Book 7

Topic 14
Materials Chemistry

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49.1 Metallic crystal structures: close-packed structures (p.91)

Metals account for about two thirds of all the elements. They are all around you in such forms as steel structures, copper wires, aluminium foil and gold jewellery. Metals are widely used because of their properties: strength, ductility, high melting point, thermal and electrical conductivities.

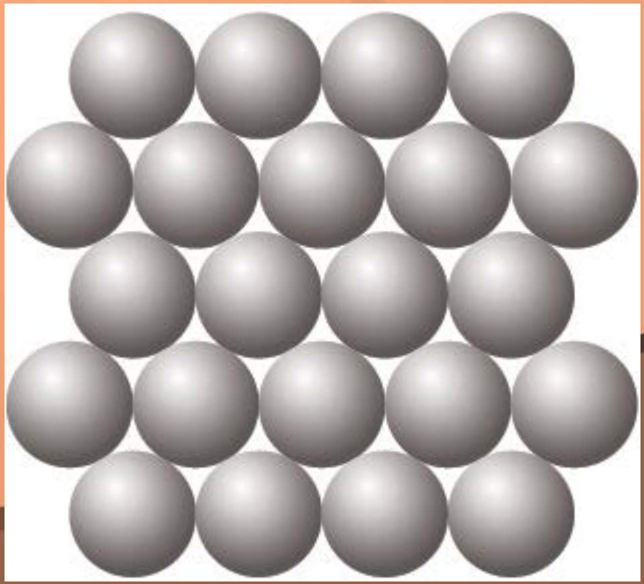
Over 90% of naturally occurring and man-made solids are crystalline. Most solids form with a regular arrangement of their particles. The overall attractive interactions between the particles are maximised when the particles pack in the most efficient manner.

49.1 Metallic crystal structures: close-packed structures (p.91)

A pure metal is a crystalline solid with positive metal ions packed closely together in a repeating pattern in a sea of electrons. To form the strongest metallic bonds, the ions in metals are packed together as closely as possible.

If you treat the ions in a metal as hard spheres of equal size, the close-packed arrangement of spheres in a plane is shown below where each sphere is in contact with six other spheres.

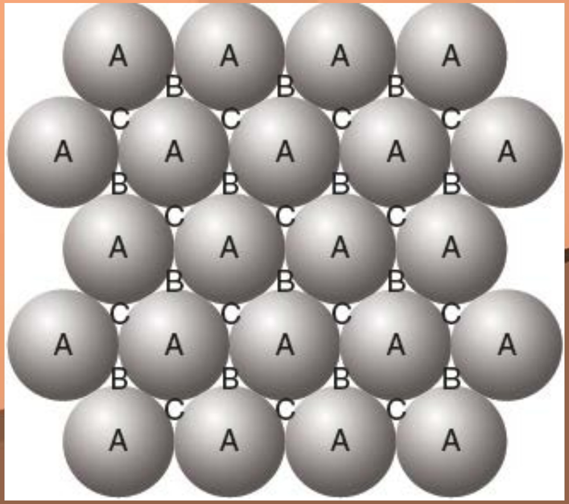
Close-packed arrangement of spheres in a plane



49.1 Metallic crystal structures: close-packed structures (p.91)

Label the centres of all the spheres in one close-packed plane A. Associated with this plane are two sets of equivalent triangular depressions formed by three adjacent spheres, into which the next close-packed plane of spheres may rest. Those having the triangle vertices pointing up are arbitrarily designated as B positions, while the remaining depressions are those with the down vertices, which are marked C below.

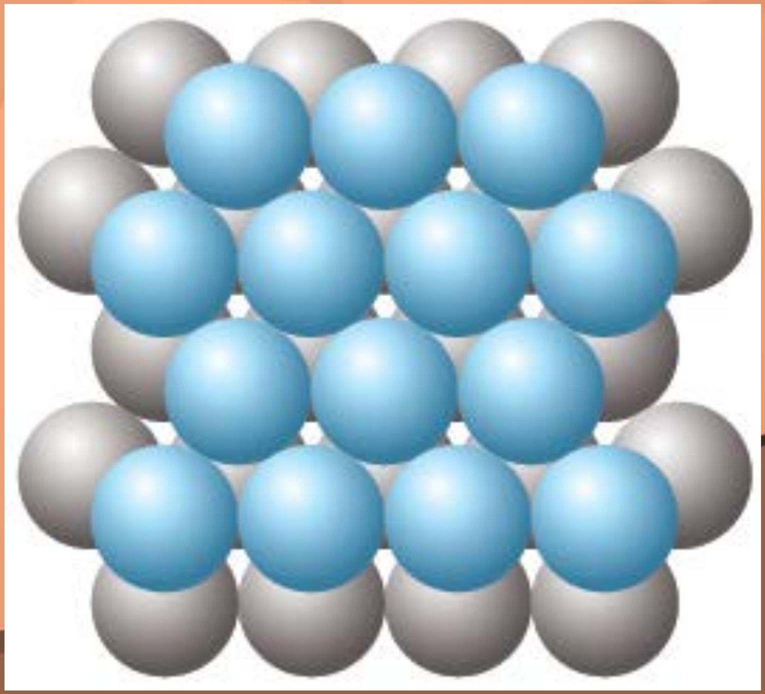
First layer top view of close arrangement of spheres with two sets of equivalent triangular depressions, B and C



49.1 Metallic crystal structures: close-packed structures (p.91)

A second close-packed plane may be positioned with the centres of its spheres over either B or C sites; at this point both are equivalent. Suppose that the B positions are chosen; the stacking sequence is termed AB, which is illustrated below.

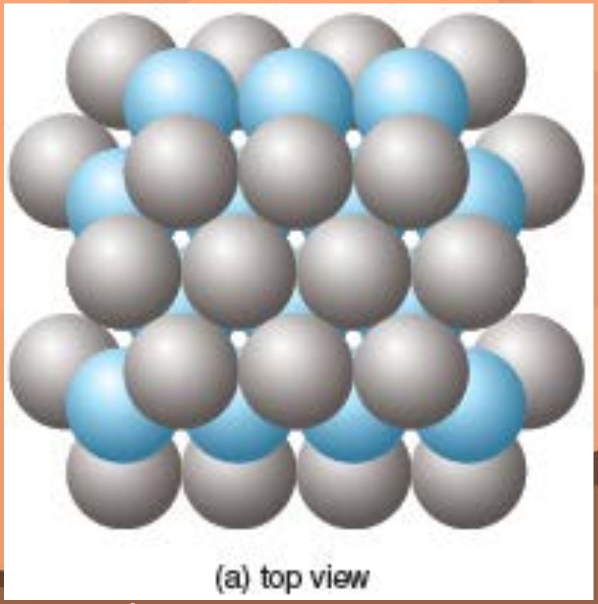
First and second layers top view of close arrangement of spheres with stacking sequence AB

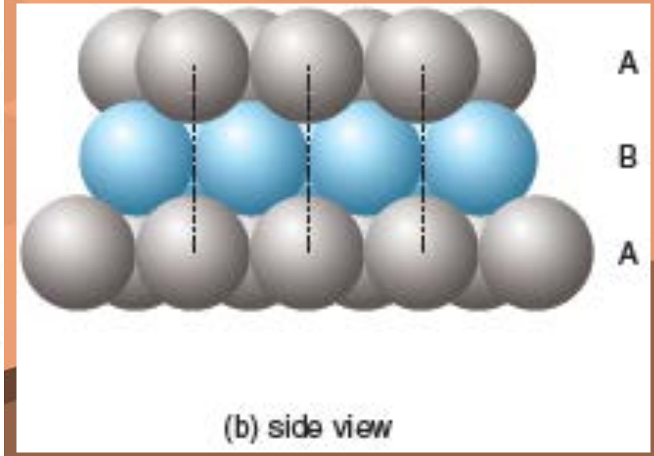


49.1 Metallic crystal structures: close-packed structures (p.91)

The third layer can be positioned in one of two ways.
The first way is centres of spheres of the third layer lying directly above the original A positions. This stacking sequence, ABABAB... Is repeated over and over again. This arrangement is known as **hexagonal close-packing (六方緊密裝填)** (h.c.p.). 74% of the volume of this structure is filled by spheres.

