Cambridge IGCSE · Chemistry 0620 · Notes

Acids, bases and oxides

Read online at **pastopic.com/cambridge/chemistry-0620/notes/acids-bases-and-oxides**

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Read first: **Formulae and equations**, **Ionic and metallic bonding**

What you need to know

By the end of this topic you should be able to:

1. **Describe how acids react** with metals, with bases and with carbonates, and name the products.
2. **Describe what acids do to indicators**: litmus, thymolphthalein and methyl orange.
3. **State that bases are oxides or hydroxides of metals**, and that **alkalis are bases that dissolve in water**.
4. **Describe how bases react** with acids and with ammonium salts.
5. **Describe what alkalis do to indicators**: litmus, thymolphthalein and methyl orange.
6. **State that acids in water contain $\mathrm{H^+}$ ions** and **alkalis in water contain $\mathrm{OH^-}$ ions**.
7. **Compare solutions using pH and universal indicator paper**: how acidic, neutral or alkaline they are, and how many hydrogen ions they contain.
8. **Describe neutralisation**: an acid and an alkali react to make water, $\mathrm{H^+(aq) + OH^-(aq) \rightarrow H_2O(l)}$.
9. **Extended only:** define **acids as proton donors** and **bases as proton acceptors**.
10. **Extended only:** define a **strong acid** as one that is **completely dissociated** in water, and a **weak acid** as one that is **partially dissociated**.
11. **Extended only:** state that **hydrochloric acid is strong**: $\mathrm{HCl(aq) \rightarrow H^+(aq) + Cl^-(aq)}$.
12. **Extended only:** state that **ethanoic acid is weak**: $\mathrm{CH_3COOH(aq) \rightleftharpoons H^+(aq) + CH_3COO^-(aq)}$.
13. **Classify oxides as acidic** (such as $\mathrm{SO_2}$ and $\mathrm{CO_2}$) **or basic** (such as CuO and CaO), using whether the element is a metal or a non-metal.
14. **Extended only:** describe **amphoteric oxides** as oxides that react with acids **and** with bases to give a salt and water.
15. **Extended only:** classify $\mathrm{Al_2O_3}$ **and ZnO as amphoteric**.

Understand it

What makes an acid an acid

Hydrochloric acid, sulfuric acid, nitric acid and ethanoic acid all behave in the same ways because, in water, they all release **hydrogen ions,** $\mathrm{H^+}$. The $\mathrm{H^+}$ ion is what reacts in every acid reaction, and it is what makes indicators change colour.

- Hydrochloric acid, HCl, gives $\mathrm{H^+}$ and chloride ions, $\mathrm{Cl^-}$.
- Sulfuric acid, $\mathrm{H_2SO_4}$, gives $\mathrm{H^+}$ and sulfate ions, $\mathrm{SO_4^{2-}}$.
- Nitric acid, $\mathrm{HNO_3}$, gives $\mathrm{H^+}$ and nitrate ions, $\mathrm{NO_3^-}$.
- Ethanoic acid, $\mathrm{CH_3COOH}$, gives $\mathrm{H^+}$ and ethanoate ions, $\mathrm{CH_3COO^-}$.

The negative ion decides the **name of the salt** an acid makes: hydrochloric acid makes **chlorides**, sulfuric acid **sulfates**, nitric acid **nitrates** and ethanoic acid **ethanoates**.

Three reactions of acids

An acid reacts in three standard ways. In each, the metal (or ammonium) part of the other reactant ends up in a salt with the acid's negative ion.

Acid +	Products	What you see	Example
metal	salt + hydrogen	fizzing; the metal gets smaller	$\mathrm{Mg + 2HCl \rightarrow MgCl_2 + H_2}$
base (metal oxide or hydroxide)	salt + water	the solid dissolves; no fizzing	$\mathrm{CuO + H_2SO_4 \rightarrow CuSO_4 + H_2O}$
carbonate	salt + water + carbon dioxide	fizzing; the solid dissolves	$\mathrm{CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2O + CO_2}$

Only metals **above hydrogen** in the reactivity series give hydrogen with dilute acids. Copper, silver and gold do not react. Hydrogen gives a squeaky pop with a lighted splint; carbon dioxide turns limewater milky.

Bases and alkalis

A **base** is an oxide or hydroxide of a metal, such as copper(II) oxide, CuO, calcium oxide, CaO, or sodium hydroxide, NaOH. Bases **neutralise acids**, making a salt and water.

Most bases do not dissolve in water. The ones that do are called **alkalis**: an alkali is a **soluble base**. Sodium hydroxide, potassium hydroxide and calcium hydroxide (limewater) are alkalis; aqueous ammonia is also alkaline. Copper(II) oxide and iron(III) hydroxide are bases but not alkalis, because they are **insoluble**. So every alkali is a base, but not every base is an alkali.

Alkalis in water contain **hydroxide ions,** $\mathrm{OH^-}$. A basic oxide that dissolves makes a hydroxide: $\mathrm{CaO + H_2O \rightarrow Ca(OH)_2}$.

Bases and ammonium salts. A base (usually an alkali) warmed with an **ammonium salt** gives off **ammonia gas**, plus a salt and water:

$$\mathrm{NH_4Cl + NaOH \rightarrow NaCl + NH_3 + H_2O}$$

Ammonia is the only common **alkaline gas**: it turns **damp red litmus paper blue**. This works with any ammonium salt and any base, which is why farmers should not spread lime and an ammonium fertiliser together: the nitrogen escapes as ammonia.

