Website: contoureducation.com.au | **Phone:** 1800 888 300
Email: hello@contoureducation.com.au

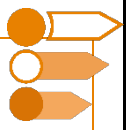
VCE Chemistry ½
Metal Reactions & Recycling [1.4]
Workbook

Outline:

Learning Objectives:

- **CH34 [1.4.1]** – Write balanced equations for the reactions between a metal and oxygen and between a metal and water, and explain any relevant implications of these reactions.
- **CH34 [1.4.2]** – Apply trends in the periodic table to metal reactivity.
- **CH34 [1.4.3]** – Explain how metals are obtained and recycled, and their associated advantages and disadvantages.

Section A: Reactivity of Metals



Sub-Section: Introduction to Metal Reactions

Discussion: What substances do metals typically react with?

O_2, acids, H_2O

Let's explore this further!

Exploration: Reactions with Metals

- Consider Lithium:

Li

- What is the electronic configuration of lithium?

2, 1

- According to the Octet Rule, what will this lithium (Li) atom try to do?

lose $1e^-$

- Lithium can also lose its electron by _____reacting_____ with another substance.
- Hence, lithium will be **[reactive] / [unreactive].**

- As lithium is highly reactive, it reacts as follows when in contact with oxygen gas (O_2) in air:

$$4Li(s) + O_2(g) \rightarrow 2Li_2O(s)$$

  - What do we call the number in front of each chemical? *(Label Above)*
    co-efficient
  - What do we call the small numbers at the bottom of each chemical? *(Label Above)*
    subscript
  - What do the letters in the brackets represent? *(Label Above)*
    states
  - What are the species on either side of the arrow called? *(Label Above)*
    reactants → products

NOTE: This is known as a redox reaction – we'll cover this later in the year.

Chemical Equations

- **Definition**:
  - Chemical equations are used to describe what chemical reactions occur in the form of an equation.

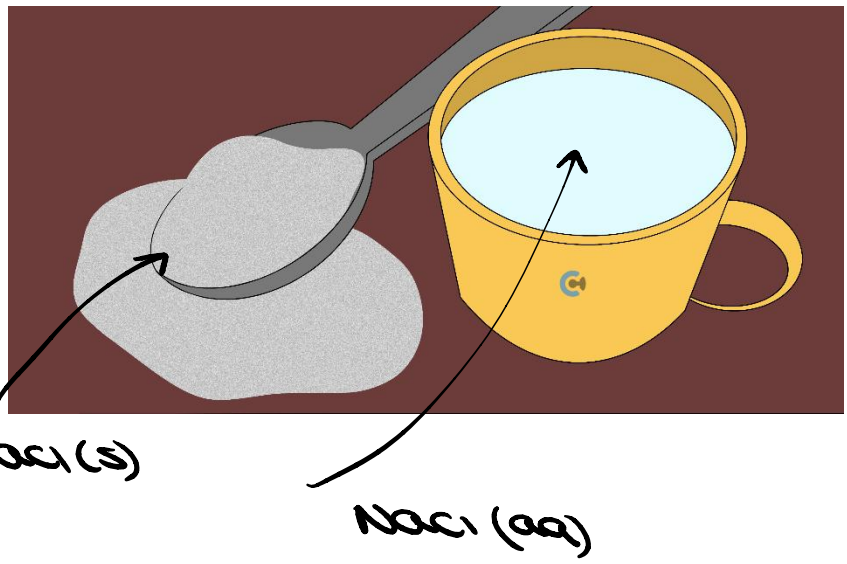
Feature Name	Feature Definition
Subscript	Tells how many of **each atom** are present in chemical equation.
Coefficient	Represents how many of the **entire** compound/element is present.
Reactants	Substances on the **left** side of the equation.
Products	Substances on the **right** side of the equation.
States	Letter in brackets that tells **state of matter** of compound.

- Four states are seen in chemical equations:
  - (s)- solid
  - (l)- liquid → [H2O, molten]
  - (g)- gas
  - (aq)- aqueous

Discussion: What does it mean to be in an aqueous (aq) state?

dissolve in water

Discussion: What are some examples of substances that are in an aqueous state?



NOTE: We'll have a look at solubility later on in the year!

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Let's have a look at a specific metal reaction!

Exploration: Metal & Oxygen Reaction

$$4Li(s) + O_2(g) \rightarrow 2Li_2O(s)$$

- Lithium metal reacts with oxygen in the air to form lithium oxide.

Metal & Oxygen Reaction

- Metal (s) + Oxygen (g) → Metal Oxide (s)
- For example:

$$4Li(s) + O_2(g) \rightarrow 2Li_2O(s)$$

What do lithium (Li) and lithium oxide (Li_2O) look like?