(a) Top view and (b) side view of ABAB stacking sequence (hexagonal close-packing)

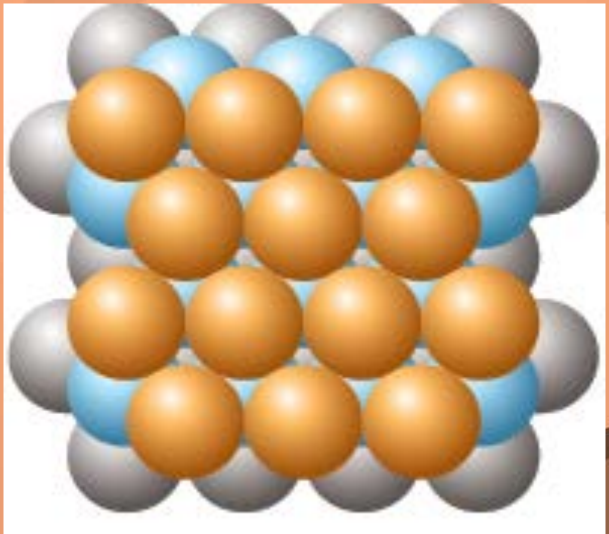


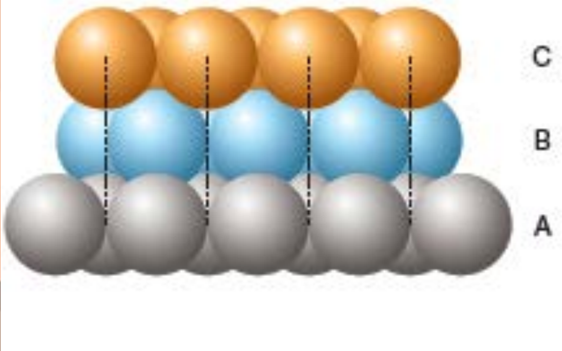


49.1 Metallic crystal structures: close-packed structures (p.91)

Magnesium, titanium and zinc are among the common metals to adopt the hexagonal close-packed structure in the solid state. The second way is spheres in the third layer sitting over the C sites of the first plane. This yields an ABCABCABC… stacking sequence. This arrangement is known as **cubic close-packing （立方緊密裝填）** (c.c.p.). 74% of the volume of this structure is filled by spheres.

(a) Top view and (b) side view of ABCABC stacking sequence (cubic close-packing)


(a) top view



(b) side view

49.1 Metallic crystal structures: close-packed structures (p.91)

Aluminium, copper, silver and gold are among the common metals to adopt the cubic closed-packed structure in the solid state.

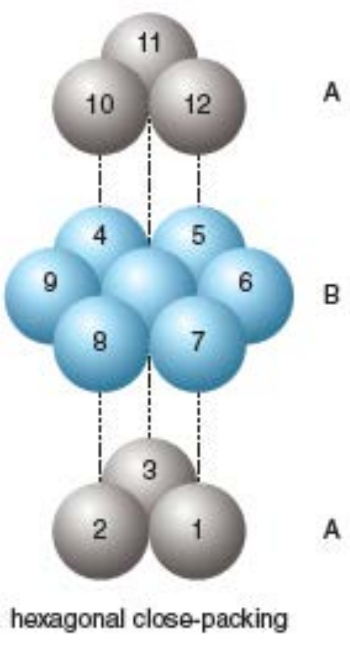
One important characteristic of a crystal structure is the coordination number.

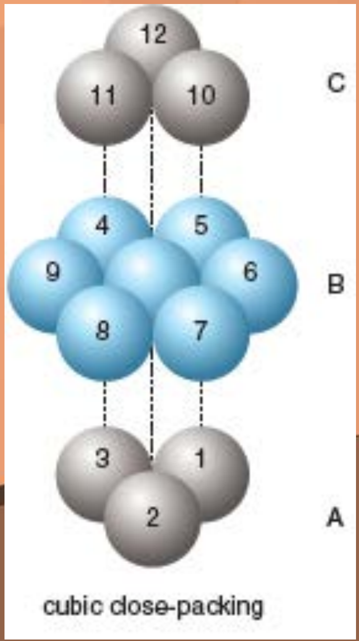
The **coordination number (配位數)** of one atom (or ion) in a crystal is the number of its nearest neighbours.

49.1 Metallic crystal structures: close-packed structures (p.91)

The figure shows expanded views of arrangement of particles in a hexagonal close-packed structure and a cubic close-packed structure. In both close-packed structures, every particle has twelve nearest neighbours, six surrounding it in its own plane, three above and three below this plane. Hence the coordination number of every particle is 12.

The coordination number of every particle in hexagonal close-packed structure and cubic close-packed structure is 12

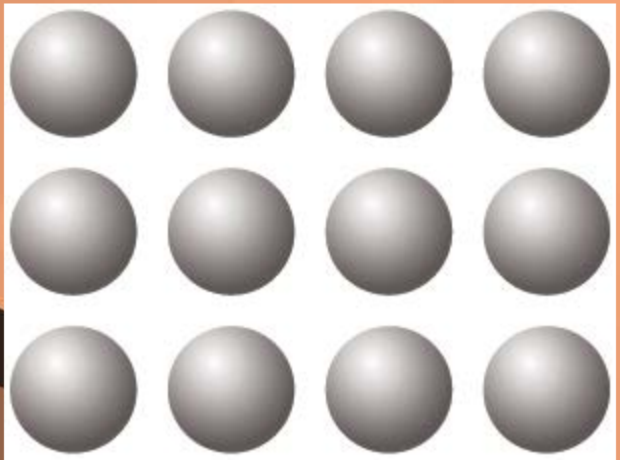




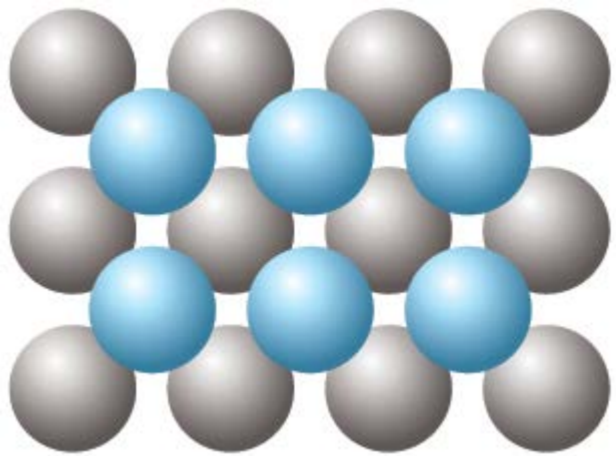
49.2 Body-centred cubic structures (p.95)

Another approach of packing spheres of equal size is by separating the spheres to form a square-packed plane in which they do not touch each other, as shown in (a). The spheres in the second plane sit in the depressions between the spheres in the first plane, as shown in (b).

