What are earrings made from? What is the best material for body piercings? Do you like gold, and, if so, do you prefer yellow, pink or white? Do you like silver, stainless steel or titanium? Some people’s skin reacts chemically with different metals so they must choose jewellery carefully. Metals have different properties, so it is important to choose the right metal for the purpose. All metals, however, have a similar lattice and bonding structure that determines their properties and uses.

**YOU WILL EXAMINE:**
- metallic bonding as the strong bonding within metals
- the relationship between the structure and bonding of metals and their properties
- how the properties of transition metals compare with those of main group metals
- the importance and limitations of the metallic bonding model
- the reactivity of metals
- the modification of metals by processes such as coating, alloying and heat treatment
- metallic nanomaterials and their properties.

Achievements are precious and timeless, just like the precious metal platinum.

Vijender Singh

Titanium panels 0.5 millimetres thick cover the Guggenheim Museum Bilbao (in Spain) like fish scales. They are guaranteed to last over 100 years without significant change. What aspects of the metal’s structure give it these properties?
Metals

It has been known for centuries that elements can be divided into two broad groups: metals and non-metals. The largest group is the metals. A metal is generally a hard, shiny solid that can be shaped, and is a relatively good conductor of heat and electricity. The discovery and use of metals moved civilization beyond the Stone Age.

The first metal to gain widespread use was copper, which was first mined and used on the island of Cyprus around 5000 years ago. Copper’s popularity was mainly due to its relatively low melting point (1084 °C) and the ease with which it could be extracted from its ores. In contrast, aluminium, which is the most common metal in the Earth’s crust, was difficult and expensive to extract from its ore and has become widespread only in the last century due to technological advances.

Copper can be extracted from the ore chalcopyrite (a). In human history, copper ranks second only to iron in its importance. Today the main use of copper is in electrical cables, pipes and wires, shown here ready for recycling (b).

Properties of metals

Since there are more than 80 metal elements, it is not surprising that some of their properties vary widely. Group 1 metals, such as lithium, sodium and potassium, must be stored in oil or kerosene because they react violently with water, whereas metals such as copper, silver and gold are chemically unreactive and are used in coins and jewellery. At room temperature, mercury is a liquid, but magnesium is a solid. Zinc is brittle, iron is hard, and lead sheet can be bent easily. Nevertheless, most metals have the following properties.

Metals:
• are lustrous. They have a shiny surface when polished.
• are good conductors of heat
• are good conductors of electricity
• are malleable. They can be hammered, bent or rolled into sheets or other shapes.
• are ductile. They can be drawn out into wires.
• generally have a high density (mass per unit volume)
• have a range of melting points but most are quite high
• are often hard. They have high resistance to denting, scratching and bending.
• have high tensile strength, meaning that they offer high resistance to the stresses of being stretched or drawn out and, therefore, do not break easily.

Structure of metals

Metallic atoms have low electronegativities, which means they tend to lose their outer shell electrons easily. Once a metallic atom has lost its outer shell
electron, it becomes a positively charged cation. This produces electron configurations similar to the group 18 elements (noble gases) and hence a more stable state.

X-ray studies show that metals occur as crystal lattices. Chemists imagine these metallic lattice structures as being made up of an array of cations. The electrons from each metallic atom are found in a common pool and are free to move between all the cations. They are referred to as delocalised electrons. Electrostatic forces of attraction between the positively charged cations and the negatively charged electrons hold the lattice together.

A metal can therefore be imagined as a rigid framework of cations immersed in a ‘sea’ of electrons that serve as the cement that holds the three-dimensional cationic network together, as shown in the figure on the left. This type of bonding is known as metallic bonding.

We think of a metal crystal as containing spherical atoms packed together, as modelled by the orange arrangement in the photo below. These atoms are bonded to each other equally in all directions. This means that metal atoms are hard to separate but relatively easy to move, provided the atoms stay in contact with each other. We can model this structure by packing uniform hard spheres in a way that uses the available space most efficiently, as the orange model demonstrates.

Metallic bonding may be compared with oranges packed in a box. The oranges represent the fixed, closely packed cations in the lattice. Electrons may be found moving freely in the spaces between the oranges.

**Revision questions**

1. Lithium exists as a crystalline solid at temperatures less than 180 °C.
   (a) Write the electron configuration of a lithium atom.
   (b) Write the symbol and electron configuration of its cation.
   (c) Describe how lithium atoms are bonded together in the solid.
2. Which of the atomic numbers below belong to a metal?
   (a) 2
   (b) 11
   (c) 17
   (d) 19
   (e) 25
3. Why is the structure of a metal stable? Illustrate your answer using the example of aluminium and its electron configuration.
Metallic properties and lattice structure

The lattice structure of metals may be used to explain many of their properties. It is these properties that give metals their many applications in our society. These are discussed in the next section.

Lustre
The lustrous appearance of a metal is due to the mobile electrons within the lattice being able to reflect light, causing the metal to shine.

Conduction of heat
Electrons can gain kinetic energy in hotter areas of the metal and quickly transfer it to other parts of the metal lattice because of their freedom of movement. The heat causes the electrons to move faster, and the “bumping” of these electrons with each other and the protons transfers the heat.

Density
Most metals have relatively high densities because metallic lattices are close-packed.

Conduction of electricity
When an electric field is applied to a metal, one end of the metal becomes positive and the other becomes negative. All the electrons experience a force towards the positive end. This movement of electrons is what we call an electric current.

Melting point and hardness
The generally high melting points and hardness of metals indicate that metallic bonding is quite strong. Melting points and hardness increase with an increase in the number of outer shell electrons, since there is a greater attractive force between the cations and the electrons.

Malleability and ductility
Metals are malleable and ductile, rather than brittle, as a result of the non-directional nature of metallic bonds. The attractive forces exerted by the positive metal ions for the mobile electrons occur in all directions. This means that layers of atoms can move past one another without disrupting the force between the positive ions and the negative sea of electrons. The nature of the metal does not change when the metal becomes thinner.

Revision questions

4. Explain why iron is:
   (a) hard
   (b) malleable and ductile
   (c) able to conduct electricity in solid and molten form.
5. Magnesium is produced from the mineral dolomite, CaCO₃·MgCO₃.
   (a) Describe the bonding in magnesium metal crystals.
   (b) Magnesium crystals are silver-white and shiny. Explain this property of lustre in terms of structure and bonding.

Alloys

Not all the properties of a metal may be suited to the specific use we wish to make of it. By mixing a metal with other metals or some non-metals, we can change its properties. This process is called alloying and the resulting metal is called an alloy. For example, pure gold (24 carat) is a relatively soft element and is easily deformed. We therefore use the alloy 18 carat gold in jewellery, as it contains 75 per cent (by mass) gold with the other 25 per cent made up of silver and copper to make the product stronger and more durable. The term ‘carat’ is used to indicate the ratio of precious metal to base metal in an alloy. For example, 18 carat gold is \( \frac{18}{24} \) or three-quarters gold to one-quarter base metal, and 24 carat gold is \( \frac{24}{24} \) or pure gold.

