Extracting Metals Notes

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Metals are one of those everyday objects that we take for granted. As a species we have only been using metals for about 7000 years. Most metals are extracted from their ores, which are found in the earth's crust.

An ore: naturally occurring rocks that contain metals or metal compounds in sufficient amounts to make it worthwhile extracting them.

Though some metals are just found as they are in the ground and all we have to do is dig them up. Metals like gold are found in the ground as uncombined elements.

Most metals, though, need to be extracted from their ores and this is usually done using displacement reactions. Displacement reactions involve a more reactive metal displacing a less reactive metal from its compound. After it has been displaced we then collect the less reactive metal.

The Reactivity Series

In a reactivity series, the most reactive element is placed at the top and the least reactive element at the bottom. More reactive metals have a greater tendency to lose electrons and form cations.

How to remember the Reactivity Series

Please	**P**otassium	Most reactive
Stop	**S**odium	
Lions	**Li**thium	
Calling	**Cal**cium	
Me	**M**agnesium	
A	**A**luminium	
Careless	**Car**bon	
Zebra	**Z**inc	
Instead	**I**ron	
Try	**T**in	
Learning	**Le**ad	
How	**H**ydrogen	
Copper	**Copper**	
Saves	**S**ilver	
Gold	**Gold**	Least reactive

It is useful to place carbon and hydrogen into the reactivity series because these elements can be used to extract metals.

Metals below carbon in the reactivity series can be displaced from their oxides using carbon but not using hydrogen. Metals below hydrogen, can be extracted using carbon or hydrogen.

We do have to learn the reactivity series, they will not give us a complete one to use in the exams. It can be a bit of a pain to learn so use the rhyme above 😊

The lower down in the reactivity series a metal is the more resistant to corrosion (rusting) it is. Iron rusts quite quickly if it is not protected. Gold never rusts.

As we mentioned earlier, extracting metals involves displacement reactions, these reactions are in fact redox reactions. Redox reactions involve reduction and oxidation.

Reduction and Oxidation

Reduction and oxidation is one of those really important parts of chemistry that we really do need to understand. It can seem a bit odd at first but once we understand it it's fine 😊 First, let's look at the key definitions.

Reduction: the gain of electrons and the loss of oxygen.

Oxidation: the loss of electrons and the gain of oxygen.

We can use **OILRIG** to help us remember this. **O**xidation **I**s **L**oss (of electrons) **R**eduction **I**s **G**ain (of electrons).

A reducing agent: is the substance that causes reduction to happen by losing electrons itself. The substance is oxidised in the process.

An oxidising agent: is the substance that causes oxidation to happen by gaining electrons itself. The substance is reduced in the process.

Let's have a look at a few equations to see how this all plays out…

The equation below shows a displacement reaction in which zinc is used to displace copper from copper sulfate. This reaction could be used to extract copper if we wanted to.

$$Zn + CuSO_4 \rightarrow ZnSO_4 + Cu$$

Which species is oxidised? Which is reduced? Also which is the oxidising agent and which is the reducing agent? So, there are clues… Look at where each species is after the reaction.

Zinc – has been oxidised as it went from being on its own to being bonded with the sulfate ion. In order for zinc to have reacted with the SO_4 ion it will have needed to lose 2 electrons and formed a Zn^{2+} ion.

The half equation for that is:

$$Zn \rightarrow Zn^{2+} + 2e^-$$

Copper ion – has been reduced as it went from being bonded to the sulfate ion to being on its own. It has been reduced to being itself 😊. In order for copper to be stable enough to be on its own it would have had to gain two electrons. **Where did it get these?** The copper took them from the zinc.

The half equation for that is:

$$Cu^{2+} + 2e^- \rightarrow Cu$$

Oxidising agent – remember this is the species that causes oxidation to happen by gaining electrons. In this equation copper is the oxidising agent as it gained electrons.

Reducing agent – remember that this is the species that causes reduction to occur by losing electrons. In this equation zinc is the reducing agent as it has lost electrons.