(a) A layer of spheres in a body-centred cubic structure



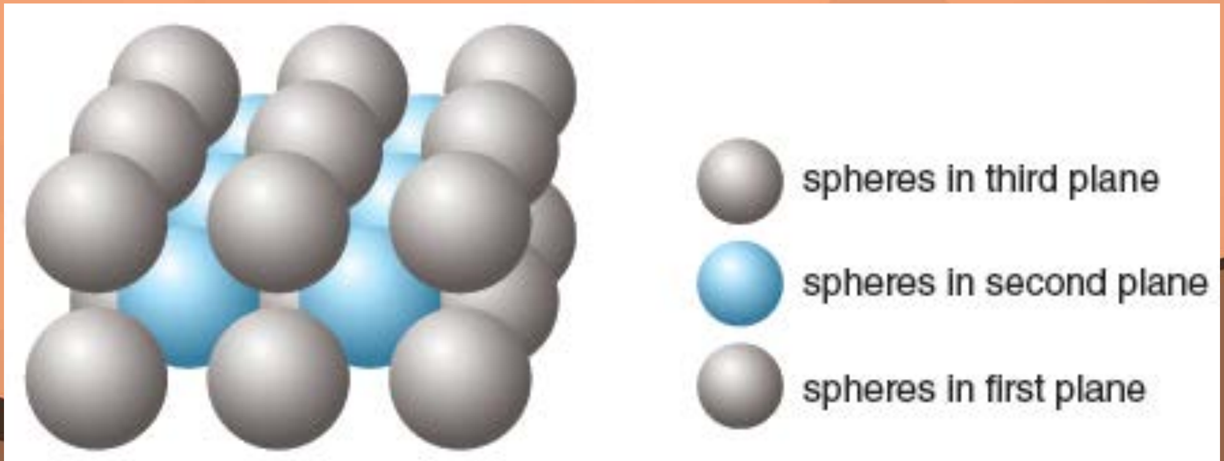
(b) First and second layers of spheres in a body-centred cubic structure



49.2 Body-centred cubic structures (p.95)

Spheres in the third plane sit in the depressions in the second plane. Spheres in the fourth plane sit in the depressions in the third plane, and so on. The result is a structure in which the odd-numbered planes of spheres are identical and the even-numbered planes of spheres are identical. This arrangement is known as **body-centred cubic packing (體心立體裝填)**. 68% of the volume of this structure is filled by spheres.

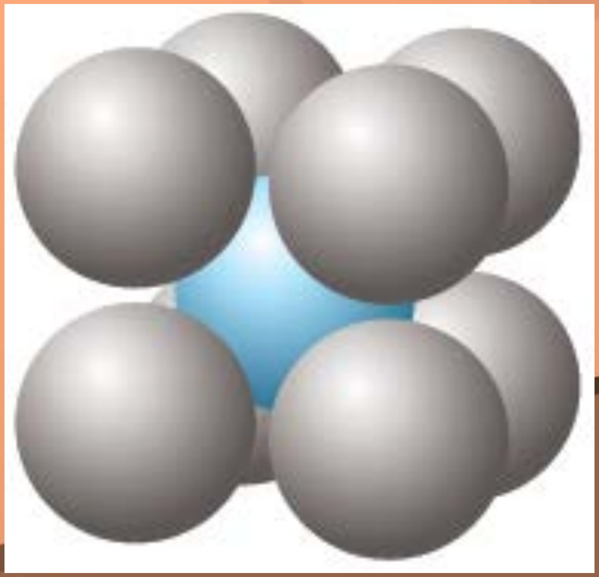
Spheres in a body-centred cubic packing arrangement



49.2 Body-centred cubic structures (p.95)

Group I metals adopt the body-centred cubic structure, and their low densities reflect the relative openness of this structure, compared with the close-packed structures described above. In this structure, every particle has eight nearest neighbours at its corner. Hence the coordination number of every particle is 8.

In a body-centred cubic structure, the coordination number of every particle is 8



49.2 Body-centred cubic structures (p.95)

The table below summarises some information of the three types of structure discussed above.

Some information of the three types of structure		
Type of structure	**Percentage of volume filled by spheres**	**Coordination number**
Hexagonal close-packed structure	74%	12
Cubic close-packed structure	74%	12
Body-centred cubic structure	68%	8

It is easy to understand why many metals adopt hexagonal or cubic close-packed structures. Not only do these structures use space efficiently, they also have the largest possible coordination numbers, which allows each metal atom to form bonds to the largest number of neighbouring metal atoms.

49.3 Unit cell (p.96)

The structure of a metal is best described by considering its simplest repeating unit, which is referred to as its unit cell.

The **unit cell (晶胞)** is the smallest repeating entity which, by repeated translation in three dimensions, builds up the whole structure.

The unit cell is the basic building block of the crystal structure of a metal.

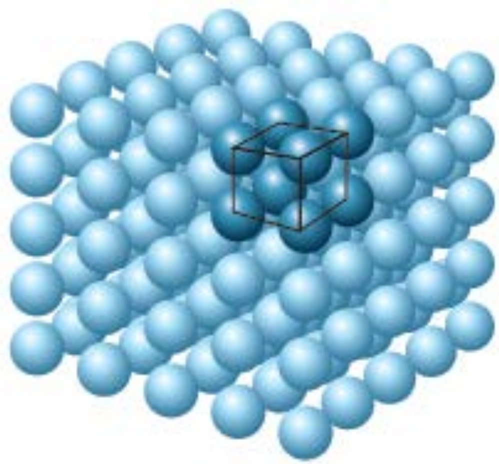
Building models of the close-packed structures of metallic crystal *Ref.*

49.3 Unit cell (p.96)

Body-centred cubic structure

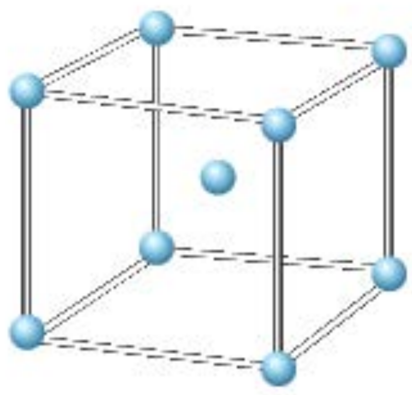
A collection of particles depicting a body-centred cubic structure is shown in (a), whereas (b) and (c) are diagrams of unit cells with particles represented by hard spheres and reduced spheres respectively. A particle is present at the centre of the cube in addition to particles at the corners.