Indicators

An indicator has one colour in acid and another in alkali. Learn these three:

Indicator	In acid	In alkali
litmus	red	blue
thymolphthalein	colourless	blue
methyl orange	red	yellow

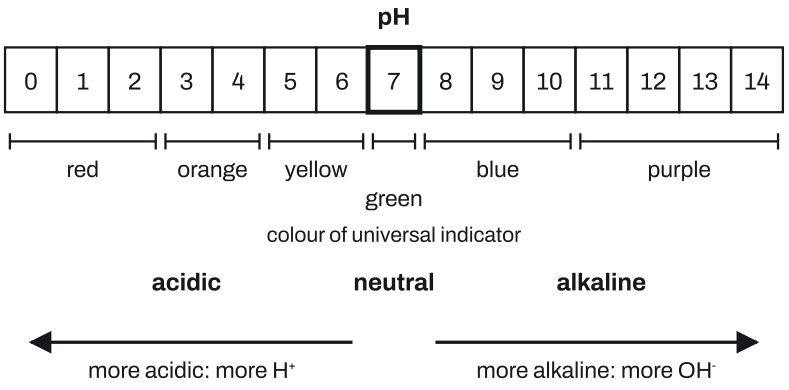
Methyl orange is **yellow** in alkali, not orange, and thymolphthalein is **colourless** (not "clear") in acid. A colour change is always given **from** the first colour **to** the second: adding excess acid to an alkali containing thymolphthalein turns it from blue to colourless.

pH and universal indicator

The **pH scale** runs from 0 to 14 and tells you how acidic or alkaline a solution is:

- **pH 7 is neutral** (pure water, salt solutions such as NaCl);
- **below 7 is acidic**; the **lower** the pH, the **more acidic**, and the **higher the concentration of $\mathrm{H^+}$ ions**;
- **above 7 is alkaline**; the **higher** the pH, the **more alkaline**, and the higher the concentration of $\mathrm{OH^-}$ ions.

Universal indicator is a mixture of indicators, so it has a different colour at each pH. To measure a solution's pH, **put a drop of the solution on universal indicator paper** (or dip the paper in), then **compare the colour with the pH colour chart**. The chart comparison is how you get a number.



Typical values: dilute hydrochloric, nitric or sulfuric acid about pH 1; ethanoic acid about pH 3 to 4; aqueous ammonia about pH 10 to 11; limewater about pH 12; sodium hydroxide solution about pH 13 to 14.

Neutralisation

When an acid reacts with an alkali, the $\mathrm{H^+}$ ions from the acid and the $\mathrm{OH^-}$ ions from the alkali join to make water. The other ions stay in solution as the salt. The **ionic equation** is the same for every acid and alkali:

$$\mathrm{H^+(aq) + OH^-(aq) \rightarrow H_2O(l)}$$

For example, $\mathrm{NaOH + HNO_3 \rightarrow NaNO_3 + H_2O}$. As alkali is added to acid, the pH rises from about 1, passes through 7 when the amounts exactly match, and ends up high when the alkali is in excess. Adding **excess** of either reactant leaves its ions over: excess acid leaves $\mathrm{H^+}$, so the mixture is acidic.

Bases are also used to neutralise acids in the real world: **calcium oxide (lime)**, **calcium hydroxide (slaked lime)** or calcium carbonate are spread on **acidic soil** so crops grow well, and are used to treat acidic waste water from factories.

Proton donors and acceptors (Extended)

A hydrogen atom that loses its electron is just a proton, so an $\mathrm{H^+}$ ion **is** a proton. That gives a more general definition:

- an **acid is a proton donor** (it gives $\mathrm{H^+}$ away);
- a **base is a proton acceptor** (it takes $\mathrm{H^+}$).

This lets you spot the acid and base in any reaction, even one without a metal oxide. When ammonia dissolves in water,

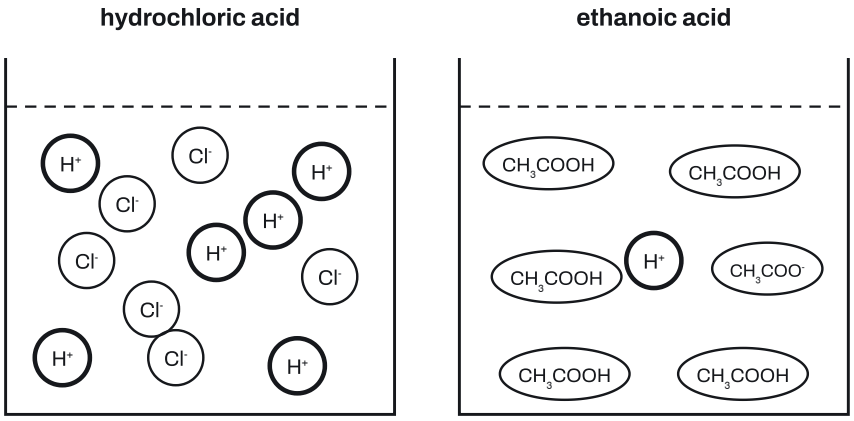
$$\mathrm{NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-}$$

water **gives** a proton to ammonia, so water acts as the **acid** and ammonia as the **base**. When ethanoic acid dissolves, ethanoic acid gives a proton to water, so there water acts as the base. Look at who **loses** $\mathrm{H^+}$ (the acid) and who **gains** it (the base).

Strong and weak acids (Extended)

When an acid dissolves, its molecules split up (**dissociate**) into ions.

