When iron (steel) is exposed to the weather it **rusts**. It can easily be established that neither water nor air (oxygen) alone will cause iron to rust. Therefore the process of rusting has been discovered to be the reaction of iron and oxygen, in the presence of water, forming a new substance which is a **compound** of iron and oxygen.

If a weighed amount of iron filings is kept moist and exposed to the air for a week or two, then dried and weighed again, the mass of rust will be greater than the original mass of iron.

For many centuries the process of rusting was poorly understood. During the eighteenth century many scientists tried and failed to understand the processes of burning and rusting. The key element that they were missing was oxygen.

Some metals react readily with oxygen to form a layer of **oxide**. In the case of aluminium and zinc the oxide layer is coherent and seals the surface of the metal protecting it from further oxidation. **Rust** or iron oxide, on the other hand, does not form a coherent layer and does not stick to the iron surface.

**The Iron Age**

Although the centre of the Earth is probably mostly molten iron, elemental iron does not occur naturally in the Earth's crust. Many early cultures discovered how to convert iron ore (compounds of iron and oxygen or sulfur) to metallic iron; this marked the beginning of the 'iron age'. In the Near East this happened around 1200 BC but was as late as 600 BC in Northern Europe.

**What exactly is rust?**

Rust is the red-brown **oxide** of iron formed by the action of moisture and oxygen on the metal. It consists mainly of hydrated iron(III) oxide (Fe₂O₃ · H₂O) and iron(III) hydroxide (Fe(OH)₃). If oxygen is in short supply the formation Fe₂O₃ is favoured; this can be regarded as a mixture of Fe₃O₄ (magnetite) and FeO.

**The rusting process**

The steps in the formation 'e' represented as follows:

\[
\begin{align*}
\text{Fe} & \rightarrow \text{Fe}^{2+} + 2e^- \\
2e^- + \frac{1}{2} \text{O}_2 + \text{H}_2\text{O} & \rightarrow 2\text{OH}^- \\
\text{Fe}^{2+} + 2\text{OH}^- & \rightarrow \text{Fe(OH)}_2
\end{align*}
\]

The hydroxide ions react with the iron(II) ions (Fe²⁺) and more dissolved oxygen to form iron (III) oxide, usually in hydrated form:

\[
2\text{Fe(OH)}_2 + \frac{1}{2} \text{O}_2 + x\text{H}_2\text{O} \rightarrow \text{Fe}_x\text{O}_y\cdot x\text{H}_2\text{O} + 2\text{H}_2\text{O}
\]

In salt or acid solutions rusting occurs more rapidly as the water becomes increasingly conductive due to the presence of dissolved ionic particles.

**Steel**

Iron is an **element**. Steel is an **alloy**; it is a mixture of iron (typically more than 98%) with variable amounts of carbon, manganese and other elements, depending on the properties required. The hulls of ships are generally made of **mild steel**.

Pure iron is not used for structural purposes as steel has preferred physical and chemical properties such as superior strength.

Steel comes in a great variety of compositions; these can be roughly divided as follows:

<table>
<thead>
<tr>
<th>Type of steel</th>
<th>Carbon</th>
<th>Manganese</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild steel</td>
<td>0.05%</td>
<td>0.4%</td>
</tr>
<tr>
<td>Medium carbon steel</td>
<td>0.29%</td>
<td>1% (variable)</td>
</tr>
<tr>
<td>High carbon steels</td>
<td>0.5%–1%</td>
<td>0.3%–0.9%</td>
</tr>
</tbody>
</table>

**Why does stainless steel not rust?**

The composition of stainless steel can vary; it usually contains substantial amounts of nickel or chromium. Steel that contains more than about 10% chromium is generally resistant to corrosion. Apart from iron, chromium and carbon, stainless steel can also contain nitrogen, sulfur, nickel, niobium, manganese, titanium and molybdenum.

When the metal surface is cut the metal react with oxygen to form a thin (about a nanometre) layer that is coherent (unbroken) and adheres well to the metal. This oxide layer seals the surface preventing further corrosion.

**A bacterial connection**

Corrosion of iron can be caused by both aerobic and anaerobic bacteria. **Aerobic bacteria** produce carbon dioxide which can combine with water to form carbonic acid. The lower pH accelerates corrosion.

In anaerobic conditions such as ocean depths and deep bore-holes, sulfate-reducing bacteria use the oxidation of iron as their energy source; they convert iron to iron sulfide and iron hydroxide: FeS and Fe(OH)₃. They also produce hydrogen sulfide (H₂S) which is a weakly acidic gas that is soluble in water. Hydrogen sulfide (H₂S) has an odour similar to rotten eggs.

**How to prevent rusting**

The two traditional methods used to prevent rusting of ships are to seal the surface with paint, grease, plastic, tin etc. as in the barrier method or to ‘sacrifice’ a piece of more reactive metal, such as zinc or magnesium, that is attached to the iron but not usually covering it, as in the electrolytic method.