Magnesium is unsuitable for industrial use because of its high reactivity. Yet, when alloyed with other metals, such as aluminium, zinc and manganese, it can be used for aircraft and guided missile parts where lightness and high tensile strength are essential. Other uses include aircraft and car wheels, artificial limbs and skis.

Aluminium can be mixed with other metals to form very strong, light alloys that are ideal for making cars, aeroplanes, ships and bridges. In order to reduce fuel emissions from cars, fuel efficiency must be increased and this can be done by reducing the weight of the car. Aluminium alloys have thus been substituted for heavier metals such as steel.

Today, intensive research is concentrated on producing higher quality magnesium alloys for lightweight magnesium car components as magnesium alloys are 35 per cent lighter than aluminium and use less energy in the casting process.

Alloys are prepared by melting the metals or other materials together and cooling the mixture. Most of the metallic materials in everyday use are alloys rather than pure metals. Sometimes, non-metallic atoms such as carbon and silicon are used to form an alloy.
Two types of alloys are substitutional and interstitial alloys.

Sterling silver is a substitutional alloy.

If the atoms of the metals being used to form an alloy are about the same size, they can replace each other in the metal crystals. This type of alloy is called a substitutional alloy. Sterling silver is a substitutional alloy made from silver and copper.

有时，金属在合金中的原子尺寸有很大差异。较小的原子可能进入较大原子之间的空隙，形成一种称为间隙合金的合金。钢是由铁和碳组成的间隙合金。

Steel is an interstitial alloy.

Polarised light micrograph of a thin section of common brass, a copper–zinc alloy, showing the distinct grain structure of this metal alloy. The grain boundaries — the three-dimensional surfaces that enclose grains — show up as fine lines around the more or less polygonal grains.

Polarised light micrograph of a thin section of common brass, a copper–zinc alloy, showing the distinct grain structure of this metal alloy. The grain boundaries — the three-dimensional surfaces that enclose grains — show up as fine lines around the more or less polygonal grains.
The properties of alloys differ from those of their component metals. For example, sterling silver is harder than pure silver, and stainless steel is stronger and more resistant to corrosion than iron. Solder is composed of 70% lead (melting point 327 °C) and 30% tin (melting point 232 °C). It is used to join metals together as it melts at 180 °C, lower than either of its components.

Some common metals and their alloys are shown in the figure on page 72.

Revision questions

6. Solder (melting point 180 °C) is an alloy made from 30% tin (melting point 232 °C) and 70% lead (melting point 327 °C). It is commonly used to join metal surfaces or parts.
   (a) Describe how solder could be made.
   (b) The atoms of tin and lead are similar in size. Decide which coin model (interstitial or substitutional) better represents the structure of solder.
   (c) What properties of solder differ from that of tin and lead? Relate this to its use.

7. Using the figure on page 72, predict which of the alloys shown might be suitable for making:
   (a) a trumpet
   (b) the fuel tanks of a space shuttle
   (c) the hull of a ship
   (d) rollerskates.

8. Automatic fire sprinkler plugs are used in most modern buildings. When they melt, they release water onto the fire. The plugs are made from an alloy of tin, lead, bismuth and cadmium, each of which melts at a temperature well over 200 °C. What properties would you expect this alloy to exhibit, and how do these properties differ from those of the metals from which it is made? Explain your answer.

9. Conduct an internet search to find three examples of metal alloys and their uses in society. Present your findings as a visual poster that clearly identifies the properties of each alloy and the metals used to make it.

An alloy of mercury is called amalgam. Dental fillings are amalgams of mercury (50%), silver (35%) and tin (13%) with copper and zinc. It has been estimated that Australian dentists use over 4.5 tonnes of mercury in amalgam fillings per year. The amalgam filling starts as a pliable substance but undergoes a chemical reaction causing it to harden after it is used to fill a cavity.
### Common Metals and Their Alloys

<table>
<thead>
<tr>
<th>Name and composition of alloy</th>
<th>Properties</th>
<th>Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aluminium</strong></td>
<td>Too soft and brittle to be useful</td>
<td><strong>Alloys</strong></td>
</tr>
<tr>
<td><strong>duralumin</strong></td>
<td>94.9% Al, 4% Cu, 0.6% Mn, 0.5% Mg</td>
<td>mixture of Al and Mn</td>
</tr>
<tr>
<td></td>
<td>three times as hard as steel but one-third as heavy</td>
<td>resistant to tarnishing</td>
</tr>
<tr>
<td></td>
<td>aircraft; racing bikes</td>
<td>window frames; kitchen foil</td>
</tr>
</tbody>
</table>

| **Iron** | Hard but too brittle to be useful | **Alloys** |
| **mild steel** | Fe with traces of carbon | **stainless steel** | 73% Fe, 18% Cr, 9% Ni |
| | hard, strong and more resistant to corrosion | four times as strong as mild steel; very resistant to corrosion | very hard and very strong |
| | cars; ships | surgical equipment; sinks; cutlery; razor blades | high-speed tools to work metals |

| **Copper** | Soft and workable but corrodes easily | **Alloys** |
| **brass** | 90% Cu, 6% Sn, 4% Zn | **brass** | 65–70% Cu, 35–25% Zn |
| | resistant to corrosion; harder and stronger | strong and workable; resistant to corrosion | highly resistant to wear |
| | parts of ship’s decks and propellers | wires; musical instruments; plumbing; door handles; beds | car clutch disks; valves; pumps |

| **Gold and Silver** (precious metals) | Resistant to corrosion but soft | **Gold alloys** | **Silver alloys** |
| **18 carat gold** | 75% Au, 12.5% Ag, 12.5% Cu | **sterling silver** | 92.5% Ag, 7.5% Cu |
| | harder | harder |
| | jewellery | jewellery and silverware |

Jewellery made from gold alloys is harder than pure gold.
Specific properties and uses of s-block metals

Metals are widely used in our society. Their different properties make them useful for particular purposes. The alkali metals are very reactive; they are not found in elemental form and so most uses involve their compounds. A knife can easily cut through these metals as they have such a low density. They have relatively low melting points due to having only one outer shell electron to participate in bonding. Also, the atoms are larger than other atoms in the same period, and they are not as efficiently packed together. Alkaline earth metals are less reactive, harder and have higher melting points than alkali metals. Usually, these reactive elements are found as compounds. The elements and compounds have a variety of applications. s-block metals usually form compounds that are white.

s-block metals are reactive and generally have a low density.