- A **strong acid** is **completely dissociated**: every molecule gives up its $\mathrm{H^+}$. Hydrochloric, nitric and sulfuric acids are strong. Their equations use a one-way arrow: $\mathrm{HCl \rightarrow H^+ + Cl^-}$ and $\mathrm{H_2SO_4 \rightarrow 2H^+ + SO_4^{2-}}$.
- A **weak acid** is **partially dissociated**: only a small fraction of its molecules give up $\mathrm{H^+}$ at any moment, and the rest stay whole. Ethanoic acid and the other carboxylic acids are weak. Their equations use the **reversible arrow**: $\mathrm{CH_3COOH \rightleftharpoons H^+ + CH_3COO^-}$.



strong: completely dissociated
6 H^+ ions

weak: partially dissociated
1 H^+ ion, 5 whole molecules

Compare the two acids at the **same concentration**:

	Strong acid (HCl)	**Weak acid (CH_3COOH)**
Dissociation	complete	partial
Concentration of H^+	higher	lower
pH	lower (about 1)	higher (about 3)
Rate with magnesium or a carbonate	faster	slower
Total gas made (acid in excess or same amount)	same	same

The total volume of gas is the same because, as the weak acid's H^+ ions are used up, more molecules dissociate, until all the acid has reacted.

Strong and weak are not the same as concentrated and dilute. Concentration is how much acid is dissolved in each dm^3; strength is what fraction of it is dissociated. A dilute strong acid and a concentrated weak acid both exist.

Acidic, basic and amphoteric oxides

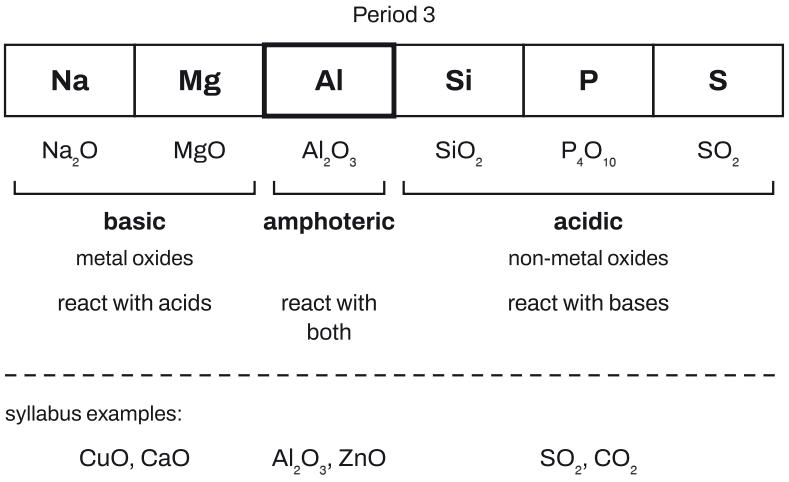
Whether an oxide is acidic or basic depends on its element:

- **Metal oxides are basic.** They react with acids to make a salt and water (CuO, CaO, MgO, Na_2O). The ones that dissolve (Group I oxides, CaO) make alkaline solutions.
- **Non-metal oxides are acidic.** They react with bases and alkalis to make a salt and water ($CO_2 + 2NaOH \rightarrow Na_2CO_3 + H_2O$). The ones that dissolve make acidic solutions: SO_2, NO_2 and CO_2 give acid rain. Silicon(IV) oxide, SiO_2, is acidic too; it reacts with basic calcium oxide in the blast furnace.

Extended only: a few metal oxides are **amphoteric**: they react with **acids and with bases**, giving a salt and water both times. You must know **aluminium oxide,** Al_2O_3, and **zinc oxide, ZnO**.

$$ZnO + 2HCl \rightarrow ZnCl_2 + H_2O \qquad ZnO + 2NaOH \rightarrow Na_2ZnO_2 + H_2O$$
$$Al_2O_3 + 6HCl \rightarrow 2AlCl_3 + 3H_2O \qquad Al_2O_3 + 2NaOH \rightarrow 2NaAlO_2 + H_2O$$

With sodium hydroxide the metal ends up in a **negative ion** with oxygen (zincate $\mathrm{ZnO_2^{2-}}$, aluminate $\mathrm{AlO_2^-}$), and sodium is the positive ion. Both reactions give a colourless solution and no gas.



Across a period, oxides change from **basic** (metals, left) through **amphoteric** to **acidic** (non-metals, right).

Key facts and formulas

"Given" means the exam paper prints it. "Learn it" means you must remember it. Chemistry 0620 has no formula sheet, so everything here must be learned.

Formula	Status
acid + metal → salt + hydrogen	Learn it
acid + base (metal oxide or hydroxide) → salt + water	Learn it
acid + carbonate → salt + water + carbon dioxide	Learn it
base + ammonium salt → salt + ammonia + water (on warming)	Learn it
Salt names: hydrochloric → chloride; sulfuric → sulfate; nitric → nitrate; ethanoic → ethanoate	Learn it
Litmus red / blue; thymolphthalein colourless / blue; methyl orange red / yellow (acid / alkali)	Learn it
Acids in water contain $\mathrm{H^+}$; alkalis in water contain $\mathrm{OH^-}$	Learn it
pH < 7 acidic, $= 7$ neutral, > 7 alkaline; lower pH = more $\mathrm{H^+}$	Learn it

