mission, one of the oxygen tanks exploded. The mission was aborted, but in order for the spacecraft to return to Earth safely, many problems needed to be solved. A number of them involved chemistry.



The spacecraft consisted of three sections:

- the Service Module (SM)
- the Command Module (CM)
- the Lunar Module (LM).

The Lunar Module was designed to hold two astronauts for the short trip between lunar orbit and the moon's surface. On the trip back to Earth, the astronauts were required to spend more time than expected in the lunar module.

One of the problems encountered was how to remove the carbon dioxide breathed out by the astronauts from the atmosphere in the spacecraft. This was done by reacting it with lithium hydroxide, which was housed in canisters.

(a) Write an equation for the reaction between carbon dioxide gas and lithium hydroxide to form lithium carbonate and water. (2 marks)

(b) A typical lithium hydroxide canister contains 750.0 g of lithium hydroxide. What mass of carbon dioxide would be required to react completely with the lithium hydroxide in each canister? (3 marks)

On returning to Earth, a partially-used canister was analysed to determine the percentage of lithium hydroxide remaining.

A 12.33 g sample of the canister contents was dissolved in distilled water and sufficient barium nitrate solution was added to precipitate the carbonate ions. The solution was filtered and transferred to a 500.00 mL volumetric flask, which was then filled to the mark. 20.00 mL aliquots of the solution were transferred to conical flasks and titrated against a standardised 0.116 mol L^{-1} solution of hydrochloric acid.

The following results were obtained from the titrations.

Volume (mL)	**1**	**2**	**3**	**4**
Final Volume	18.55	34.90	18.50	34.85
Initial Volume	1.50	18.55	2.20	18.50
Titre				

(c) Complete the results table above and calculate the percentage of lithium hydroxide remaining in the canister. (6 marks)

(d) From the list of indicators given below, identify **two** that could be used in the titration between lithium hydroxide and hydrochloric acid. Explain why both indicators are appropriate choices for this titration. (4 marks)

Indicator	Low pH colour	Transition pH range	High pH colour
Methyl violet	yellow	0.0 – 1.6	blue
Bromothymol blue	yellow	6.0 – 7.6	blue
Phenolphthalein	colourless	8.3 – 10.0	pink
Thymolphthalein	colourless	9.4 – 10.6	blue

Indicator one: _____

Indicator two: _____

Explanation: _____

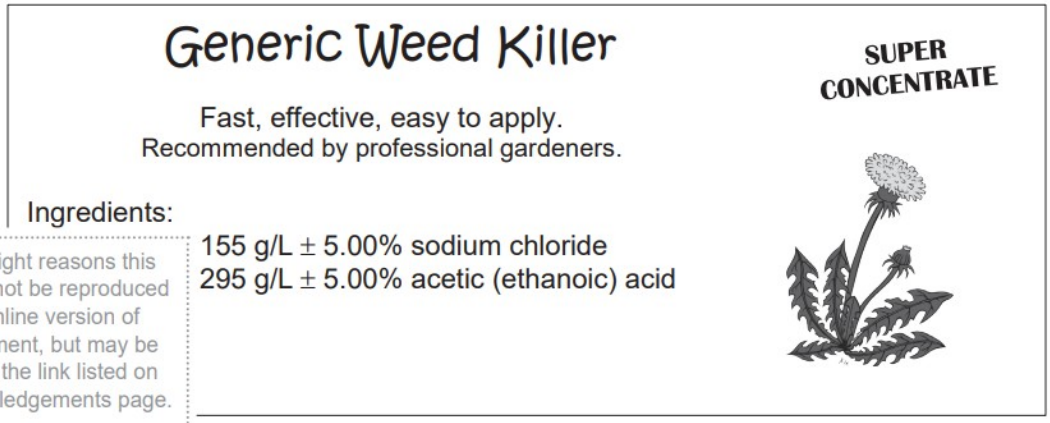
_____

_____

_____

_____

Herbicides are chemicals that kill plants, including weeds. The label of a commercially-ava herbicide concentrate is shown below.



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A chemist was given the task of verifying the concentrations of sodium chloride and acetic (ethanoic) acid stated for this herbicide.

The sodium chloride content of the herbicide was analysed. It was found to be consistent wi the tolerance of ± 5.00% of the stated concentration. The chemist then performed a series c titrations with sodium hydroxide to measure the acetic (ethanoic) acid concentration.

The herbicide solution used in the titrations was prepared by pipetting 5.00 mL of the concentrate into a 250.0 mL volumetric flask. The solution in the flask was then made up to mark with distilled water.

A 20.00 mL sample of the diluted herbicide was pipetted into a conical flask and a few drops a suitable indicator were added. This solution was then titrated with standardised 0.0947 mo NaOH solution.

After an initial 'rough titration', a further four titrations were performed. The results are show the following table.

(a) Complete the table and determine the average titre. (2 m

Titration number	Burette readings (mL)		
	Initial	Final	Titre
1	1.28	20.75	
2	20.75	40.19	
3	1.48	21.82	
4	21.82	41.21	
		Average titre	

(b) Identify with what solution each of these pieces of glassware should be rinsed prior to their use in these titrations. (3 marks)

Glassware item	Rinse solution
5.00 mL pipette	
20.00 mL pipette	
250.0 mL volumetric flask	

(c) Demonstrate whether or not the experimentally-determined value of the acetic (ethanoic) acid concentration matches the value given on the herbicide label, bearing in mind that a difference of $\pm$ 5.00% is considered acceptable. Show **all** workings and reasoning. (8 marks)

A student standardised an approximately 0.1 mol L^{-1} sodium hydroxide solution with a standard 0.0958 mol L^{-1} hydrochloric acid solution. The student pipetted 20.00 mL of the sodium hydroxide solution into a conical flask, added 2 drops of indicator and titrated to the end point with the hydrochloric acid. Five titrations were performed.