Let's have a look at another equation on the next page.

The equation below shows a displacement reaction in which aluminium is used to displace silver from silver nitrate. This reaction could be used to extract silver, but there are much more cost effective ways of extracting silver.

$$Al + 3AgNO_3 \rightarrow Al(NO_3)_3 + 3Ag$$

Which species is oxidised? Which is reduced? Also which is the oxidising agent and which is the reducing agent? So, there are clues… Look at where each species is <u>after</u> the reaction.

Aluminium – <u>has been oxidised</u> as it went from being on its own to being bonded with the nitrate ion. In order for aluminium to have reacted with the NO_3 ion it will have needed to lose 3 electrons and formed a Al^{3+} ion.

The half equation for that is:

$$Al \rightarrow Al^{3+} + 3e^-$$

Silver ion – <u>has been reduced</u> as it went from being bonded to the nitrate ion to being on its own. It has been reduced to being itself 😊. In order for silver to be stable enough to be on its own it would have had to gain an electron.

The half equation for that is:

$$Ag^+ + e^- \rightarrow Ag$$

Oxidising agent – <u>silver is the oxidising agent</u> as each silver ion gained an electron to become a silver atom.

Reducing agent – <u>aluminium is the reducing agent</u> as it has lost electrons.

Half Equations

So far we have used **four** half equations to show whether reduction or oxidation have been happening in a reaction. But, what is a half equation and how do we use them?

A half equation: <u>a way of showing either oxidation or reduction in a redox reaction</u>.

A redox reaction: <u>a reaction in which both reduction and oxidation take place</u>. Or oxidation and reduction if we want to think of it in that order. Most chemical reactions are redox reactions but not all of course.

Let's look at the two half equations that we used in the reaction between zinc and copper sulfate on page 35.

$$Cu^{2+} + 2e^- \rightarrow Cu \qquad\qquad Zn \rightarrow Zn^{2+} + 2e^-$$

We can see that apart from the atoms themselves being different, the main difference is which side of the reaction the electrons are. Yes, it does matter what side of the reaction the electrons are on.

Half equation rule:

Electrons on the left hand side is reduction.

Electrons on the right hand side is oxidation.

So for the two half equations above we can now say that…

$$Cu^{2+} + 2e^- \rightarrow Cu \qquad\qquad Zn \rightarrow Zn^{2+} + 2e^-$$

Reduction **Oxidation**

Let's look now at the most common metal extractions that we are asked about in the GCSE.

Extraction of Aluminium

Aluminium is the most abundant metal in the Earth's crust. It is expensive, mostly due to amount of electricity that is required to actually extract it from its ore.

Aluminium is extracted from its ore using the following steps:

1. Aluminium ore is called **bauxite**. This is crushed to produce bauxite powder.
2. Bauxite powder is mixed with **molten cryolite** to lower its melting point.
3. Electrolysis is then conducted on the aluminium oxide to produce aluminium metal.

During the electrolysis: the aluminium cations gain electrons from the cathode, and form molten aluminium.

Oxide anions lose electrons at the anode, and form oxygen molecules. The oxygen reacts with the carbon in the electrodes, forming carbon dioxide which bubbles off.

Carbon is therefore lost from the positive electrodes, so they must be replaced frequently. This adds to the cost of the process.

All metals <u>above carbon</u> in the reactivity series are extracted by <u>electrolysis</u>.

All metals <u>below carbon</u> in the reactivity series are extracted by <u>reduction with carbon</u>.

Extraction of Iron

Iron is one of the most common metals in everyday objects from cutlery to cars. It is usually an alloy of iron called steel that is used (steel is an alloy of iron and carbon).

How is iron extracted? Iron is extracted from iron ore in a huge container called a <u>blast furnace</u>. Iron ores such as haematite contain iron(III) oxide, Fe_2O_3.

Why is it called a blast furnace? Carbon monoxide gas (CO) is "blasted" into the furnace.