Formula	Status
Neutralisation: $\mathrm{H^+(aq) + OH^-(aq) \rightarrow H_2O(l)}$	Learn it
Base = oxide or hydroxide of a metal; alkali = soluble base	Learn it
Extended only: acid = proton donor; base = proton acceptor	Learn it
Extended only: strong acid = completely dissociated; weak acid = partially dissociated	Learn it
Extended only: $\mathrm{HCl(aq) \rightarrow H^+(aq) + Cl^-(aq)}$	Learn it
Extended only: $\mathrm{CH_3COOH(aq) \rightleftharpoons H^+(aq) + CH_3COO^-(aq)}$	Learn it
Metal oxides basic (CuO, CaO); non-metal oxides acidic ($\mathrm{SO_2}$, $\mathrm{CO_2}$)	Learn it
Extended only: amphoteric oxide reacts with acids and with bases to give a salt and water; $\mathrm{Al_2O_3}$ and ZnO	Learn it

How to do it

In the questions we have tagged for this topic (242 questions, 2021–2025), the types came up this often. 41 of the 242 questions mix types, so the counts add up to 322.

Question type	Questions
Classify an oxide as acidic or basic (and give the reason)	66
State an indicator's colour or colour change	51
Name the products of an acid's reactions or complete the equation	45
Define acid, base or alkali; name the $\mathrm{H^+}$/$\mathrm{OH^-}$ ion; spot the proton donor and acceptor	32
Explain strong and weak acids (dissociation, pH, rate)	26
Link pH to acidity or alkalinity; measure pH with universal indicator	26
Predict ammonia from an ammonium salt and a base	24
Recognise amphoteric oxides; write their reaction with sodium hydroxide	22
Identify neutralisation; write $\mathrm{H^+ + OH^- \rightarrow H_2O}$	13
Use lime or slaked lime to neutralise soil or waste acid	10
Pick out an acid or alkali from a set of properties	7

1. Classify an oxide as acidic or basic (66 questions)

1. **Find the element joined to oxygen** and decide: metal or non-metal? Use the Periodic Table: Groups I and II and the transition elements are metals; C, N, P, S (and Si) are non-metals.
2. **Metal → basic oxide. Non-metal → acidic oxide.** (Extended: Al_2O_3 and ZnO are amphoteric.)
3. **For "give a reason"**, say it: "acidic, because nitrogen is a **non-metal**" or "basic, because calcium is a **metal**".

Variations you will meet:

- **Clues from behaviour.** An oxide that neutralises an acid, or whose solution turns thymolphthalein blue, universal indicator blue or purple, or has a pH above 7, is **basic**. One that reacts with sodium hydroxide, or whose solution turns universal indicator red (pH below 7), is **acidic** (or, Extended, amphoteric if it also reacts with acid).
- **From a place in the table**: "element E is in Group II", so it is a metal and its oxide is basic. "Which parts of the table form only basic oxides?": Group I (every element is a metal), not a whole period.
- **Pick three acidic oxides** from a list: only non-metal oxides, such as CO_2, NO_2, SO_2. Any list containing CaO or Na_2O is wrong.
- **An acidic oxide reacting with a basic oxide**, such as $CaO + SiO_2 \rightarrow CaSiO_3$ (slag in the blast furnace), is an acid–base reaction.
- **Removing acidic gases**: calcium oxide or calcium hydroxide (basic) removes sulfur dioxide (acidic) from factory waste gases.

2. State an indicator's colour or colour change (51 questions)

1. **Decide whether the solution is acidic or alkaline** (and, for a change, what it is at the start and at the end).
2. **Give the colour from the table**: litmus red/blue, thymolphthalein colourless/blue, methyl orange red/yellow.
3. **For a change**, write "from ... to ..." with both colours in the right order.

For example: aqueous potassium hydroxide is added to dilute hydrochloric acid containing litmus until the alkali is in excess. Litmus goes **from red to blue**.

Variations you will meet:

- **Working backwards** (multiple choice): a table of colours before and after adding solution Y. Colourless thymolphthalein and red methyl orange mean acid; blue and yellow mean alkali. So if Y turns an acid's colours to blue and yellow, Y is an **alkali**, such as NaOH(aq).
- **"Which indicators turn blue in aqueous ammonia?"**: litmus, thymolphthalein and universal indicator (not methyl orange, which turns yellow).
- **Why universal indicator is not used in a titration**: it changes colour gradually, so there is no sharp end-point.

- **Name the indicator** when a question says "suitable indicator": "thymolphthalein turns blue", not "the indicator turns blue".

3. Name the products of an acid's reactions or complete the equation (45 questions)

1. **Identify the reaction type**: metal, base (oxide or hydroxide), carbonate, or ammonia.
2. **Write the products**: salt + hydrogen; salt + water; salt + water + carbon dioxide; ammonium salt only (for ammonia).
3. **Name the salt**: metal name first, then chloride, sulfate, nitrate or ethanoate from the acid.
4. **Balance** a symbol equation by counting atoms of each element on both sides.

For example, zinc with sulfuric acid: zinc sulfate + hydrogen, $\mathrm{Zn} + \mathrm{H_2SO_4} \rightarrow \mathrm{ZnSO_4} + \mathrm{H_2}$. Sodium carbonate with sulfuric acid: $\mathrm{Na_2CO_3} + \mathrm{H_2SO_4} \rightarrow \mathrm{Na_2SO_4} + \mathrm{H_2O} + \mathrm{CO_2}$.