Sodium is used as a coolant in nuclear reactors, in the manufacture of titanium and for street lights. Lithium is used in rechargeable batteries, and, because of its lightness, it is combined with other metals to make alloys. As already described, magnesium is alloyed because it produces superior qualities. The compound calcium carbonate is used to make calcium oxide for neutralising soils, glass making and as a component of cement.

### TABLE 4.1 Properties of metals in the s block

<table>
<thead>
<tr>
<th>Metal</th>
<th>Symbol</th>
<th>Density (g mL(^{-1}))</th>
<th>Melting point (°C)</th>
<th>Thermal conductivity at 25 °C (watts m(^{-1}) K(^{-1}))</th>
<th>Electrical conductivity at 25 °C (ohm(^{-1}) m(^{-1}) × 10(^7))</th>
<th>Hardness</th>
</tr>
</thead>
<tbody>
<tr>
<td>lithium</td>
<td>Li</td>
<td>0.53</td>
<td>181</td>
<td>85</td>
<td>1.1</td>
<td>soft</td>
</tr>
<tr>
<td>sodium</td>
<td>Na</td>
<td>0.97</td>
<td>98</td>
<td>140</td>
<td>2.1</td>
<td>soft</td>
</tr>
<tr>
<td>potassium</td>
<td>K</td>
<td>0.66</td>
<td>64</td>
<td>100</td>
<td>1.4</td>
<td>soft</td>
</tr>
<tr>
<td>beryllium</td>
<td>Be</td>
<td>1.86</td>
<td>1278</td>
<td>190</td>
<td>3.1</td>
<td>hard</td>
</tr>
<tr>
<td>magnesium</td>
<td>Mg</td>
<td>1.75</td>
<td>649</td>
<td>160</td>
<td>2.3</td>
<td>medium</td>
</tr>
<tr>
<td>calcium</td>
<td>Ca</td>
<td>1.55</td>
<td>839</td>
<td>200</td>
<td>3.0</td>
<td>medium</td>
</tr>
</tbody>
</table>
Revision questions

10. (a) State the charge on ions formed from group 1 elements.
    (b) State the charge on ions formed from group 2 elements.

11. Use the properties of sodium and potassium to predict the approximate values of the density, melting point, thermal conductivity, electrical conductivity and hardness of rubidium, the next element in group 1.

Specific properties and uses of $p$-block metals

A can can be manufactured from aluminium or tin-coated steel. Aluminium and tin are metals found in the $p$ block of the periodic table, which also contains metalloids and non-metals. Aluminium is the most abundant metal in the Earth’s crust and is very versatile. It has a coating of aluminium oxide, $\text{Al}_2\text{O}_3$, and this prevents it from reacting with oxygen so it does not corrode further. As well as its uses in transport and building, it is a useful material for drink cans and saucepans. The good electrical conductivity and low density of aluminium make it ideal for use in overhead wires. Tin is used as a coating to prevent corrosion, such as in ‘tin’ cans, which are made from tin-coated steel. The alloys solder, bronze and pewter all contain tin.

Lead, another $p$-block metal, has been used since Roman times because it is easily worked and resistant to corrosion. Lead was used for pipes and to line aqueducts to bring water to homes and public baths. Roofing, pottery glazes and jewellery were also regular uses for lead. It is less commonly used now for pigments, as a petrol additive and in jewellery because it is hazardous to health. Current uses include car batteries, roofing, weights and bullets.

Table 4.2 Properties of metals in the $p$ block

<table>
<thead>
<tr>
<th>Metal</th>
<th>Symbol</th>
<th>Density (g mL$^{-1}$)</th>
<th>Melting point (°C)</th>
<th>Thermal conductivity at 25 °C (watts m$^{-1}$ K$^{-1}$)</th>
<th>Electrical conductivity at 25 °C (ohm$^{-1}$ m$^{-1}$ × 10$^7$)</th>
<th>Hardness</th>
</tr>
</thead>
<tbody>
<tr>
<td>aluminium</td>
<td>Al</td>
<td>2.7</td>
<td>660</td>
<td>236</td>
<td>3.8</td>
<td>medium</td>
</tr>
<tr>
<td>tin</td>
<td>Sn</td>
<td>7.3</td>
<td>232</td>
<td>66.8</td>
<td>0.9</td>
<td>medium</td>
</tr>
<tr>
<td>lead</td>
<td>Pb</td>
<td>11.3</td>
<td>327</td>
<td>35.3</td>
<td>0.5</td>
<td>soft</td>
</tr>
</tbody>
</table>

Revision question

12. Explain why aluminium is used for drink cans whereas ‘tin’ cans are used for other foods.

Specific properties and uses of $d$-block elements

The presence of transition metal compounds is responsible for the colourful stained glass windows in churches and other buildings. The formation of coloured compounds is an interesting characteristic of the $d$-block elements;
Exceptions are scandium and zinc. The metals that display magnetism — iron, cobalt and nickel — are transition metals. As with other metals, most are used in the form of alloys. They can form ions with different charges; for example, iron forms two compounds with chlorine — FeCl₂, which is a green compound, and FeCl₃, which is an orange compound. Another valuable feature of transition metals is that they are very useful catalysts. A catalyst is a substance that increases the rate of a chemical reaction without itself being changed.

$\textbf{d}$-block elements form coloured compounds and are good catalysts.

Transition metals are an ever-present part of our daily lives, from the iron in the oxygen transport molecule, haemoglobin, in our blood to the $\$2$ coins in our pockets which are 92% copper. Iron is widely used in construction, often in alloy form as steel, which is less brittle and more resistant to corrosion than elemental iron. It is used in the manufacture of tools and vehicles and is a catalyst in the production of ammonia. Copper is used in electrical wiring and as bases on saucepans because of its good electrical and heat conduction. Interestingly, copper forms the basis of blood in crustaceans, which results in it being a blue colour. Silver and gold, as well as being used for jewellery, are good conductors of electricity and are used in electrical contacts. Apart from its presence in baked beans, the element nickel is used in making stainless steel, in batteries, in coins and as a catalyst in the manufacture of margarine.

$\textbf{TABLE 4.3}$ Properties of transition metals

<table>
<thead>
<tr>
<th>Metal</th>
<th>Symbol</th>
<th>Density (g mL$^{-1}$)</th>
<th>Melting point (°C)</th>
<th>Thermal conductivity at 25 °C (watts m$^{-1}$ K$^{-1}$)</th>
<th>Electrical conductivity at 25 °C (ohm$^{-1}$ m$^{-1}$ x 10$^7$)</th>
<th>Hardness</th>
</tr>
</thead>
<tbody>
<tr>
<td>iron</td>
<td>Fe</td>
<td>7.9</td>
<td>1535</td>
<td>75</td>
<td>1.0</td>
<td>hard</td>
</tr>
<tr>
<td>copper</td>
<td>Cu</td>
<td>8.9</td>
<td>1083</td>
<td>401</td>
<td>6.0</td>
<td>hard</td>
</tr>
<tr>
<td>silver</td>
<td>Ag</td>
<td>10.5</td>
<td>961</td>
<td>429</td>
<td>6.3</td>
<td>medium</td>
</tr>
<tr>
<td>gold</td>
<td>Au</td>
<td>19.3</td>
<td>1059</td>
<td>318</td>
<td>4.3</td>
<td>soft</td>
</tr>
</tbody>
</table>

$\textbf{study on}$

Main group and transition metals
Summary screen and practice questions
Revision questions

13. Give three reasons why silver and gold are used for jewellery.

14. How do (a) gold, (b) mercury and (c) zinc differ from the majority of transition metals?

15. Choose a metal that would be best suited for fabrication of:
   (a) car bodies
   (b) beer cans
   (c) household electrical wiring
   (d) fishing sinkers.
   Justify your choices.