Exploration: Metal and Metal Oxide Appearance

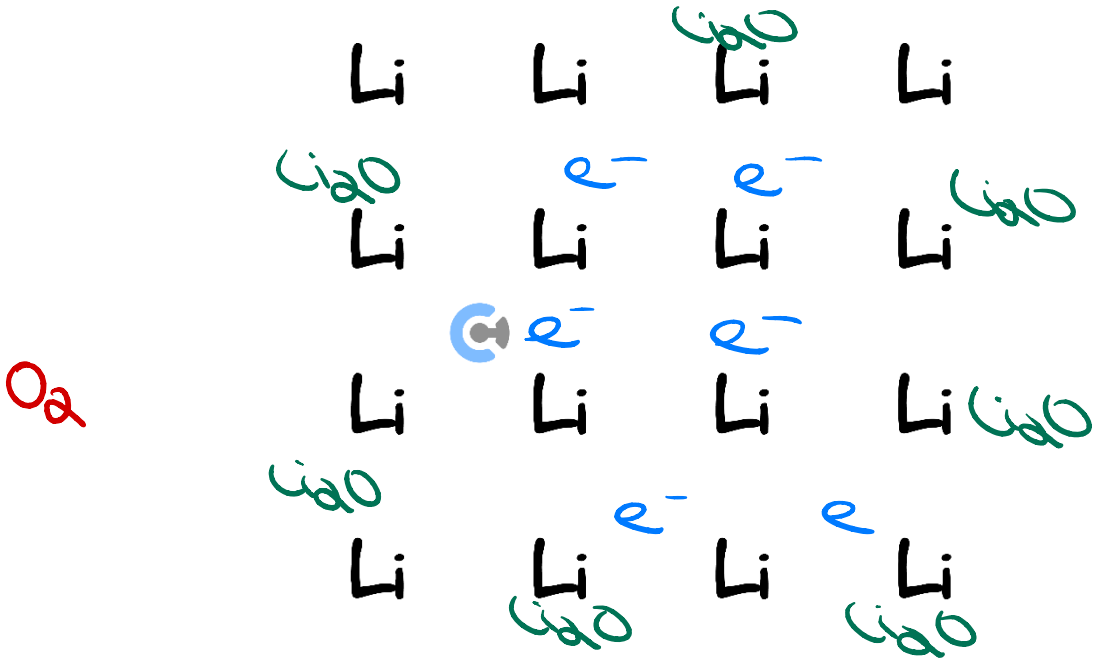
Lithium

Lithium Oxide

- What appearance does lithium have? [Shiny] / [Dull]
- What appearance does lithium oxide have? [Shiny] / [Dull]

- Consider the metallic bonding of lithium in this reaction:

$$4Li(s) + O_2(g) \rightarrow 2Li_2O(s)$$



- Oxygen contacts a block of lithium on the **[inside]** / **[outside]**.
- What will this oxidised lithium turn into?

Li2O

- Therefore, the exterior will look **[shiny]** / **[dull]**.
- On the inside, the lithium metal **[will]** / **[will not]** be exposed to oxygen?
- As such, it _____ as lithium metal (Li) on the inside.
- Therefore, the interior will look **[shiny]** / **[dull]**.

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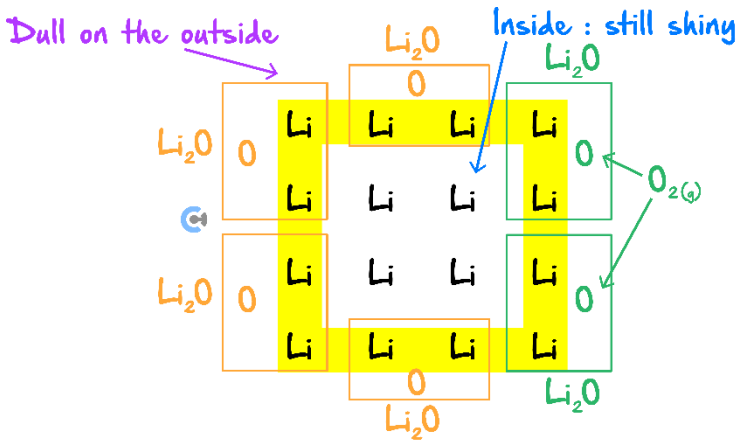
Metal and Metal Oxide Appearance



Lithium metal turns into lithium oxide on the outside

- When a metal is exposed to oxygen:

Outside the metal	Inside the metal
Physically exposed to oxygen and turns into metal oxide which is **dull.**	No contact with oxygen and remains as the pure metal which is **lustrous.**

Discussion: What happens if we cut lithium metal (covered in lithium oxide on the outside) to expose the lithium metal on the inside?

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Let's have a look at this!

