TOPIC 9: METALS

DARRELL ER (COPYRIGHTED) ©

THE ABOUT

CHAPTER ANALYSIS

TIME

- Heavy content chapter
- 5 **key** concepts
- 2 **advanced** concepts

EXAM

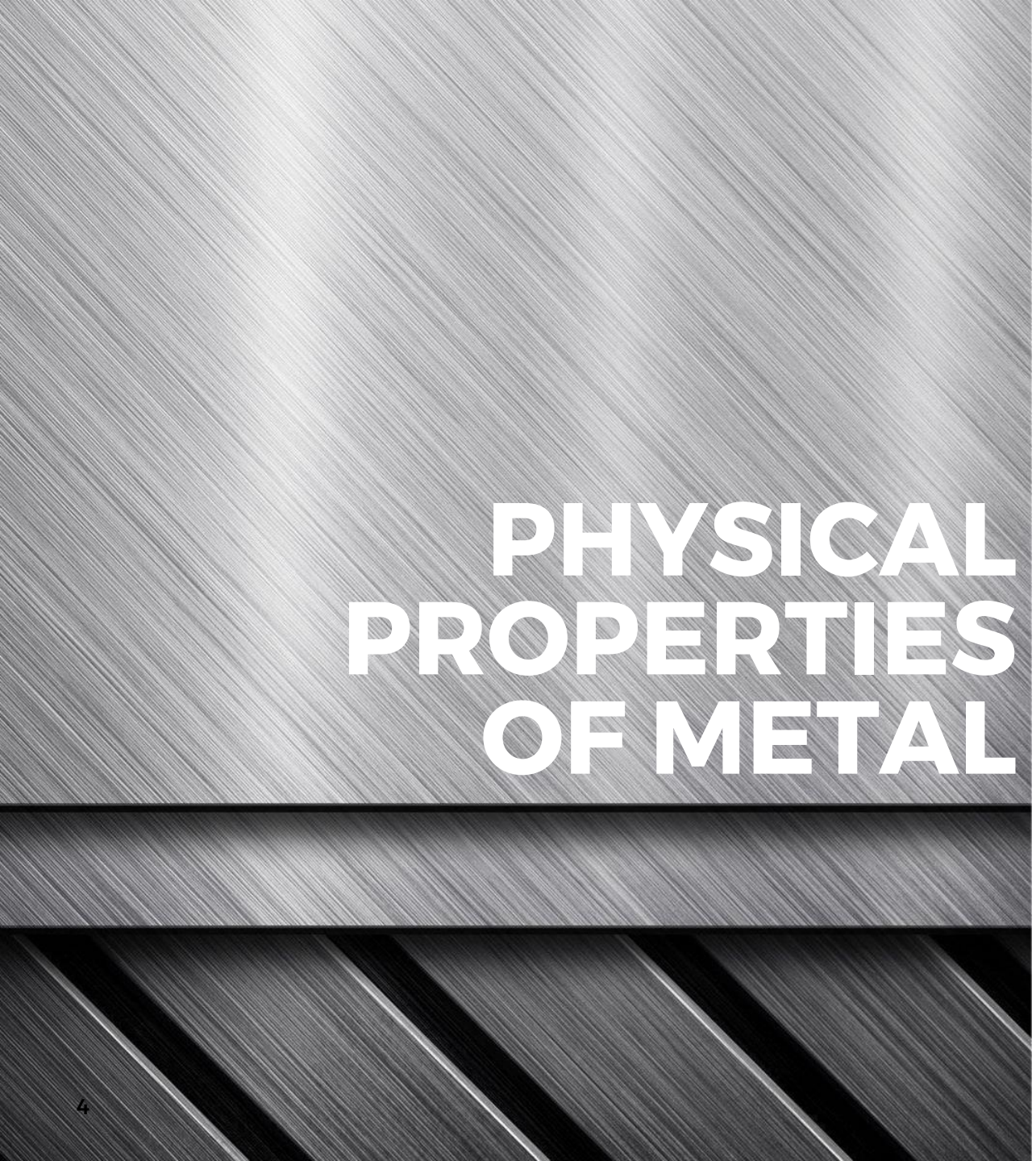
- Always tested in exams, MCQ and FRQ
- Require knowledge from chapters like:
  → Periodic Table, Oxidation & Reduction

WEIGHTAGE

- Heavy-Medium overall weightage
- Constitute to **5.5%** of marks for past 5 year papers

KEY CONCEPT

METALS
PHYSICAL PROPERTIES OF METAL ALLOYS



PHYSICAL PROPERTIES OF METAL

1) Metals are **ductile** (able to be stretched into wires without losing toughness).

2) Metals are **malleable** (able to be bent into different shapes without breaking).

3) Metals are **good conductors of electricity and heat**.

4) Metals have **high melting and boiling points** and generally are solids at room temperature.

5) Metals have **high density.**

6) Metals are generally **strong and shiny**.