16. Electricity transmission lines for industry are usually made from aluminium even though copper is a better electrical conductor. Suggest two reasons why aluminium is used.

17. Copy the table below and complete it by listing as many metals as you can and linking their uses to their properties.

<table>
<thead>
<tr>
<th>Metal name and symbol</th>
<th>Use</th>
<th>Property demonstrated</th>
</tr>
</thead>
</table>

18. Prepare a multimedia presentation that shows how metals are used in relation to their properties. A digital camera could be used to obtain examples from your environment.

Other models that explain metallic properties

Although many of the properties of metals can be explained using the lattice model, other properties are not explained.

- Why is iron magnetic and copper non-magnetic?
- Why is platinum twenty times as dense as sodium?
- Why is lead quite malleable whereas iron is tough?

Different models may be used to explain some of these properties. We will examine the ball bearing model.

Metal strength — the ball bearing model

Some metals bend easily whereas others are strong. When a metal bends, layers of atoms slide over each other. The more easily they slide, the more easily the metal bends.

A metal with perfect rows of atoms bends easily. If the rows are distorted, they cannot slide over each other as freely, so the metal does not bend easily.

Metals do not crystallise with perfect rows of atoms all through the lattice. They form areas of perfect close-packing called grains. The boundaries between the grains are called grain boundaries. Although the atoms in metal grains are packed in a regular order, the grains themselves are irregularly shaped crystals of the metal pushed tightly together.

The structure of a metal may be modelled by using ball bearings to show the arrangement of cations into grains. The model shows that:

- Metals with large grains have fewer dislocations and they bend easily.
- Metals with small grains have many dislocations and they do not bend easily.

The crystal structure, and therefore the properties, of metals can be changed in a number of ways. The next section discusses some of these.
(a) This ball bearing model shows small areas of perfect packing that simulate the arrangement of metal cations in a single crystal grain. This metal would not bend easily.

(b) Grains are large areas of regular arrangement; they represent a single metal crystal. Grain boundaries are narrow areas of disorder seen between one crystal grain and another. Vacant sites occur when an atom is missing from the crystal structure. Dislocations happen when a row of atoms is displaced and the regular packing stops.

Modifying metals

Modifying a metal by work hardening

Bending or hammering cold metals causes their crystal grains to become smaller. Since bending is now made more difficult, the metal is toughened, or **work hardened**. This is easily seen by bending a metal coathanger and then trying to bend it back to its original shape. It does not bend back in the area that has been work hardened.

Work-hardened metals are usually more brittle owing to the increased number of dislocations in the crystal structure. Constantly bending a piece of metal backwards and forwards causes it to snap since more and more dislocations are being produced in the metal crystal.

Modifying a metal using heat

The neatness of rows of atoms in a metal may be disrupted by heat. There are three main ways of doing this:

- **Annealed** metals are heated until they are red hot and then cooled slowly. Larger metal crystals are formed so that the metal produced is softer. Annealing is an intermediate step in metal-forming processes. It is used to restore ductility lost due to work hardening in items such as the coiled copper pipes in hot water systems.

- **Quenched** metals are heated until they are red hot and then allowed to cool quickly in cold water. Smaller crystals are formed, which makes the metal harder but more brittle. For example, blacksmiths formerly quenched horse-shoes by plunging them into cold water.

- **Tempered** metals are produced when quenched metals are warmed again to a lower temperature and then allowed to cool slowly. This procedure reduces the brittleness of the metal while retaining the hardness. For example, metals used to make special wood-carving tools such as lathes and chisels, as well as axes and rock drills, are tempered. Quenching, annealing and tempering alter the properties of a metal because these processes disrupt the metal lattice.

The properties of metals can be modified by work hardening, heat treatment and alloying.
Revision questions

19. What are some of the limitations of the ‘delocalised sea’ of electrons lattice model for metals?
20. How does the ball bearing model explain why some metals bend more easily than others?
21. Samurai swords were tempered to make them stronger and harder.
   (a) Describe how tempering alters the properties of a metal.
   (b) Name two other methods that use heat to modify the properties of a metal, and explain how they work.
22. Explain why work-hardened copper requires annealing before it may be further bent into a coiled shape.
23. When a metal paperclip is straightened out, it is difficult to bend it back to its original shape. Why?

Coating metals

Metals may be coated for decorative, protective reasons or to make them more useful, such as non-stick frypans, chrome-plated pipes and jewellery. Generally, however, metals, particularly iron, are coated to prevent corrosion.

Surface protection

Surface protection is used to prevent the air and water from coming into contact with the metal. A number of methods may be used for surface protection of iron and steel:
• Plastic is the most common form of surface protection. It is used to cover items ranging from simple household coathangers to commercial cables and wiring.
• Paint is used for many large objects, such as ships and bridges, as shown below.
• Grease or oil may be used to coat the moving parts of machinery.
• Metal coatings are used on steel.
There are two types of such coatings.

Metals can be protected with plastic, paint, grease or another metal.

Painters must be permanently employed to ensure that the Sydney Harbour Bridge is protected against corrosion.
A coating using a metal that is less reactive than steel is called noble coating, and it serves purely as a covering. Any scratch or break in the coating results in rapid corrosion of the exposed steel. Noble coating is used where scratching is unlikely and where zinc coating is not suitable, as zinc salts are poisonous. Steel food containers are plated with tin, and chromium is used as a noble coating on steel parts in cars and household items.

A coating using a metal that is more reactive than steel is called a sacrificial coating. A break in a sacrificial coating results in the formation of an electrochemical cell. The coating corrodes and the steel is protected. Zinc is the most common form of sacrificial coating. Objects coated in this way are said to be galvanised. When used on an iron roof, for example, the zinc coating reacts with carbon dioxide in air to form a layer of basic zinc carbonate, $\text{Zn(OH)}_2\cdot\text{ZnCO}_3$, over its surface, thus protecting it and slowing its rate of corrosion. Prepainted galvanised steel sheets for roofs, walls and household appliances are now commercially available. Australians make extensive use of galvanised iron for roofing, guttering, pipes, rubbish bins, fencing wire and nails.