Exploration: Cutting a Metal

- Watch: https://www.youtube.com/watch?v=uixxJtJPVXk just for the first 30 seconds (ignore the rest of the video for now).
  - By slicing the lithium metal, the inside is now visible, showing its **[lustrous] / [dull]** form.
  - Therefore, the inside must be **[lithium] / [lithium oxide].**
  - However, in air, this lithium metal is now exposed to _____, causing it to form _____.
  - Subsequently, the metal becomes **[shiny] / [dull].**

Cutting a Metal

- When sliced, the pure metal on the inside is shiny. However, as it is now exposed to oxygen, the metal turns into its oxide form, in turn becoming dull.

Let's have a look at writing an equation together!

Question 1 Walkthrough.

Al^{3+} O^{2-}

Write the reaction which occurs between aluminium metal and oxygen in the air.

$2\,Al(s) + \frac{3}{2}O_2(g) \rightarrow Al_2O_3(s)$

4 3 2

NOTE: First find the charge of aluminium metal and oxygen when they form ions, and write the product that will form.

REMINDER: Be sure to balance every single element and include states!

Your turn!

Question 2

Mg^{2+} O^{2-}

Write the reaction that occurs when the following metals are exposed to oxygen in the air.

a. Magnesium metal.

$Mg(s) + \frac{1}{2}O_2(g) \rightarrow MgO(s)$

K^+ O^{2-}

b. Potassium metal.

$2K(s) + \frac{1}{2}O_2(g) \rightarrow K_2O(s)$

Ga^{3+} O^{2-}

c. Gallium metal.

$2Ga(s) + \frac{3}{2}O_2(g) \rightarrow Ga_2O_3(s)$

Question 3 Additional.

Write the balanced equation for barium reacting with oxygen, and state the name of the product formed.

NOTE: You are allowed to use fractions as coefficients when balancing chemical equations!

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Sub-Section: Reactivity of Metals

Context

- Lithium quickly reacts with oxygen in the air to form lithium oxide, a trend seen for all group 1 metals.
- As such, it is important to consider the **reactivity** of metals.

Active Recall: What does a metal do when it reacts?

lose e^-

Discussion: What concept/trend affects how easily metals will lose their electrons and thus how easily metals can react?

First ionisation energy

Metal Reactivity

- **Definition:**
  - How reactive metals are depends on how easily they can lose their electrons, hence it depends on the **first ionisation energy/metallic character**.

Exploration: Metal Reactivity

- Which metal has the lowest first ionisation energy?

Fr

- This is equivalent to saying francium has the **[greatest] / [least]** metallic character.
- As such, what is francium's reactivity? **[Highest] / [Lowest]**

Extension:

- While francium (Fr) is theoretically the most reactive metal, reaction with francium has never taken place as it is very unstable with the longest half-life of 22 minutes and thus readily decays into another atom.

NOTE: Even if a reaction were to occur with francium, it would be so explosive that it would be too dangerous. Here's a funny video (**don't take this seriously**) showing what a reaction of francium with water could look like:

https://www.youtube.com/watch?v=UEasDa0Fsd0&ab_channel=FrankOloffsen

Let's have a look at how metal reactivity can vary!

Exploration: Trends with Reactivity

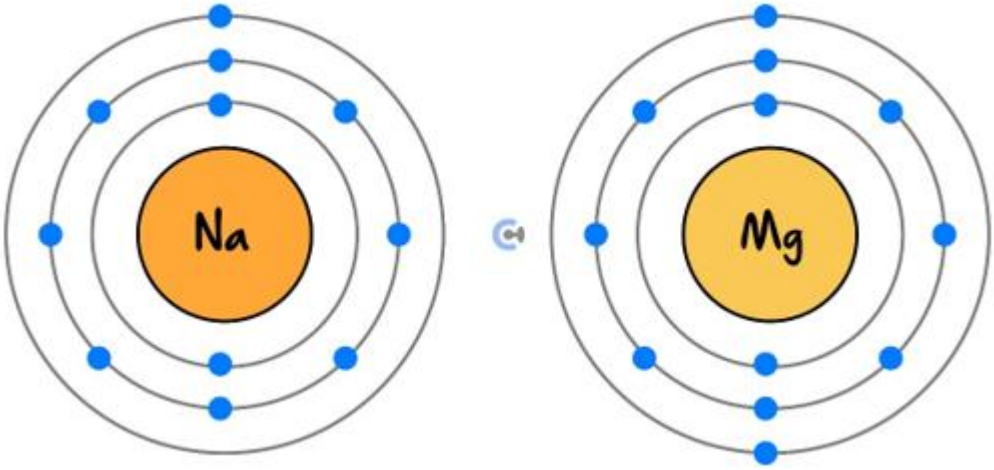
- Down a group, atomic radii **[increases] / [decreases] / [stays the same].**
- Thus, first ionisation energy down a group **[increases] / [decreases] / [stays the same].**
- Hence, metal reactivity down a group **[increases] / [decreases] / [stays the same].**
- Group 1 Metals:

Group 1*A*	Configuration	Condensed Configuration
Li	$1s^2 2s^1$	$[He]2s^1$
Na	$1s^2 2s^2 2p^6 3s^1$	$[Ne]3s^1$
K	$1s^2 2s^2 2p^6 3s^2 3p^6 4s^1$	$[Ar]4s^1$
Rb	$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^1$	$[Kr]5s^1$
Cs	$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^{10} 5p^6 6s^1$	$[Xe]6s^1$
Fr	$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^{10} 5p^6 6s^2 4f^{14} 5d^{10} 6p^6 7s^1$	$[Rn]7s^1$

- What is the most and least reactive group 1 metal?