Exceptions:

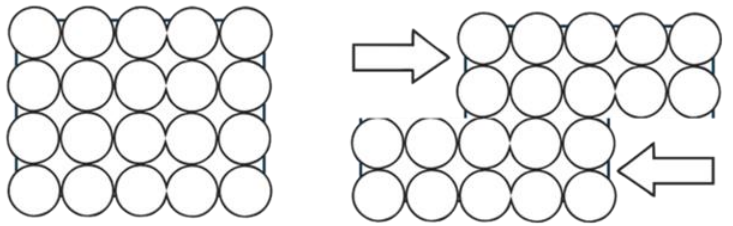
- Mercury has a low melting point (–39 °C) and exists as a liquid at room temperature.

- Group I metals such as lithium, sodium and potassium have low densities and float on water.

ALLOYS

PURE METAL

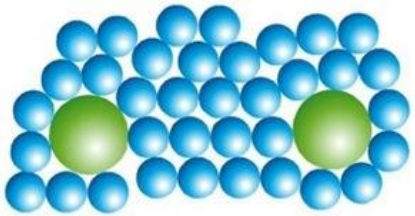
Pure metals are soft and as the **layers of metal atoms** would **slide over one another easily** when an external force is applied to them.



ALLOYS

Alloys are a **mixtures of metals with other elements.**

In alloys, since the **atoms have different size**, the **orderly arrangement** of the metal atoms would be **disrupted**, making it tougher to slide over as easily. Hence, alloys are much **stronger and harder.**



Examples:

Steel: Iron, carbon (bodies of cars)
Stainless Steel: iron, carbon, chromium, nickel (medical instruments)
Brass: Copper, zinc (electrical plugs)
Bronze: Copper, tin (trophies)

STEEL

Steel is a good example of an alloy that is a mixture of iron with carbon or other metals.

By controlling the percentage of carbon in steel, it will form **high carbon** steels **or low carbon** steels**.**

Category	Type of Steel	Uses	Special Properties
Carbon Steels	**Mild Steel** *0.25% Carbon*	Car bodies and machinery	**Hard, strong and malleable**
	High Carbon Steel *0.45 – 1.5% Carbon*	Cutting and boring tools, e.g. knives, hammers	**Strong but brittle** (more carbon atoms to prevent sliding)
Alloy Steels	**Stainless Steel** *Alloy of iron, chromium, nickel & carbon.*	Equipments in chemical plants, cutlery, surgical instruments	Extremely **durable, resistant to rust and corrosion** even when heated

Qn: Explain how the properties of low carbon and high carbon steel differ.

Low carbon steel is softer as it is more malleable.

High carbon steel contains more carbon atoms which prevent sliding of the iron atoms. Hence, high carbon steel is harder but brittle.