The body-centred cubic structure



(a) an aggregate of many particles

(b) a hard-sphere unit cell representation



(c) a reduced-sphere unit cell representation

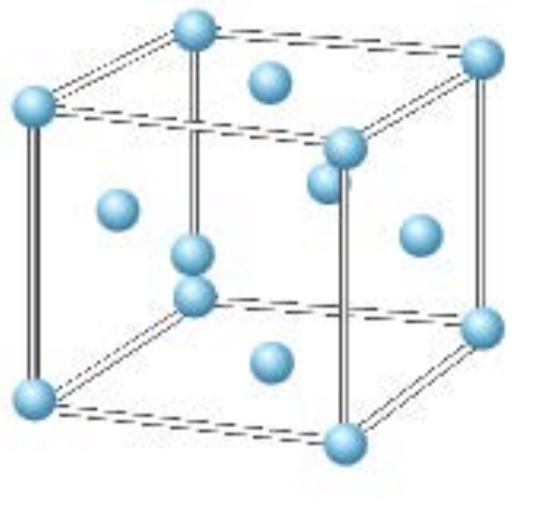
49.3 Unit cell (p.96)

Cubic close-packed structure

The unit cell of a cubic close-packed structure is the **face-centred cubic (面心立方)** unit cell. Particles are present at the centre of each face of the cube in addition to particles at the corners.

Unit cell of a cubic close-packed structure — face-centred cubic unit cell

(a) a hard-sphere unit cell representation

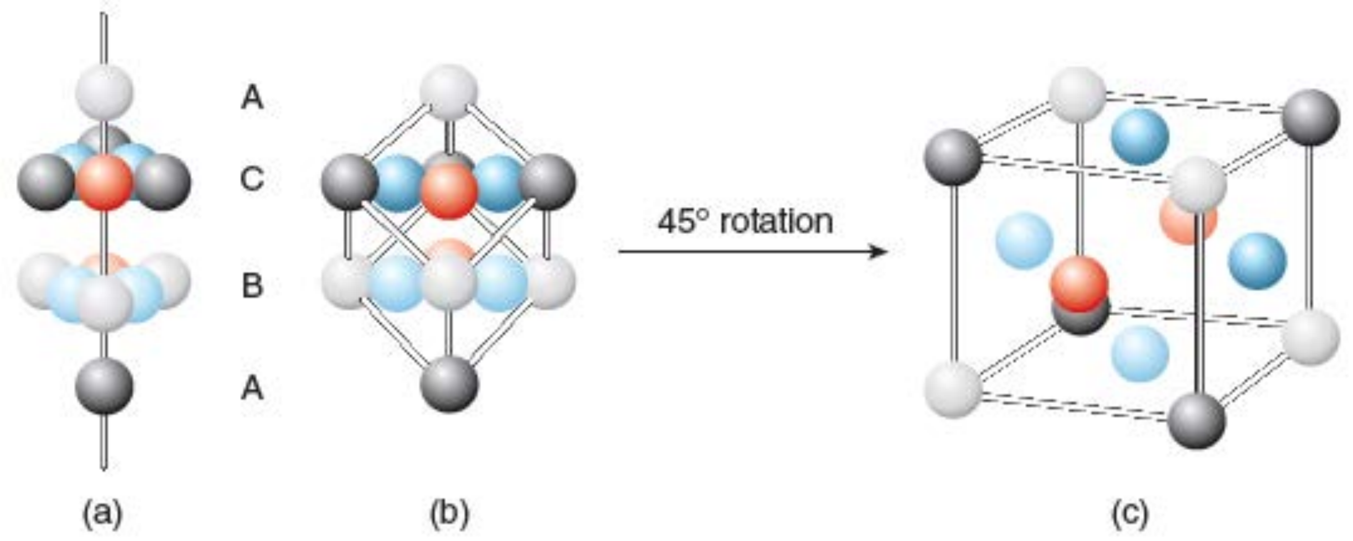


(b) a reduced-sphere unit cell representation

49.3 Unit cell (p.96)

To show the unit cell for a cubic closed-packed structure, you need parts of four planes (a–b). One particle from the first plane sits below a triangle of six particles in the second plane. There is an inverted triangle of six particles in the third plane. The fourth plane includes one particle in the same position as in the first plane. If the cubic close-packed structure is rotated by 45°, the face-centred cubic unit cell can be viewed (c).

The face-centred cubic unit cell is drawn by rotating an ABCA packing arrangement of the cubic close-packed structure

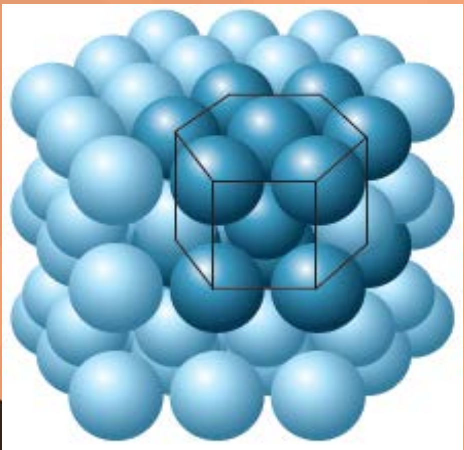


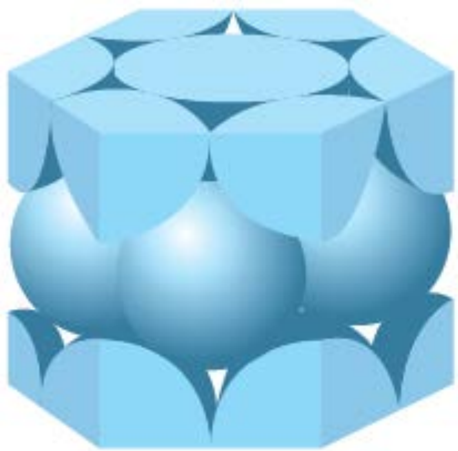
49.3 Unit cell (p.96)

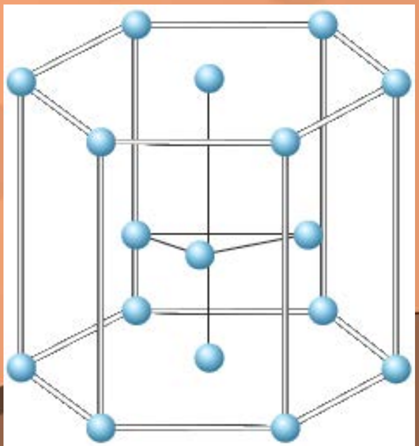
Hexagonal close-packed structure

A collection of particles depicting a hexagonal close-packed structure is shown in (a), whereas (b) and (c) are diagrams of unit cells with particles represented by hard spheres and reduced spheres respectively. Particles are present in the middle and at the centres of two faces of the hexagonal prism, in addition to particles at the corners.

The hexagonal close-packed structure


(a) an aggregate of many particles


(b) a hard-sphere unit cell representation


(c) a reduced-sphere unit cell representation

49.4 Calculating the number of particles in one unit cell (p.99)

In order to calculate the number of particles in a unit cell, you need to consider the extent to which various particles in a particular unit cell are shared between adjacent cells.

Each particle at the corner of a cubic unit cell is shared by eight unit cells in the structure and hence contributes only $\frac{1}{8}$ to a particular unit cell (a).

