Acids, Bases and Salts

Laboratory Preparation of a Salt
Acids, Bases and Salts
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Acids, Bases and Salts

What do I need to know and understand about the laboratory preparation of salts?
Acids, Bases and Salts

Salts

(a) Describe the techniques used in the preparation, separation and purification of salts (methods for preparation should include precipitation and titration together with reactions of acids with metals, insoluble bases and insoluble carbonates).

(b) Describe the general rules of solubility for common salts to include nitrates, chlorides (including silver and lead), sulfates (including barium, calcium and lead), carbonates, hydroxides, Group 1 cations and ammonium salts.

(c) Suggest a method of preparing a given salt from suitable starting materials, given appropriate information.
1. Why is salt preparation important? What are salts used for?
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Salt Preparation – Uses of Salts

- Ammonium phosphate – \((\text{NH}_4\text{)}_3\text{PO}_4\) – is a fertiliser used to provide plants with the elements nitrogen and phosphorus, essential for the plants’ healthy growth.

- Barium sulfate – \(\text{BaSO}_4\) – is an insoluble salt used to provide “barium meals” for patients. Once ingested, barium sulfate allows the patient’s digestive system to be imaged using x-rays.

- Calcium ethanoate – \(\text{Ca(CH}_3\text{COO)}_2\) – is used to coagulate soy milk to produce tofu.
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Salt Preparation – Uses of Salts

- Iron(II) sulfate – FeSO$_4$ – is used to treat anaemia, a lack of haemoglobin in the blood. This reduces the blood’s ability to carry oxygen, which can result in fatigue.

- Monosodium glutamate (MSG) – NaC$_5$H$_8$NO$_4$ – is the sodium salt of glutamic acid. It is used as a flavour enhancer in the food industry, and is especially used to enhance the taste of savoury foods.

- Sodium fluoride – NaF – and tin(II) fluoride – SnF$_2$ – are used to provide the fluoride ions in toothpaste. The fluoride ions prevent cavities and tooth decay.
2. What is the **big idea** behind salt preparation?
Acids, Bases and Salts

Salt Preparation – Overview

- A salt is an *ionic compound* composed of a *positive cation* (usually a metal) and a *negative anion*. Salts are often formed by replacing the hydrogen ion(s) of an acid with a metal ion(s).

- A salt is prepared in the laboratory by reacting together *two reagents*. One reagent contains the *desired cation* (+), while the other reagent contains the *desired anion* (−).
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Salt Preparation – Overview

- Examples of possible reactions that can be used to prepare salts include:
  - acid + metal $\rightarrow$ salt + hydrogen
  - acid + alkali / base $\rightarrow$ salt + water
  - acid + carbonate $\rightarrow$ salt + water + carbon dioxide
  - salt A + salt B $\rightarrow$ salt C + salt D
3. What are the general solubility rules for common salts?
Acids, Bases and Salts

Solubility Rules

• All ammonium salts are _______ in water.
• All potassium salts* are _______ in water.
• All sodium salts* are _______ in water.
• All carbonates are _______ in water, except ___________________
• All chlorides* are _______ in water, except ___________________
  • All ethanoates (CH$_3$COO$^-$) are _______ in water.
• All hydroxides are _______ in water, except ___________________
  • All nitrates are _______ in water.
• All sulfates are _______ in water, except ___________________
• All phosphates are _______ in water, except ___________________
Acids, Bases and Salts

Solubility Rules

- All ammonium salts are soluble in water.
- All potassium salts* are soluble in water.
- All sodium salts* are soluble in water.
- All carbonates are insoluble in water, except $\text{Na}_2\text{CO}_3, \text{K}_2\text{CO}_3, (\text{NH}_4)_2\text{CO}_3$
- All chlorides* are soluble in water, except $\text{AgCl}, \text{PbCl}_2$
  - All ethanoates ($\text{CH}_3\text{COO}^-$) are soluble in water.
- All hydroxides are insoluble in water, except $\text{NaOH}, \text{KOH}, \text{NH}_4\text{OH}$
  - All nitrates are soluble in water.
- All sulfates are soluble in water, except $\text{BaSO}_4, \text{CaSO}_4, \text{PbSO}_4$
- All phosphates are insoluble in water, except $\text{Na}_3\text{PO}_4, \text{K}_3\text{PO}_4, (\text{NH}_4)_3\text{PO}_4$

*Assume that the salts of all Group 1 metals are soluble in water.

*Assume that bromides and iodides follow the same rule.
4. What are the different ways of preparing a salt in the laboratory?
Acids, Bases and Salts

Salt Preparation – Overview
Acids, Bases and Salts

Salt Preparation – Overview

Start here
Acids, Bases and Salts

Salt Preparation – Overview

Start here

Is the salt soluble in water?
Acids, Bases and Salts

Salt Preparation – Overview

Start here

Is the salt soluble in water?

No

Ionic precipitation technique

two solutions react to produce an insoluble salt
Acids, Bases and Salts

Salt Preparation – Overview

Start here

Is the salt soluble in water?

Yes

Are both reactants soluble in water?

No

Ionic precipitation technique

two solutions react to produce an insoluble salt
Acids, Bases and Salts

Salt Preparation – Overview

Start here → Is the salt soluble in water? → Ionic precipitation technique

- acid + water soluble base or metal carbonate
- often used to prepare the salts of Group 1 metals

Yes → Are both reactants soluble in water?

No → two solutions react to produce an insoluble salt
Acids, Bases and Salts

Salt Preparation – Overview

Start here → Is the salt soluble in water? → No → Ionic precipitation technique

Yes → Are both reactants soluble in water? → Yes → Titration technique

No only one → Excess insoluble base / carbonate / metal technique

acid + water soluble base or metal carbonate

often used to prepare the salts of Group 1 metals

two solutions react to produce an insoluble salt

excess insoluble base or metal carbonate or metal is added to an acid
5. Overview of ionic precipitation.
A precipitate is formed when two clear solutions react together to form an opaque solid product.

- All solutions are clear.
- Solutions may be coloured, e.g. we may refer to a “blue solution of copper(II) sulfate.”
- All precipitates are opaque. There is no such thing as a clear precipitate!
- Precipitates may be coloured, e.g. we may refer to a “yellow precipitate of lead(II) iodide.”
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Preparation of an Insoluble Salt – *Ionic Precipitation*

- The ionic precipitation technique is used to prepare salts that are *insoluble in water*, for example, barium sulfate (formula, BaSO$_4$), lead(II) iodide (formula, PbI$_2$) and silver chloride (formula, AgCl).

- Two soluble salts are added together to form the insoluble salt. One of the soluble salts contains the desired *anion*, while the second soluble salt contains the desired *cation*.

\[
\text{(cation A, anion B)}_{(aq)} + \text{(cation C, anion D)}_{(aq)} \rightarrow \text{(cation A, anion D)}_{(s)} + \text{(cation C, anion B)}_{(aq)}
\]
Acids, Bases and Salts

Preparation of an Insoluble Salt – *Ionic Precipitation*

- The *nitrate* of the desired *cation* should be used, as all *nitrates* are soluble in water.

- A *sodium salt* of the desired *anion* should be used, as all sodium salts are soluble in water.

\[(\text{cation A, nitrate})_{(aq)} + (\text{sodium, anion D})_{(aq)} \rightarrow (\text{cation A, anion D})_{(s)} + (\text{sodium, nitrate})_{(aq)}\]

\[
\text{Ba(NO}_3\text{)}_2(aq) + \text{Na}_2\text{SO}_4(aq) \rightarrow \text{BaSO}_4(s) + 2\text{NaNO}_3(aq)
\]

\[
\text{Pb(NO}_3\text{)}_2(aq) + 2\text{NaI(aq)} \rightarrow \text{PbI}_2(s) + 2\text{NaNO}_3(aq)
\]

\[
\text{AgNO}_3(aq) + \text{NaCl(aq)} \rightarrow \text{AgCl(s)} + \text{NaNO}_3(aq)
\]
Acids, Bases and Salts

Preparation of an Insoluble Salt – Ionic Precipitation

• Acids also contain aqueous solutions of anions, e.g. sulfuric acid contains $SO_4^{2-}(aq)$ and hydrochloric acid contains $Cl^-(aq)$.

• For the preparation of some insoluble salts, it may be possible to use an acid that contains the desired anion.