Forming an air-tight barrier by sealing the iron surface with paint may improve the appearance of a ship but it has the following disadvantages:

- It is time consuming and costly
- It must be checked and repaired regularly otherwise the exposed iron can become pitted and eventually perforated
- The process requires the ship to be removed from the water to dry-dock in order to carry out repairs
The electrolytic method in which ‘sacrificial anodes’ are used to prevent rusting may not be as aesthetically pleasing but it has the following advantages:

- it can be carried out relatively easily and economically
- the ship does not have to be removed from the water

The electrolytic method focuses on the dissociation properties of iron. If an iron nail is placed in water some iron atoms lose electrons and go into solution as Fe²⁺ ions; the electrons remain on the iron nail making it slightly negative. Other metals behave similarly; the extent to which ions go into solution varies from metal to metal. If different metals are placed in the same solution (and are not touching one another) then their relative tendency to form ions can easily be checked with a voltmeter; the metals can be placed in a particular order known as the activity series or electrochemical series.

Best results are achieved by a combination of barrier and electrolytic methods. These same methods are used to protect other steel structures such as bridges, water tanks, lamp posts and motor vehicles.

Sometimes iron structures are protected by completely covering their surface with zinc; a process known as galvanising.

**Change in mass and volume**

Because it is a compound, iron oxide is about 60% heavier than the iron from which it forms. Iron oxide is also less dense than iron (3.6 vs. 7.8 g/cm³). For these reasons rust takes up more than three times the volume of the original iron. The expansion due to rust in enclosed spaces can cause blistering and flaking of paintwork and fracturing of the metal surface. This causes more of the metal surface to become exposed and accelerates its corrosion.

**New rust-treatment products**

Polymer-based ‘paints’ are now available that contain ingredients that react chemically with rust to form a tough polymer layer that bonds well to the metal surface. These have the following features:

- only the loose flakes of rust need be removed prior to treatment
- they are generally more fluid than paint and so are more easily applied
- some kinds can be applied under water (for small areas)
- very long lifetimes are claimed for these products

**Rusting and Rust Prevention**

The Irish Maritime Development Office (IMDO) is the State Agency responsible for the development and promotion of the Irish shipping services sector and related industries. Since its creation, the office has focused on implementing a strategy that will underpin the long-term sustainable development of the Irish shipping services sector.

The shipping services sector in Ireland is a dynamic multifaceted industry and it contains many different niche components such as maritime finance, banking, legal and technology sectors, ship broking, ship management, ship ownership, ship agency, ports, liner shipping, education and training. When combined, these segments form an essential part of the Irish economic strategic infrastructure that facilitates the Irish economy to connect with the global market. A key component of this industry is its lifeblood, the seafarer.

**Life at Sea**

Life at sea has always appealed to young people who want to combine travel with a challenging career offering exciting future prospects. This is the life for those who relish the challenge of working with the sea – one of Nature’s most powerful and temperamental elements.

Ships carry 95% of world trade and seaborne traffic is forecast to double by the year 2010. This is generating a great demand for high-quality personnel to manage and operate today’s technically sophisticated ships. Ship’s Officers are key members of a highly qualified team, whether on a giant supertanker, a container ship, a cross-channel ferry, a cruise liner, a specialised vessel servicing the offshore oil industry or on a small cargo ship.

**National Maritime College of Ireland (NMCI)**

Merchant Navy Officers are trained at Ireland’s new National Maritime College, located in Cork harbour close to Haulbowline Naval Base. A combination of state of the art fire fighting, sea survival and simulator facilities ensure that the NMCI leads the world in navigation and marine engine technology.

You can find out more about the work of the Irish Maritime Development Office (IMDO) at [www.imdo.ie](http://www.imdo.ie) or [www.sta.ie](http://www.sta.ie)
The hydroxide ions react with the iron(II) ions (\(\text{Fe}^{2+}\)) and oxygen to form iron (III) oxide, usually in hydrated form:

\[
\text{2Fe}^{2+} + \text{2OH}^{-} + \frac{1}{2}\text{O}_2 \rightarrow \text{2Fe(OH)}_3
\]

Oxidation and Reduction

When the metal surface is cut the metal react with oxygen to form carbonic acid. The lower 

\[
\text{2CO}_2 + \text{2H}_2\text{O} \rightarrow \text{2H}_2\text{CO}_3
\]

sulphides)

- Iron(III) oxide, \(\text{Fe}_2\text{O}_3\), is red in colour
- Iron(II) oxide, \(\text{FeO}\), is black in colour.
- Magnetic tape recording has been in use for more than seventy years

Alloys

- alloys of iron and carbon are known as steel; there are many varieties of steel
- iron occurs naturally in the form of compounds (mainly oxides and sulfides)
- rust is the product of the reaction between iron, oxygen and water
- iron oxide takes up more space than the iron from which it forms; the consequent expansion loosens paintwork and causes pitting or flaking of the metal surface
- understand why some metals corrode more readily than others
- appreciate that there are many naturally occurring compounds of iron with other elements
- appreciate that certain bacteria can greatly accelerate the process of rusting
- recall a number of different ways to prevent rusting of iron

Examination Questions


Reactivity tests were carried out on calcium, copper, magnesium and zinc in four test tubes containing an acid.