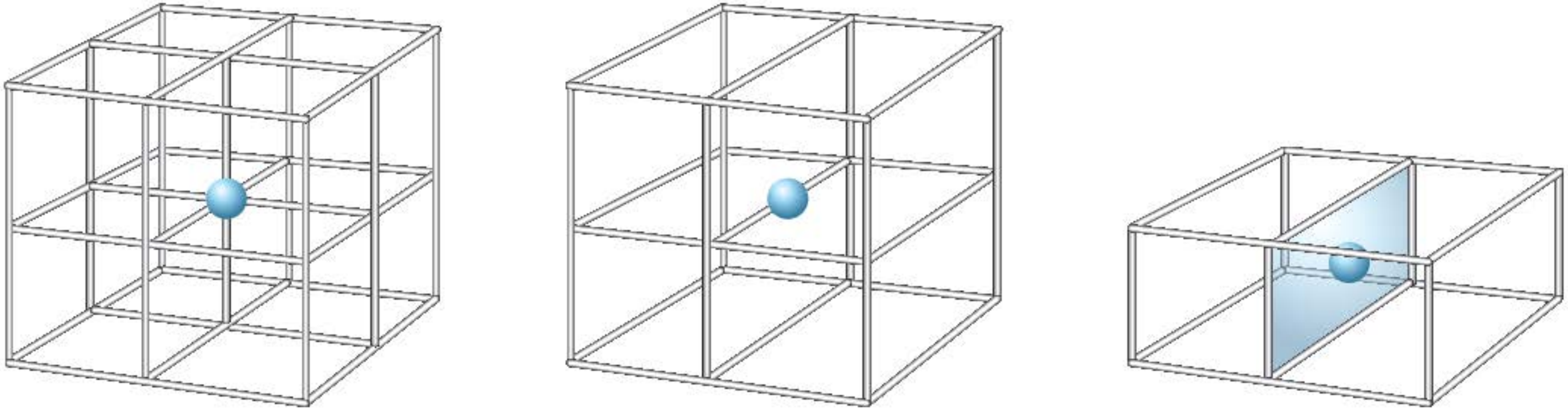
A particle at the edge centre of a cubic unit cell is shared by four unit cells in the structure and hence contributes only $\frac{1}{4}$ to a particular cell (b).

A particle at the centre of the face of a cubic unit cell is shared by two unit cells in the structure and contributes only $\frac{1}{2}$ to a particular unit cell (c).

49.4 Calculating the number of particles in one unit cell (p.99)

A particle at the body centre of a unit cell belongs only to the particular unit cell = 1 particle.

Illustrations showing the extent to which various particles in a particular unit are shared between adjacent cells



(a) (b) (c)

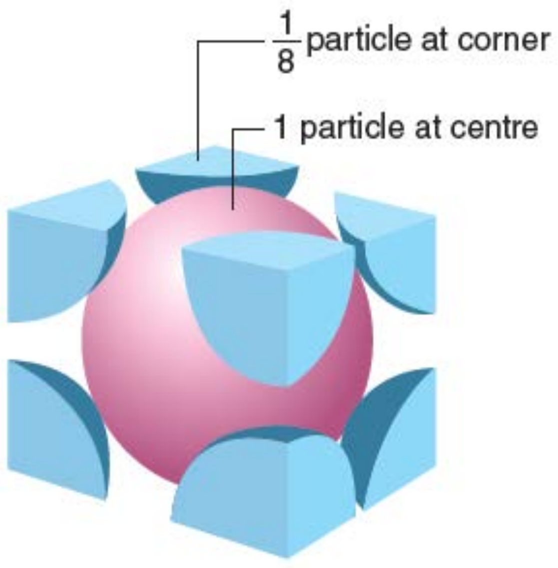
49.4 Calculating the number of particles in one unit cell (p.99)

Unit cell of body-centred cubic structure

The unit cell of a body-centred cubic structure has eight particles at corners and one at the centre. A particle at each corner makes $\frac{1}{8}$ contribution and the particle at the centre belongs only to the particular unit cell.

Hence the unit cell of a body-centred cubic structure has [8 (at corners) x $\frac{1}{8}$ + 1 (at centre)] particles = 2 particles

Unit cell of body-centred structure



49.4 Calculating the number of particles in one unit cell (p.99)

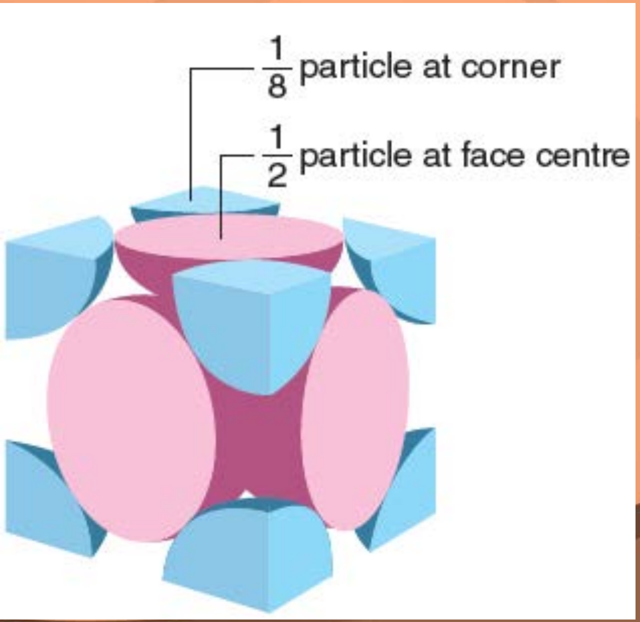
Unit cell of close-packed structure-face-centred cubic unit cell

A face-centred cubic unit cell has one particle at each corner (a cube has eight corners) and one particle at each face centre (a cube has six faces). A particle at each face centre is being shared by two unit cells and makes a contribution of only to a particular unit cell.

49.4 Calculating the number of particles in one unit cell (p.99)

Hence a face-centred cubic unit cell has [8 (at corners) x $\frac{1}{8}$ + 6 (at face centres) x $\frac{1}{2}$] particles = 4 particles

Unit cell of cubic close-packed structure



49.4 Calculating the number of particles in one unit cell (p.99)

Unit cell of hexagonal close-packed structure

The unit cell of a hexagonal close-packed structure has one particle at each corner (a hexagonal prism has twelve corners), one particle at the top layer and one at the bottom layer, and three particles in the middle.