• For example, solid barium sulfate may be prepared by mixing aqueous barium nitrate with dilute sulfuric acid:

$$\text{Ba(NO}_3\text{)}_2(aq) + \text{H}_2\text{SO}_4(aq) \rightarrow \text{BaSO}_4(s) + 2\text{HNO}_3(aq)$$

• For example, solid silver chloride may be prepared by mixing aqueous silver nitrate with dilute hydrochloric acid:

$$\text{AgNO}_3(aq) + \text{HCl}(aq) \rightarrow \text{AgCl}(s) + \text{HNO}_3(aq)$$
Acids, Bases and Salts

Preparation of an Insoluble Salt – Ionic Precipitation

Aqueous Silver Nitrate + Aqueous Sodium Chloride

Silver Ion \( \text{Ag}^+ \)  Nitrate Ion \( \text{NO}_3^- \)  Sodium Ion \( \text{Na}^+ \)

Chloride Ion \( \text{Cl}^- \)  Water Molecule

\[ \text{Aqueous Silver Nitrate} + \text{Aqueous Sodium Chloride} \rightarrow \text{Insoluble Salt} + \text{Water} \]
Acids, Bases and Salts

Preparation of an Insoluble Salt – *Ionic Precipitation*

Mixture of Aqueous Silver Nitrate and Aqueous Sodium Chloride

![Diagram of ionic precipitation](image)
Acids, Bases and Salts

Preparation of an Insoluble Salt – *Ionic Precipitation*

Silver Chloride Precipitating from a Solution of Sodium Nitrate

- Silver Ion ($\text{Ag}^+$)
- Nitrate Ion ($\text{NO}_3^-$)
- Sodium Ion ($\text{Na}^+$)
- Chloride Ion ($\text{Cl}^-$)
- Water Molecule
Acids, Bases and Salts

Preparation of an Insoluble Salt – Ionic Precipitation

Silver Chloride Precipitating from a Solution of Sodium Nitrate

\begin{center}
\begin{tikzpicture}
  \node[draw, circle, fill=gray!30] (water) at (0,0) {H$_2$O};
  \node[draw, circle, fill=red!30] (silver) at (1,1) {Ag$^+$};
  \node[draw, circle, fill=blue!30] (chloride) at (2,2) {Cl$^-$};
  \node[draw, circle, fill=red!30] (nitrate) at (3,3) {NO$_3^-$};
  \node[draw, circle, fill=red!30] (sodium) at (4,4) {Na$^+$};

  \draw[->] (water) -- (silver);
  \draw[->] (silver) -- (nitrate);
  \draw[->] (silver) -- (chloride);
  \draw[->] (chloride) -- (water);

\end{tikzpicture}
\end{center}

- Silver Ion
- Nitrate Ion
- Sodium Ion
- Chloride Ion
- Water Molecule
Acids, Bases and Salts

Preparation of an Insoluble Salt – Ionic Precipitation

White Precipitate of Silver Chloride
Preparation of an Insoluble Salt – Ionic Precipitation

Procedure

1) Add an aqueous solution of soluble salt \( X \) to an aqueous solution of soluble salt \( Y \) until no more precipitate is observed to be formed.
Acids, Bases and Salts

Preparation of an Insoluble Salt – *Ionic Precipitation*

Procedure

2) Separate the insoluble salt from the soluble salt by *filtration*. The insoluble salt will be the *residue* while the soluble salt will be the *filtrate.*
Acids, Bases and Salts

Preparation of an Insoluble Salt – Ionic Precipitation

Procedure

3) Wash the insoluble salt (residue) with a small volume of cold distilled water. This will remove any excess salt solution that will contaminate the final product.

4) Dry the insoluble salt (residue) by pressing it between several layers of filter paper.
Acids, Bases and Salts

6. Overview of *titration*. 

Main Menu
Acids, Bases and Salts

Preparation of a Soluble Salt – *Titration*

- Titration is used to prepare a *soluble salt* from an *acid* and an *alkali*, or a *soluble metal carbonate*.

- Titration can be used to prepare *ammonium salts*, such as ammonium sulfate (formula, \((\text{NH}_4)_2\text{SO}_4\)), and the salts of *Group 1 metals*, such as potassium chloride (formula, \(\text{KCl}\)) and sodium nitrate (formula, \(\text{NaNO}_3\)).
Acids, Bases and Salts

Preparation of a Soluble Salt – *Titration*

- The *acid* will provide the desired *anion*. For example, hydrochloric acid (formula, HCl) will provide the *chloride ion*, nitric acid (formula, HNO₃) will provide the *nitrate ion* and sulfuric acid (formula, H₂SO₄) will provide the *sulfate ion*.

- The *alkali* or *soluble metal carbonate* will provide the desired *cation*. For example, aqueous ammonia (formula, NH₄OH) will provide the *ammonium ion*, potassium hydroxide (formula, KOH) will provide the *potassium ion* and sodium carbonate (formula, Na₂CO₃) will provide the *sodium ion*. 
Acids, Bases and Salts

Preparation of a Soluble Salt – *Titration*

- acid + alkali → salt + water

- aqueous ammonia + sulfuric acid → ammonium sulfate + water
  \[ 2\text{NH}_4\text{OH}(aq) + \text{H}_2\text{SO}_4(aq) \rightarrow (\text{NH}_4)_2\text{SO}_4(aq) + 2\text{H}_2\text{O}(l) \]

- potassium hydroxide + hydrochloric acid → potassium chloride + water
  \[ \text{KOH}(aq) + \text{HCl}(aq) \rightarrow \text{KCl}(aq) + \text{H}_2\text{O}(l) \]

  soluble metal
  - acid + carbonate → salt + water + carbon dioxide

- sodium carbonate + nitric acid → sodium nitrate + water + carbon dioxide
  \[ \text{Na}_2\text{CO}_3(aq) + 2\text{HNO}_3(aq) \rightarrow 2\text{NaNO}_3(aq) + \text{H}_2\text{O}(l) + \text{CO}_2(g) \]
1) Titrate the acid against the alkali, using a suitable indicator that will change colour at the end-point of the reaction (the point at which the acid and alkali have exactly neutralised each other). Repeat the titration until two results within ± 0.10 cm³ are obtained.
Acids, Bases and Salts

Preparation of a Soluble Salt – *Titration*

- Both methyl orange and phenolphthalein are suitable indicators for strong acid – strong alkali titrations.
Preparation of a Soluble Salt – *Titration*

**Procedure**

2) Repeat the titration once more *without* the indicator, adding together exactly the same volumes of acid and alkali that were determined by the previous titration experiment. This needs to be done so that the indicator does not contaminate the final product.
Acids, Bases and Salts

Preparation of a Soluble Salt – *Titration*

Procedure

3) Pour the resulting salt solution into an evaporating basin, and heat over a Bunsen burner until the solution is *saturated*. 
Acids, Bases and Salts

Preparation of a Soluble Salt – Titration

Procedure

Test for a Saturated Solution: When a glass rod is dipped into a hot saturated solution and then removed, crystals will form on the end of the glass rod as the drop of saturated solution cools.
4) Leave the hot saturated salt solution to cool to room temperature. As the hot saturated salt solution cools, the desired salt will begin to \textit{crystallise}.
Acids, Bases and Salts

Preparation of a Soluble Salt – *Titration*

**Procedure**

5) Once most of the salt has crystallised, but some solution still remains, filter the mixture and wash the crystals (residue) with a little ice-cold distilled water. This is done to remove any water soluble impurities. Dry the crystals between layers of filter paper.
Acids, Bases and Salts

Preparation of a Soluble Salt – *Titration*

Procedure

**Note:** The salt is *not* heated to dryness over a non-luminous Bunsen burner flame because the salt may be *thermally unstable* and *decompose* at high temperatures, *e.g.* hydrated salts such as $\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$. 
7. Overview of acid with *excess insoluble base / metal carbonate*. 
Preparation of a Soluble Salt – *Excess Insoluble Base*

- This technique is used to prepare a *soluble salt* from an *acid* and either an *insoluble base* or an *insoluble metal carbonate*.

- Examples of salts that can be prepared this way include copper(II) sulfate (formula, \(\text{CuSO}_4\)), iron(III) chloride (formula, \(\text{FeCl}_3\)) and barium nitrate (formula, \(\text{Ba(NO}_3)_2\)).
Acids, Bases and Salts

Preparation of a Soluble Salt – *Excess Insoluble Base*

- The **acid** will provide the desired **anion**. For example, *hydrochloric acid* (formula, HCl) will provide the **chloride ion**, *nitric acid* (formula, HNO₃) will provide the **nitrate ion** and *sulfuric acid* (formula, H₂SO₄) will provide the **sulfate ion**.

- The **insoluble base** or **insoluble metal carbonate** will provide the desired **cation**. For example, *copper(II) oxide* (formula, CuO) will provide the **copper(II) ion**, *iron(III) oxide* (formula, Fe₂O₃) will provide the **iron(III) ion** and *barium carbonate* (formula, BaCO₃) will provide the **barium ion**.
Acids, Bases and Salts

Preparation of a Soluble Salt – *Excess Insoluble Base*

- acid + base $\rightarrow$ salt + water
  - copper(II) oxide + sulfuric acid $\rightarrow$ copper(II) sulfate + water
    \[
    \text{CuO(s)} + \text{H}_2\text{SO}_4(\text{aq}) \rightarrow \text{CuSO}_4(\text{aq}) + \text{H}_2\text{O(}l\text{)}
    \]
  - iron(III) oxide + nitric acid $\rightarrow$ iron(III) nitrate + water
    \[
    \text{Fe}_2\text{O}_3(\text{s}) + 6\text{HCl(}aq\text{)} \rightarrow 2\text{FeCl}_3(\text{aq}) + 3\text{H}_2\text{O(}l\text{)}
    \]

  insoluble metal

- acid + carbonate $\rightarrow$ salt + water + carbon dioxide
  - barium carbonate + nitric acid $\rightarrow$ barium nitrate + water + carbon dioxide
    \[
    \text{BaCO}_3(\text{s}) + 2\text{HNO}_3(\text{aq}) \rightarrow \text{Ba(NO}_3)_2(\text{aq}) + \text{H}_2\text{O(}l\text{)} + \text{CO}_2(\text{g})
    \]
Acids, Bases and Salts

Preparation of a Soluble Salt – *Excess Insoluble Base*

Procedure

1) Pour the desired acid into a beaker. Place the beaker of acid on a tripod and gauze over a Bunsen burner.