Variations you will meet:

- **"Which substances make copper(II) chloride with hydrochloric acid?"**: copper(II) oxide, carbonate and hydroxide do; **copper metal does not**, because copper is below hydrogen in the reactivity series.
- **Observations**: metal and carbonate **fizz** (bubbles of gas) and the solid disappears; an oxide or hydroxide dissolves **without fizzing**. With excess solid, some is left over.
- **Ethanoic acid**: calcium + ethanoic acid gives **calcium ethanoate** + hydrogen; with sodium carbonate it gives sodium ethanoate + water + carbon dioxide. It does all the same reactions as a strong acid, just more slowly.
- **Acid + ammonia** makes an ammonium salt only: $\mathrm{NH_3} + \mathrm{HCl} \rightarrow \mathrm{NH_4Cl}$; $2\mathrm{NH_3} + \mathrm{H_2SO_4} \rightarrow (\mathrm{NH_4})_2\mathrm{SO_4}$.
- **"Name another compound that makes aluminium nitrate with nitric acid"**: any other base or carbonate of aluminium, such as aluminium oxide.

4. Define acid, base or alkali; name the ions; proton donor and acceptor (32 questions)

1. **Core definitions**: acids contain $\mathrm{H^+}$ ions in water; alkalis contain $\mathrm{OH^-}$ ions; an alkali is a **soluble base**; a base is an oxide or hydroxide of a metal.
2. **Extended definitions**: acid = **proton donor**; base = **proton acceptor**. Use the word "proton".
3. **In an equation**, find the species that **loses** $\mathrm{H^+}$ (acid) and the one that **gains it** (base).

Variations you will meet:

- **"State the formula of the ion all acids produce"**: $\mathrm{H^+}$, with its charge. For alkalis: $\mathrm{OH^-}$.
- **The negative ion of an acid**: $\mathrm{SO_4^{2-}}$ from sulfuric acid, $\mathrm{CH_3COO^-}$ from ethanoic acid, $\mathrm{NO_3^-}$ from nitric acid, $\mathrm{Cl^-}$ from hydrochloric acid.
- **"$\mathrm{Al(OH)_3}$ is a base but not an alkali. What does this tell you?"**: it is **insoluble** in water.
- **Water can act as either.** With ammonia, water donates a proton (acid); with ethanoic acid or HBr, water accepts one (base). In $\mathrm{HBr} + \mathrm{NH_3} \rightarrow \mathrm{NH_4^+} + \mathrm{Br^-}$, HBr is the proton donor.

- **Mixed Paper 4 questions** add parts from other topics, for example the gases from electrolysing dilute sulfuric acid (hydrogen at the cathode, oxygen at the anode; see Electrochemistry) or the oxidation number of nitrogen in a nitrate (see Redox). Show the working: in $\mathrm{Al(NO_3)_3}$ there are 9 oxygens at -2, so $+3 + 3x + 9(-2) = 0$, $3x = 15$ and $x = +5$.

5. Explain strong and weak acids (26 questions)

1. **Definition**: strong = **completely** dissociated (into ions) in water; weak = **partially** dissociated.
2. **Equations**: one-way arrow for strong ($\mathrm{HNO_3 \rightarrow H^+ + NO_3^-}$); reversible arrow for weak ($\mathrm{CH_3COOH \rightleftharpoons H^+ + CH_3COO^-}$).
3. **Compare at the same concentration**: the weak acid has a lower $\mathrm{H^+}$ concentration, so a **higher pH** and a **slower reaction**, but it makes the **same total volume** of gas.

Variations you will meet:

- **"Which acid has the highest pH?"** from a strong and a weak acid at the same concentration: the **weak** one (ethanoic).
- **A graph of gas volume against time** for two acids with the same concentration and volume, reacting with the same mass of magnesium: the steeper curve is the **stronger** acid; both curves level off at the same volume.
- **Fraction dissociated**: if 0.0030 mol of a 0.50 mol sample is dissociated, only 0.6% has split up, so it is a weak acid. A strong acid would be 100% dissociated.
- **Multiple-choice traps**: "weak acids are always dilute" (no: strength is not concentration); "a weak acid only donates some protons to excess alkali" (no: it reacts completely with alkali; it is only **partly dissociated in water**).
- **Placing an unknown acid's pH**: a weak acid of the same concentration as HCl has a pH above HCl's but below 7.

6. Link pH to acidity or alkalinity; measure pH (26 questions)

1. **Match pH to type**: below 7 acidic, 7 neutral, above 7 alkaline. Strong acids about 1; sodium hydroxide about 13 to 14; weak alkalis about 8 to 11.
2. **Measuring pH**: put a drop of the solution on **universal indicator paper**, then **compare the colour with the colour chart**.
3. **Order by $\mathrm{H^+}$**: the lowest pH has the highest $\mathrm{H^+}$ concentration; the highest pH has the most $\mathrm{OH^-}$.

Variations you will meet:

- **Universal indicator colours**: red (strongly acidic), orange or yellow (weakly acidic), green (neutral), blue (weakly alkaline), purple (strongly alkaline, most $\mathrm{OH^-}$).
- **Reading a pH curve** during neutralisation: read the starting pH at zero volume, and the volume added when the pH first reaches 7.
- **"Which description matches the pH?"** (multiple choice): pH 1 very acidic, pH 7 neutral, pH 13 very alkaline; pH 9 turns universal indicator blue, not yellow.