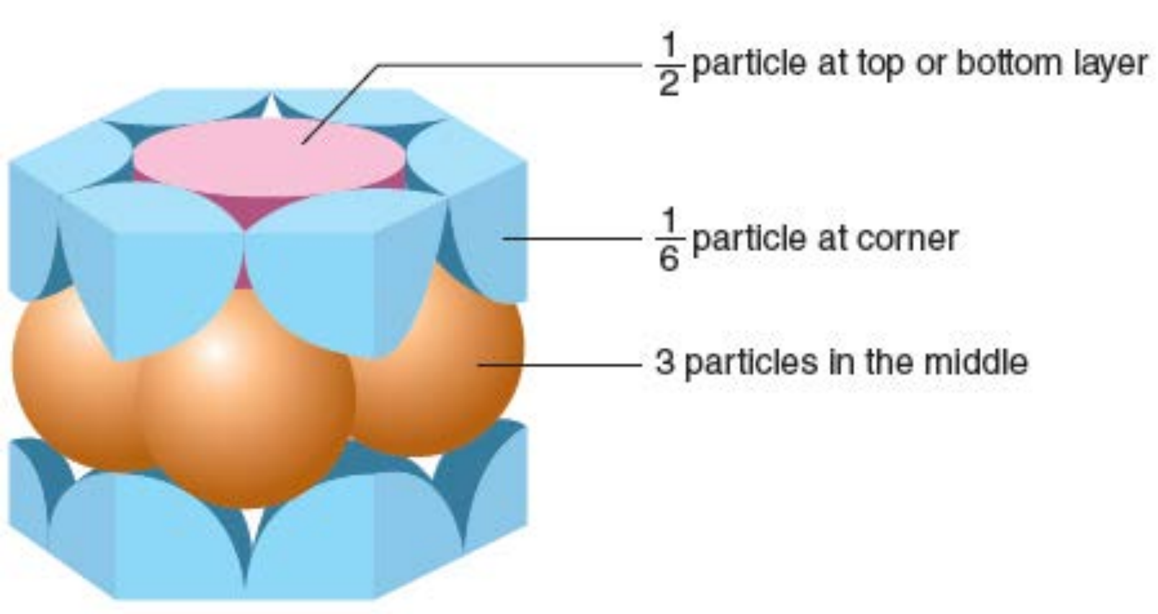
A particle at each corner makes $\frac{1}{6}$ contribution; a particle at the top or bottom layer makes $\frac{1}{2}$ contribution and three particles in the middle belong only to the particular unit cell on the next page.

49.4 Calculating the number of particles in one unit cell (p.99)

Hence the unit cell of a hexagonal close-packed structure has

[12 (at corners) x $\frac{1}{6}$ + 2 (top and bottom layers) x $\frac{1}{2}$ + 3 (in the middle)] particles = 6 particles

Unit cell of hexagonal close-packed structure



49.4 Calculating the number of particles in one unit cell (p.99)

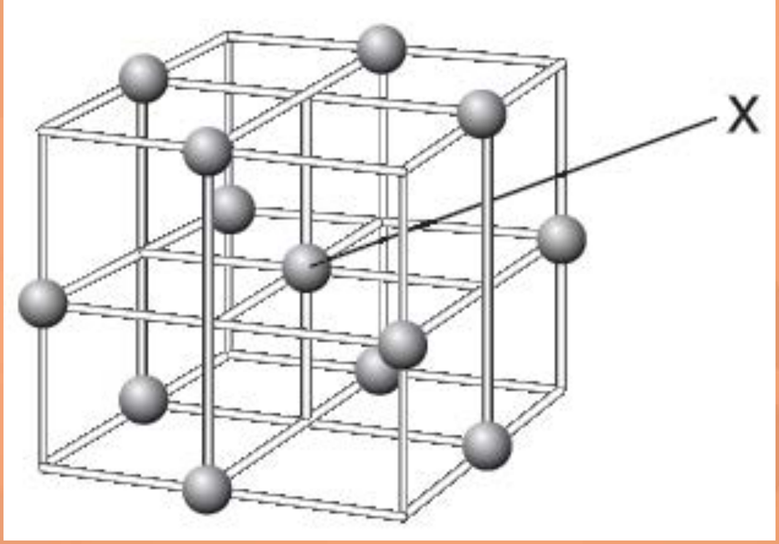
The table below summarises some information of the three types of structure discussed above.

Information for unit cells of different structures		
Unit cell	**Number of particles involved**	**Number of particles per unit cell**
Body-centred cubic	1 at each corner and a central particle	2
Face-centred cubic (cubic close-packed)	1 at each corner and 1 on each face	4
Hexagonal close-packed	1 at each corner, 1 at top/bottom layer and 3 particles in the middle	6

49.4 Calculating the number of particles in one unit cell (p.99)

Q (Example 49.1)

The diagram below shows the unit cell of metal X.



49.4 Calculating the number of particles in one unit cell (p.99)

Q (Example 49.1)

a) Calculate the number of atoms in the unit cell.
b) What is the coordination number of the atom labelled 'X'?
c) The density of a substance is its mass to volume ratio. Given that the edge length of the unit cell of metal X is 3.89×10^{-10} m, calculate the density of solid X, in g cm^{-3}.
(Relative atomic mass: X=106.4;
Avogadro constant = 6.02×10^{23} mol^{-1})

49.4 Calculating the number of particles in one unit cell (p.99)

A

a) The unit cell has 12 particles at edge centres and 1 at the centre.

b) 12

c) Edge length of unit cell = 3.89×10^{-8} cm

Volume of one unit cell = $(3.89 \times 10^{-8})^3$ cm^3

= 5.89×10^{-23} cm^3

Mass of one atom of X = $\frac{106.4 \text{ g mol}^{-1}}{6.02\times10^{23} \text{ mol}^{-1}}$

= 1.77×10^{-22} g

Density of solid X = $\frac{\text{mass of one unit cell}}{\text{volume of one unit cell}}$

= $\frac{4\times1.77\times10^{-22}\text{g}}{5.89\times10^{-23}\text{cm}^3}$

= 12.0 g cm^{-3}

∴ the density of solid X is 12.0 g cm^{-3}.

49.4 Calculating the number of particles in one unit cell (p.99)

Practice 49.1

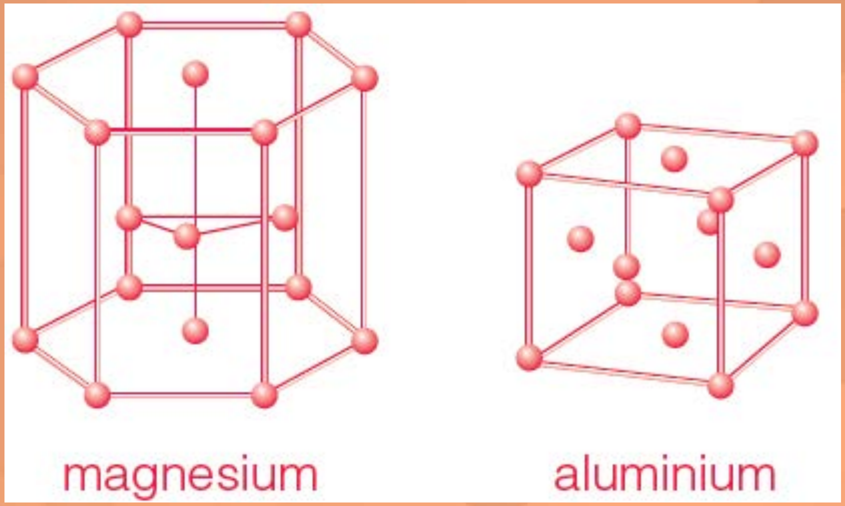
1 The table gives the crystal structures of two metals.

Metal	Crystal structure
Magnesium	Hexagonal close-packed
Aluminium	Cubic close-packed

a) Sketch a unit cell for each metal.
b) State ONE similarity between the packing of aluminium crystal and that of magnesium crystal.
c) Discuss the difference between the packing of aluminium crystal and that of magnesium crystal.

49.4 Calculating the number of particles in one unit cell (p.99)

1a)



1b) Both have close-packed structures / the same coordination number (12).

1c) Aluminium has ABC type packing.
Magnesium has AB type packing.