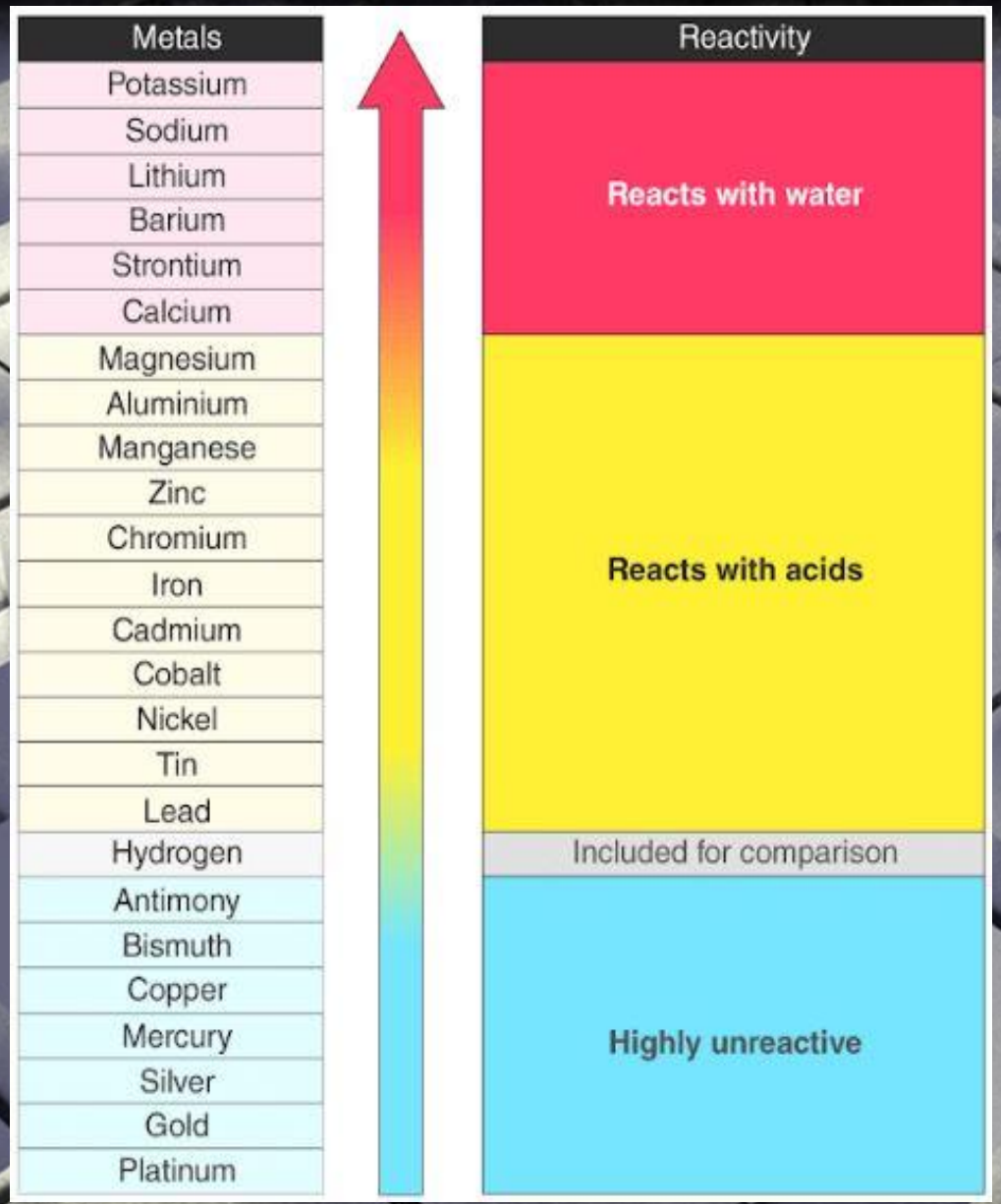
KEY CONCEPT

REACTIVITY SERIES
CHEMICAL REACTIONS OF METALS
DISPLACEMENT, DECOMPOSITION, RUSTING

MUST KNOW

Complete Summary Table

<table>
<tr><th>Acroymn</th><th>Metal</th><th>Periodic Table</th><th>Stability</th><th>Reaction with water</th><th>Reaction with acid</th></tr>
<tr><td>Please</td><td>Potassium (K)</td><td rowspan="2">Group I</td><td rowspan="5">Compound broken down by electrolysis</td><td rowspan="2">Can react with cold water to form metal hydroxide</td><td rowspan="8">React with acid</td></tr>
<tr><td>Stop</td><td>Sodium (Na)</td></tr>
<tr><td>Calling</td><td>Calcium (Ca)</td><td rowspan="2">Group II</td><td rowspan="4">Can react with steam to form metal oxide</td></tr>
<tr><td>Me</td><td>Magnesium (Mg)</td></tr>
<tr><td>A</td><td>Aluminium (Al)</td><td>Group III</td></tr>
<tr><td>Cute</td><td>Carbon (C)</td><td>---</td><td>---</td></tr>
<tr><td>Zombie</td><td>Zinc (Zn)</td><td rowspan="3">Transition Metals</td><td rowspan="3">Compound broken down by reduction with carbon</td></tr>
<tr><td>I</td><td>Iron (Fe)</td></tr>
<tr><td>Like</td><td>Lead (Pb)</td><td rowspan="4">Does not react with steam or cold water</td></tr>
<tr><td>Hwa</td><td>Hydrogen (H)</td><td>---</td><td>---</td><td>---</td></tr>
<tr><td>Chong</td><td>Copper (Cu)</td><td rowspan="3">Unreactive Metals</td><td rowspan="3">Compound broken down by thermal decomposition</td><td rowspan="3">Does not react with acid</td></tr>
<tr><td>Sexy</td><td>Silver (Ag)</td></tr>
<tr><td>Guys</td><td>Gold (Au)</td></tr>
</table>



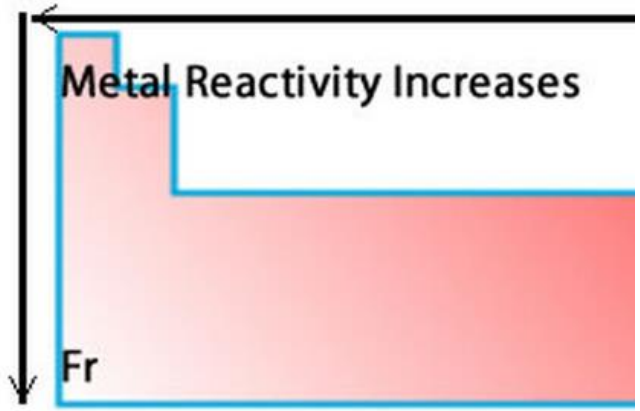
REACTIVITY OF METALS

Reactivity **increases going down the group** and from **right to left in the periodic table**.

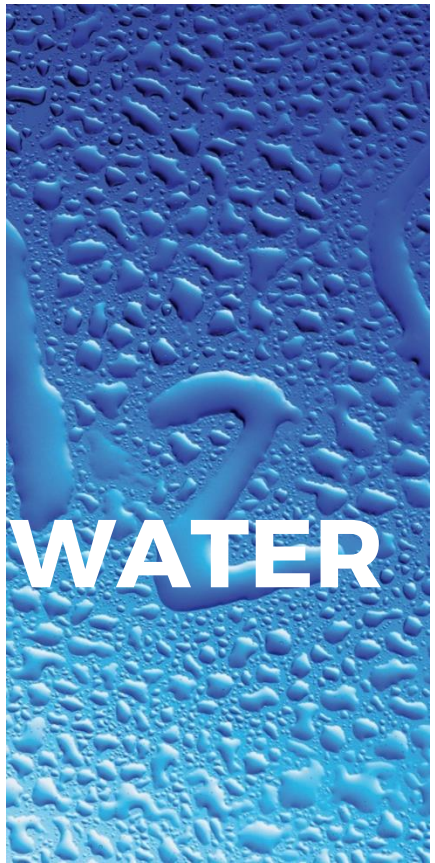
This means that **Group I metals have the best reactivity**.