2) Add the desired insoluble base or insoluble metal carbonate to the acid while gently warming the acid over the Bunsen burner. Stir the mixture continuously. **Note:** Warming and stirring the reagents increases the rate of reaction between the insoluble base / metal carbonate and the acid.
Acids, Bases and Salts

Preparation of a Soluble Salt – *Excess Insoluble Base*

**Procedure**

3) Continue to add the insoluble base or insoluble metal carbonate to the acid until an *excess* of the insoluble base or insoluble metal carbonate is observed in the bottom of the beaker. This ensures that all of the acid has reacted so the acid will not contaminate the soluble salt.

4) Allow the mixture to cool down and then separate the excess insoluble base or insoluble metal carbonate from the salt solution by *filtration*. The solution of the desired salt will be the *filtrate*. 
5) Pour the resulting salt solution into an evaporating basin, and heat over a Bunsen burner until the solution is saturated.
Preparation of a Soluble Salt – *Excess Insoluble Base*

**Procedure**

**Test for a Saturated Solution:** When a glass rod is dipped into a hot saturated solution and then removed, crystals will form on the end of the glass rod as the drop of saturated solution cools.
Acids, Bases and Salts

Preparation of a Soluble Salt – *Excess Insoluble Base*

**Procedure**

1. Heat
2. Dilute Solution of Soluble Salt
3. Saturated Solution of Soluble Salt
4. Filter and then leave water to evaporate
5. Salt Crystals

---

6) Leave the hot saturated salt solution to cool to room temperature. As the hot saturated salt solution cools, the desired salt will begin to *crystallise*.
Acids, Bases and Salts

**Preparation of a Soluble Salt – *Excess Insoluble Base***

**Procedure**

1. Heat a dilute solution of soluble salt.
2. Evaporate to form a saturated solution of soluble salt.
3. Filter and then leave water to evaporate.
5. Once most of the salt has crystallised, but some solution still remains, filter the mixture and wash the crystals (residue) with a little ice-cold distilled water. This is done to remove any water soluble impurities.
6. Dry the crystals between layers of filter paper.

7) Once most of the salt has crystallised, but some solution still remains, filter the mixture and wash the crystals (residue) with a little ice-cold distilled water. This is done to remove any water soluble impurities. Dry the crystals between layers of filter paper.
Acids, Bases and Salts

Preparation of a Soluble Salt – *Excess Insoluble Base*

**Procedure**

Note: The salt is *not* heated to dryness over a non-luminous Bunsen burner flame because the salt may be *thermally unstable* and *decompose* at high temperatures, *e.g.* hydrated salts such as $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$. 
Acids, Bases and Salts

Preparation of a Soluble Salt – *Excess Insoluble Base*

**Procedure**

1. **Heat**
   - Watch Glass
   - Dilute Solution of Soluble Salt
   - Water

2. **Filter and then leave water to evaporate**
   - Saturated Solution of Soluble Salt
   - Salt Crystals

**Examples of thermal decomposition**

- **Blue crystals**
  \[ \text{CuSO}_4 \cdot 5\text{H}_2\text{O}(s) \rightarrow \text{CuSO}_4(s) + 5\text{H}_2\text{O}(g) \]

- **Green powder**
  \[ \text{CuCO}_3(s) \rightarrow \text{CuO}(s) + \text{CO}_2(g) \]

- **White powder**
  \[ \text{CuSO}_4 \cdot 5\text{H}_2\text{O}(s) \rightarrow \text{CuSO}_4(s) + 5\text{H}_2\text{O}(g) \]
hydrated salt
CuSO$_4$.5H$_2$O

anhydrous salt
CuSO$_4$
Blue crystals of *hydrated* copper(II) sulfate decompose to form the white powder of *anhydrous* copper(II) sulfate when heated strongly. Heating to dryness removes the water of crystallisation.

\[
\text{CuSO}_4 \cdot 5\text{H}_2\text{O}(s) \rightarrow \text{CuSO}_4(s) + 5\text{H}_2\text{O}(g)
\]
8. What are solubility curves, and why are they useful?
Acids, Bases and Salts

Preparation of a Soluble Salt

Solubility Curve

• In the preparation of soluble salts, the solid salt is obtained by evaporating away most of the water and allowing the hot solution to cool. As the solution cools, it becomes saturated, meaning that it has the maximum amount of solute (i.e. salt) dissolved in the solvent.

• Solubility is the maximum amount of salt (mass in grams) that dissolves in a solvent (usually 100 cm$^3$) at a given temperature. Solubility decreases as temperature decreases. Therefore, as the solution continues to cool, there is a decrease in the amount of salt that can remain dissolved – all of the extra salt crystallises.
Acids, Bases and Salts

Preparation of a Soluble Salt

Solubility Curve

- It is important to leave some water after evaporation for two reasons:

1. Any impurities will be left in the remaining solution after cooling, and will not contaminate the crystals.

2. Many salts require water to be present in order to form crystals – known as *water of crystallisation* – e.g. hydrated copper(II) sulfate – CuSO$_4$·5H$_2$O.
Acids, Bases and Salts

Preparation of a Soluble Salt

Solubility Curve

• **Solubility** is a measure of how many grams of solute dissolve in 100 cm³ of solvent.

• A *solubility curve* is a graph of solubility plotted against temperature. It shows how the solubility of a chemical changes with temperature.
The solubility of some salts, e.g. $\text{KNO}_3$, decrease a lot on cooling, so large amounts of these salts crystallise on cooling a hot solution.

The crystals of many salts can be obtained by cooling a hot saturated solution of the salt, a process called *crystallisation*. 
Acids, Bases and Salts

Preparation of a Soluble Salt

Solubility Curve

• The solubility of other salts, e.g. NaCl, show very little variation on cooling, so very little solid is formed when a hot solution of NaCl is cooled.

• To obtain crystals of NaCl from an aqueous solution, all of the water must be evaporated, a process known as evaporation to dryness.
A saturated solution is a solution that contains the maximum amount of solute dissolved in a solvent at a given temperature.

A super saturated solution is a solution in which the solvent has more solute dissolved in it than a saturated solution, i.e. there is more solute dissolved in the solvent than the solvent should normally be able to hold at a given temperature.
A Note About Efflorescent Salts

• When some chemicals are exposed to air, they lose water to the atmosphere, thereby decreasing in weight. Such salts are said to be efflorescent. Solids that behave in this way are those that contain water of crystallization. The molecules of water of crystallization are either partially or completely lost to the atmosphere, causing the salt to lose its crystalline structure.

• For example, $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$ loses all its water of crystallization when exposed to air, $\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$ loses nine of its molecules of water of crystallization and $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ loses all its molecules of water of crystallization.
Acids, Bases and Salts

A Note About Deliquescent Salts

• A *deliquescent* salt is one which *absorbs water* when exposed to the air, sometimes absorbing enough water to form a solution. Examples of deliquescent salts include solid CaCl$_2$, FeCl$_3$, KOH, MgCl$_2$ and NaOH.

• Substances which absorb water from air can be used as drying agents for gases. For example, CaCl$_2$ can be used to dry most gases, except NH$_3$(g). Concentrated H$_2$SO$_4$ is used to dry acidic gases such as HCl(g). CaO is used to dry alkaline / basic gases such as NH$_3$(g).
Acids, Bases and Salts

Crystallisation

• The Dead Sea is a salt lake bordered by Jordan to the East and Israel and Palestine to the West.

• The shore of the Dead Sea are 429 m below sea level, making it the Earth’s lowest elevation on land.

• At 304 m deep, the Dead Sea is the world’s deepest hypersaline lake. With 32.4 % salinity, the Dead Sea is 9.6 times more salty than the ocean.

• The concentration of ions in g/kg of water at the surface of the Dead Sea is $\text{Cl}^{-} = 181.4$, $\text{Br}^{-} = 4.2$, $\text{SO}_{4}^{2-} = 0.4$, $\text{HCO}_{3}^{-} = 0.2$, $\text{Ca}^{2+} = 14.1$, $\text{Na}^{+} = 32.5$, $\text{K}^{+} = 6.2$ and $\text{Mg}^{2+} = 35.2$. 
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Crystallisation

- For a project called *Salt Bride*, Israeli artist Sigalit Landau submerged a black dress in the Dead Sea.