Most Reactive	Least Reactive
Fr	Li

- If we look at two metals in the **same period** such as sodium (Na) and magnesium (Mg):



  - **[Na] / [Mg]** will have a greater core charge.
  - Hence, **[Na] / [Mg]** will have a higher first ionisation energy.
  - Therefore, **[Na] /[Mg]** is more reactive.
- As such, as we go across (left to right) a period, metal reactivity: **[Increases] / [Decreases].**

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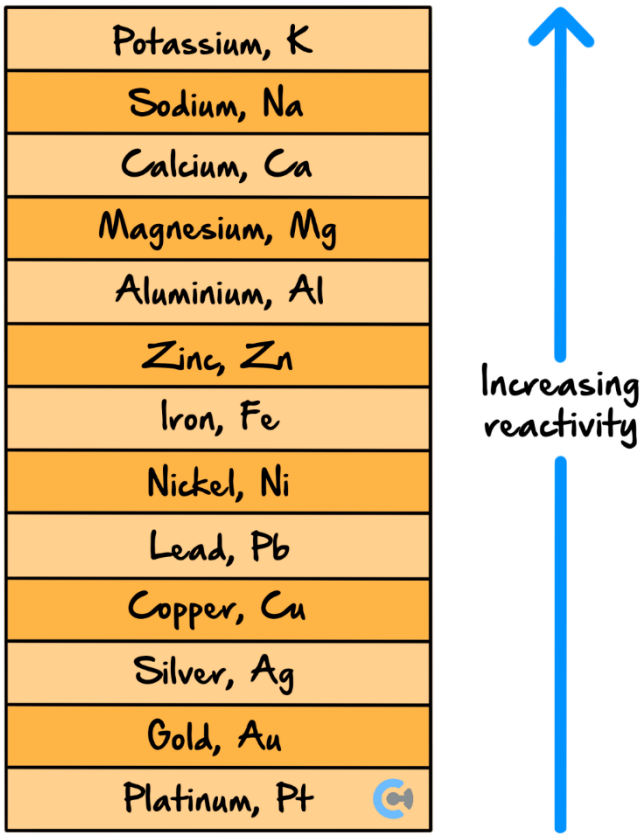
Metal Reactivity Trends



- Metal reactivity **increases** down a group, as first ionisation energy **decreases.**
- Metal reactivity **decreases** across a period, as first ionisation energy **increases.**

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Let's have a look at a question together!

Question 4 (3 marks) **Walkthrough.**

Explain whether ~~sodium (Na)~~ Rb or calcium (Ca) will be more reactive.

- Rb is more reactive
- Rb is further down the periodic table → larger atomic radius → e^- further → easier to remove
- Rb has a lower core charge (+1) ∴ easier to remove e^-.

NOTE: In general, group 1 metals are the most reactive metals.

Your turn!

Question 5 (4 marks)

State and explain which of the following metals are more reactive:

a. Potassium (K) or Caesium (Cs). (2 marks)

Cs → Cs has more e^- shell ∴ ↑ atomic radius → easier to remove e^-

b. Calcium (Ca) or Gallium (Ga). (2 marks)

Ca → Ca has a core charge of (+2) but gallium is (+3) → ∴ easier to remove Ca's electrons.

Question 6 (3 marks) **Additional.**

Explain why francium is the most reactive metal in theory.

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Sub-Section: Other Metals

Let's have a look at some other metals now!

Exploration: 'Expensive' Metals

- What are some expensive metals that exist?

  Au, Ag, Pt

  - Why are they expensive (apart from the fact that they are rare)?

    unreactive

  - As such, what form are they typically found in? **[Metal]** / **[Metal Oxide]**
  - Hence, what is their appearance even after years of exposure? **[Shiny]** / **[Dull]**

'Expensive' Metals

- Expensive metals such as gold (Au), platinum (Pt), and silver (Ag) are all fairly unreactive and exist in their metallic form rather than as a metal oxide.
- They remain lustrous/shiny rather than having a dull appearance like lithium (Li) would normally.

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Try a question!

Question 7

Select the correct sentence to explain why sodium metal is never found in minerals on Earth as the pure element, but gold is found as the pure metal.