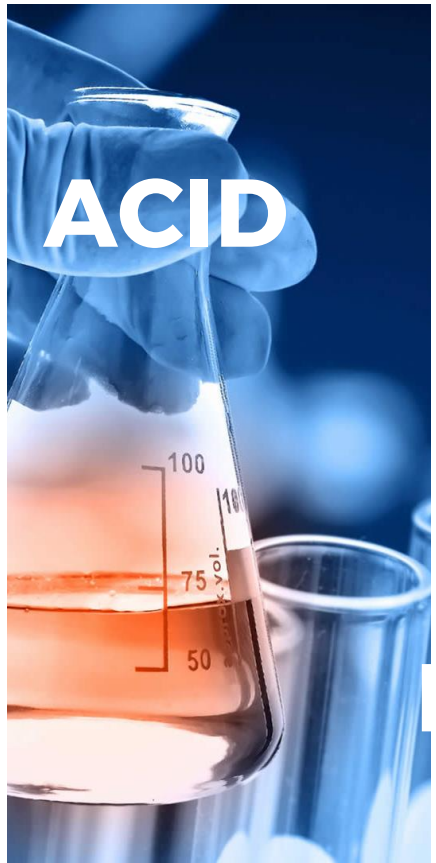
Going down the group, the metal has **more valence shells,** allowing it to **lose its valence electrons more readily,** hence it is more reactive.

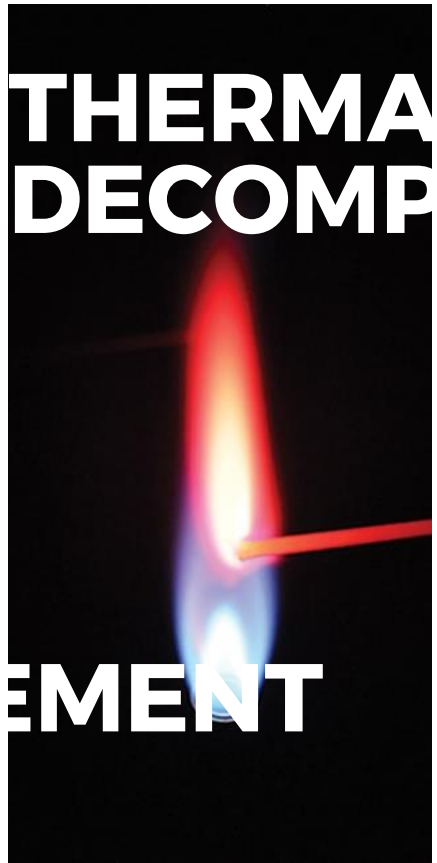
(from chapter 'Periodic Table'.)



CHEMICAL REACTIONS OF METALS







METAL + WATER

METAL + WATER METAL OXIDE / HYDROXIDE + HYDROGEN GAS

When metals react with water/steam, metal oxide or hydroxide is formed, along with hydrogen gas*.

Reactive metals (Group I and Ca) are able to react with cold H_2O.

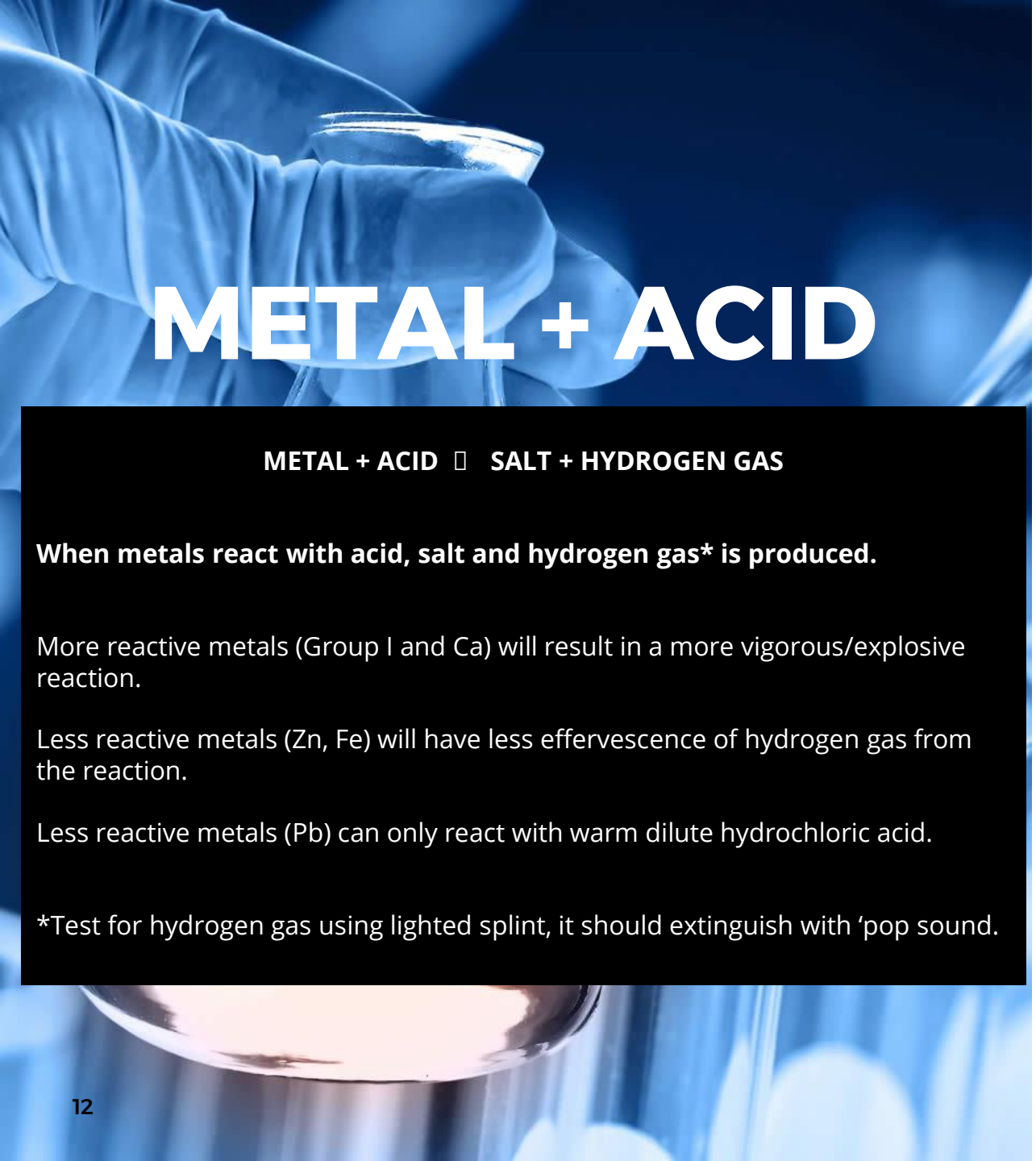
Less reactive metals (Mg, Al and Zn) would only able to react with steam.

