Iron

Dirk Wiersma/SPL

Iron is a relatively abundant element and humans have made widespread use of it since the Iron Age (about 750 BC). This article looks at the chemistry of iron.

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Left: *An iron ore mine in western Australia*

GCSE key words
Iron
Iron manufacture
Steel
Oxidation and reduction

Iron is an Anglo-Saxon word. The Latin for iron is *ferrum*, hence Fe.

Table 1 *Properties of iron*

Symbol	**Fe**
Atomic number	26
Density	7.9 g/cm^3
Atomic mass	55.85
Atomic radius	124.1 pm
Common ions	Fe^{2+} and Fe^{3+}
Melting point	1538°C
Boiling point	2861°C

The **core** of the Earth (which is approximately 3440 km in radius) is thought to be largely composed of iron. The metal is also the fourth most abundant element by weight in the Earth's **crust**. It is plentiful elsewhere in the universe too (see Box 1).

Table 1 lists the key properties of iron. It is a cheap, abundant and useful metal, but iron must be extracted from its ore before it can be used.

Iron ore

Iron ore is a mineral substance which, when heated in the presence of a reducing agent, yields metallic iron (Fe). It normally consists of iron oxides, the primary forms of which are magnetite (Fe_3O_4) and haematite (Fe_2O_3).

Iron ore is the main source of iron for the world's iron and steel industries. Almost all iron ore (98%) is used in steelmaking. Iron ore is mined in about 50 countries, but just seven of these countries account for about three quarters of total world production. Australia and Brazil, in particular, dominate the world's iron ore exports.

Box 1 Iron in space

Iron is found in the Sun and many types of stars. It is the heaviest element which can be made in the nuclear fusion furnace that runs in the centre of a typical star. The nuclei of its atoms are very stable, so once the core of a star has become mainly iron, that star has run out of its primary energy source.

Extraction of iron

Before 1709, furnaces could only use charcoal to produce iron. At the beginning of the eighteenth century, forests were being cleared for farmland and timber. This meant that charcoal became expensive. Although coal was cheap and plentiful, it could not be used for iron extraction because it contained sulphur which made the iron too brittle to be of any use.

However, in 1709 Abraham Darby succeeded in smelting iron with coke. This technological achievement allowed a major expansion of the iron trade and, ultimately, it helped lead to the Industrial Revolution.

In the space of 40 years, the Darby's home at Coalbrookdale went from being a small village to a major industrial site which employed about 500 people (see 'Places to visit', page 14). After 1709, the first cast-iron bridge was made there and built over the River Severn at Ironbridge and the first cast-iron framed building was built upriver at Shrewsbury.

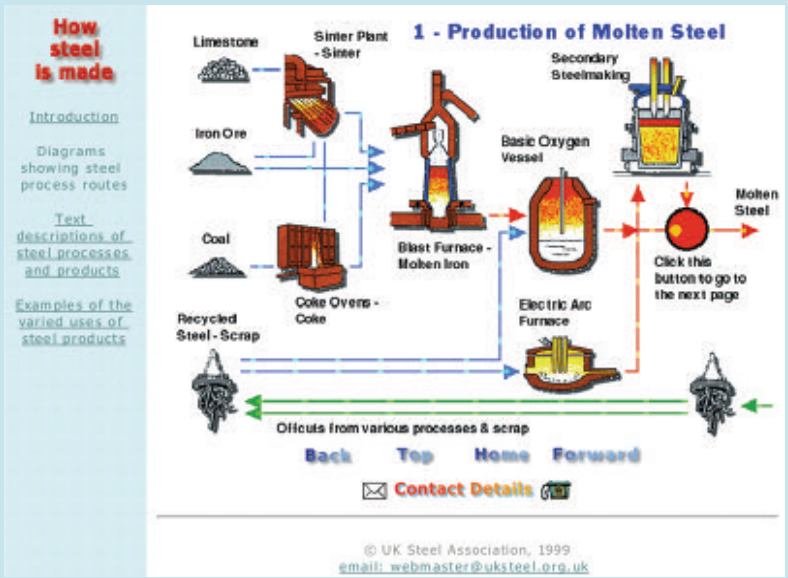
A remarkable iron pillar, dating to about AD 400, remains standing in Delhi, India. This solid shaft of wrought iron is 7.25 m high and 0.4 m in diameter.

- **Look up iron in the periodic table on the Radiochemistry Society website (www.radiochemistry.org/periodictable/index.shtml).**

Time exposure photograph of a blast furnace in a steel foundry

Box 2 Useful website

To find out more about how steel is made go to the following page on the UK Steel Association website and click on the links in the interactive diagram: www.uksteel.org.uk/diag1.htm



Box 3 Raw materials for a blast furnace

Coke	From coal heated in the absence of air
Limestone (calcium carbonate)	Quarried in the Peak District (in Derbyshire)
Iron ore (haematite, Fe_2O_3)	From Australia

The blast furnace

The furnaces devised in the 1700s were developed further into the modern blast furnace. The purpose of a blast furnace is to chemically reduce iron oxides into liquid iron known as 'hot metal' (Box 2).

