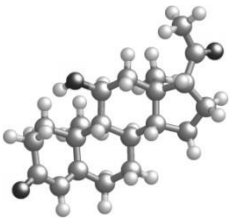

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Metals – Macroconcepts: Systems and Change – Answers

Metals are an important part of modern-day living, conducting electricity through the integrated circuit boards in computers and mobile phones and giving strength to skyscrapers, aircraft fuselages and the chassis of motorcars. Some metals are better than others for certain applications, based upon their properties, availability and cost. It is also possible to modify the properties of a metal by combining it with small quantities of other elements to form *alloys*.

Most metals do not occur in nature as the pure element, but exist chemically combined with oxygen in the Earth's crust. To be of any use, the metal must first be extracted from its ore. The recycling of metals is also becoming increasingly important in order to safeguard the Earth's limited natural resources.

Many metals corrode (oxidise) upon exposure to air and water, and this is especially evident with the rusting of iron. Precautions can be taken in order to reduce the corrosion of iron and therefore extend the useful working life of cars, bridges and household tools.

Question 1.

List the typical physical and chemical properties of metals. For each property, state an application that makes use of this property.

Property	Application
• High melting points and boiling points	• Cooking utensils, internal combustion engines
• Hard and Strong	• Manufacture of aircraft, bridges, cars
• Malleable	• Motorcar bodies, household water pipes
• Ductile	• Electrical wires
• Good conductor of heat	• Cooking utensils
• Good conductor of electricity	• Electrical wires
• Sonorous	• Bells and tuning forks
• Shiny (metallic lustre)	• Jewellery and mirrors
• High density	• Weights used on diving belts / sports equipment
• Form basic oxides	• Regulate pH of acidic soil
• React by losing electrons to form cations	• Reducing agents

Question 2.

a) What is an *alloy*?

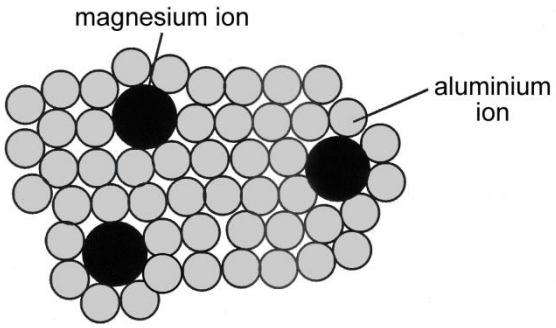
An alloy is a mixture of a metal with another element. Alloying a metal is done by combining a metal with another metallic or non-metallic element in order to improve the properties of the original metal.

b) Give some examples of alloys.

Brass is an alloy of copper and zinc. Steel is an alloy of iron and (most commonly) carbon.

Bronze is an alloy of copper and tin. Stainless steel is an alloy of iron and chromium.

c) Study the structure of the alloy shown below:



i) In what ways are the properties of the alloy *similar* to those of the metals that it is made from?

The alloy will be a good conductor of heat and electricity. It will be sonorous. It will have a metallic lustre. It will have a high density. It will have high melting and boiling points.

ii) In what ways are the properties of the alloy *different* to those of the metals that it is made from?

The alloy will be harder and stronger (less malleable and ductile) because the large magnesium ions disrupt he regular, ordered, crystalline structure of the aluminium, making it difficult for the layers of aluminium ions to side over each other.

Question 3.

a) Why is it important to recycle metals?

The Earth's resources are finite, meaning that there is a limited supply of metal ores, and a limited supply of the chemicals that are necessary to extract the metals from their ores. Recycling therefore means that metals will be available in large quantities for a longer time. Recycling metals also saves energy and reduces the volume of greenhouse gases (*e.g.* carbon dioxide) that are released, reducing the effects of climate change.

b) What are the advantages and disadvantages / problems of recycling metals?