7. Predict ammonia from an ammonium salt and a base (24 questions)

1. **Spot the pair**: an ammonium salt (name starts "ammonium") with a base or alkali, usually warmed.
2. **Products**: salt + **ammonia** + water.
3. **Test**: ammonia turns **damp red litmus paper blue** (it is the alkaline gas).
4. **Balance** if asked: $2\mathrm{NH_4Cl} + \mathrm{Ca(OH)_2} \rightarrow \mathrm{CaCl_2} + 2\mathrm{NH_3} + 2\mathrm{H_2O}$; $\mathrm{(NH_4)_2SO_4} + 2\mathrm{NaOH} \rightarrow \mathrm{Na_2SO_4} + 2\mathrm{NH_3} + 2\mathrm{H_2O}$.

Variations you will meet:

- **Farming**: lime (or slaked lime) added at the same time as an ammonium fertiliser releases ammonia, so nitrogen is lost from the soil.
- **"Which compounds give ammonia when heated with NaOH?"**: only those containing the ammonium ion, $\mathrm{NH_4^+}$. Aluminium nitrate does not.
- **"A gas turns damp red litmus blue. What made it?"**: an ammonium salt and a base (not two acids, not a metal and acid).
- **Name it correctly**: "ammonia", not "ammonium" or "nitrogen".

8. Recognise amphoteric oxides; write their reaction with sodium hydroxide (22 questions)

Extended only.

1. **Definition** (both halves for the mark): an amphoteric oxide reacts with **acids and with bases** to form a **salt and water**.
2. **Know the two**: aluminium oxide and zinc oxide.
3. **Equation with NaOH**: the products are a **sodium salt** containing the metal and oxygen in a negative ion, plus water. Use the anion the question gives, balance the sodium with NaOH, then balance hydrogen with water.

For example, lead(IV) oxide gives the ion $\mathrm{PbO_3^{2-}}$, so the salt is $\mathrm{Na_2PbO_3}$: $\mathrm{PbO_2} + 2\mathrm{NaOH} \rightarrow \mathrm{Na_2PbO_3} + \mathrm{H_2O}$.

Variations you will meet:

- **"Which metal oxide reacts with aqueous sodium hydroxide?"**: the amphoteric one (aluminium oxide). Basic oxides such as CaO, CuO and $\mathrm{Na_2O}$ do not.
- **A flow chart or table**: an oxide that forms a salt and water with both HCl(aq) and NaOH(aq) is amphoteric.
- **What you see**: an amphoteric oxide dissolves in excess acid and in excess alkali, giving a colourless solution, with no fizzing.
- **Trend across a period**: basic → amphoteric → acidic.
- **Neutral oxides**: a few oxides react with neither acids nor bases; one older question used carbon monoxide.

9. Identify neutralisation; write the ionic equation (13 questions)

1. **Recognise it**: acid + alkali (or base) → salt + water is **neutralisation**.
2. **Ionic equation**: $\mathrm{H^+(aq) + OH^-(aq) \rightarrow H_2O(l)}$. On Paper 3 you may just need to complete it with $\mathrm{OH^-}$.
3. **Choose reactants for a salt**: the metal comes from the alkali and the negative ion from the acid. Potassium chloride: potassium hydroxide + hydrochloric acid.

Variations you will meet:

- **"Which ion makes the mixture acidic?"** after excess acid: $\mathrm{H^+}$.
- **"Which two ions react?"**: $\mathrm{H^+}$ and $\mathrm{OH^-}$ (not $\mathrm{Na^+}$ and $\mathrm{Cl^-}$, which stay in solution).
- **A titration calculation** often follows in Paper 4; that is covered in The mole.

10. Use lime or slaked lime to neutralise soil or waste acid (10 questions)

1. **Name the compound**: calcium oxide (lime), calcium hydroxide (slaked lime) or calcium carbonate (limestone).
2. **Why**: they are bases, so they **neutralise** the acid in soil (crops grow poorly in acidic soil) or in acidic factory waste water.
3. **Equation** if asked: $\mathrm{Ca(OH)_2 + H_2SO_4 \rightarrow CaSO_4 + 2H_2O}$.

11. Pick out an acid or alkali from a set of properties (7 questions)

1. **Acid signs**: fizzes with carbonates ($\mathrm{CO_2}$) and with reactive metals ($\mathrm{H_2}$); turns litmus red and methyl orange red; pH below 7.
2. **Alkali signs**: releases ammonia from ammonium salts; turns litmus blue, methyl orange yellow and thymolphthalein blue; no reaction with magnesium; pH above 7.
3. **Test every statement**: a single wrong half makes an option wrong.

Worked examples

The bold codes show where marks are earned, as in Cambridge mark schemes. The number is how many marks.

- **M1** method mark: for a correct method, even if the numbers slip.
- **A1** accuracy mark: for a correct answer; it needs the M mark before it.
- **B1** mark for a correct result on its own, with no method needed.

Example 1

A student adds dilute hydrochloric acid to magnesium ribbon in one test-tube and to calcium carbonate powder in another.

(a) Circle the pH of dilute hydrochloric acid: pH 1 · pH 7 · pH 10 · pH 13. **[1]**

(b) Give **two** observations when the acid is added to the calcium carbonate. **[2]**

(c) Complete the word equation: magnesium + hydrochloric acid → ... + ... **[2]**

(d) Complete the symbol equation: $\mathrm{CaCO_3} + \ldots \mathrm{HCl} \rightarrow \mathrm{CaCl_2} + \ldots + \ldots$ **[2]**

(e) Methyl orange is added to the acid, then sodium hydroxide solution is added until it is in excess. State the colour change. **[2]**

(a) pH 1. **B1**

(b) Fizzing (bubbles of gas) **B1**; the solid gets smaller and disappears. **B1**

(c) Magnesium chloride **B1** + hydrogen. **B1**

(d) $\mathrm{CaCO_3} + 2\mathrm{HCl} \rightarrow \mathrm{CaCl_2} + \mathrm{H_2O} + \mathrm{CO_2}$. **B1** for $\mathrm{H_2O}$ and $\mathrm{CO_2}$, **B1** for the 2.