A. Sodium is too reactive with oxygen and water, whereas gold reacts with neither.

B. Sodium is too unreactive and will not form on Earth.

C. Sodium reacts only with water, whereas gold reacts with water and oxygen.

D. Sodium reacts with water and oxygen, whereas gold reacts only with oxygen.

Question 8 (2 marks) **Additional.**

Explain why silver chains are shiny even after being worn for long period of time.

_____

_____

_____

Discussion: How are reactive metals typically stored?

→ Oil

→ noble gases (argon)

Discussion: Why is argon gas used to prevent these metals from reacting with oxygen in the air?

- cheap
- available

Storing Metals

- **Definition:**
  - To prevent reactive metals from reacting with oxygen in the air, they are stored in oil or argon gas.
- This acts as a barrier between the metal and oxygen.
- Argon is used as it is a noble gas, making it inert, and it is cheap and readily available.

Try some more questions!

Question 9 (2 marks)

State a method in which to prevent caesium metal from spontaneously reacting with oxygen in the air. Justify your answer.

- Cs (s) can be submerged in oil
- The oil acts as a barrier to prevent contact with O_2 (g)
  - thus, reaction is prevented.

Question 10 (3 marks) **Additional.**

Explain which metal is most likely to react out of sodium (Na), potassium (K), and calcium (Ca).

Sub-Section: Metal Reactions with Water

Let's have a look at another type of reaction metals can undergo!

Exploration: Metal Reactions with Water

- Aside from reacting with oxygen in the air, these metals can also react with water (H_2O).

$$Na(s) + H_2O(l) \rightarrow \_\_\_\_\_$$

  - The anion that will form with the sodium is:

  - After adding in the salt, what is in surplus?

- Sodium reacts with water to form sodium hydroxide $(NaOH)$ and hydrogen gas (H_2).

Metal Reactions with Water

- Metals react with water to form a hydroxide salt and hydrogen gas.

$$Na(s) + H_2O(l) \rightarrow \_\_\_\_\_$$

-

NOTE: We'll cover the balancing of these equations and metal ionic compounds after we look at ionic compounds in depth.

ALSO NOTE: Here is a video of group 1 metals reacting with water (and oxygen):

https://www.youtube.com/watch?v=uixxJtJPVXk

Exploration: Metal Reaction with Water Observations

- When metals react with water, an explosive / combustion occurs.
  - Why do we observe this? (Hint: Look at the products)
  - Hydrogen gas is formed, which is flammable as it reacts with oxygen in the air to burn as such:

$$2H_2(g) + O_2(g) \rightarrow 2H_2O(g)$$

  - Here's a video of hydrogen gas exploding in the air:

    https://www.youtube.com/watch?v=nLuOM9aOWvk&ab_channel=TheRoyalInstitution

Metal Reaction with Water Observations

- When metals react with water, **hydrogen gas** is produced.
- This often causes an **explosion**, as hydrogen is very flammable.

Let's look at a question together!

Question 11 Walkthrough. Mg^{2+} OH^-

Write the equation for the reaction between magnesium and water.

$Mg(s) + 2H_2O(l) \rightarrow Mg(OH)_2(aq) + H_2(g)$

NOTE: Be sure to check the charge of the metal and figure out how many hydroxides (OH^-) for it to be balanced.

Your turn!

Question 12

K^+ OH^-

Write the equation for the reaction between potassium and water.

$K(s) + H_2O(l) \rightarrow KOH(aq) + \frac{1}{2}H_2(g)$

Question 13

Ba^{2+} OH^-

Write the equation for the reactions that occur when the following metals are dipped into a tub of water.

a. Barium

$Ba(s) + 2H_2O(l) \rightarrow Ba(OH)_2(aq) + H_2(g)$

Al^{3+} OH^-

b. Aluminium

$Al(s) + 3H_2O(l) \rightarrow Al(OH)_3(aq) + \frac{3}{2}H_2(g)$

Question 14 Additional.

Which one of the following metals is most likely to react with cold water to form hydrogen gas?

A. Lead

B. Sodium

C. Silver

D. Copper

Key Takeaways

- Metals lose electrons when reacting to gain a full outer shell.
- General formula for metal-air reaction: Metal (s) + Oxygen (g) → Metal Oxide (s).
- Outside of a metal turns into dull metal oxide.
- Inside has no contact with oxygen, and so remains as the pure, lustrous metal.
- When sliced, the metal on the inside is shiny. However, it is now exposed to oxygen so will convert to an oxide form and become dull.
- Metal reactivity is directly correlated with metallic character and first ionisation energy.
- Metal reactivity increases down a group but decreases across a period.
- Expensive metals are all fairly unreactive and thus exist in their usual metallic form, remaining shiny.
- To prevent reactive metals from reacting with oxygen in the air, they are usually stored in oil or argon gas.
- The general formula for metals reacting in water is: Metal (s) + Water (l) → Hydroxide Salt (aq) + Hydrogen (g).
- This produces hydrogen gas, which is flammable, and hence can cause an explosion.

