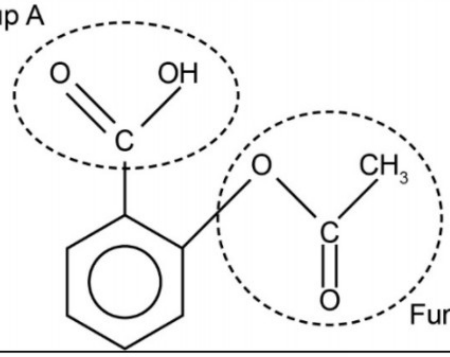
(a) (i) On the diagram of aspirin above, circle the **two** functional groups. Label them A and B. (2 marks)

Description	Marks
One mark for each valid group. Maximum two marks.	
Functional group A 	1–2
Total	**2**

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

Description	Marks
Group A: carboxylic acid	1
Group B: ester	1
Total	**2**

(b) (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)

Description	Marks
Recognition that at the equivalence point the Na^+ and $C\ell^-$ ions are neutral (or do not undergo hydrolysis)	1
The carboxylate ions react with water to a slight extent to form hydroxide ions $RCOO^-(aq) + H_2O(\ell) \rightarrow RCOOH(aq) + OH^-(aq)$	1
The hydrolysis of the ion makes it slightly basic which means that it is necessary to use an indicator that changes colour on the base side of pH 7	1
Total	**3**

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

Description	Marks
$n(H^+) = cv = 0.125 \times 0.01789 = 2.236 \times 10^{-3}$ mol	1
$n(OH^-)_{excess}$ in 20 mL = $n(H^+) = 2.236 \times 10^{-3}$ mol	1
$n(OH^-)_{excess}$ in 100 mL = $2.236 \times 10^{-3} \times 5 = 1.118 \times 10^{-2}$ mol	1
$n(OH^-)_{initially}$ in 100 mL = $cv = 0.204 \times 0.1 = 0.0204$ mol	1
$n(OH^-)_{reacting\ with\ aspirin} = 0.0204 - 0.01118$ $= 0.00921$ or 9.21×10^{-3} mol	1
Total	**5**

(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)

Description	Marks
$n(aspirin) = ½\ n(OH^-) = ½ \times 0.00921 = 0.00461$ mol	1
$m(aspirin) = 0.00461 \times 180.154 = 0.8304$ g	1
m(aspirin) in 1 tablet = 0.8304 ÷ 3 = 0.2768 g	1
% aspirin in 1 tablet = 0.2768/0.3 x 100 = 92.3%	1
Total	**4**

(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)

Description			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	**no change**	**no change**	1–2
The burette was washed with distilled water	**increased**	**decrease**	1–2
		Total	**4**

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

Description	Marks
$2\ LiOH(s) + CO_2(g) \rightarrow Li_2CO_3(s) + H_2O(g)$	2
Equation with one minor error	1
Total	**2**

(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)

Description	Marks
$n(LiOH) = 750.0/23.976$ $= 31.28$ mol	1
$n(CO_2) = 0.5 \times n(LiOH)$ $= 15.64$ mol	1
$m(CO_2) = 44.01 \times 15.64$ $= 6.883 \times 10^2$ g	1
Total	**3**

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	17.05	16.35	16.30	16.35

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

Description	Marks
Correctly completing the table above	1
Average = (16.35 + 16.30 + 16.35) / 3 = 16.33 mL	1
$n(HCl) = 0.01633 \times 0.116$ $= 1.89 \times 10^{-3}$ mol = n(LiOH) in 20.00 mL	1
n(LiOH) in 500.0 mL $= 1.89 \times 10^{-3}(500.0/20.00)$ $= 4.74 \times 10^{-2}$ mol	1
$m(LiOH) = 4.74 \times 10^{-2}\ (23.976)$ = 1.136 g	1
% LiOH = 1.136/12.33 x 100 = 9.21 %	1
Total	**6**

(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

Description	Marks
One mark for each indicator	
Bromothymol blue	1
Phenolphthalein	1
Two marks for explanation	
Equivalence point for this titration occurs at pH = 7 (strong acid + strong base produces neutral salt)	1
These indicators will change colour/end point at or near pH = 7	1
Total	**4**

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

Description	Marks
Table correctly completed	1
Average titre correctly calculated	1
Example of a two mark response:	