- The dress was submerged in the hypersaline waters of the Dead Sea for two months.
Acids, Bases and Salts

- Over two months, various salts, e.g. NaCl and MgCl$_2$ crystallised over the surface of the dress.

- The formation of salt crystals changed the appearance of the dress from dull black to sparkling white.
9. Why can’t I prepare an insoluble salt by the excess insoluble base method?
Acids, Bases and Salts

Preparation of a Soluble Salt – Excess Insoluble Base

- The insoluble salt will precipitate over the surface of the insoluble base or metal carbonate, for example:
  - barium carbonate + sulfuric acid $\rightarrow$ barium sulfate + water + carbon dioxide
  \[ \text{BaCO}_3(s) + \text{H}_2\text{SO}_4(aq) \rightarrow \text{BaSO}_4(s) + \text{H}_2\text{O}(l) + \text{CO}_2(g) \]
  - The insoluble salt will then form a solid layer (barrier) between the acid and the insoluble base or metal carbonate.
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Preparation of a Soluble Salt – Excess Insoluble Base
Acids, Bases and Salts

Preparation of a Soluble Salt – Excess Insoluble Base

Insoluble Base or Carbonate
Acids, Bases and Salts

Preparation of a Soluble Salt – Excess Insoluble Base

Insoluble Base or Carbonate

Acid

Acid

Acid

Acid
Preparation of a Soluble Salt – Excess Insoluble Base

Acids, Bases and Salts

• Layer of Insoluble Salt

Acid

Insoluble Base or Carbonate

Acid

Acid

Acid
Acids, Bases and Salts

Preparation of a Soluble Salt – Excess Insoluble Base

• The layer of insoluble salt will prevent the acid from reacting with the insoluble base or metal carbonate.

• When the reaction has stopped, the flask will contain a mixture of insoluble salt and unreacted insoluble base or metal carbonate.

• Because of this, the reaction will be incomplete and the reaction product will be impure. In addition, the mixture of insoluble salt and unreacted insoluble base or metal carbonate will be very difficult (impossible) to separate.
10. Is it possible to prepare a salt by reacting an acid with a metal?
Acids, Bases and Salts

Preparation of a Salt – Acid and Metal

• It is possible to prepare a salt by reacting a metal with an acid. Excess metal will be added to the acid to ensure that all of the acid has reacted. The excess metal will then be removed by filtration before the salt is crystallised from solution. There are however two problems with this method…

• Problem Number One: *Not all metals react with acids*. For example, copper does not react with acids, so it is impossible to prepare copper(II) sulfate by reacting copper with sulfuric acid.

• Problem Number Two: *Metals such as sodium and potassium are very reactive*. It is very dangerous to add these metals to an acid because the reaction is very vigorous and potentially explosive because the hydrogen gas that is produced may be ignited by the energy that is released.
• Most, but not all metals react with acids.

• Metals below hydrogen in the reactivity series do not react with acids.

Potassium
Sodium
Calcium
Magnesium
Aluminium
Zinc
Iron

→ Hydrogen ←
Copper
Silver

• Copper ore.
Acids, Bases and Salts

Preparation of a Salt – Acid and Metal

• Remember the tale of Goldie Locks and the Three Bears?
  → Some metals are too reactive, e.g. potassium, sodium and calcium.
  → Some metals aren’t reactive enough, e.g. copper and silver.
  → Some metals are just right, e.g. magnesium, zinc and iron.
11. Which reagents are unsuitable for preparing salts in the laboratory?
Acids, Bases and Salts

Reagents Unsuitable for Preparing Salts – Ca(OH)\(_2\)(aq)

- Calcium hydroxide is *sparingly soluble* in water, meaning its solution will be *very dilute* (the maximum solubility of calcium hydroxide is 1.73 g/dm\(^3\) or 0.0233 mol/dm\(^3\) at 20.0 °C).

- Even though an *aqueous solution of calcium hydroxide* could be used to prepare an insoluble calcium salt by ionic precipitation, or a soluble calcium salt by titration, the use of this reagent is *not recommended*, as the mass of salt produced would be *very small*.

- Using an aqueous solution of calcium hydroxide to prepare an insoluble calcium salt by ionic precipitation:
  \[
  \text{Ca(OH)}_2(aq) + \text{Na}_2\text{SO}_4(aq) \rightarrow \text{CaSO}_4(s) + 2\text{NaOH}(aq)
  \]

- Using an aqueous solution of calcium hydroxide to prepare a soluble calcium salt by titration:
  \[
  \text{Ca(OH)}_2(aq) + 2\text{HCl}(aq) \rightarrow \text{CaCl}_2(aq) + 2\text{H}_2\text{O}(l)
  \]
Acids, Bases and Salts

Reagents Unsuitable for Preparing Salts – Ca(OH)$_2$(aq)

- Calcium hydroxide has a very low solubility in water. To increase the mass of insoluble calcium salt produced by ionic precipitation, a calcium compound that has a much greater solubility should be used as the starting material.

- A good example would be calcium nitrate, which has a maximum solubility of 1212 g/dm$^3$ or 7.39 mol/dm$^3$ at 20.0 °C. This would produce a much greater mass of insoluble calcium salt than an aqueous solution of calcium hydroxide.

\[
\text{Ca(NO}_3\text{)}_2(\text{aq}) + \text{Na}_2\text{SO}_4(\text{aq}) \rightarrow \text{CaSO}_4(\text{s}) + 2\text{NaNO}_3(\text{aq})
\]

- **Note:** Calcium salts that are soluble in water should be made by the excess insoluble base / excess insoluble carbonate method, and not by titration using an aqueous solution of calcium hydroxide.
Acids, Bases and Salts

Reagents Unsuitable for Preparing Salts – \( \text{H}_2\text{CO}_3(\text{aq}) \)

- The solubility of carbon dioxide gas in water is 1.45 g/dm\(^3\) or 0.0330 mol/dm\(^3\). Assuming that all of the carbon dioxide gas reacts with water to form carbonic acid, the concentration of carbonic acid in aqueous solution will be very low.
  \[
  \text{CO}_2(\text{g}) + \text{H}_2\text{O}(l) \rightleftharpoons \text{H}_2\text{CO}_3(\text{aq})
  \]

- Even though an aqueous solution of carbonic acid could be used to prepare an insoluble carbonate by ionic precipitation, or a soluble carbonate by titration, the use of this reagent is not recommended, as the mass of salt produced would be very small.

- Preparing an insoluble carbonate by ionic precipitation:
  \[
  \text{Cu(NO}_3)_2(\text{aq}) + \text{H}_2\text{CO}_3(\text{aq}) \rightarrow \text{CuCO}_3(\text{s}) + 2\text{HNO}_3(\text{aq})
  \]

- Preparing a soluble carbonate by titration:
  \[
  2\text{NaOH}(\text{aq}) + \text{H}_2\text{CO}_3(\text{aq}) \rightarrow \text{Na}_2\text{CO}_3(\text{aq}) + 2\text{H}_2\text{O}(l)
  \]
Acids, Bases and Salts

Reagents Unsuitable for Preparing Salts – \( \text{H}_2\text{CO}_3(\text{aq}) \)

- Carbonic acid has a very low solubility in water. To increase the mass of insoluble carbonate produced by ionic precipitation, a carbonate that has a much greater solubility should be used as the starting material.

- A good example would be sodium carbonate, which has a maximum solubility of 503 g/dm\(^3\) or 4.75 mol/dm\(^3\) at 30.0 °C. This would produce a much greater mass of insoluble carbonate than an aqueous solution of carbonic acid.

\[
\text{Cu(NO}_3)_2(\text{aq}) + \text{Na}_2\text{CO}_3(\text{aq}) \rightarrow \text{CuCO}_3(\text{s}) + 2\text{NaNO}_3(\text{aq})
\]

- **Note:** There is little choice except to prepare soluble carbonates, such as \((\text{NH}_4)_2\text{CO}_3\), \(\text{K}_2\text{CO}_3\) and \(\text{Na}_2\text{CO}_3\), in the laboratory by titration. The large scale, industrial manufacture of these carbonates is more complex.
12. Could I please have some questions to test my understanding?
Acids, Bases and Salts

Question 1:
How would you prepare a pure, dry sample of silver nitrate?
Acids, Bases and Salts

Question 1:
How would you prepare a pure, dry sample of silver nitrate?

Answer:
Add excess insoluble base to an acid.

silver oxide + nitric acid → silver nitrate + water

\[ \text{Ag}_2\text{O(s)} + 2\text{HNO}_3(\text{aq}) \rightarrow 2\text{AgNO}_3(\text{aq}) + \text{H}_2\text{O}(l) \]

\[ \text{Ag}_2\text{O(s)} + 2\text{H}^+(\text{aq}) \rightarrow 2\text{Ag}^+(\text{aq}) + \text{H}_2\text{O}(l) \]
Acids, Bases and Salts

Question 2:
How would you prepare a pure, dry sample of *potassium sulfate*?
Acids, Bases and Salts

Question 2:
How would you prepare a pure, dry sample of potassium sulfate?