State one thing you would do to make the tests fair. List the four metals in order of reactivity with the acid, starting with the most reactive.

The millennium spire, in Dublin, is made from steel. Iron and steel are can suffer from corrosion. Iron and steel show visible signs of corrosion. Give one visible sign of corrosion.
Oxygen and water together are necessary for the corrosion of iron or steel. Describe, with the aid of labeled diagrams, experiments to show that:

(i) oxygen alone, will not lead to the corrosion of iron (or steel).
(ii) water alone, will not lead to the corrosion of iron (or steel).

2006 Leaving Certificate Higher Level
Name two metals, one a main group metal, the other a transition element, both of which are protected from further corrosion by the oxide layer which forms on their surfaces.

2005 Leaving Certificate Higher Level
Give one way in which the rusting of iron can be prevented and say how the method that you have given works.

2005 Leaving Certificate Ordinary Level
(i) Name the English scientist who isolated sodium and potassium in the early 1800s.
(ii) Both sodium and potassium corrode easily. What is meant by corrosion?
The corrosion of iron can be prevented by galvanising.
(iii) How is a piece of iron galvanised?
(iv) How does this prevent the iron from corroding?
(v) State one method, other than galvanising, which helps prevent iron from corroding.

2004 Leaving Certificate Ordinary Level
(a) Define oxidation in terms of electron transfer.
When zinc is added to copper sulfate solution the copper is displaced according to the equation: $Zn + CuSO_4 \rightarrow Cu + ZnSO_4$.
(i) State one change observed as the reaction proceeds.
(ii) Which substance is oxidised?
(iii) Scrap iron can be used to extract copper metal. Which of these two metals is higher up the electrochemical series?

For further examples of past paper examination questions check www.sta.ie

Minerals, older names and uses
- Iron(II) oxide, FeO, is black in colour.
- A hydrated form of iron(II) oxide is called Goethite; its chemical composition is FeO·OH. It was used as a pigment in the ancient cave paintings at Lascaux in France.
- Iron(III) oxide, Fe$_3$O$_4$, is red in colour and was used for cosmetic purposes as rouge (‘rouge’ is French for ‘red’).
- For hundreds of years rouge has also been used by jewelers as a mild abrasive to polish metals to a mirror-like finish.
- The mineral haematite is a crystalline form of iron(III) oxide. It is dark grey in colour and is commonly used in jewellery items and small carvings.
- Magnetic tape recording has been in use for more than seventy years and although the use of tape cassettes for audio recording may be declining they are still widely used for video recording and digital backup storage. The tape is composed of a thin film of plastic (PVC or Mylar) impregnated with metal oxide – iron (III) oxide or chromium (IV) oxide.
- Another common form is iron sulfide (FeS) – more accurately named iron persulfide – the crystalline form of which is called pyrite. It is more important as a source of sulfur than of iron.

Biographical Notes
Antoine Laurent Lavoisier (1777–1794)
In the 1780s and 1790s the properties of some gases were studied and it gradually became clear that gases were not as immaterial as they seemed at first. Instead of being considered as forms of air it was realised that some were elements and some were compounds. Lavoisier is usually credited with the discovery of oxygen. He showed that mercury combined with oxygen to form mercury oxide and that this oxide could be decomposed again into its constituent elements. Until that time the process of combustion was explained in terms of a mythical substance called phlogiston.

Read more about other famous scientists on www.sta.ie

Revise The Terms
Can you recall the meaning of these terms? Reviewing the terminology is a powerful tool for recall and retention.
- iron; steel; air; oxygen; compound; iron filings; burning and rusting; oxide; aluminium; zinc; coherent; Earth’s crust; sulfur; metallic iron; bronze; magnetite; ions; Fe$^{2+}$ ions; electrons; volt-meter; activity series or electrochemical series; alloy; aerobic bacteria; carbon dioxide; pH; anaerobic; pitted; perforated; electrolytic; sacrificial anode; galvanising

Check the Glossary of Terms for this lesson at www.sta.ie

Did You Know?
Copper and bronze are somewhat easier to produce and for this reason the Bronze Age preceded the Iron Age, usually by thousands of years.

Meteorites
Before the Iron Age the only iron that people found was the odd meteorite that happened to survive its passage through the Earth’s atmosphere. Iron is readily oxidised and iron in the Earth’s crust does not last long in metallic form.

Most meteorites are composed of iron and nickel. Metallic iron is not found in the Earth’s crust. There are no mines of metallic iron; the iron in iron ore is usually a compound such as an oxide, sulfide or carbonate of iron but not the element.