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Section B: Production & Recycling Metals

Sub-Section: Extraction of Metals

Discussion: Where are metals found?

Crust

Context

- Metals are inseparable from human development, and thus need to be obtained and produced.

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Analogy: Minecraft

- When playing Minecraft, what form is metal found in?

ore

- What do you have to do with that ore before it can be turned into 'proper' metal?

smelting

What form do metals typically exist, in real life?

Exploration: Natural Form of Sodium

Form	Na	Na^+
Electron Configuration	2,8,1	2,8
Stable/Unstable	unstable	stable

- Sodium will more likely exist in its **[ion]** / **[metal]** form when mined from the ground.

Metal Extraction

- Metals are typically found in their **stable, ion** form.
- After the metal ore is extracted, the pure metal is obtained by heating it at high temperatures with carbon, which is a process called smelting process

NOTE: The metals can also be obtained from the ores via **electrolysis** in molten conditions (we'll cover this process in VCE Chemistry ¾).

Discussion: What are some environmental issues with the production of metals from this method?

- land degredation / clearance
- energy → fossil fuels

Disadvantages of Obtaining Metals

- Mining process uses land that needs to be cleared by deforestation which can lead to habitat loss.
- The smelting and electrolysis processes to extract pure metal from the ground uses coal (fossil fuel)
  - 8% of the total global energy supply is used to produce and manufacture metals.
  - This use of energy is provided by **fossil fuels,** leading to more greenhouse gases emissions.

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Try some questions!

Question 15

Select the main reason why iron does not exist as a pure element in nature.

A. Iron is too rare in the Earth's crust to exist as a pure element.

B. Iron cannot exist as a pure metal.

C. Iron reacts with water and oxygen.

D. Iron is relatively unreactive.

Question 16 Additional.

Select the most correct alternative regarding metal extraction.

A. Metals are typically found in their pure form in the ground.

B. The land cleared to mine for metals is typically designed to be destroyed.

C. Lots of energy and resources are used to mine and purify metals.

D. Fossil fuels are released by metals.

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Sub-Section: Metal Recycling

How can these disadvantages be offset?

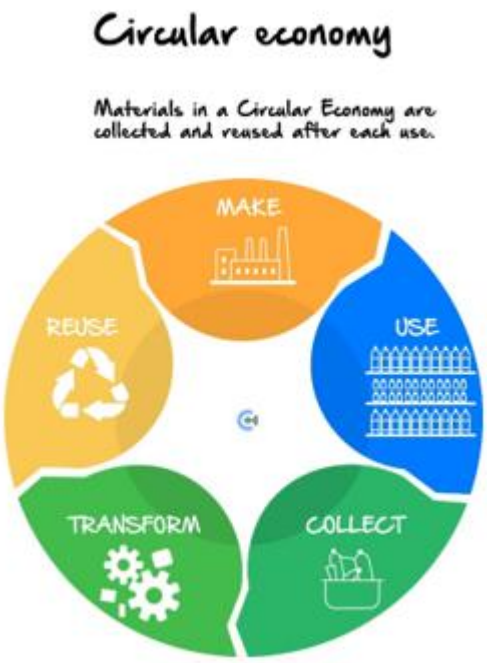
Context

- Due to the environmental consequences of metal production, metal recycling is very important to achieve sustainable economic growth. Moreover,
  - resources are becoming scarcer,
  - prices of raw materials are increasing,
  - and the demand for manufactured goods is increasing.
- As such, **metal recycling is very important.**

Exploration: Linear v/s Circular Economy

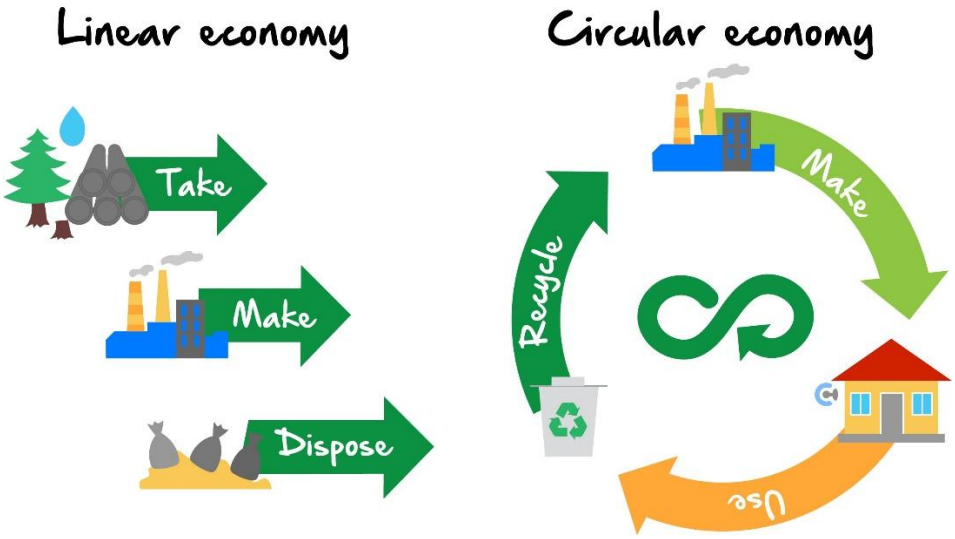
- In the past, a linear **economy** occurred, when metals were produced and then dispose