What happens in a blast furnace? The carbon monoxide reacts with the molten iron oxide and removes the oxygen from the iron oxide. The carbon monoxide gains the oxygen and leaves as carbon dioxide, CO_2.

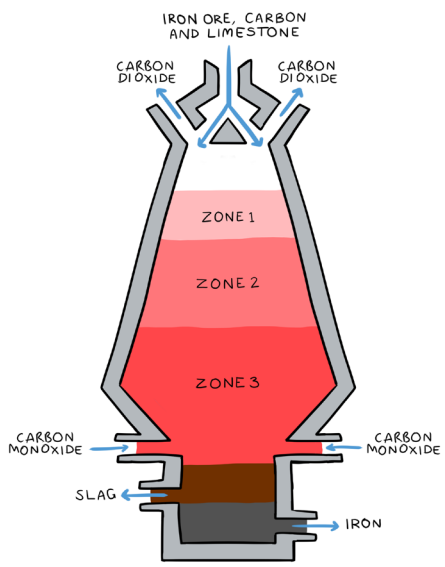
The reaction is:

Iron(III) oxide + carbon monoxide → iron + carbon dioxide

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

Molten iron is collected from the bottom of the blast furnace.

For the current specification, we <u>do not need to know how a blast furnace works</u>. A diagram of a blast furnace is shown below to provide a bit of context but we <u>do not need to learn how it works</u>. 😊



Alternative methods of the extracting metals

Bioleaching

What is bioleaching? Bioleaching is using bacteria to extract metals from their ores.

When is this used? It's used on low grade ores when other methods of extracting the metal aren't cost effective.

How does it work? Bacteria break down minerals in ores and release metal ions into a solution. The equation below shows an example of bioleaching occurring. This process produces a solution of metal ions called a **leachate**.

$$CuS + O_2 + H_2O \xrightarrow{\text{bacteria}} Cu^{2+} + SO_4^{2-} + H^+$$

The copper ions can be extracted as copper metal by either electrolysis or by displacement reaction. Displacement reactions are much cheaper as we usually use iron to displace copper and iron is much cheaper than copper.

What are the advantages of bioleaching?

1. It's cost effective – its relatively cheap as it doesn't need much energy for the reaction to take place. If electrolysis is used this will increase the cost though.
2. It doesn't need high temperatures – we don't have to heat the metal ore in order to extract the metal.

What are the disadvantages of bioleaching?

1. It is a slow process – it can take a long time for the bacteria to break down the metal compounds into ions.
2. Toxic products – bioleaching can produce acidic pollution and other toxic compounds which can damage the environment if they are not disposed of correctly.

Phytoextraction

What is phytoextraction? Phytoextraction is the process of using plants to extract metals from their ores.

When is this used? It's used on low grade ores when other methods of extracting the metal aren't cost effective.

How does it work? We plant some plants in a field. Let's say we plant a crop of wheat in a field. We then wait for the crop to grow and we harvest it when it's ready. While the crop was growing, the plant was absorbing metal ions from the soil to make its structures. After we harvest the crop we get the straw and burn it.

After it has been burned we are left with a metal rich ash. We can then do other chemical reactions such as using acids or electrolysis to extract the metals.

What are the advantages of phytoextraction?

1. **It's cost effective** – as we don't have to heat the metal to extract it. The cost of phytoextraction is very low.
2. **Land cleaning** – phytoextraction can be used to remove toxic metal ions from soils if they have become contaminated due to pollution or accidents.
3. **Environmental** – phytoextraction is more environmentally friendly then normal mining which can cause damage to ecosystems and habitats as well as leading to pollution.

What are the disadvantages of phytoextraction?

1. **Slow** – as we have to wait for the plants to grow this process can take quite a long time.
2. **Depends on the plants growing well** – if the plant doesn't grow well or dies this will affect how much metal compounds that we get at the end of the process.
3. **Low yield** – phytoextraction produces a low yield for metal compounds compared to normal mining.