49.4 Calculating the number of particles in one unit cell (p.99)

2 Nickel has a cubic unit cell. The edge length of the unit cell of nickel is 3.52 x 10^{-10} m and the density of nickel at solid state is 8.90 g cm^{-3}.
(Relative atomic mass: Ni = 58.7; Avogadro constant = 6.02 x 10^{23} mol^{-1})

a) What is the number of nickel atoms in the unit cell?
b) Deduce whether nickel has a body-centred cubic structure or cubic close-packed structure.

49.4 Calculating the number of particles in one unit cell (p.99)

2a) Volume of unit cell = $(3.52 \times 10^{-8})^3$ cm^3

= 4.36×10^{-23} cm^3

Mass of unit cell = density x volume of unit cell

= 8.90 g cm^{-3} x 4.36×10^{-23} cm^3

= 3.88×10^{-22} g

Mass of one nickel atom = $\frac{58.7 \text{ g mol}^{-1}}{6.02 \times 10^{23} \text{ mol}^{-1}}$

= 9.75×10^{-23} g

Number of nickel atoms in unit cell = $\frac{3.88 \times 10^{-22} \text{g}}{9.75 \times 10^{-23} \text{g}}$

= 4

2b) Cubic close-packed structure, with a face-centred cubic unit cell.

49.5 Alloys (p.103)

An **alloy (合金)** is a mixture of metals or a mixture of a metal and a non-metal, usually carbon but sometimes phosphorus.

The alloying of metals is of great importance because it is one of the primary ways of modifying the properties of pure metals. For example, pure gold is too soft to be used in jewellery, whereas alloys of gold and copper are quite hard. Pure gold is termed 24 carat, the common alloy used in jewellery is 14 carat, meaning that it is about 58% gold (i.e. $\frac{14}{24} \times 100\%$) .

49.5 Alloys (p.103)

Alloys are usually divided into ferrous and non-ferrous alloys. Ferrous alloys include the carbon steels, which are alloys of iron containing up to 2% carbon. The majority of non-ferrous alloys are based on copper. Familiar alloys of copper are **brass(黃銅)** and **bronze(青銅)**. Other well-known alloys include **solder(焊錫)** and **duralumin(硬鋁)**.

49.5 Alloys (p.103)

The table below summarises the approximate composition of some common alloys and their uses.

Table 49.3 Approximate composition and uses of some alloys

Alloy	Approximate composition	Uses
Carbon steel	iron, up to 2% of carbon	construction materials, tools, car body panels
Stainless steel	iron 72–76% chromium 16–18% nickel 8–10% carbon < 0.1%	kitchen fixtures (Fig. 49.18), cultery, surgical equipment
Brass	copper 65% zinc 35%	water taps, musical instruments (Fig. 49.19), decorative items
Bronze	copper 90% tin 10%	status, bearings
Solder	lead 67% tin 33%	joining electric wires and components
Duralumin	aluminium 95% copper 3% magnesium 1% manganese 1%	aircraft, bicycles (Fig. 49.20)

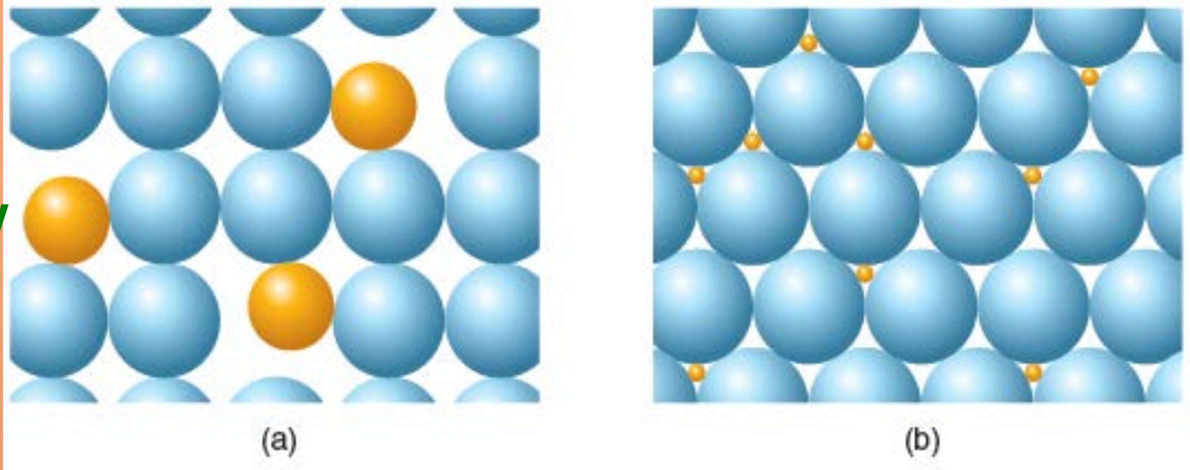
49.5 Alloys (p.103)

Atomic arrangements in alloys

Many alloys have just two components. The components can blend in two ways:

- particles of the added component can take up spaces that are normally occupied by particles of the host metal, forming a **substitutional alloy (取代合金)** (a); or
- particles of the added component can occupy spaces in between particles of the host metal, forming an **interstitial alloy (間隙合金)** (b).

(a) Substitutional and (b) interstitial alloys. The blue spheres represent particles of the host metal; the yellow spheres represent particles of the other components of the alloy



49.5 Alloys (p.103)

Brass is a substitutional alloy. The zinc particles take up about one-third of the spaces that are normally occupied by copper particles. Steel is interstitial — small carbon particles fill spaces between the larger and closely packed iron particles. Substitutional alloys are much more common than interstitial alloys.

To form a substitutional alloy, the two components must have similar particle sizes and similar chemical bonding characteristics. Transition metals form a wide range of alloys with each other.

49.6 Explaining the properties of alloy in terms of its structure (p.106)

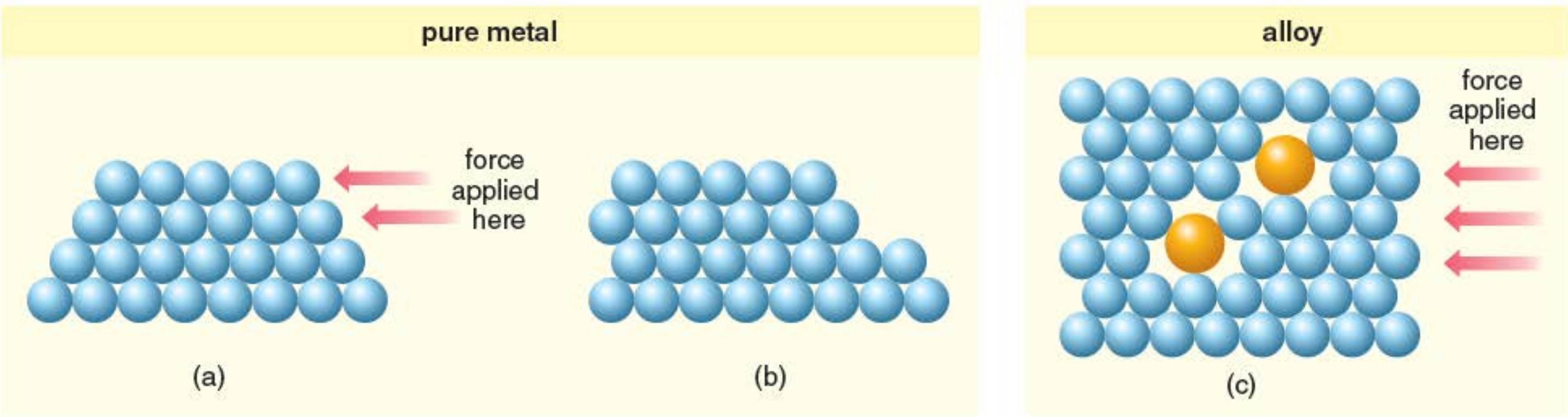
Hardness and strength of alloy

A pure metal has a giant metallic structure in which the particles are arranged regularly in layers (a) on the next page. In a pure metal, the layers of particles slide over each other to new positions when a small force is applied (b). Hence pure metal is relatively soft.