Titration Number	Volume Added (mL)
1	19.47
2	19.44
3	20.34
4	19.39
Average titre	**19.43(3)**

Total	**2**

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

Description		Marks
Glassware item	**Rinse solution**	
5.00 mL pipette	The (concentrated) herbicide	1
20.00 mL pipette	diluted herbicide	1
250.0 mL volumetric flask	Distilled (deionised) water	1
	Total	**3**

(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 ± 5.00% is considered acceptable. Show **all** workings and reasoning. (8 marks)

Description	Marks
Average NaOH titre volume from part (a) = 0.01943 L	
Moles NaOH on average n = cV = 0.0947 x 0.01943 = 0.001840 mol	1
In 20 mL conical flask $n(CH_3COOH) = n(NaOH) = 0.001840$ mol	1
Concentration = 0.001840 / 0.02 = 0.09200 mol L^{-1}	1
In 250 mL volumetric flask, n = 0.09200 x 0.25 = 0.02300 mol	1
All from 5 mL sample… original concentration = 0.02300 / 0.005 = 4.6001 mol L^{-1}	1
$c(CH_3COOH)$ = 4.6001 x 60.052 = 276 g/L	1
The 5% range 295 is 280.25 – 309.75	1
• No • The experimentally determined concentration of acetic acid of 276.3 g L^{-1} falls outside of the error range (280.25 – 309.75 g L^{-1}) stated on the package and so does NOT match the value given on the herbicide label.	1
Total	**8**

Note:
- If the correct answer is clearly stated, full marks maybe awarded for:
  - the correct calculated concentration and error range is calculated
  - and the calculations and reasoning provided clearly demonstrates a correct method for determining the answer.
- If the answer is incorrect or ambiguous, marks may be awarded to the parts correctly completed as set out above.

(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	

Description	Marks
Average titre = (20.05 + 20.15 + 20.10)/3 = 20.10 mL	1
Total	**1**
Note: • Also accept 20.1 mL as the 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)

Description	Marks
$n(HC\ell) = cV = 0.0958 \times 0.0201 = 0.00193$ mol	1
1 mol NaOH reacts with 1 mol $HC\ell$	1
$c(NaOH) = 0.00193/0.020 = 0.0963$ mol L^{-1}	1
Total	**3**

(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)

Description	Marks
$n(NaOH) = 0.0963 \times 0.0245 = 0.00235$ mol	1
Stoichiometry: $3\ NaOH + H_3PO_4 \rightarrow Na_3PO_4 + 3\ H_2O$ So, $3\ NaOH : 1 H_3PO_4$	1
$n(H_3PO_4$ reacting in the titration$) = (1 \times 0.00235)/3$ $= 0.000785$ mol in 10 mL	1
$n(H_3PO_4$ in 250 mL volumetric flask$) = (0.000785 \times 250)/10$ $= 0.0196$ mol in 10.05 g	1
$M(H_3PO_4) = 97.994$ g mol^{-1}	1
$m(H_3PO_4$ in rust cleaner sample$) = 0.0196 \times 97.994 = 1.92$ g	1
% H_3PO_4 in the rust cleaner $= (1.92/10.05) \times 100 = 19.1\%$	1
3 significant figures = 19.1%	1
Total	**8**

or

Description	Marks
$n(NaOH) = 0.0963 \times 0.0245 = 0.00235$ mol	1
Stoichiometry: $2\ NaOH + H_3PO_4 \rightarrow Na_2HPO_4 + 2\ H_2O$ So, $2\ NaOH : 1\ H_3PO_4$	1
$n(H_3PO_4$ reacting in the titration$) = (1 \times 0.00235)/2$ $= 0.00118$ mol in 10 mL	1
$n(H_3PO_4$ in 250 mL volumetric flask$) = (0.\ 00118 \times 250)/10$ $= 0.0294$ mol in 10.05 g	1
$M(H_3PO_4) = 97.994$ g mol^{-1}	1
$m(H_3PO_4$ in rust cleaner sample$) = 0.0294 \times 97.994 = 2.88$ g	1
% H_3PO_4 in the rust cleaner $= (2.88/10.05) \times 100 = 28.7\%$	1
3 significant figures = 28.7%	1
Total	**8**
Note: • Phosphoric acid is a weak acid with only two of its three hydrogen atoms reacting with hydroxide to give the 2:1 ratio of $NaOH:H_3PO_4$. This is beyond the scope of the syllabus, and was not expected of students.	