Reactivity of metals

The reactivity of metals can be determined experimentally by how readily they react with oxygen, water, steam and dilute acids. Using these reactions, the activity series of metals can be established. Potassium and gold are at opposite ends of the reactivity series of metals, shown in table 4.4 below.

<table>
<thead>
<tr>
<th>Element</th>
<th>Appearance of metal</th>
<th>Reaction with oxygen</th>
<th>Reaction with water or steam</th>
<th>Reaction with dilute acids</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>dull, stored under oil</td>
<td>oxidises in air at room temperature to give oxides</td>
<td>hydrogen formed from cold water</td>
<td>hydrogen formed violently</td>
</tr>
<tr>
<td>Na</td>
<td>generally dull</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ca</td>
<td>generally dull</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mg</td>
<td>generally dull</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Al</td>
<td>generally dull</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zn</td>
<td>generally dull</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fe</td>
<td>generally dull</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sn</td>
<td>generally dull</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pb</td>
<td>generally dull</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cu</td>
<td>generally dull</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hg</td>
<td>generally shiny</td>
<td>no reaction</td>
<td>no reaction</td>
<td>no visible reaction</td>
</tr>
<tr>
<td>Ag</td>
<td>generally shiny</td>
<td>no reaction</td>
<td>no reaction</td>
<td>no reaction</td>
</tr>
<tr>
<td>Au</td>
<td>generally shiny</td>
<td>no reaction</td>
<td>no reaction</td>
<td>no reaction</td>
</tr>
</tbody>
</table>

Note: Aluminium metal often appears to be less reactive than the reactivity series indicates because it has a coating of aluminium oxide and this protects it from reacting further with oxygen. This coating can be thickened by a process called anodising.
Reactivity of metals and the periodic table

Reaction with oxygen

The most reactive metals are found on the very left of the periodic table, and reactivity increases down the group. Sodium reacts directly with air and so it is stored in oil to prevent it reacting in air or water.

\[
\text{metal} + \text{oxygen} \rightarrow \text{metal oxide} \\
\text{sodium} + \text{oxygen} \rightarrow \text{sodium oxide} \\
4\text{Na(s)} + \text{O}_2(g) \rightarrow 2\text{Na}_2\text{O(s)}
\]

Reaction with water

Group 1 metals are called alkali metals because they react readily with water to produce alkalis (soluble hydroxide compounds) and hydrogen gas.

\[
\text{group 1 metal} + \text{water} \rightarrow \text{group 1 metal hydroxide} + \text{hydrogen} \\
2\text{K(s)} + 2\text{H}_2\text{O(l)} \rightarrow 2\text{KOH(aq)} + \text{H}_2(g)
\]

The experiment illustrated below shows how the relative reactivity of magnesium and calcium can be observed. When magnesium and calcium react with water in beakers A and B as shown, hydrogen gas and a hydroxide compound are formed. The presence of the hydroxide compound is indicated by phenolphthalein. After 45 minutes, beaker B has a more intense pink colour, suggesting that more hydroxide compound has been produced by the reaction. We can deduce from this that calcium is more reactive with water than is magnesium.

![Reaction with water](image)

Reaction with acid

Hydrogen is also produced when the more reactive metals react with acids.

\[
\text{metal} + \text{acid} \rightarrow \text{ionic salt} + \text{hydrogen} \\
\text{iron} + \text{hydrochloric acid} \rightarrow \text{iron(II) chloride} + \text{hydrogen} \\
\text{Fe(s)} + 2\text{HCl(aq)} \rightarrow \text{FeCl}_2(aq) + \text{H}_2(g)
\]

Metallic nanomaterials

The reactivity of a metal is influenced by the size of its particles. The very high surface area to volume ratio of nanoparticles increases reactivity and catalytic ability because of the greater contact with reactant particles.

As the size of the particles decreases, the surface area increases. This has significant effects on the properties of nanomaterials.
Socks that are permeated with nanosilver and can be worn for extended periods of time may or may not be appealing to many people. Due to the presence of silver nanoparticles that have antibacterial properties, much of the odour is eliminated. Some clothing, food packaging, surfaces, appliances, bedding and even baby bottles have also undergone the same treatment. The antimicrobial properties of nanosilver make it useful for bandages, dressings and surfaces in hospitals. Its proven effectiveness is due to its extremely large surface area, a characteristic of nanoparticles in general. However, there is evidence of increasing bacterial resistance to nanosilver and concern about the effects of its use on the environment.

Nanoparticles have a diameter between 1 and 100 nm. In just 1 millimetre, there are 1 million nanometres. Metallic nanomaterials are not new. Nanogold has been used in Roman pottery and in medieval stained glass windows, as have nanocopper and nanosilver. Scientists are interested in their huge potential in biomedical science and engineering. The properties discussed so far in this chapter have referred to what is described as bulk materials or at the macro level. At the macro level, solid samples can contain billions of atoms whereas a nanoparticle has between 10 and 70,000 atoms. Metallic nanomaterials have the same metallic structure but the number of atoms in a sample is very much smaller; this results in different properties. At the nanoscale, many of the classical laws of physics do not operate; it is here that quantum effects apply.

Nanomaterials look different from and react faster than bulk samples. They may be stronger and better conductors of electricity; they are good catalysts. In bulk metals, the high density of electrons on the surface causes light to be fully reflected. When the particles are much smaller, some parts of visible light are absorbed, resulting in the appearance of a colour that depends on the size of the nanoparticles. Nanosilver is yellow; nanogold is red for particles of about 20 nm diameter but can be orange or even blue if the particle size is different. Bulk gold boils at 1064 °C but nanogold boils at a few hundred degrees. Nanogold is used in electronic chips and in diagnosis and treatment of disease. It is also an effective catalyst.

The colour of nanogold depends on the size of the clusters of particles.

In the future, metallic nanotechnology has significant potential to contribute to smaller and faster electronics, biotechnology, the environment and industry. Understanding the implications of nanotechnology is essential to minimising risks to health and the environment.
Connecting chemistry to society

Titanium bicycles — a material advantage?

Materials research has become an important component of competition preparation in many sports. Track and field athletes look for running shoes that provide stability, support and track grip. Tennis players seek the ultimate racquet that will give them a larger ‘sweet spot’ (the optimum position on the mesh from which to hit the ball), greater power and more control. Bicycle frames have recently been built from steel, aluminium and carbon fibre composites. A new material has now emerged as the preferred frame material — titanium. Each frame material has its advantages and disadvantages, as shown in table 4.5.