Unreactive metals (after Fe) are unable to react with water at all.

*Test for hydrogen gas using lighted splint, it should extinguish with 'pop sound.

METAL + WATER

Metal	Speed of Reaction	Observation	Chemical Equation
Potassium (K)	explosively in cold water	burns with lilac flame	$2K\,(s) + 2H_2O\,(l) \rightarrow 2KOH\,(aq) + H_2\,(g)$
Sodium (Na)	violently in cold water	burns with yellow flame	$2Na\,(s) + 2H_2O\,(l) \rightarrow 2NaOH\,(aq) + H_2\,(g)$
Calcium (Ca)	readily in cold water	vigorous effervescence	$Ca\,(s) + 2H_2O\,(l) \rightarrow Ca(OH)_2\,(aq) + H_2\,(g)$
Magnesium (Mg)	very slowly in cold water violently with steam	little effervescence burns with white glow	$Mg\,(s) + H_2O\,(g) \rightarrow MgO\,(s) + H_2\,(g)$
Aluminium (Al)	readily in steam		$2Al\,(s) + 3H_2O\,(g) \rightarrow Al_2O_3\,(s) + 3\,H_2\,(g)$
Zinc (Zn)	readily in steam	ZnO is yellow when hot white when cooled	$Zn\,(s) + H_2O\,(g) \rightarrow ZnO\,(s) + H_2\,(g)$
Iron (Fe)	slowly in steam	requires constant heating	$3Fe\,(s) + 4H_2O\,(g) \rightarrow Fe_3O_4\,(s) + 4H_2\,(g)$



METAL + ACID

METAL + ACID SALT + HYDROGEN GAS

When metals react with acid, salt and hydrogen gas* is produced.

More reactive metals (Group I and Ca) will result in a more vigorous/explosive reaction.

Less reactive metals (Zn, Fe) will have less effervescence of hydrogen gas from the reaction.

Less reactive metals (Pb) can only react with warm dilute hydrochloric acid.

*Test for hydrogen gas using lighted splint, it should extinguish with 'pop sound.

METAL + ACID

Metal	Speed of Reaction	Chemical Equation
Potassium (K)	Explosively in acid	$2\,K(s) + 2\,HCl\,(aq) \rightarrow 2KCl\,(aq) + H_2\,(g)$
Sodium (Na)	Explosively in acid	$2\,Na(s) + 2HCl\,(aq) \rightarrow 2NaCl\,(aq) + H_2\,(g)$
Calcium (Ca)	Violently in acid	$Ca(s) + 2HCl\,(aq) \rightarrow CaCl_2\,(aq) + H_2\,(g)$
Magnesium (Mg)	Rapidly in acid	$Mg(s) + 2HCl\,(aq) \rightarrow MgCl_2\,(aq) + H_2\,(g)$
Aluminium (Al)	Readily in acid	$4\,Al\,(s) + 6HCl\,(aq) \rightarrow 2\,Al_2Cl_3\,(s) + 3\,H_2\,(g)$
Zinc (Zn)	Moderately in acid	$Zn(s) + 2HCl\,(aq) \rightarrow ZnCl_2\,(aq) + H_2\,(g)$
Iron (Fe)	Slowly in acid	$Fe(s) + 2\,HCl\,(aq) \rightarrow FeCl_2\,(aq) + H_2\,(g)$
Lead (Pb)	Slowly in acid	$Pb(s) + 2\,HCl\,(aq) \xrightarrow{\text{heating}} PbCl_2\,(s) + H_2\,(g)$