(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)

Description	Marks
Phenolphthalein	1
Recognition that PO_4^{3-} present in the solution at equivalence point. ($3\ OH^-(aq) + H_3PO_4(aq) \rightarrow PO_4^{3-}(aq) + 3\ H_2O(\ell)$)	1
The phosphate ion undergoes hydrolysis to form hydroxide ions. $PO_4^{3-} + H_2O \rightleftharpoons HPO_4^{2-} + OH^-$	1
The solution at the equivalence point will be (slightly) basic (with a pH of approximately 9) due to the excess of hydroxide ions ($[OH^-] > [H^+]$)	1
The pH at which the indicator changes colour approximates the pH of the equivalence point.	1
Total	**5**

Note:
- No hydrolysis equation – maximum 4 marks
- Do not accept a statement about strong base is added to weak acid, gives a weakly basic solution as part of the explanation.

Alternative responses that some students may provide
Methyl orange
The pH of the first equivalence point is around 4.7. If students identify this and supply appropriate logic with equations, up to full marks may be awarded.

If a student recognises that the third equivalence point is beyond the end point of phenolphthalein and explains why none of the indicators would be appropriate with sufficient reasoning, up to full marks may be awarded.

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:

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

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

(2 marks)

Description	Marks
$n(NaOH) = 0.0286 \times 8.00$ $= 0.2288$ mol	1
$n(H^+) = n(OH^-) = 0.229$ mol	1
Incorrect	0
Total	**2**

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)

$$Ag^+(aq) + C\ell^-(aq) \rightarrow AgC\ell(s)$$

Description	Marks
Correctly balanced equation	1
Incorrect	0
Total	**1**

NB: State symbols not required.

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

Description	Marks
$M(AgC\ell) = 143.35\ g\ mol^{-1}$	1
$n(AgC\ell) = \frac{24.6}{143.35} = 0.1716\ mol$	1
$n(HC\ell) = n(C\ell^-) = n(AgC\ell) = 0.172\ mol$	1
Incorrect	0
Total	**3**

(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)

Description	Marks
$n(HNO_3) = n(H^+)total - n(HC\ell) = 0.2288 - 0.1716 = 0.0572\ mol$	1
$Ratio = \frac{n(HC\ell)}{n(HNO_3)} = \frac{0.1716}{0.0572} = 3.00$	1
Yes the ratio of $HC\ell$ to HNO_3 is 3:1	1
Incorrect	0
Total	**3**

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

Description	Marks
Any two of the following:	
• does not have high molar mass • absorbs moisture/is deliquescent/hygroscopic • reacts with CO_2 from the atmosphere • mass varies over time • cannot be obtained pure	1-2
Incorrect	0
Total	**2**

(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)

Description	Marks
$n(HC\ell) = 0.01745 \times 0.105 = 1.832 \times 10^{-3}$ mol	1
$n(NaOH) = n(HC\ell) = 1.832 \times 10^{-3}$ mol	1
$c(NaOH) = \frac{n}{v} = \frac{1.832 \times 10^{-3}}{0.02} = 9.16 \times 10^{-2}$ mol L^{-1}	1
Incorrect	0
Total	**3**

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

Description	Marks
Differences in initial and final readings = 21.80, 20.85, 20.90, 20.95	1
Titre volume = $\frac{20.85 + 20.90 + 20.95}{3} = 20.90$ mL	1
Incorrect	0
Total	**2**

(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)

Description	Marks
$n(NaOH) = 0.02090 \times 0.0916 = 1.914 \times 10^{-3}$ mol	1
In 20 mL of dilute citric acid, $n(citric) = \frac{1.914 \times 10^{-3}}{3} = 6.381 \times 10^{-4}$ mol	1
$n(citric)$ in 100 mL $= 6.381 \times 10^{-4} \times 5 = 0.003191$ mol	1
hence in 10 mL original = 0.003191 mol	1
$m(citric) = n \times M = 0.003191 \times 192.124 = 0.613$ g	1
Therefore % composition $= \frac{0.613}{10.4} \times 100 = 5.89\%$	1
Incorrect	0
Total	**6**

(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

Description	Marks
Thymol blue	1
The citrate ion hydrolyses to give hydroxide ions and so an equivalence point in the basic region or appropriate equation	1
Incorrect	0
Total	**2**