Answer:
Titrate acid against alkali.

potassium hydroxide + sulfuric acid → potassium sulfate + water

\[
2\text{KOH(aq)} + \text{H}_2\text{SO}_4(\text{aq}) \rightarrow \text{K}_2\text{SO}_4(\text{aq}) + 2\text{H}_2\text{O(}l)\
\]

\[
2\text{OH}^- (\text{aq}) + 2\text{H}^+ (\text{aq}) \rightarrow 2\text{H}_2\text{O(}l)\
\]

\[
\text{OH}^- (\text{aq}) + \text{H}^+ (\text{aq}) \rightarrow \text{H}_2\text{O(}l)\
\]
Acids, Bases and Salts

**Question 3:**
How would you prepare a pure, dry sample of *lead(II) chloride*?
Acids, Bases and Salts

Question 3:
How would you prepare a pure, dry sample of lead(II) chloride?

Answer:
Ionic precipitation reaction.

\[
Pb(\text{NO}_3)_2(\text{aq}) + 2\text{NaCl}(\text{aq}) \rightarrow \text{PbCl}_2(\text{s}) + 2\text{NaNO}_3(\text{aq})
\]

\[
Pb^{2+}(\text{aq}) + 2\text{Cl}^-(\text{aq}) \rightarrow \text{PbCl}_2(\text{s})
\]
Acids, Bases and Salts

Question 4:
How would you prepare a pure, dry sample of calcium carbonate?
Acids, Bases and Salts

Question 4:
How would you prepare a pure, dry sample of calcium carbonate?

Answer:
Ionic precipitation reaction.

calcium nitrate + sodium carbonate → calcium carbonate + sodium nitrate

\[
\text{Ca(NO}_3\text{)}_2(\text{aq}) + \text{Na}_2\text{CO}_3(\text{aq}) \rightarrow \text{CaCO}_3(\text{s}) + 2\text{NaNO}_3(\text{aq})
\]

\[
\text{Ca}^{2+}(\text{aq}) + \text{CO}_3^{2-}(\text{aq}) \rightarrow \text{CaCO}_3(\text{s})
\]
Acids, Bases and Salts

Question 5:
How would you prepare a pure, dry sample of copper(II) nitrate?
Acids, Bases and Salts

Question 5:
How would you prepare a pure, dry sample of \textit{copper(II) nitrate}? 

Answer:
Add excess insoluble base to an acid.

copper(II) oxide + nitric acid → copper(II) nitrate + water
\[ \text{CuO(s) + 2HNO}_3(aq) \rightarrow \text{Cu(NO}_3)_2(aq) + \text{H}_2\text{O(l)} \]

\[ \text{CuO(s) + 2H}^+(aq) \rightarrow \text{Cu}^{2+}(aq) + \text{H}_2\text{O(l)} \]
Acids, Bases and Salts

MCQ Question 1.
Which one of the following salts cannot be prepared by a reaction between a dilute acid and an excess of an insoluble base?

A. Copper(II) chloride
B. Magnesium nitrate
C. Potassium sulfate
D. Zinc sulfate
MCQ Question 1.
Which one of the following salts cannot be prepared by a reaction between a dilute acid and an excess of an insoluble base?

A. Copper(II) chloride
B. Magnesium nitrate
C. Potassium sulfate ✓
D. Zinc sulfate

A. \( \text{CuO(s)} + 2\text{HCl(aq)} \rightarrow \text{CuCl}_2(\text{aq}) + \text{H}_2\text{O(l)} \)
B. \( \text{MgO(s)} + 2\text{HNO}_3(\text{aq}) \rightarrow \text{Mg(NO}_3)_2(\text{aq}) + \text{H}_2\text{O(l)} \)
C. \( 2\text{KOH(aq)} + \text{H}_2\text{SO}_4(\text{aq}) \rightarrow \text{K}_2\text{SO}_4(\text{aq}) + 2\text{H}_2\text{O(l)} \)
D. \( \text{ZnO(s)} + \text{H}_2\text{SO}_4(\text{aq}) \rightarrow \text{ZnSO}_4(\text{aq}) + \text{H}_2\text{O(l)} \)

Note: Potassium oxide is soluble in water. It reacts with water to form an aqueous solution of potassium hydroxide: \( \text{K}_2\text{O(s)} + \text{H}_2\text{O(l)} \rightarrow 2\text{KOH(aq)} \)
MCQ Question 2.
Lead(II) sulfate can be prepared by the reaction of sulfuric acid with…

I  Lead(II) oxide  
II  Lead(II) nitrate solution  
III Lead(II) carbonate

A. I only  
B. II only  
C. I and II only  
D. I, II and III
MCQ Question 2.
Lead(II) sulfate can be prepared by the reaction of sulfuric acid with...

I. Lead(II) oxide
II. Lead(II) nitrate solution
III. Lead(II) carbonate

A. I only
B. II only ✓
C. I and II only
D. I, II and III

Lead(II) sulfate is *insoluble* in water. It should be made by ionic precipitation by adding a solution of lead(II) ions to a solution of sulfate ions:

\[
Pb(NO_3)_2(aq) + H_2SO_4(aq) \rightarrow PbSO_4(s) + 2HNO_3(aq)
\]

\[
Pb^{2+}(aq) + SO_4^{2-}(aq) + PbSO_4(s)
\]

Note: Lead(II) oxide and lead(II) carbonate are both *insoluble* in water. *Insoluble salts* should *not* be prepared from *insoluble starting materials.*
Acids, Bases and Salts

MCQ Question 3.
Which one of the following chemicals *cannot* be prepared by ionic precipitation?

A. Barium sulfate
B. Calcium carbonate
C. Lead(II) chloride
D. Silver nitrate
MCQ Question 3.
Which one of the following chemicals *cannot* be prepared by ionic precipitation?

A. Barium sulfate
B. Calcium carbonate
C. Lead(II) chloride
D. Silver nitrate ✓

- Ionic precipitation is used to prepare *insoluble* salts from *soluble* starting materials. Barium sulfate (A), calcium carbonate (B) and lead(II) chloride (C) are all *insoluble* in water, and *can* be prepared by ionic precipitation. Silver nitrate is *soluble* in water, and should be prepared by adding excess insoluble base or metal carbonate to an acid:

  \[
  \text{Ag}_2\text{O}(s) + 2\text{HNO}_3(\text{aq}) \rightarrow 2\text{AgNO}_3(\text{aq}) + \text{H}_2\text{O}(l)
  \]

  \[
  \text{Ag}_2\text{CO}_3(s) + 2\text{HNO}_3(\text{aq}) \rightarrow 2\text{AgNO}_3(\text{aq}) + \text{H}_2\text{O}(l) + \text{CO}_2(\text{g})
  \]
Acids, Bases and Salts

MCQ Question 4.
Which pair of compounds could be used in the preparation of calcium sulfate?

A. Calcium carbonate and sodium sulfate.
B. Calcium chloride and ammonium sulfate.
C. Calcium hydroxide and barium sulfate.
D. Calcium nitrate and lead(II) sulfate.
MCQ Question 4.
Which pair of compounds could be used in the preparation of calcium sulfate?

A. Calcium carbonate and sodium sulfate.

B. Calcium chloride and ammonium sulfate. ✓

C. Calcium hydroxide and barium sulfate.

D. Calcium nitrate and lead(II) sulfate.

- Calcium sulfate is *insoluble* in water and should therefore be prepared by *ionic precipitation*, adding an aqueous solution of calcium ions to an aqueous solution of sulfate ions:
  \[
  \text{CaCl}_2(\text{aq}) + (\text{NH}_4)_2\text{SO}_4(\text{aq}) \rightarrow \text{CaSO}_4(\text{s}) + 2\text{NH}_4\text{Cl}(\text{aq}) \\
  \text{Ca}^{2+}(\text{aq}) + \text{SO}_4^{2-}(\text{aq}) \rightarrow \text{CaSO}_4(\text{s})
  \]
Acids, Bases and Salts

MCQ Question 5.
Which reactants could be used safely to prepare sodium nitrate?

A. Aqueous sodium hydroxide and dilute nitric acid.
B. Aqueous sodium sulfate and aqueous potassium nitrate.
C. Sodium and aqueous potassium nitrate.
D. Sodium and dilute nitric acid.
MCQ Question 5.
Which reactants could be used safely to prepare sodium nitrate?

A. Aqueous sodium hydroxide and dilute nitric acid. ✓
B. Aqueous sodium sulfate and aqueous potassium nitrate.
C. Sodium and aqueous potassium nitrate.
D. Sodium and dilute nitric acid.