(a) Below is a table of the student's results. Determine the average titre. (1 mark)

Titration number	**Burette readings (mL)**		
	Initial	**Final**	**Titre**
Rough	1.35	22.45	21.10
1	21.45	41.50	20.05
2	3.50	23.65	20.15
3	23.65	43.05	19.40
4	2.75	22.85	20.10
		Average titre	

(b) Show that the concentration of the sodium hydroxide solution is 0.0963 mol L^{-1}, correct to three significant figures. (3 marks)

The student used the standardised sodium hydroxide solution to determine the percentage by mass of phosphoric acid (H_3PO_4) in a commercial brand of rust remover.

The student weighed a sample of the rust remover into a small beaker and then transferred it to a 250.0 mL volumetric flask. The beaker was rinsed several times with distilled water and each time the wash water was added to the volumetric flask. The volumetric flask was then made up to the mark with more distilled water. The student titrated 10.00 mL aliquots of the diluted rust remover with the standardised sodium hydroxide solution.

The student's results were as follows:

- mass of undiluted rust remover = 10.05 g
- average titre of standardised sodium hydroxide solution = 24.45 mL.

(c) Calculate the percentage, by mass, of phosphoric acid in the original, undiluted rust remover. Express your answer to the appropriate number of significant figures. Assume that the rust remover contains no other substances that react with sodium hydroxide.

(8 marks)

The following table provides some information about three different acid-base indicators.

Indicator	pH range	Acid colour	Base colour
methyl orange	3.2 – 4.4	red	yellow
bromothymol blue	6.0 – 7.6	yellow	blue
phenolphthalein	8.3 – 10.0	colourless	pink

(d) Which of these indicators should the student use when titrating phosphoric acid with sodium hydroxide? Justify your choice with the aid of a relevant balanced chemical equation. (5 marks)

Aqua regia is a mixture of concentrated hydrochloric acid and nitric acid that is able to dissolve gold. One of its uses is in the analysis of gold content in gold ore.

As part of quality control processes, a chemist in a gold analysis laboratory analysed aqua regia to ensure the required 3:1 mole ratio of hydrochloric acid to nitric acid. The chemist found that 20.0 mL of aqua regia needed 28.6 mL of 8.00 mol L^{-1} sodium hydroxide for complete neutralisation. The reaction for the neutralisation reaction between the sodium hydroxide and acid is represented by the equation below:

$$H^+(aq) \quad + \quad OH^-(aq) \quad \rightarrow \quad H_2O(\ell).$$

(a) Calculate the moles of hydrogen ions present in the 20.0 mL sample of aqua regia.

(2 marks)

The chemist analysed the chloride content of the aqua regia by adding excess silver nitrate solution to a separate 20.0 mL sample of aqua regia. This resulted in the precipitation of 24.6 g of solid.

(b) Write the balanced ionic equation for precipitation of silver chloride from aqua regia. (1 mark)

(c) Calculate the moles of hydrochloric acid in the 20.0 mL of aqua regia. (3 marks)

(d) Determine whether the aqua regia had the required ratio of hydrochloric acid to nitric acid. State clearly whether the ratio was as required and support your answer with clear workings. (3 marks)

Citric acid is the active ingredient in some bathroom and kitchen cleaning solutions. A student determined the content of citric acid in a cleaner by titration with sodium hydroxide solution.

The sodium hydroxide solution first needed to be standardised. To do this, the student dissolved approximately 4 g of sodium hydroxide pellets in water, to give an approximately 0.1 mol L^{-1} solution. This solution was standardised by titrating 20.00 mL of the NaOH solution with a 0.105 mol L^{-1} standard hydrochloric acid solution. The average titration volume was 17.45 mL.

(a) Explain why sodium hydroxide is not suitable as a primary standard. (2 marks)

(b) Show that the concentration of the sodium hydroxide solution is 0.0916 mol L^{-1}. Show sufficient workings to justify your answer. (3 marks)

The student then weighed a 10.00 mL aliquot of the cleaner and found it weighed 10.4 g. This 10.00 mL aliquot was next diluted to 100.0 mL in a volumetric flask. Against the standardised sodium hydroxide solution, 20.00 mL aliquots of the diluted cleaner were titrated. The table below shows the results of the titrations.

Titre	1	2	3	4
Final reading (mL)	25.30	23.55	22.40	22.25
Initial reading (mL)	3.50	2.70	1.50	1.30
Titre volume (mL)				

(c) Calculate the average titre volume to be used in the calculation of the citric acid content. (2 marks)

(d) Given that citric acid ($C_6H_8O_7$) is a weak triprotic acid, determine the percentage composition by mass of citric acid in the cleaner. The molar mass of citric acid is 192.124 g mol^{-1}. (6 marks)

(e) Select a suitable indicator for this titration from the table below. Explain your choice. (2 marks)

Indicator	Colour change (low pH – high pH)	pH range
Methyl yellow	red-yellow	2.4 – 4.0
Litmus	red-blue	5.0 – 8.0
Bromothymol blue	yellow-blue	6.0 – 7.6
Thymol blue	yellow-blue	8.0 – 9.6