(e) From red **B1** to yellow. **B1** (Not "orange".)

Example 2

Four oxides are listed: sodium oxide, sulfur dioxide, magnesium oxide, carbon dioxide.

(a) State which **two** are basic oxides. Give a reason. **[2]**

(b) Sodium oxide dissolves in water. Write the symbol equation, and give the colour of thymolphthalein in the solution. **[2]**

(c) A farmer spreads slaked lime, $\mathrm{Ca(OH)_2}$, and ammonium sulfate, $\mathrm{(NH_4)_2SO_4}$, on a field at the same time. Write a balanced equation for the reaction and explain why this wastes fertiliser. **[3]**

(d) Describe a test for the gas made in (c). **[2]**

(a) Sodium oxide and magnesium oxide **B1**; sodium and magnesium are metals (and metal oxides are basic). **B1**

(b) $\mathrm{Na_2O} + \mathrm{H_2O} \rightarrow 2\mathrm{NaOH}$. **B1** Blue. **B1**

(c) $\mathrm{(NH_4)_2SO_4} + \mathrm{Ca(OH)_2} \rightarrow \mathrm{CaSO_4} + 2\mathrm{NH_3} + 2\mathrm{H_2O}$. **B1** for $\mathrm{NH_3}$ as a product, **B1** for balancing. Nitrogen is lost from the soil as ammonia gas. **B1**

(d) Damp red litmus paper **B1** turns blue. **B1**

Example 3

Extended. Nitric acid is a strong acid. Propanoic acid, $\mathrm{C_2H_5COOH}$, is a weak acid. Both are used at a concentration of $0.10\ \mathrm{mol/dm^3}$.

(a) Explain what is meant by *strong acid* and *weak acid*. **[2]**

(b) Write an equation for the dissociation of propanoic acid in water. **[1]**

(c) State which acid has the higher pH. Explain your answer. **[2]**

(d) 0.12 g of magnesium ribbon is added to $150\ \mathrm{cm^3}$ of each acid (the acid is in excess). Compare the rate of reaction and the total volume of hydrogen produced. Calculate that volume at r.t.p. (A_r: Mg = 24; one mole of gas occupies $24\ \mathrm{dm^3}$ at r.t.p.) **[4]**

(e) $\mathrm{NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-}$. Identify the base in the forward reaction. Explain your answer. **[2]**

(a) A strong acid is **completely** dissociated in water **B1**; a weak acid is **partially** dissociated. **B1**

(b) $\mathrm{C_2H_5COOH \rightleftharpoons H^+ + C_2H_5COO^-}$ (the reversible arrow is needed). **B1**

(c) Propanoic acid **B1**: it is only partly dissociated, so its concentration of $\mathrm{H^+}$ ions is lower. **B1**

(d) Nitric acid reacts faster (more $\mathrm{H^+}$ ions, so more frequent collisions). **B1** The total volume is the same, because the same amount of magnesium reacts. **B1**

$$n(\mathrm{Mg}) = \frac{0.12}{24} = 0.005\ \mathrm{mol} \qquad \mathbf{M1}$$

$\mathrm{Mg + 2H^+ \rightarrow Mg^{2+} + H_2}$, so 0.005 mol of hydrogen: $0.005 \times 24\,000 = 120\ \mathrm{cm^3}$. **A1**

(Excess check: $150\ \mathrm{cm^3}$ of $0.10\ \mathrm{mol/dm^3}$ acid is 0.015 mol, more than the 0.010 mol needed.)

(e) Ammonia **B1**, because it accepts a proton (from water). **B1**

Example 4

Extended. Beryllium oxide, BeO, is an amphoteric oxide.

(a) State what is meant by *amphoteric oxide*. **[1]**

(b) Beryllium oxide reacts with hydrochloric acid. Write the symbol equation. **[1]**

(c) Beryllium oxide reacts with aqueous sodium hydroxide to form a salt containing the ion $\mathrm{BeO_2^{2-}}$ and water only. Write the symbol equation. **[2]**

(d) Sodium oxide is a basic oxide. Explain why sodium oxide reacts with hydrochloric acid but not with sodium hydroxide. **[1]**

(e) Name the other amphoteric oxide in the syllabus besides aluminium oxide. **[1]**

(a) An oxide that reacts with acids **and** with bases to form a salt and water. **B1**

(b) $\mathrm{BeO} + 2\mathrm{HCl} \rightarrow \mathrm{BeCl_2} + \mathrm{H_2O}$. **B1**

(c) $\mathrm{BeO} + 2\mathrm{NaOH} \rightarrow \mathrm{Na_2BeO_2} + \mathrm{H_2O}$. **M1** for $\mathrm{Na_2BeO_2}$ as a product, **A1** for the balanced equation.