Titanium is preferred by cyclists for use in bicycle frames due to its combination of toughness, elasticity and resilience. Bicycles that are built stiffly, so that they resist pedalling forces, often provide a harsh, uncomfortable ride. Although titanium frames are very stiff against high pedalling forces, they seem to transmit much less road shock than bicycles made of other materials. Steel, for example, has a significantly higher density than titanium, but shock waves travel faster in steel than in titanium. Despite the fact that titanium’s high vibration-dampening properties are not yet fully understood, we do know that titanium provides three things crucial to cyclists: low weight, stiffness and a smooth ride.

Titanium is a lustrous, silvery metal with a high melting point (1667 °C). Found as an ore, titanium is quite abundant in the Earth’s crust, ranking ninth of all the elements. Metals are usually extracted from their ores by heating them with carbon. The extraction of titanium, however, is quite difficult since carbon cannot be used due to the formation of titanium carbides. Titanium’s unusual ability to stretch makes it hard to shape by machine. It tends to push away from even a very sharp cutting blade, giving a rather unpredictable final edge. However, the superior bicycle that results is worth all these difficulties.

Revision questions

24. Choose a sport that uses metals in its equipment. Draw a timeline to show how the materials used to make the equipment have been modified over time.

25. Use the internet to find out how titanium is modified for use in different applications. Tabulate your findings then use your table to produce a pie chart or graph. The following key words could be used in your search:
   - titanium usage research
   - sporting materials.

<table>
<thead>
<tr>
<th>Material</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>aluminium</td>
<td>• light</td>
<td>• low resistance to repeated stresses</td>
</tr>
<tr>
<td></td>
<td>• stiff</td>
<td></td>
</tr>
<tr>
<td>steel</td>
<td>• strong</td>
<td>• rusts</td>
</tr>
<tr>
<td></td>
<td>• economical</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• easily shaped to required specifications</td>
<td></td>
</tr>
<tr>
<td>carbon fibre composites</td>
<td>• high strength-to-mass ratio</td>
<td>• very expensive</td>
</tr>
<tr>
<td></td>
<td>• good shock-dampening power</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• good vibration-dampening power</td>
<td></td>
</tr>
<tr>
<td>titanium</td>
<td>• less than half the density of steel</td>
<td>• expensive</td>
</tr>
<tr>
<td></td>
<td>• excellent resistance to metal fatigue</td>
<td>• difficult to shape</td>
</tr>
<tr>
<td></td>
<td>• high corrosion resistance</td>
<td></td>
</tr>
</tbody>
</table>
Extraction of metals

The method used to extract metals from their ores depends on their reactivity.

The reactivity of a metal also influences how easily it is extracted. Silver and gold, for example, are unreactive and so are found naturally in their elemental state, which is why they have been known and used since ancient times. More reactive metals must be extracted from their ores. Ores are rocks that are mixtures of different compounds and from which it is economically viable to separate out the metal.

<table>
<thead>
<tr>
<th>Reactivity</th>
<th>Metal</th>
<th>Extraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>very reactive</td>
<td>K, Na, Ca, Mg, Al</td>
<td>electrolysis of molten compound, using electricity to cause a chemical reaction</td>
</tr>
<tr>
<td>reactive</td>
<td>Zn, Fe, Sn, Pb</td>
<td>heating the metal ore with carbon</td>
</tr>
<tr>
<td>less reactive</td>
<td>Cu, Hg, Ag</td>
<td>heating the metal ore in air</td>
</tr>
<tr>
<td>unreactive</td>
<td>Ag, Pt, Au</td>
<td>occur as free elements</td>
</tr>
</tbody>
</table>

Extraction of iron

Our society is highly dependent on the use of iron. Iron is needed to manufacture steel for transport and construction and to a lesser degree for machinery, containers and appliances. About 5% of the Earth’s crust is iron; it is the fourth most abundant element after oxygen, silicon and aluminium. Because iron is a metal of medium reactivity, it is extracted from its ores by reaction with carbon in a blast furnace. Iron can be extracted from the following compounds, which are obtained from the ores in parentheses: Fe₃O₄ (magnetite), Fe₂O₃ (haematite), FeS (iron pyrite), Fe₂O₃·3H₂O (cimonite), FeCO₃ (siderite).

The blast furnace

The first stage in the manufacture of iron or steel is preparing the ore (the rock that contains the iron) for the blast furnace. It has to be crushed to fist-sized lumps of rock. These rocks are heated to drive off any water or other impurities that will evaporate.

The second stage involves the reduction of iron oxides to iron in the blast furnace. To do this, carbon in the form of coke and limestone (calcium carbonate) are added.

The furnace itself is a tapered cylindrical tower about 40 metres high. It is made of steel and is lined with bricks.

A mixture of iron ore, coke and limestone is added at the top of the furnace in such a way that no gas escapes while it is being added. At the same time, blasts of hot air at about 720 °C are blown into the furnace through small holes near the base. The purpose of the air is to burn the coke to form carbon monoxide. The carbon monoxide reduces the iron oxide to iron in a reaction that also produces carbon dioxide and great quantities of heat.
The iron falls to the bottom of the furnace and eventually melts at about 1500 °C. It is drained off every few hours.

The role of the limestone is to remove impurities inside the furnace. Impurities such as silica, SiO$_2$, and alumina, Al$_2$O$_3$, are removed. The substances formed are known as 'slag'. The slag floats on top of the iron and is drained off at a different level.

The iron obtained from a blast furnace is not completely pure and is called 'pig-iron'. It is hard and brittle and melts at about 1300 °C.

(a) The coke reacts with oxygen in the air, giving carbon dioxide:

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

(b) The limestone decomposes to calcium oxide and carbon dioxide:

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

(c) The carbon dioxide reacts with more coke, giving carbon monoxide:

$$C(s) + CO_2(g) \rightarrow 2CO(g)$$

(d) This reacts with iron oxide in the ore, giving liquid iron:

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

The iron trickles to the bottom of the furnace.

(e) Calcium oxide from step (b) reacts with sand in the ore, to form calcium silicate or slag:

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

The slag runs down the furnace and floats on the iron. The slag and iron are drained from the bottom of the furnace.

**Revision question**

26. State the chemical name for the iron compounds obtained from the different iron ores.

**Impacts of iron production on society, the economy and the environment**

The benefits to society of iron production include not only providing essential materials but also offering employment in mining, production, transport and sales. Exporting iron ore contributes to the economy and therefore the wealth of the nation. These benefits must be balanced with the costs of
obtaining and transport of raw materials and the energy requirements for the process. The cost to the environment may also be considerable. The destruction of the landscape for open-cut mining, the significant waste materials that must be disposed of, and the particulate matter and waste gases all contribute to environmental damage. The waste carbon dioxide contributes to the greenhouse effect, and sulfur dioxide gas contributes to acid rain. Recycling iron can reduce some of these problems. Less energy is used to recycle metals than the original process, and resources are conserved, resulting in lower costs and less pollution.