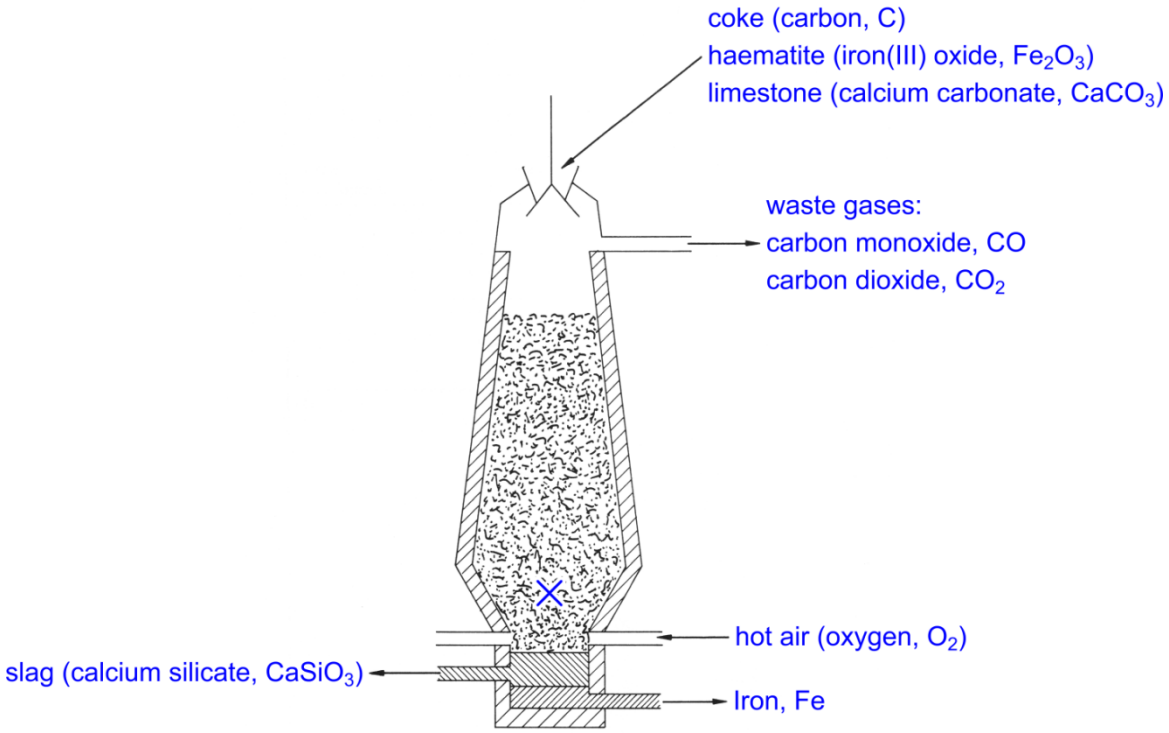
Recycling metals conserves the Earth's natural resources, saves energy and reduces pollution. It also makes good economic sense to recycle metals, as producing 1000 kg of iron through recycling is much cheaper than extracting the same mass of iron from its ore. The recycling of metals also produces jobs for people. The main disadvantage or problem with recycling metals is public apathy. Only a small percentage of the metals that could be recycled are recycled – people need to be educated and

encouraged to recycle metals. The recycling of metals requires purpose built factories, and the collection of metals for recycling from households and industry poses another problem.

Question 4.

Iron is extracted from the ore, haematite, by heating it with coke and limestone in a blast furnace.

a) Label the diagram of the blast furnace to clearly indicate where the various chemicals enter and leave the system.



b) Use a cross (×) to identify the hottest part of the blast furnace.

c) Haematite is iron(III) oxide. Explain why iron can be extracted from haematite by heating it with coke (carbon).

Carbon is more reactive than iron and can therefore displace iron from iron(III) oxide to form iron and carbon dioxide as the reaction products.

d) **i)** Write a balanced chemical equation for the reaction between coke (carbon) and oxygen to form carbon dioxide. What effect does this reaction have on the temperature inside the blast furnace?

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

The combustion of carbon to form carbon dioxide is exothermic and therefore increases the temperature inside the blast furnace.

ii) Write a balanced chemical equation for the thermal decomposition of limestone (calcium carbonate) into calcium oxide and carbon dioxide.

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

iii) Write a balanced chemical equation for the reaction between carbon dioxide and coke (carbon) to form carbon monoxide. Why is it hazardous to form carbon monoxide on an industrial scale?

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

Carbon monoxide is a toxic gas and that poses a threat to the factory workers' health.

iv) Write a balanced chemical equation for the reaction between haematite (iron(III) oxide) and carbon monoxide to form iron and carbon dioxide.

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

v) Sand is an impurity present in the haematite. Write a balanced chemical equation for the reaction between calcium oxide and sand (silicon dioxide) to form slag (calcium silicate).

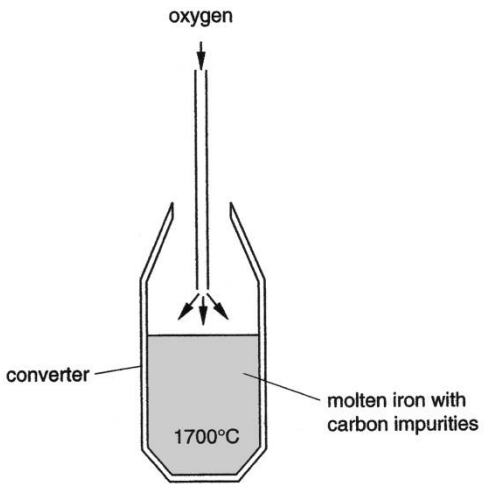
$CaO(s) + SiO_2(s) \rightarrow CaSiO_3(s)$

Question 5.