DISPLACEMENT REACTION

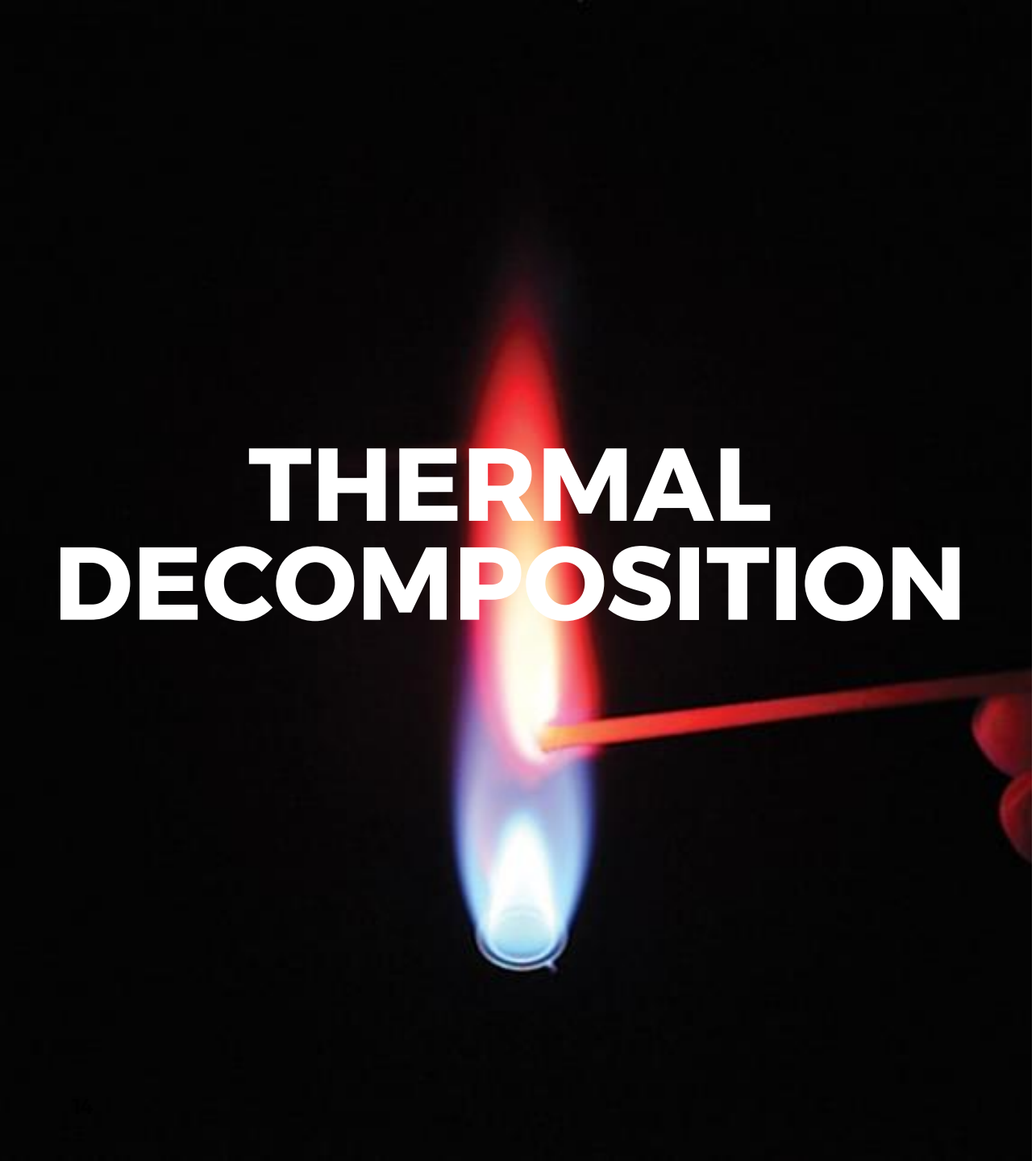
When a **more reactive metal displaces a less reactive metal** from its solution or oxide, it is known as displacement reaction.

This is because the more reactive metal is able to **lose its electrons more readily** to form cations.

We can use the result from displacement reaction to deduce the relative reactivity of two metals.

If a metal precipitates when another metal is added to the solution, then the metal that was added would be more reactive one.

If no change is observed (i.e. no reaction), it means that the metal added is less reactive as it wasn't able to displace the metal in the solution.



THERMAL DECOMPOSITION OF METAL CARBONATES

Metal carbonates would decompose when heated strongly, producing a metal oxide and carbon dioxide gas.

Example:

$$CaCO_3\,(s) \rightarrow CaO\,(s) + CO_2\,(g)$$

Explanation:

The **greater the reactivity a metal has, the more heat-stable** its carbonate.

More reactive metals' carbonates (Group I, Ca, Al) would require **electrolysis** to extract the metal while the less reactive metals' carbonates can be broken down by **reduction with carbon** or by **heating**.