Revision questions

27. Find out what methods are used by industry to minimise the effects on the environment of iron production.

28. What differences would you notice in your daily life if iron were not available?

Australia is one of the world’s largest producers of iron ore; most of it is mined in Western Australia.
Summary

- When metallic atoms combine, a lattice is formed consisting of cations in a sea of delocalised electrons. The electrostatic attraction between the cations and electrons is called metallic bonding.
- The metallic lattice structure influences the properties of metals, which, in turn, determine their use.
- Metals are generally:
  - lustrous due to the mobile electrons being able to reflect light
  - good conductors of heat due to the mobile electrons
  - able to transfer the kinetic energy in hotter areas of the metal to cooler areas
  - good conductors of electricity due to the electrons being able to move when an electric field is applied
  - malleable and ductile because the attractive forces that bind the cations and mobile electrons occur in all directions, so that one layer of metal atoms can easily slip over another, without breaking the bonds
  - high-density substances because their lattices are close packed
  - hard and tough and have high tensile strength and high melting points due to the strong attraction between the electrons and cations.
- Alloys are made by melting metals or other materials together and cooling the mixture.
  - The alloy has different properties from that of the original materials.
  - There are two types of alloy: substitutional alloys, where the metal atoms are the same size, and interstitial alloys, where the metal atoms differ in size.
- The properties of metals in different blocks of the periodic table show variations from the general properties.
  - s-block metals are reactive and some have lower density.
  - p-block metals have varied properties.
  - d-block metals usually form coloured compounds and are useful as catalysts.
- The ball bearing model was developed to explain different metal strengths.
  - Metals with large areas of perfect close packing (grains) have fewer dislocations (flaws in the packing) and they bend easily.
  - Metals with small grains have many dislocations and do not bend easily.
- Metals can be modified by:
  - work hardening. Work-hardened or toughened metals are more brittle because the crystal grains are smaller and have more dislocations.
  - different heat treatment
  - alloying
  - coating. Coating is used to improve usefulness and prevent corrosion.
- The three types of heat-modified metal are:
  - annealed metals, which are heated and then cooled slowly to produce larger crystals and hence a softer metal
  - quenched metals, which are heated until red hot and then cooled quickly in cold water to produce smaller crystals and hence a harder but more brittle metal
  - tempered metals, which are made by warming a quenched metal and allowing it to cool slowly to reduce brittleness but retain hardness.
- Metals vary in their reactivity. Reactivity decreases across the periods and increases down a group of the periodic table.
- Because of their extremely small size and resulting large surface area, the properties of metallic nanoparticles are different from those of the corresponding bulk materials, including colour and reactivity.
- Nanosilver is a useful antibacterial agent.
- Nanogold has beneficial applications in disease detection and treatment.
- The method of metal extraction from their ores depends on their reactivity. Iron is a reactive metal and is extracted by reaction with carbon in a blast furnace.
- Iron is an essential material for construction and manufacturing, but its production has impacts on the environment, including land degradation and pollution. These effects may be reduced by collecting waste gases and revegetation.

Multiple choice questions

1. A characteristic of metals is that their atoms:
   A are smaller than those of non-metals
   B readily form ionic bonds with atoms of other metals
   C have few electrons in their outer shells, and these are readily lost in chemical reactions
   D have high electronegativity.

2. The structure and bonding in solid sodium metal at room temperature can best be described as:
   A a network lattice of closely packed sodium atoms, held together by strong ionic bonds
   B a lattice of Na₂ molecules
   C a network lattice of sodium ions, held together by a ‘sea’ of electrons
   D a lattice of Na₂ molecules held together by weak bonds.
3. Which of the following properties is not characteristic of metals? They are:
   A  good conductors of heat
   B  capable of being polished
   C  relatively dense solids at room temperature
   D  hard and brittle
4. The property of metals that enables them to conduct an electric current is:
   A  the outer electrons of metal atoms are not firmly bound to the atom
   B  metal atoms are better suited as charge carriers than non-metal atoms
   C  ions in the metal can move freely through the metallic lattice
   D  metal atoms are not as firmly bonded to each other as are non-metallic atoms
5. The physical properties of solid metals can best be explained by proposing that:
   A  each metal atom is held in the crystal lattice by covalent bonds
   B  positive metal ions are arranged in an orderly way, with valence electrons able to move freely throughout the crystal
   C  positive and negative metal ions are arranged in an orderly way, with valence electrons able to move freely through the crystal lattice
   D  each metal atom is surrounded by a variable number of valence electrons, which complete a ‘noble gas’ electronic structure in the crystal lattice
6. The term ‘malleable’ is applied to a metal that:
   A  can be hammered into thin sheets
   B  resists corrosion
   C  can be drawn out to form thin wire
   D  can be used to form alloys
7. Both copper and sodium chloride have high melting points. Copper, in its solid and liquid states, is a good conductor of electricity while sodium chloride conducts electricity only when molten or dissolved in water. This difference in electrical conductivity can be explained by the fact that:
   A  there are much stronger bonding forces between atoms in sodium chloride than between those in copper
   B  electrons in solid copper have much greater mobility than those in solid NaCl
   C  chlorine is a poor electrical conductor
   D  copper has only one kind of atom
8. The structure of a solid formed by heating a mixture of two metallic elements at high temperature is likely to be:
   A  a metallic solid called an alloy
   B  an ionic solid
   C  a mixed ionic lattice and metallic lattice
   D  separate molecules of each element
9. Which of the following is not a possible mechanism for the formation of an alloy of two metals?
   A  Atoms of one metal fit into the interstitial spaces between atoms of the other.
   B  A new element is formed.
   C  Atoms of one metal replace atoms of the other in the crystal lattice.
   D  Separate crystals of one metal are dispersed throughout the other.
10. Which element can be found in nature in elemental (uncombined) form?
    A  K
    B  Ca
    C  Au
    D  Al
11. Aluminium, although a fairly reactive metal, does not react with oxygen gas in air because:
    A  it is protected by small amounts of its own impurities
    B  its oxide forms a hard protective layer on the metal
    C  nitrogen and carbon dioxide gas in the air prevent oxidation
    D  it forms a hard protective layer by a reaction with sulfur in the air
12. Iron rubbish bins coated with a complete layer of zinc do not rust because:
    A  the zinc acts as a sacrificial metal, reacting to prevent the iron rusting
    B  iron is a more reactive metal than zinc
    C  the zinc combines with the iron to form a new compound that does not rust
    D  particles of rust are unable to stick to the zinc surface
13. Consider the following:
    ■ Metal G slowly reacts with cold water.
    ■ Metal H is generally shiny.
    ■ Metal E readily reacts with oxygen.
    ■ Metal F produces hydrogen when it reacts with acid.
    What is their reactivity order, from the most to the least reactive?
    A  H > G > F > E
    B  H > E > F > G
    C  F > H > G > E
    D  E > G > F > H
14. Which is formed by the reaction of zinc with hydrochloric acid?
    A  zinc hydroxide + hydrogen
    B  zinc sulfate + chlorine
    C  zinc chloride + hydrogen
    D  zinc chloride + water
15. When a piece of sodium metal is carefully added to water, it reacts vigorously. A piece of caesium metal would:
    A  react with about the same vigour
    B  react more vigorously
    C  react less vigorously
    D  not react at all with the water.