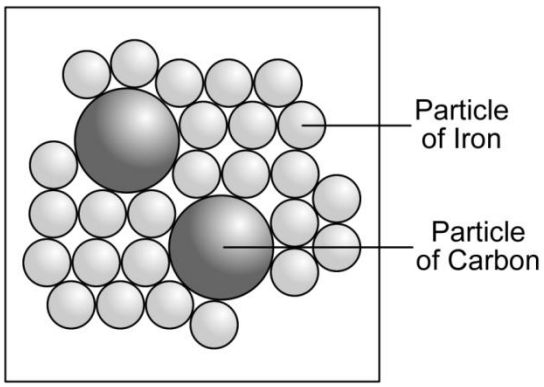
The carbon content of iron produced in a blast furnace can be adjusted in a *converter*. When oxygen is blown onto the surface of the iron / carbon mixture, the carbon is oxidised to carbon dioxide which is removed as a gas. Consequently, the carbon content of the iron is reduced.

a) What is the origin of the carbon that is mixed with the iron?

The carbon originates from the raw material *coke* that was added into the blast furnace along with the iron ore and limestone.



b) The diagram below represents the structure of *low carbon steel* or *mild steel*.

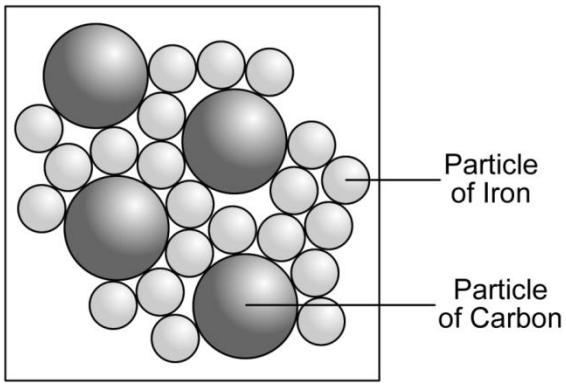


Explain how the properties of low carbon steel are different from the properties of pure iron.

What are some uses of low carbon steel?

Low carbon steel – compared to high carbon steel – is relatively soft, and therefore more easily shaped (*i.e.* more malleable and ductile). Low carbon steel is used to manufacture the bodies of motorcars.

c) The diagram below represents the structure of *high carbon steel*.



Explain how the properties of high carbon steel are different from the properties of pure iron.

What are some uses of high carbon steel?

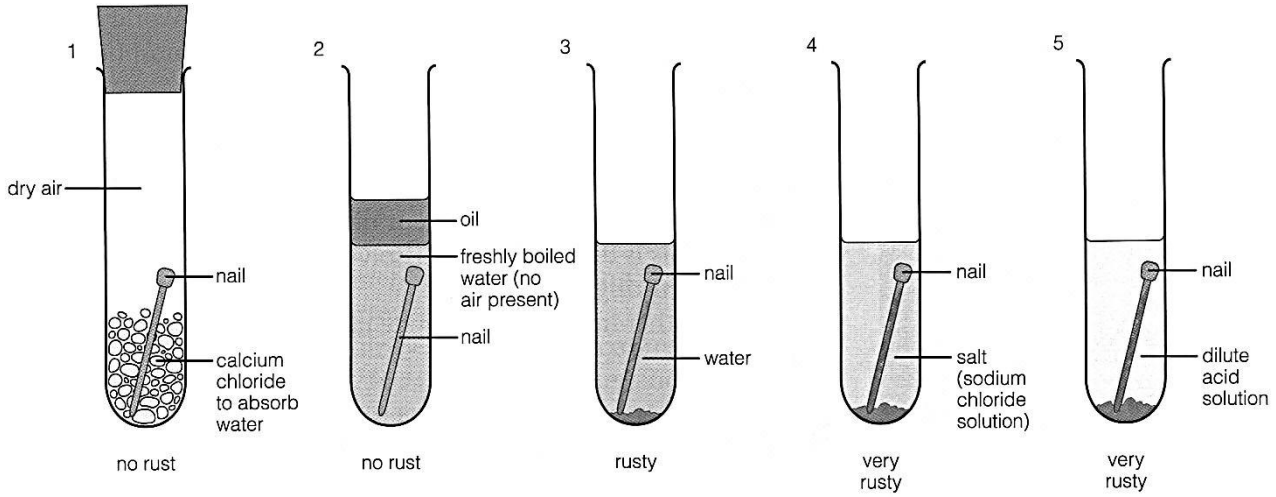
High carbon steel – compared to low carbon steel – is very hard (less malleable and ductile), but also quite brittle. High carbon steel is used to make springs, knife blades, and masonry drills.

d) What is added to iron ion order to produce *stainless steel*? State some uses of stainless steel.