What is a blast furnace?

A blast furnace is a huge, steel stack which is lined with refractory brick. Iron ore, coke and limestone (Box 3) are dumped into the top, and preheated air is blown — or blasted — in at the bottom. The iron ore, limestone and coke are sintered together first to make large lumps around which the gases can flow readily. The air blast is preheated by heat exchangers which extract heat from the hot waste gases heading out the top of the furnace.

Liquid iron

Because the furnace temperature is in the region of 1500°C, the metal is produced in a molten state and runs down to the base of the furnace. The raw materials take 6–8 hours to descend to the bottom of the furnace where they become liquid slag and liquid iron.

Liquid iron is drained from a tap hole near the bottom of the furnace at regular intervals. The impurities (CaS and CaSiO3) form a liquid that floats on top of the molten iron. This slag is collected after the denser iron has been run out.

Hot air

The hot air that was blown into the bottom of the furnace ascends to the top in 6–8 seconds, after being involved in numerous chemical reactions in the furnace (the back page has more details). The waste gases which leave the blast furnace at the top are mainly carbon dioxide, carbon monoxide and unreacted nitrogen (from the air).

A continuous process

The production of iron in a blast furnace is a **continuous process**. The furnace is heated constantly and is recharged with raw materials from the top while it is being tapped from the bottom. Iron making in a furnace usually continues for about 10 years before the furnace linings have to be renewed.

Energy costs

The energy costs of the operation are kept to a minimum by collecting and cleaning the hot gas that leaves the furnace. This gas contains a lot of carbon

Molten iron being tapped from a blast furnace

Dirk Wiersma/SPL

- **Look up any elements with which you are unfamiliar in one of the web-based versions of the periodic table.**

Table 2 *Steel alloys*

Name	Approximate composition	Special properties	Use
Manganese steel	86% Fe, 13% Mn, 1% C	Toughness	Drill bits
Stainless steel	73% Fe, 8% Ni, 18% Cr, 1% C	Non-rusting	Cutlery, sinks
Cobalt steel	90% Fe, 9% Co, 1% C	Hardness	Ball bearings
Tungsten steel	81% Fe, 18% W, 1% C		Armour plate

monoxide. It can be reused as a fuel for other steel-making processes, as well as to heat up the air blast to the furnace.

Overall equation

The overall equation for what goes on in a blast furnace is:

$$Fe_2O_3 + 3CO \longrightarrow 2Fe + 3CO_2$$

Iron into steel

The metal that leaves the blast furnace contains between 4% and 5% carbon. This much carbon makes a hard but brittle metal which is not much use. The carbon is reduced to about 0.1% by blowing pure oxygen through the molten metal in a converter. This burns off the excess carbon as carbon monoxide and carbon dioxide.

The iron, which is now called steel, is ready for use. The steel that remains can be turned into an alloy such as stainless steel or tungsten steel by the addition of transition metals which confer specialised properties to it (Box 4).

A modern furnace produces about 10 000 tonnes of iron per day.

An alloy is mixture of elements, of which a metal is the main component.

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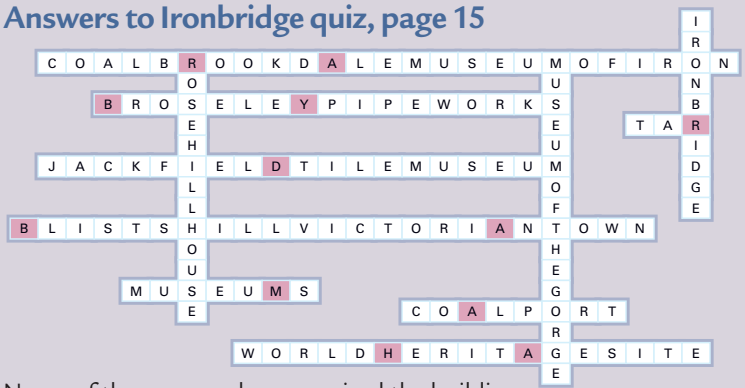
Box 4 Alloys

Iron itself is hard and brittle so it is normally made into alloys:

- Pig iron is an alloy containing about 3% carbon with varying amounts of sulphur, silicon, manganese and phosphorus.
- Wrought iron contains only a few tenths of a percent of carbon, is tough, malleable, less fusible and usually has a 'fibrous' structure.
- Carbon steel is an alloy of iron with small amounts of manganese, sulphur, phosphorus and silicon.
- Alloy steels are carbon steels with other additives such as nickel, chromium or vanadium (Table 2).

Answers to Ironbridge quiz, page 15



Name of the person who supervised the building of the first iron bridge: **Abraham Darby**.