RUSTING

The **corrosion of iron and steel** is called rusting. This occurs when iron corrodes due to a chemical reaction with oxygen in air and water.

After rusting occurs, iron becomes **hydrated iron(III) oxide,** a brown solid with the chemical formula:

$$Fe_2O_3 . xH_2O$$

Iron **must be in contact** with **both air (oxygen) and water** in order for it to rust.

Seawater will cause rusting faster due to the presence of ions in seawater that act as a charge carrier.

PREVENTING RUSTING

Surface Protection

Paint, oil, plastic and metal plating are some commonly used protective layers that would prevent air and water from coming into contact with iron (or steel) under the protective layer.

Sacrificial Metals

If iron is in contact with a **more reactive metal** like magnesium or zinc, then the rusting of iron is greatly minimised. These reactive metals would be diminished in place of iron.

Stainless Steel

Stainless steel is an **iron alloy** that consists of iron and chromium or nickel.

It does not rust easily, as these metals would react with the oxygen in the air to produce a **stable metal oxide layer**.

KEY CONCEPT

EXTRACTION OF METALS
ELECTROLYSIS, REDUCTION, HYDROGEN
BLAST FURNACE

EXTRACTION OF METALS

The method chosen to extract a given metal from its ore depends on the **reactivity of the metal** and the **stability of the metal oxides**.

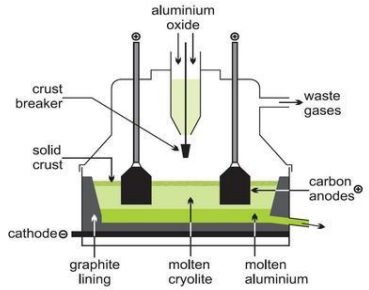
In general, very reactive metals can only be extracted using electrolysis, while less reactive metals would be extracted by reduction with carbon/hydrogen.

Metal	Extraction method	Reduction by hydrogen
Potassium (**K**)	**Electrolysis**	**Cannot be reduced by hydrogen**
Sodium (**Na**)		
Calcium (**Ca**)		
Magnesium (**Mg**)		
Aluminium (**Al**)		
Carbon (**C**)	---	
Zinc (**Zn**)	**Displacement / reduction with carbon**	**Reduced by hydrogen**
Iron (**Fe**)		
Lead (**Pb**)		
Hydrogen (**H**)	---	
Copper (**Cu**)	**Heating in air**	
Silver (**Ag**)	**Exist naturally as metal**	
Gold (**Au**)		

REDUCTION BY ELECTROLYSIS

Electrolysis is the most powerful extraction method. Due to the high usage of electricity, it is a highly expensive process.

Hence, electrolysis would only be utilised for the **most reactive metals** like potassium, sodium, calcium, magnesium and aluminium.



REDUCTION BY CARBON

Metals that can be extracted by this method are **zinc, iron, tin and lead.**

Lead(II) oxide is reduced by carbon to become pure lead metal.

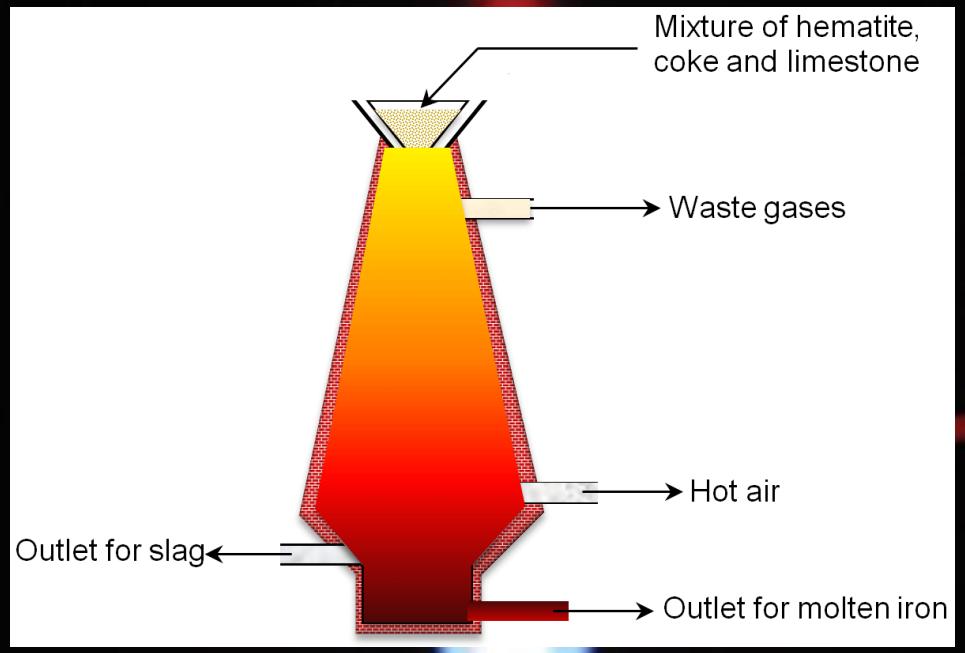
$$\mathbf{PbO\ (s) + C\ (s) \rightarrow Pb\ (s) + CO\ (g)}$$

REDUCTION BY HYDROGEN

Metals that can be extracted by this method from their oxides are **iron, copper and lead.**

$$\mathbf{CuO\ (s) + H_2\ (g) \rightarrow Cu\ (s) + H_2O\ (g)}$$

EXTRACTION OF IRON



BLAST FURNACE

Production of carbon dioxide

Carbon in coke reacts with oxygen in air to produce carbon dioxide.

$$C(s) + O_2(g) \rightarrow CO_2(g)$$

Limestone thermally decompose to form carbon dioxide and calcium oxide.

$$CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$$

Production of carbon monoxide

Carbon dioxide reacts with more carbon in coke to form carbon monoxide.

$$CO_2(g) + C(s) \rightarrow 2CO(g)$$

The first 2 steps are meant to produce CO that will reduce the iron (III) oxide!