- Sodium nitrate is the salt of a Group 1 metal. It is soluble in water and should be prepared by titration, reacting aqueous sodium hydroxide with dilute nitric acid:
  \[ \text{NaOH(aq)} + \text{HNO}_3(\text{aq}) \rightarrow \text{NaNO}_3(\text{aq}) + \text{H}_2\text{O(l)} \]

**Note:** Although metallic sodium will react directly with dilute nitric acid (D) to produce sodium nitrate, the reaction is very *exothermic* (produces a lot of heat) and also produces flammable hydrogen gas. This method is therefore *unsafe*:

\[ 2\text{Na(s)} + 2\text{HNO}_3(\text{aq}) \rightarrow 2\text{NaNO}_3(\text{aq}) + \text{H}_2(\text{g}) \]
Acids, Bases and Salts

MCQ Question 6.
Which three salts are all prepared by precipitation?

A. Barium sulfate, calcium nitrate, lead(II) sulfate.
B. Barium sulfate, calcium nitrate, silver chloride.
C. Barium sulfate, lead(II) sulfate, silver chloride.
D. Calcium nitrate, lead(II) sulfate, silver chloride.
Acids, Bases and Salts

**MCQ Question 6.**
Which three salts are all prepared by precipitation?

A. Barium sulfate, calcium nitrate, lead(II) sulfate.
B. Barium sulfate, calcium nitrate, silver chloride.
C. Barium sulfate, lead(II) sulfate, silver chloride. ✓
D. Calcium nitrate, lead(II) sulfate, silver chloride.

- Ionic precipitation is used to prepare salts that are **insoluble** in water.
  
  A. Barium sulfate = insoluble. Calcium nitrate = soluble. Lead(II) sulfate = insoluble.
  D. Calcium nitrate = soluble. Lead(II) sulfate = insoluble. Silver chloride = insoluble.
Acids, Bases and Salts

MCQ Question 7.
In which one of the following reactions is the sulfate ion removed from solution?

A. \( \text{BaCl}_2 + \text{H}_2\text{SO}_4 \rightarrow \text{BaSO}_4 + 2\text{HCl} \)

B. \( 2\text{NaOH} + \text{H}_2\text{SO}_4 \rightarrow \text{Na}_2\text{SO}_4 + 2\text{H}_2\text{O} \)

C. \( \text{Mg} + \text{H}_2\text{SO}_4 \rightarrow \text{MgSO}_4 + \text{H}_2 \)

D. \( \text{Na}_2\text{CO}_3 + \text{H}_2\text{SO}_4 \rightarrow \text{Na}_2\text{SO}_4 + \text{H}_2\text{O} + \text{CO}_2 \)
Acids, Bases and Salts

MCQ Question 7.
In which one of the following reactions is the sulfate ion removed from solution?

A. $\text{BaCl}_2 + \text{H}_2\text{SO}_4 \rightarrow \text{BaSO}_4 + 2\text{HCl}$ ✓

B. $2\text{NaOH} + \text{H}_2\text{SO}_4 \rightarrow \text{Na}_2\text{SO}_4 + 2\text{H}_2\text{O}$

C. $\text{Mg} + \text{H}_2\text{SO}_4 \rightarrow \text{MgSO}_4 + \text{H}_2$

D. $\text{Na}_2\text{CO}_3 + \text{H}_2\text{SO}_4 \rightarrow \text{Na}_2\text{SO}_4 + \text{H}_2\text{O} + \text{CO}_2$

- In option A, sulfate ions are removed from aqueous solution as an insoluble precipitate of barium sulfate is formed.

A. $\text{BaCl}_2(aq) + \text{H}_2\text{SO}_4(aq) \rightarrow \text{BaSO}_4(s) + 2\text{HCl(aq)}$

B. $2\text{NaOH(aq)} + \text{H}_2\text{SO}_4(aq) \rightarrow \text{Na}_2\text{SO}_4(aq) + 2\text{H}_2\text{O(l)}$

C. $\text{Mg(s)} + \text{H}_2\text{SO}_4(aq) \rightarrow \text{MgSO}_4(aq) + \text{H}_2(g)$

D. $\text{Na}_2\text{CO}_3(aq) + \text{H}_2\text{SO}_4(aq) \rightarrow \text{Na}_2\text{SO}_4(aq) + \text{H}_2\text{O(l)} + \text{CO}_2(g)$
Acids, Bases and Salts

MCQ Question 8.
Which solutions, when mixed together, form an insoluble salt?

A. Dilute hydrochloric acid and barium nitrate.
B. Dilute sulfuric acid and sodium hydroxide.
C. Dilute hydrochloric acid and lead(II) nitrate.
D. Dilute sulfuric acid and zinc chloride.
Acids, Bases and Salts

MCQ Question 8.
Which solutions, when mixed together, form an insoluble salt?

A. Dilute hydrochloric acid and barium nitrate.
B. Dilute sulfuric acid and sodium hydroxide.
C. Dilute hydrochloric acid and lead(II) nitrate. ✓
D. Dilute sulfuric acid and zinc chloride.

\[
\text{A. } 2\text{HCl}(aq) + \text{Ba(NO}_3\text{)}_2(aq) \rightarrow \text{no observed reaction}
\]
\[
2\text{H}^+(aq) + 2\text{Cl}^-(aq) + \text{Ba}^{2+}(aq) + 2\text{NO}_3^-(aq) \rightarrow \text{Ba}^{2+}(aq) + 2\text{Cl}^-(aq) + 2\text{H}^+(aq) + 2\text{NO}_3^-(aq)
\]

Attempting to write an ionic equation for A – everything cancels – there is no reaction.

\[
\text{B. } \text{H}_2\text{SO}_4(aq) + 2\text{NaOH}(aq) \rightarrow \text{Na}_2\text{SO}_4(aq) + 2\text{H}_2\text{O}(l)
\]

\[
\text{C. } 2\text{HCl}(aq) + \text{Pb(NO}_3\text{)}_2(aq) \rightarrow \text{PbCl}_2(s) + 2\text{HNO}_3(aq)
\]

\[
\text{D. } \text{H}_2\text{SO}_4(aq) + \text{ZnCl}_2(aq) \rightarrow \text{no observed reaction}
\]
\[
2\text{H}^+(aq) + \text{SO}_4^{2-}(aq) + \text{Zn}^{2+}(aq) + 2\text{Cl}^-(aq) \rightarrow \text{Zn}^{2+}(aq) + \text{SO}_4^{2-}(aq) + 2\text{H}^+(aq) + 2\text{Cl}^-(aq)
\]

Attempting to write an ionic equation for D – everything cancels – there is no reaction.
Aqueous solutions of silver nitrate and barium chloride are added together and the resulting mixture is poured through filter paper. Which one of the following correctly identifies the filtrate and residue?

<table>
<thead>
<tr>
<th>Residue</th>
<th>Filtrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. silver nitrate</td>
<td>barium chloride</td>
</tr>
<tr>
<td>B. barium chloride</td>
<td>silver nitrate</td>
</tr>
<tr>
<td>C. silver chloride</td>
<td>barium nitrate</td>
</tr>
<tr>
<td>D. barium nitrate</td>
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MCQ Question 9.
Aqueous solutions of silver nitrate and barium chloride are added together and the resulting mixture is poured through filter paper. Which one of the following correctly identifies the filtrate and residue?

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</tr>
<tr>
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<td>silver nitrate</td>
</tr>
<tr>
<td>C. silver chloride</td>
<td>barium nitrate ✓</td>
</tr>
<tr>
<td>D. barium nitrate</td>
<td>silver chloride</td>
</tr>
</tbody>
</table>

\[ 2\text{AgNO}_3(aq) + \text{BaCl}_2(aq) \rightarrow 2\text{AgCl}(s) + \text{Ba(NO}_3)_2(aq) \]

- The solid precipitate of silver chloride will be collected in the filter paper as the residue, while the solution of barium nitrate will pass through the filter paper to be collected as the filtrate.
### MCQ Question 10.
Which one of the following reactions is *least* suitable for preparing the given salt?

<table>
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<tr>
<th>Reactants</th>
<th>Salt</th>
</tr>
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<td>A. iron + hydrochloric acid</td>
<td>iron(II) chloride</td>
</tr>
<tr>
<td>B. copper(II) oxide + nitric acid</td>
<td>copper(II) nitrate</td>
</tr>
<tr>
<td>C. magnesium chloride + sulfuric acid</td>
<td>magnesium sulfate</td>
</tr>
<tr>
<td>D. lead(II) carbonate + nitric acid</td>
<td>lead(II) nitrate</td>
</tr>
</tbody>
</table>
Acids, Bases and Salts

MCQ Question 10.
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<td>magnesium sulfate ✓</td>
</tr>
<tr>
<td>D. lead(II) carbonate + nitric acid</td>
<td>lead(II) nitrate</td>
</tr>
</tbody>
</table>

A. Fe(s) + 2HCl(aq) → FeCl₂(aq) + H₂(g)
B. CuO(s) + 2HNO₃(aq) → Cu(NO₃)₂(aq) + H₂O(l)
C. MgCl₂(aq) + H₂SO₄(aq) → no observed reaction

Mg²⁺(aq) + 2Cl⁻(aq) + 2H⁺(aq) + SO₄²⁻(aq) → Mg²⁺(aq) + SO₄²⁻(aq) + 2H⁺(aq) + 2Cl⁻(aq)

Attempting to write an ionic equation for C – *everything cancels* – there is no reaction.