- Now, a _____ **economy** is being adopted, where metals are recycled and _____ in production.



Definition

Economy Types



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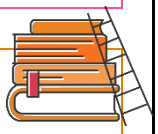
Discussion: How much less energy does recycling metals require than producing raw metals from the Earth's crust?

75%.



Extension: The energy savings reported for metal recycling are:

- Aluminium (Al) 95%
- Copper (Cu) 84%
- Zinc (Zn) 75%
- Lead (Pb) 65%
- Steel (Fe & C alloy) 60%

Metal Recycling & Energy Saving

- The more reactive a metal, the more energy it requires to extract the metal and store it safely.
- As such, more energy is saved when recycling these metals.

Discussion: Why aren't group 1 or 2 metals generally used in the industry?

reactive → unsafe

Is recycling actually being used in society?

Discussion: Of all the gold that has ever been mined from the Earth's crust, how much of it has been recycled?

80%.

NOTE: There are large systems in place to recycle metals!

Active Recall: Describe and explain the differences between a linear and circular economy.

linear → mine, use, dispose (waste)

circular → mine, use, recycle (no waste).

How are metals actually recycled?

Exploration: The Recycling Process

- The recycling process, or the secondary production of metals, is sourced primarily from scrap metal, which is just waste metal.
- Watch the following **videos in the playlist**:

https://youtube.com/playlist?list=PL2hVhOVQpiYRo2bMz66X6Xtr5V_kW_30f&si=RtuVjkRTYSLeTVM8

- There are a couple of steps involved in the recycling process:
  - **Video 1:** The scrap metal is washed and smashed

- **Video 2:** Scrap metal is classified into ferrous (containing iron) and non-ferrous, separated by magnets.
- **Video 3:** The scrap metal is then smelted to extract the metal.
- **No Video :(** The metals undergo purification to remove any impurities.

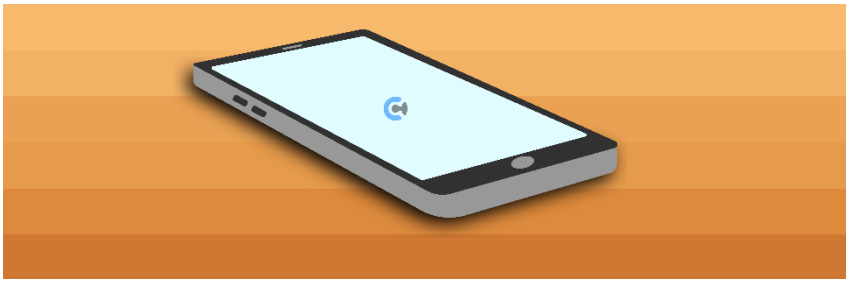
The Recycling Process

Scrap metal collected → Shredded → Classified into ferrous and non-ferrous → Smelted → Purified

Let's have a look at an interesting application of this!

Exploration: E-waste

- E-waste is electronic waste, which primarily stems from the discarding of mobile phones.



- Mobile phones contain small amounts of valuable gold and palladium.
- Before the Tokyo Olympic Games, Japan collected unwanted electronic devices to produce some of the **Olympic Medals**!

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E-waste

- Electronic waste involves the discarded electronic devices containing trace amounts of valuable metals.
- Oftentimes extracting these metals is not energetically and financially viable.

Try some questions!

Question 17

Which one of the following describes a linear economy?

A. An approach to using resources that end in waste.

B. A production system that aims to use materials sustainably.

C. A model of production and consumption with the objective of using existing materials as long as possible.

D. A framework for resource use that takes environmental challenges into consideration.

Question 18

Indicate whether the following statements about metal recycling are True or False.

	True	False
By mass, the metal used most in manufacturing worldwide is aluminium.		✗
In general, the more reactive a metal is, the more energy it requires to extract that metal.	✓	
The rate of recycling of lithium-ion batteries is able to keep pace with new demand for these products in electric cars.		✗

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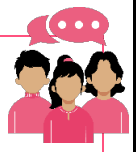
Question 19

Indicate whether the following statements about metal recycling are True or False.

	True	False
Recycling of metals is also known as secondary production.	✓	
Scrap metal is sorted magnetically and classified as ferrous or nonferrous.	✓	



Discussion: What is the most used metal in the industry?

steel → iron

Try another question!