CHAPTER 4 Metallic bonding 87
16. Stainless steel is made by alloying iron, nickel and:
   A aluminium
   B copper
   C magnesium
   D chromium.

17. Which of the following is a metal that reacts with dilute acids but not cold water?
   A potassium
   B gold
   C iron
   D carbon

**Review questions**

**Properties and structure of metals**

1. The electron configurations of elements A, B, and C are as follows.
   - A: 2, 6
   - B: 2, 8, 1
   - C: 2, 8, 5
   Which of these elements is a metal?

2. Which of the following substances contain metallic bonding?
   (a) lithium
   (b) sulfur
   (c) sodium bromide
   (d) mercury(II) fluoride
   (e) calcium
   (f) argon

3. Explain the following properties of metals in terms of the metallic structure.
   (a) Metals are conductors of heat and electricity.
   (b) Metals are malleable.
   (c) Metals are ductile.
   (d) Metals are shiny.
   (e) Metals have high density.

**Properties and uses of metals**

4. Woks used in cooking can be made from stainless steel or normal steel. It is believed that normal steel enhances the flavour of the food. The wok is washed without an abrasive, dried, and then stored with a thin coating of oil on its inner surfaces.
   Regular saucepans, on the other hand, are usually made of the much more expensive stainless steel and often have a copper base.
   (a) Discuss the properties of these metals with reference to their use in the kitchen.
   (b) Why do people coat the woks with oil?
   (c) What other metals are used in the kitchen?
   (d) Draw a table that relates each of the metals you named in part (c) to its best use in the kitchen.

5. (a) Why was gold one of the first metals to be used?
   (b) Why was it not used for weapons?

6. Over the years, dentists have used metals for tooth fillings: first gold and then an amalgam of mercury. This amalgam is made by shaking a powdered mixture of silver, tin, copper and zinc with mercury. Within seconds, the mercury dissolves to form an amalgam that the dentist packs into the cavity. This alloy hardens in two hours.
   Copy the following table and use arrows to match the property of each metal with those of the alloy used in a dental amalgam.

<table>
<thead>
<tr>
<th>Metal</th>
<th>Property</th>
</tr>
</thead>
<tbody>
<tr>
<td>silver</td>
<td>• can be poured into the tooth easily</td>
</tr>
<tr>
<td>tin</td>
<td>• does not tarnish or react with food or drink</td>
</tr>
<tr>
<td>mercury</td>
<td>• bonds to the mercury and helps the amalgam set</td>
</tr>
<tr>
<td>copper and zinc</td>
<td>• helps the amalgam stay free from tarnish</td>
</tr>
<tr>
<td>gold</td>
<td>• gives the amalgam strength</td>
</tr>
</tbody>
</table>

**Modifying metals**

7. (a) What is the difference between a metal and an alloy?
   (b) Give examples of three alloys and indicate what advantages they have over the metal.

8. State, with reasons, whether each of the following substances is an element, a compound or an alloy.
   (a) copper
   (b) brass
   (c) gold
   (d) 18 carat gold
   (e) silver bracelet
   (f) iron
   (g) bronze
   (h) copper oxide
   (i) rust
   (j) oxygen
   (k) solder
   (l) stainless steel
   (m) tap water

9. Although mercury and mercuric compounds are toxic, mercury can safely be used in a tooth amalgam. What does this suggest about mercury and the amalgam?

10. Steel is an alloy of iron and carbon. Using steel as an example, explain why alloys are desirable.

11. Identify from which block (s, p or d) each of the following metals is found.
   (a) It corrodes easily, forming a green compound.
   (b) It has a partially filled p subshell and low density.
(c) It has a low melting point and can be cut easily with a knife.
(d) It is shiny and grey and, in nano form, has good antibacterial properties.
(e) It forms a compound that is white and has an subshell electron configuration of $1s^22s^22p^63s^23p^63d^{10}4s^2$.
(f) It is a reddish orange metal that forms blue compounds and is a good conductor of electricity.

12. Explain why it is difficult to straighten a bent metal coathanger.

13. Explain the difference between tempering and annealing a metal.

14. Explain, in terms of their bonding, why quenched metals are harder than unquenched metals.

15. Describe a situation where each of the following coatings may be used.
   (a) Plastic
   (b) Oil
   (c) Noble
   (d) Sacrificial

16. Describe an experiment that could be used to find the position of nickel in the activity series of metals.

17. Write fully balanced equations, including states, for the following reactions.
   (a) potassium + oxygen
   (b) calcium + water
   (c) tin + nitric acid, HNO$_3$

18. Complete the following table by placing ticks in the appropriate column.

<table>
<thead>
<tr>
<th>Property</th>
<th>Nanogold</th>
<th>Bulk gold</th>
<th>Both</th>
<th>Neither</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) reactive</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(b) magnetic</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(c) spreads</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>(d) range of</td>
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<td>range of colours</td>
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<td>(e) good</td>
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<td>conductor</td>
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<td>(f) very large</td>
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<td>(g) insoluble</td>
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<td>(h) unreactive</td>
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<td>(j) transition</td>
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19. Iron is an important metal for industry and consumers. It is used in greater quantity and variety than any other metal.
   (a) List four important uses of iron.
   (b) List four properties of iron that are relevant to the uses in part (a).
   (c) Why is iron used so extensively?
   (d) Why is iron usually alloyed with other metals?
   (e) Outline the reactions in the blast furnace involving carbon.
Exam practice questions

In a chemistry examination, you will be required to answer a number of short and extended response questions.

Extended response questions

1. The solders A, B and C have the following properties:
   - A is a liquid above 180 °C
   - B melts gradually from 180 °C to 230 °C
   - C has a very high melting point.
Which solder would you use for each of the following jobs?
   (a) Mending car radiators
   (b) Joining wires in an electric circuit
   (c) Filling gaps in car bodies
3 marks

2. Iron is an important metal for industry and consumers. It is used in greater quantity and variety than any other metal. There are several reasons for this:
   - Iron is malleable and ductile when hot, so that means that different articles may be made from it.
   - Iron forms a variety of alloys that may have vastly different properties.
   - Although pure iron is weak, when it is alloyed with carbon, it attains a high tensile strength. This means that it does not crack, break, bend or stretch easily.
   - Iron is the cheapest metal.
   (a) Suggest why iron is the cheapest of all metals. 2 marks
   (b) What is the name of the alloy described in the third bullet point, and what is another property of this alloy? 2 marks
   (c) List four important uses of iron. 2 marks