Stainless steel is resistant to corrosion. Chromium is added to iron in order to make stainless steel (stainless steel contains approximately 11 % chromium by mass). Stainless steel is used to make objects such as knives and forks, surgical instruments and chemical plants / factories.

Question 6.

The diagram below shows iron nails exposed to a variety of different conditions.



a) Identify the conditions that cause iron to corrode / rust.

Test tube 1 contains air and a drying agent (calcium chloride). The iron does *not* rust when oxygen is present, but no water is present. **Test tube 2** contains water that has been boiled to remove the dissolved oxygen. Iron does *not* rust when water is present, but no oxygen is present. **Test tube 3** show the iron nail rusting when *both oxygen and water are present*. **Test tubes 4** and **5** show that iron rusts very rapidly when oxygen, water and mobile ions (from the salt and the acid) are present in solution.

b) What can be done to objects made out of iron in order to reduce the extent to which they corrode / rust?

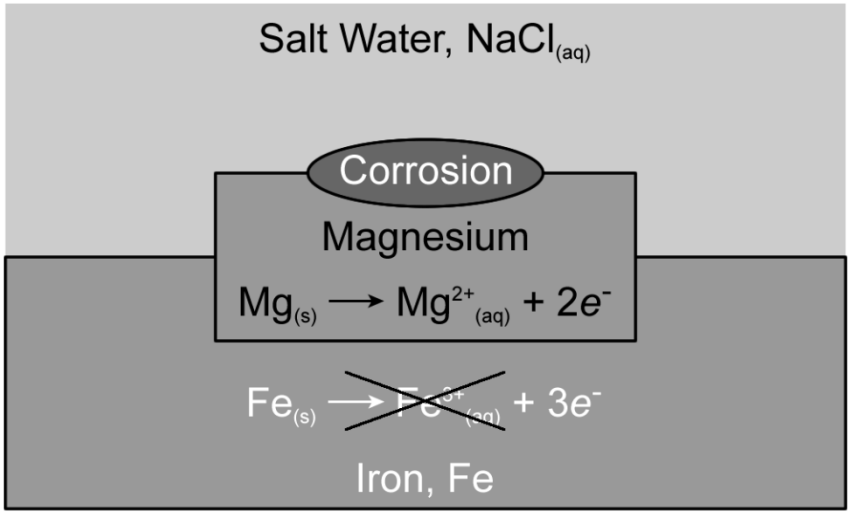
One way of protecting iron from corrosion is to place a protective barrier around the iron that prevents air / oxygen and water coming into contact with it. Methods include:

- Paint the entire surface of the iron*.
- Cover the entire surface of the iron with a layer of grease*.
- Cover the entire surface of the iron with a layer of plastic*.
- Cover the entire surface of the iron with a thin layer of tin (tin plating)*.
- Cover the entire surface of the iron with a thin layer of chromium (chrome plating)*.
- Cover the entire surface of the iron with a thin layer of zinc. This is known as *galvanising*.
- Placing a block of magnesium in contact with the iron. This is known as *sacrificial protection*.

*Note: For most of these methods, the entire surface of the iron must be covered in order for the iron to be protected. Once the protective layer is scratched, and the iron is exposed to the air / oxygen and water, the iron will corrode / rust.

A layer of zinc will still continue to protect the iron from corrosion – even when it is scratched – because zinc is more reactive than iron and will therefore oxidise / corrode in preference to the iron.

c) The diagram below illustrates the concept of *sacrificial protection*.



Describe how sacrificial protection prevents the iron from corroding / rusting.

Magnesium is more reactive that iron. This means that the magnesium will oxidise / corrode in preference to the iron, therefore preventing the iron from corroding. Because the magnesium is oxidised / corrodes in place of the iron, it can be imagined that the magnesium has "sacrificed" itself in place of the iron, hence the name "sacrificial protection". Note that, unlike many of the other ways of protecting iron, it is not necessary for a thin layer of magnesium to cover the entire surface of the iron *i.e.* the iron can be exposed to air / oxygen and water and – as long as the iron is in contact with a block of magnesium – the iron will not corrode.