(d) A basic oxide reacts only with acids (it neutralises them); a base does not react with another base. **B1**

(e) Zinc oxide. **B1**

Common mistakes

- **Giving a vague reason for an oxide's nature.** "It is acidic because it has an acidic pH" or "it contains an acid" scores nothing. Link it to the element: "nitrogen is a **non-metal**". Examiners also see nitrogen dioxide called basic.
- **Methyl orange colours.** It is **red** in acid and **yellow** in alkali. "Orange" is not accepted in either, and candidates who ignore the word "acidified" start from orange. Don't mix it up with litmus (blue in alkali).
- **Not naming the indicator.** "The indicator turns blue" earns nothing when the question asks for a suitable indicator and its colour.
- **Describing universal indicator paper without the colour chart.** Listing colours for different pH values does not describe the method. Say: put the solution on the paper and **compare the colour with the chart**.
- **Confusing ammonia and ammonium.** The gas is **ammonia**, $\mathrm{NH_3}$; the ion in the salt is ammonium, $\mathrm{NH_4^+}$. "Ammonium hydroxide", "nitrogen" and "hydrogen" are wrong for the gas. Many candidates also forget that **any** base releases ammonia from an ammonium salt.
- **Wrong formulae of ammonium salts.** Ammonium sulfate is $(\mathrm{NH_4})_2\mathrm{SO_4}$, not $(\mathrm{NH_3})_2\mathrm{SO_4}$ or $\mathrm{NH_4(SO_4)_2}$. Ammonium chloride is not "ammonia chloride".
- **Mixing up strong with concentrated.** Weak acids do not dissociate fully; that has nothing to do with how much water there is.
- **Forgetting "proton".** "A base accepts $\mathrm{H^+}$" is accepted, but "a base accepts hydrogen" or "accepts electrons" is not; reactions of acids involve moving protons, not electrons.
- **Half a definition of amphoteric.** "Reacts with acids and bases" needs "to form a salt and water" as well.
- **Giving an element instead of a compound** for what is spread on acidic soil. It is calcium oxide or calcium hydroxide, not "calcium".
- **Reading the wrong point on a pH curve.** The volume needed for neutralisation is where the pH reaches 7, not the last volume on the axis.

How to get the marks

- **"State the colour change"**: two marks, one for each colour, written "from ... to ..." in the right order.
- **"Give a reason" for an oxide**: metal → basic, non-metal → acidic, naming the element.
- **Equations**: in word equations, name the salt fully (magnesium chloride, not "salt" or "magnesium chlorine"). In symbol equations, balance every element; state symbols only when asked.

- **Definitions**: use the exact key word: "proton donor", "proton acceptor", "completely dissociated", "partially dissociated", "soluble base", "salt and water".
- **Dissociation equations**: $\rightarrow$ for a strong acid, $\rightleftharpoons$ for a weak one. The ions must have their charges.
- **"Explain" strong versus weak**: say what differs (degree of dissociation) and what it causes (concentration of H^{+}, so pH or rate).
- **"Describe" observations**: say what you **see** (fizzing, solid disappears, colour change), not the name of the gas.
- **"Suggest"**: apply the pattern to a new substance, such as the NaOH reaction of an unfamiliar amphoteric oxide from the ion given.
- **Multiple choice**: test each part of each option against the facts; many wrong options mix a true half with a false one.

Quick check

1. Name the salt made in each reaction: (a) zinc oxide + sulfuric acid; (b) ethanoic acid + sodium carbonate. Write a balanced symbol equation for (a).
2. A solution has pH 12. Give its colour with thymolphthalein, with methyl orange and with universal indicator.
3. Classify each oxide as acidic, basic or amphoteric: potassium oxide, $\mathrm{K_2O}$; phosphorus(V) oxide, $\mathrm{P_4O_{10}}$; **Extended:** zinc oxide, ZnO.
4. **Extended.** Hydrochloric acid and ethanoic acid both have a concentration of $0.20\ \mathrm{mol/dm^3}$. Which has the lower pH? Write the dissociation equation for each.
5. Ammonium chloride is warmed with calcium hydroxide. Balance the equation and name the gas. How would you show it is alkaline?

Answers

1. (a) Zinc sulfate: $\mathrm{ZnO} + \mathrm{H_2SO_4} \rightarrow \mathrm{ZnSO_4} + \mathrm{H_2O}$. (b) Sodium ethanoate (with water and carbon dioxide).
2. Thymolphthalein blue; methyl orange yellow; universal indicator purple.
3. $\mathrm{K_2O}$ basic (potassium is a metal); $\mathrm{P_4O_{10}}$ acidic (phosphorus is a non-metal); ZnO amphoteric.
4. Hydrochloric acid has the lower pH, because it is completely dissociated, so it has a higher concentration of $\mathrm{H^+}$. $\mathrm{HCl} \rightarrow \mathrm{H^+} + \mathrm{Cl^-}$; $\mathrm{CH_3COOH} \rightleftharpoons \mathrm{H^+} + \mathrm{CH_3COO^-}$.
5. $\mathrm{2NH_4Cl} + \mathrm{Ca(OH)_2} \rightarrow \mathrm{CaCl_2} + \mathrm{2NH_3} + \mathrm{2H_2O}$. The gas is ammonia; it turns damp red litmus paper blue.

Past questions to try

- **0620/42/O/N/25 Q4**: strong and weak acids, the ions they form, a base defined, and a salt of ethanoic acid.
- **0620/43/O/N/25 Q3**: parts (d) and (e), defining amphoteric and writing an oxide's equation with sodium hydroxide.
- **0620/32/O/N/25 Q5**: parts (e) and (f), a carbonate with acid and thymolphthalein's colour change.
- **0620/11/M/J/24 Q18**: lime and an ammonium fertiliser added to a field at the same time.