D. PbCO₃(s) + 2HNO₃(aq) → Pb(NO₃)₂(aq) + H₂O(l) + CO₂(g)
MCQ Question 11.
The graph on the right shows how the solubilities of three salts, \( P \), \( Q \) and \( R \), are affected by temperature. Which is the best method to recover each salt?

- A. crystallisation, filtration, heat to dryness
- B. crystallisation, heat to dryness, filtration
- C. filtration, crystallisation, heat to dryness
- D. heat to dryness, crystallisation, filtration
MCQ Question 11.
The graph on the right shows how the solubilities of three salts, \( P \), \( Q \) and \( R \), are affected by temperature. Which is the best method to recover each salt?

- **P**
  - A. crystallisation
  - B. crystallisation
  - C. filtration
  - D. heat to dryness

- **Q**
  - filtration
  - heat to dryness
  - crystallisation

- **R**
  - heat to dryness
  - filtration

The correct answer is **B. crystallisation, heat to dryness, filtration**.
**Acids, Bases and Salts**

**MCQ Question 11.**

The graph on the right shows how the solubilities of three salts, $P$, $Q$ and $R$, are affected by temperature. Which is the best method to recover each salt?

- A significant mass of salt $P$ will crystallise from a hot saturated solution of the salt as it is cooled to room temperature. Salt $P$ should be recovered by **crystallisation**.

- Salt $Q$ is quite soluble in water, but only a very small mass will crystallise from a hot saturated solution as it is cooled to room temperature. Salt $Q$ should be recovered by **heating to dryness**, i.e. boiling away all of the water.

- Salt $R$ is almost completely insoluble in water, and can be simply recovered by **filtration**.
MCQ Question 12.
Equal masses of lead(II) carbonate were reacted with three different acids of the same concentration, all other conditions being kept constant. The acids were added in excess. The mass of lead(II) carbonate was measured at regular time intervals, and results for each experiment plotted.

(a) = HCl(aq)   (b) = H$_2$SO$_4$(aq)   (c) = HNO$_3$(aq)

Which set of graphs represent the results of the experiments?
MCQ Question 12.
Equal masses of lead(II) carbonate were reacted with three different acids of the same concentration, all other conditions being kept constant. The acids were added in excess. The mass of lead(II) carbonate was measured at regular time intervals, and results for each experiment plotted.

(a) = HCl(aq)     (b) = H₂SO₄(aq)     (c) = HNO₃(aq)

Which set of graphs represent the results of the experiments?

- \[ \text{PbCO}_3(s) + 2\text{HCl}(aq) \rightarrow \text{PbCl}_2(s) + \text{H}_2\text{O}(l) + \text{CO}_2(g) \]
- \[ \text{PbCO}_3(s) + \text{H}_2\text{SO}_4(aq) \rightarrow \text{PbSO}_4(s) + \text{H}_2\text{O}(l) + \text{CO}_2(g) \]
- \[ \text{PbCO}_3(s) + 2\text{HNO}_3(aq) \rightarrow \text{Pb(NO}_3)_2(aq) + \text{H}_2\text{O}(l) + \text{CO}_2(g) \]
MCQ Question 12.

Equal masses of lead(II) carbonate were reacted with three different acids of the same concentration, all other conditions being kept constant. The acids were added in excess. The mass of lead(II) carbonate was measured at regular time intervals, and results for each experiment plotted.

(a) = HCl(aq)     (b) = H$_2$SO$_4$(aq)     (c) = HNO$_3$(aq)

Which set of graphs represent the results of the experiments?

- PbCl$_2$(s) will precipitate over the PbCO$_3$(s) stopping the reaction.
- PbSO$_4$(s) will precipitate over the PbCO$_3$(s) stopping the reaction.
- Pb(NO$_3$)$_2$(aq) is soluble in water and will not precipitate over the PbCO$_3$(s), allowing the reaction to go to completion (slides 66-72).
MCQ Question 13.
Which one of the following statements about the preparation of hydrated copper(II) chloride from copper(II) hydroxide and dilute hydrochloric acid is correct?

A. The hydrated copper(II) chloride should be prepared by titration.

B. Copper(II) hydroxide should be added in excess.

C. The hydrated copper(II) chloride should be heated to dryness.

D. Either the copper(II) or hydrochloric acid can be added in excess.
Acids, Bases and Salts

MCQ Question 13.
Which one of the following statements about the preparation of hydrated copper(II) chloride from copper(II) hydroxide and dilute hydrochloric acid is correct?

A. The hydrated copper(II) chloride should be prepared by titration.

B. Copper(II) hydroxide should be added in excess. ✓

C. The hydrated copper(II) chloride should be heated to dryness.

D. Either the copper(II) or hydrochloric acid can be added in excess.

Copper(II) chloride is soluble in water and should be prepared by the excess insoluble base method. Excess copper(II) hydroxide should be added to ensure that all of the hydrochloric acid reacts.

\[ \text{Cu(OH)}_2(s) + 2\text{HCl}(aq) \rightarrow \text{CuCl}_2(aq) + 2\text{H}_2\text{O}(l) \]
Acids, Bases and Salts

MCQ Question 14.
What is the most appropriate way to prepare magnesium carbonate in the laboratory?

A. Mix magnesium hydroxide with aqueous sodium hydroxide and then bubble carbon dioxide gas through the reaction mixture.

B. Mix magnesium sulfate with aqueous sodium hydroxide and then bubble carbon dioxide gas through the reaction mixture.

C. Mix together solid magnesium, calcium carbonate and water.

D. Dissolve solid magnesium sulfate in water and mix with aqueous sodium carbonate.
Acids, Bases and Salts

MCQ Question 14.
What is the most appropriate way to prepare magnesium carbonate in the laboratory?

A. Mix magnesium hydroxide with aqueous sodium hydroxide and then bubble carbon dioxide gas through the reaction mixture.

B. Mix magnesium sulfate with aqueous sodium hydroxide and then bubble carbon dioxide gas through the reaction mixture.

C. Mix together solid magnesium, calcium carbonate and water.

D. Dissolve solid magnesium sulfate in water and mix with aqueous sodium carbonate. ✓

- Magnesium carbonate is insoluble in water and should be prepared by ionic precipitation.

\[ \text{MgSO}_4(\text{aq}) + \text{Na}_2\text{CO}_3(\text{aq}) \rightarrow \text{MgCO}_3(\text{s}) + \text{Na}_2\text{SO}_4(\text{aq}) \]
MCQ Question 15.
Which one of the following pairs of reactants can be used to prepare a pure and dry sample of silver nitrate?

A. Ag and HNO$_3$
B. AgCl and HNO$_3$
C. AgOH and HNO$_3$
D. Ag$_2$SO$_4$ and HNO$_3$
Acids, Bases and Salts

MCQ Question 15.
Which one of the following pairs of reactants can be used to prepare a pure and dry sample of silver nitrate?

A. Ag and HNO₃
B. AgCl and HNO₃
C. AgOH and HNO₃ ✓
D. Ag₂SO₄ and HNO₃

• Silver nitrate is soluble in water and should be prepared by the excess insoluble base method. From the options available, only silver hydroxide (an insoluble base) will react with nitric acid to produce silver nitrate.

\[
\text{AgOH}(s) + \text{HNO}_3(aq) \rightarrow \text{AgNO}_3(aq) + \text{H}_2\text{O}(l)
\]
MCQ Question 16.
A student wants to prepare a pure and dry sample of hydrated sodium hydrogen sulfate by titration. A graph showing how the pH of the solution changes when aqueous sodium hydroxide is added to dilute sulfuric acid is given on the right. How should the student prepare the salt?

A. Titrate until methyl orange changes colour, then heat to dryness.
B. Titrate until methyl orange changes colour, then crystallise.
C. Titrate until bromothymol blue changes colour, then heat to dryness.
D. Titrate until phenolphthalein changes colour, then crystallise.
MCQ Question 16.
A student wants to prepare a pure and dry sample of hydrated sodium hydrogen sulfate by titration. A graph showing how the pH of the solution changes when aqueous sodium hydroxide is added to dilute sulfuric acid is given on the right. How should the student prepare the salt?

A. Titrate until methyl orange changes colour, then heat to dryness.
B. Titrate until methyl orange changes colour, then crystallise. ✓
C. Titrate until bromothymol blue changes colour, then heat to dryness.
D. Titrate until phenolphthalein changes colour, then crystallise.
MCQ Question 16.
A student wants to prepare a pure and dry sample of hydrated sodium hydrogen sulfate by titration. A graph showing how the pH of the solution changes when aqueous sodium hydroxide is added to dilute sulfuric acid is given on the right. How should the student prepare the salt?