Reduction of haematite to iron

Carbon monoxide reduces iron(III) oxide in haematite to form molten iron.

$$Fe_2O_3(s) + 3CO(g) \rightarrow 2Fe(l) + 3CO_2(g)$$

Molten iron would sink to the bottom due to its high density and it exits through the bottom of the blast furnace.

Removal of impurities

Impurities such as silicon(IV) oxide are removed by reacting with calcium oxide.

$$CaO(s) + SiO_2(l) \rightarrow CaSiO_3(l)$$

$CaSiO_3$ is called calcium silicate or slag, would float on top of molten iron due to it being less dense, is removed separately.

RECYCLING

RECYCLING OF METALS

Metals are finite resources and would need to be conserved.

As the amount of metal ores in the Earth is limited, if metal extraction continues at the current rate, the supplies of many metals will run out in the future.

	Upside	Downside
Economic	Cost savings from extraction of new metals from their ores. Fewer landfills required.	Recycling is very expensive, such as costs from collection, transportation and separation of the scrap metals.
Social	Conservation of the limited non-renewable metals on Earth. More land will be available for other uses.	If done wrongly, separation of metal waste uses more effort and resources. Time and manpower to do recycling.
Environmental	Reduce greenhouse gas like CO_2 from combustion of fossil fuels to power extraction factories. Reduces production of waste gases like CO.	The recycling process may cause additional pollution if not handled properly.

Try it yourself! (TYS Question)

29. Some of the reactions of three metals, W, X and Y, or compounds of these metals, are described.
The oxide of W is reduced both by heating with carbon and by heating with hydrogen.
The oxide of X is **not** reduced by heating with carbon or by heating with hydrogen.
W displaces Y from an aqueous solution of the sulfate of Y.
What is the order of reactivity of metals W, X and Y? (N2019/P1/Q28)

	most reactive ⟶ least reactive		
A	X	W	Y
B	X	Y	W
C	W	X	Y
D	Y	W	X

( )

Answer:

29. **A**
W must be below Zn in the reactivity series. X must be above Zn. W is more reactive than Y.

Try it yourself! (TYS Question)

30. X is a metal. It occurs naturally as an element and sometimes in ores containing its oxide.
X can be used to make a chloride of formula X*Cl* but no other chloride of X exists.
A student made some statements about metal X.

1 It can be displaced from solutions containing its ions according to the equation below.

$$3X^{+}(aq) + Fe(s) \rightarrow Fe^{3+}(aq) + 3X(s)$$

2 It can be extracted from its ore by electrolysis.
3 It can be extracted from its ore by reduction with carbon.
4 It is likely to be found as an ore containing the compound X_2O_3.

Which statements are correct? (N2020/P1/Q26)

A 1, 2 and 3 **B** 1 and 3 only
C 2 and 3 only **D** 3 and 4 ( )

Answer:

30. **B**
X is relatively unreactive as it can occur naturally as an element and must be below iron in the reactivity series and will be displaced by iron. It is not necessary to extract X using electrolysis when reduction with carbon can be used to extract X from its ore. Since no other chloride of X exists, besides X*Cl*, X is most likely to exist as X^{+} and will not form X_2O_3.

About Us

OVERMUGGED is a learning platform created by tutors, for students.

Our team of specialist tutors offer 1-to-1 private tuition, group tuitions and crash courses.

Follow us on IG and join our Telegram channel to get the latest updates on our free online revision sessions, webinars and giveaways!

If you would want to join Darrell's group tuition, contact him at:
Whatsapp: 8777 0921
Telegram: @DarrellEr
Website: https://www.overmugged.com/darrell

For more free notes & learning materials, visit: www.overmugged.com

OVERMUGGED
By Tutors, For Students

Notes prepared by:

Darrell Er

'O' Levels Chemistry & Physics

OVERMUGGED's Curated Notes

Found the free notes useful? We got something better!

OVERMUGGED's curated notes is a **highly condensed booklet** that **covers all content within the MOE syllabus**.

This booklet consist of **key concept breakdowns**, **worked examples** and **exam tips/ techniques** to required to ace your exams.

Get an **upgraded version** of the free notes and supercharge your revision!

Purchase here.

Crash courses

Check out our upcoming crash courses at:
https://www.overmugged.com/crashcourses

'O' levels subject available:
- Pure Chemistry
- Pure Physics
- Pure Biology
- Combined Science
- E-Math
-A-Math
-English
- History
- Geography
- Combined Humanities
- Principles of Accounts (POA)