Question 20 (2 marks)

Not all metals are recycled in industry. For example, a lot of phones are disposed of rather than being recycled for their precious metals. Suggest a possible reason for this phenomenon.

- small parts → hard to recycle
- financially viable

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Contour Check

Learning Objective: : [1.4.1] – Write balanced equations for the reactions between a metal and oxygen and between a metal and water, and explain any relevant implications of these reactions

Study Design

Experimental determination of a reactivity series of metals based on their relative ability to undergo oxidation with water, acids and oxygen.

Key Takeaways

- Metals **[gain] / [lose]** electrons when reacting to gain a full outer shell.
- The general formula for metals reacting in the air is: Metal (s) + $O_2(g)$ → metal oxide
- Outside of a metal turns into metal oxide, which is **[shiny] / [dull].**
- Inside **[has] / [has no]** contact with oxygen, and so remains as the pure, lustrous metal.
- When sliced, the metal on the inside is **[shiny] / [dull]**, as it is now exposed to oxygen, it converts to oxide form and becomes dull.
- The general formula for metals reacting in water is: Metal (s) + Water (l) → metal hydroxide + $H_2(g)$
- This produces hydrogen gas, which is flammable and hence can cause an explosion.

Learning Objective: [1.4.2] – Apply trends in the periodic table to metal reactivity

Study Design

Experimental determination of a reactivity series of metals based on their relative ability to undergo oxidation with water, acids, and oxygen.

Key Takeaways

- Metal reactivity is directly correlated with metallic character and first ionisation energy.
- Metal reactivity **[increases]** / **[decreases]** down a group, but **[increases]** / **[decreases]** across a period.
- Expensive metals are **[reactive]** / **[unreactive]** and exist in the usual shiny metallic form.
- To prevent reactive metals from reacting with oxygen in the air, they are usually stored in oil + argon.

Learning Objective: [1.4.3] – Explain how metals are obtained and recycled, and their associated advantages and disadvantages

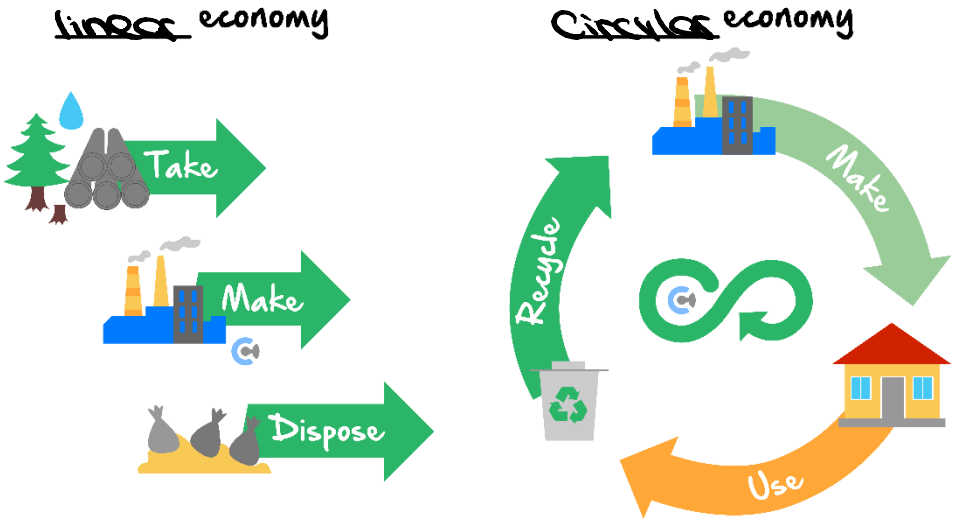
Study Design

Metal recycling is an example of a circular economy where metal is mined, refined, made into a product, used, disposed of via recycling and then reprocessed as the same original product or repurposed as a new product.

Key Takeaways

- Metals are typically found in their stable, **[atomic]** / **[ionic]** form.
- After metal ore is extracted, the pure metal is obtained by heating at high temperatures with carbon, which is a process called smelting.
- Mining process uses land that needs to be cleared by deforestation which can lead to habitat loss.

- The smelting and electrolysis processes to extract the pure metal from the ground uses large amounts of fossil fuels
- This use of energy is typically provided by [renewable] / [fossil] fuels which leads to more greenhouse gas emissions.
- Label the 2 types of economies below:



- The more reactive a metal, the [more] / [less] energy it requires to extract the metal and store it safely.
- Group 1 and Group 2 metals generally [are] / [are not] used to construct things, as they are too reactive and dangerous, thus are generally not recycled due to low use.
- Metal recycling uses scrap metal, which is first collected and sorted.
- It is then classified into ferrous and non-ferrous groups, before being smelted, and finally, purification

Space for Personal Notes