- Methyl orange will change colour to indicate the end-point for:
  \[ \text{NaOH(aq)} + \text{H}_2\text{SO}_4(\text{aq}) \rightarrow \text{NaHSO}_4(\text{aq}) + \text{H}_2\text{O}(l) \]

- Phenolphthalein will change colour to indicate the end-point for:
  \[ \text{NaOH(aq)} + \text{NaHSO}_4(\text{aq}) \rightarrow \text{Na}_2\text{SO}_4(\text{aq}) + \text{H}_2\text{O}(l) \]

- Bromothymol blue does not indicate the end-point of any stage of the reaction.

- *Methyl orange* indicates the end-point for the formation of sodium hydrogen sulfate. It should be *crystallised* because it must be *hydrated.*
Acids, Bases and Salts

MCQ Question 17.
Which one of the following is the best method for preparing calcium sulfate?

A. Add calcium carbonate to dilute nitric acid, then add the resulting mixture to aqueous sodium sulfate.
B. Add solid calcium nitrate to solid potassium sulfate.
C. Add calcium carbonate to dilute sulfuric acid.
D. Add aqueous calcium hydroxide to dilute sulfuric acid.
MCQ Question 17.
Which one of the following is the best method for preparing calcium sulfate?

A. Add calcium carbonate to dilute nitric acid, then add the resulting mixture to aqueous sodium sulfate. ✓

B. Add solid calcium nitrate to solid potassium sulfate.

C. Add calcium carbonate to dilute sulfuric acid.

D. Add aqueous calcium hydroxide to dilute sulfuric acid.

- Calcium sulfate is an insoluble salt, prepared by ionic precipitation. 
  A. This is the best method available. Calcium carbonate will react with nitric acid to form an aqueous solution of calcium nitrate.
  \[
  \text{CaCO}_3(s) + 2\text{HNO}_3(aq) \rightarrow \text{Ca(NO}_3)_2(aq) + \text{H}_2\text{O}(l) + \text{CO}_2(g)
  \]
  When the solution of calcium nitrate is added to aqueous sodium sulfate, a precipitate of calcium sulfate will be formed.
  \[
  \text{Ca(NO}_3)_2(aq) + \text{Na}_2\text{SO}_4(aq) \rightarrow \text{CaSO}_4(s) + 2\text{NaNO}_3(aq)
  \]
Acids, Bases and Salts

MCQ Question 17. Which one of the following is the best method for preparing calcium sulfate?

A. Add calcium carbonate to dilute nitric acid, then add the resulting mixture to aqueous sodium sulfate. ✓

B. Add solid calcium nitrate to solid potassium sulfate.

C. Add calcium carbonate to dilute sulfuric acid.

D. Add aqueous calcium hydroxide to dilute sulfuric acid.

B. There will be no observed reaction when solid calcium nitrate is added to solid potassium sulfate – the salts should be aqueous.

C. Calcium carbonate will react with sulfuric acid to form a small amount of calcium sulfate, but the reaction will soon stop once a layer of calcium sulfate precipitates over the surface of the calcium carbonate, preventing the reactants from coming into contact.

\[ \text{CaCO}_3(s) + \text{H}_2\text{SO}_4(aq) \rightarrow \text{CaSO}_4(s) + \text{H}_2\text{O}(l) + \text{CO}_2(g) \]
MCQ Question 17.
Which one of the following is the **best** method for preparing calcium sulfate?

A. Add calcium carbonate to dilute nitric acid, then add the resulting mixture to aqueous sodium sulfate. ✓

B. Add solid calcium nitrate to solid potassium sulfate.

C. Add calcium carbonate to dilute sulfuric acid.

D. Add aqueous calcium hydroxide to dilute sulfuric acid.

D. Aqueous calcium hydroxide will react with dilute sulfuric acid to form a *small* amount of calcium sulfate.

\[
\text{Ca(OH)}_2(\text{aq}) + \text{H}_2\text{SO}_4(\text{aq}) \rightarrow \text{CaSO}_4(\text{s}) + 2\text{H}_2\text{O}(\text{l})
\]

Calcium hydroxide is only *slightly soluble* in water (the solution is known as limewater). Because the concentration of calcium hydroxide is *low*, the amount of calcium sulfate produced will also be *low.*
Acids, Bases and Salts

MCQ Question 18.
Which salt could be obtained as the insoluble product of a reaction between a dilute acid and an aqueous salt?

A. Barium sulfate  B. Copper(II) sulfate
C. Magnesium sulfate  D. Silver nitrate
MCQ Question 18.
Which salt could be obtained as the insoluble product of a reaction between a dilute acid and an aqueous salt?

A. Barium sulfate ✓
B. Copper(II) sulfate
C. Magnesium sulfate
D. Silver nitrate

- Only option A, barium sulfate, is *insoluble* in water. Copper(II) sulfate, magnesium sulfate and silver nitrate are all *soluble* in water.

\[
\text{Ba(NO}_3\text{)}_2(\text{aq}) + \text{H}_2\text{SO}_4(\text{aq}) \rightarrow \text{BaSO}_4(\text{s}) + 2\text{HNO}_3(\text{aq})
\]

\[
\text{Ba}^{2+}(\text{aq}) + \text{SO}_4^{2-}(\text{aq}) \rightarrow \text{BaSO}_4(\text{s})
\]
Acids, Bases and Salts

MCQ Question 19.
Sodium nitrate can be prepared by reacting aqueous sodium hydroxide with dilute nitric acid. What is the ionic equation for this reaction?

A. \( \text{H}^+ + \text{OH}^- \rightarrow \text{H}_2\text{O} \)

B. \( \text{Na}^+ + \text{NO}_3^- \rightarrow \text{NaNO}_3 \)

C. \( \text{Na}^+ + \text{HNO}_3 \rightarrow \text{NaNO}_3 + \text{H}^+ \)

D. \( \text{NaOH} + \text{H}^+ \rightarrow \text{Na}^+ + \text{H}_2\text{O} \)
Acids, Bases and Salts

MCQ Question 19.
Sodium nitrate can be prepared by reacting aqueous sodium hydroxide with dilute nitric acid. What is the ionic equation for this reaction?

A. $\text{H}^+ + \text{OH}^- \rightarrow \text{H}_2\text{O} \checkmark$

B. $\text{Na}^+ + \text{NO}_3^- \rightarrow \text{NaNO}_3$

C. $\text{Na}^+ + \text{HNO}_3 \rightarrow \text{NaNO}_3 + \text{H}^+$

D. $\text{NaOH} + \text{H}^+ \rightarrow \text{Na}^+ + \text{H}_2\text{O}$

$\text{HNO}_3(\text{aq}) + \text{NaOH(}\text{aq}) \rightarrow \text{NaNO}_3(\text{aq}) + \text{H}_2\text{O}(\ell)$

$\text{H}^+(\text{aq}) + \text{NO}_3^-(\text{aq}) + \text{Na}^+(\text{aq}) + \text{OH}^-(\text{aq}) \rightarrow \text{Na}^+(\text{aq}) + \text{NO}_3^-(\text{aq}) + \text{H}_2\text{O}(\ell)$

$\text{H}^+(\text{aq}) + \text{OH}^-(\text{aq}) \rightarrow \text{H}_2\text{O}(\ell)$
Acids, Bases and Salts

MCQ Question 20.
An aqueous solution of a sulfate is made from a solid hydroxide of a metal $M$ by the reaction:

$$M\text{(OH)}_2(s) + H_2\text{SO}_4(aq) \rightarrow MSO_4(aq) + 2H_2\text{O}(l)$$

For which hydroxide would the method not work?

A. Barium hydroxide  
B. Copper(II) hydroxide  
C. Iron(II) hydroxide  
D. Magnesium hydroxide
Acids, Bases and Salts

MCQ Question 20.
An aqueous solution of a sulfate is made from a solid hydroxide of a metal M by the reaction:

\[ M(OH)_{2}(s) + H_{2}SO_{4}(aq) \rightarrow MSO_{4}(aq) + 2H_{2}O(l) \]

For which hydroxide would the method not work?

A. Barium hydroxide ✓
B. Copper(II) hydroxide
C. Iron(II) hydroxide
D. Magnesium hydroxide

• Option A will not work. Ba(OH)\(_{2}\) is soluble in water (46.8 g/dm\(^3\) or 0.273 mol/dm\(^3\) at 25°C) and BaSO\(_{4}\) is insoluble in water. The hydroxides of the other metals are all insoluble in water, and their sulfates are all soluble in water.

\[ Ba(OH)_{2}(aq) + H_{2}SO_{4}(aq) \rightarrow BaSO_{4}(s) + 2H_{2}O(l) \]
Acids, Bases and Salts

MY TEACHER THREW SODIUM CHLORIDE AT ME

THAT'S A SALT
Acids, Bases and Salts

COULD YOU PASS ME THE SALT PLEASE?

WHICH ONE?
Acids, Bases and Salts

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