An alloy is often harder and stronger than the pure metal from which it is made. This is because the introduction of particles of different sizes into the structure causes distortion of the regular arrangement of particles in the pure metal. Relative motion between the layers of particles is hindered (c). The alloy is also less malleable and ductile.

49.6 Explaining the properties of alloy in terms of its structure (p.106)

(a) The position of the particles in a pure metal before a force is applied;
(b) after the force is applied, slippage of particles has taken place;
(c) in an alloy, slippage of particles is hindered because of the introduction of particles of different sizes into the structure



49.6 Explaining the properties of alloy in terms of its structure (p.106)

For example, brass is harder and stronger than copper. It is also more resistant to corrosion. Aluminium is a light metal but it is not strong enough to be used in aeroplane manufacture until it is alloyed with copper (and smaller amounts of magnesium and manganese) to produce duralumin.

Comparing the properties of alloys and those of the pure metals from which they are made ***Ref.***

49.6 Explaining the properties of alloy in terms of its structure (p.106)

Melting point of alloy

The melting point of a solid is very much dependent on its structure. A solid with particles regularly packed has a higher melting point than one with particles packed less regularly.

The particles of different sizes in an alloy make their arrangement less regular than particles in a pure metal. Hence an alloy usually has a melting point lower than that of the pure metals from which it is made.

49.6 Explaining the properties of alloy in terms of its structure (p.106)

For example, the melting points of tin and lead are 232 °C and 328 °C respectively, while the solder melts at a lower temperature than either of these. Solder also conducts electricity well. It can join electric wires and components without damaging them.

Compared with the pure metals from which it is made, an alloy usually

- Is harder and stronger;
- Is less malleable and ductile;
- Has a lower melting point

49.7 Steels (p.107)

Steels are mainly composed of iron and carbon, and special properties are reached by introducing additional alloying elements. Carbon steels contain up to 2% carbon. Increasing the amount of carbon increases the hardness and brittleness of steel. These steels may also contain other elements, such as silicon (maximum 0.6%), copper (up to 0.6%) and manganese (up to 1.65%).

49.7 Steels (p.107)

The table below summarises the properties and uses of three main types of carbon steel; low carbon steel, medium carbon steel and high carbon steels.

The properties of and uses of three main types of carbon steel		
Name	**Properties**	**Uses**
Low carbon steel (mild steel) (carbon 0.1%–0.3%)	• Fairly strong • Rusts easily	girders, car body panels, nuts and bolts, food cans
Medium carbon steel (carbon 0.3%–0.7%)	• Harder than low carbon steel	nails and screws, metal chains, wire ropes, screwdriver
High carbon steel (carbon 0.7%–1.3%)	• Harder than medium carbon steel • brittle	chisels, hammers, drills, files, lathe tools, taps and dies

49.7 Steels (p.107)

Stainless steel is one of the most important engineering materials. This steel contains more than 12% of chromium. Chromium forms a passive oxide film on the surface, which makes it resistant against corrosion in various environments.

49.7 Steels (p.107)

Practice 49.2

1. The sword shown below is about 3 000 years old. It is made of an alloy called bronze.

a) What is an alloy?

An alloy is a mixture of metals or a mixture of a metal and a non-metal.

b) Bronze makes better swords than pure copper. This is because bronze is harder than pure copper.

Explain why bronze is harder than pure copper.

The introduction of particles of different sizes into the structure of a pure metal causes distortion of the regular arrangement of particles in the pure metal. Relative motion between the layers of particles is hindered.

49.7 Steels (p.107)

Practice 49.2

2. Steel is an alloy of iron and carbon. The melting points of iron and steel are listed below.

	Iron	Steel
Melting point (°C)	1 535	1 370

Explain why the melting point of steel is lower than that of iron.

The melting point of a solid is very much dependent on its structure. A solid with particles regularly packed has a higher melting point than one with particles packed less regularly.

The introduction of carbon into iron makes the particle arrangement less regular than that in pure iron. Thus, the melting point of steel is lower than that of iron.

49.8 Liquid crystal phase (p.110)

There are three states of matter: solid, liquid or gas. However, these states can be called by a different name — phases. A phase is a homogeneous portion of matter separated from other portions of matter by a boundary surface.

Particles in a solid phase have very little translational freedom and stay in the same position with respect to one another. Particles in a liquid phase are just the opposite: they can move anywhere in the liquid. However, some crystalline solids, when heated, melt to give a turbid phase which is fluid but the particles in it retain some of the order of the solid state. On further heating this turbid phase changes to the normal clear liquid.

49.8 Liquid crystal phase (p.110)

Three different phases

$$\text{solid crystal} \underset{}{\overset{\text{melting temperature}}{\rightleftharpoons}} \text{liquid crystal} \underset{}{\overset{\text{clearing temperature}}{\rightleftharpoons}} \text{liquid}$$

This turbid state of matter has properties intermediate between those of the solid and liquid phases, and is called the **liquid crystal phase (液晶相)**.

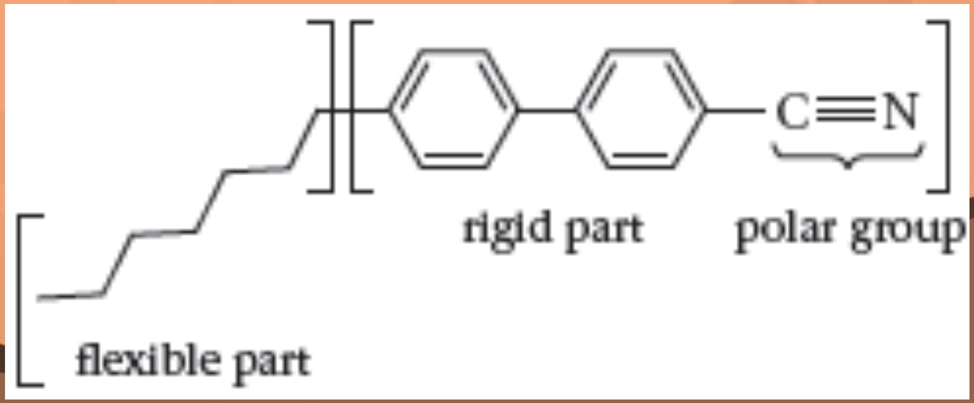
49.8 Liquid crystal phase (p.110)

Structures of substances exhibiting liquid crystal behaviour

In general, many substances that exhibit liquid crystal behaviour have a similar molecular structure: consisting of a rigid part (commonly derived from aromatic rings), a flexible part (accomplished by long hydrocarbon chain(s)) and polar group(s).

The figure below gives an illustration of the different parts of a molecule of a substance exhibiting liquid crystal behaviour. It has a rod-like molecule.

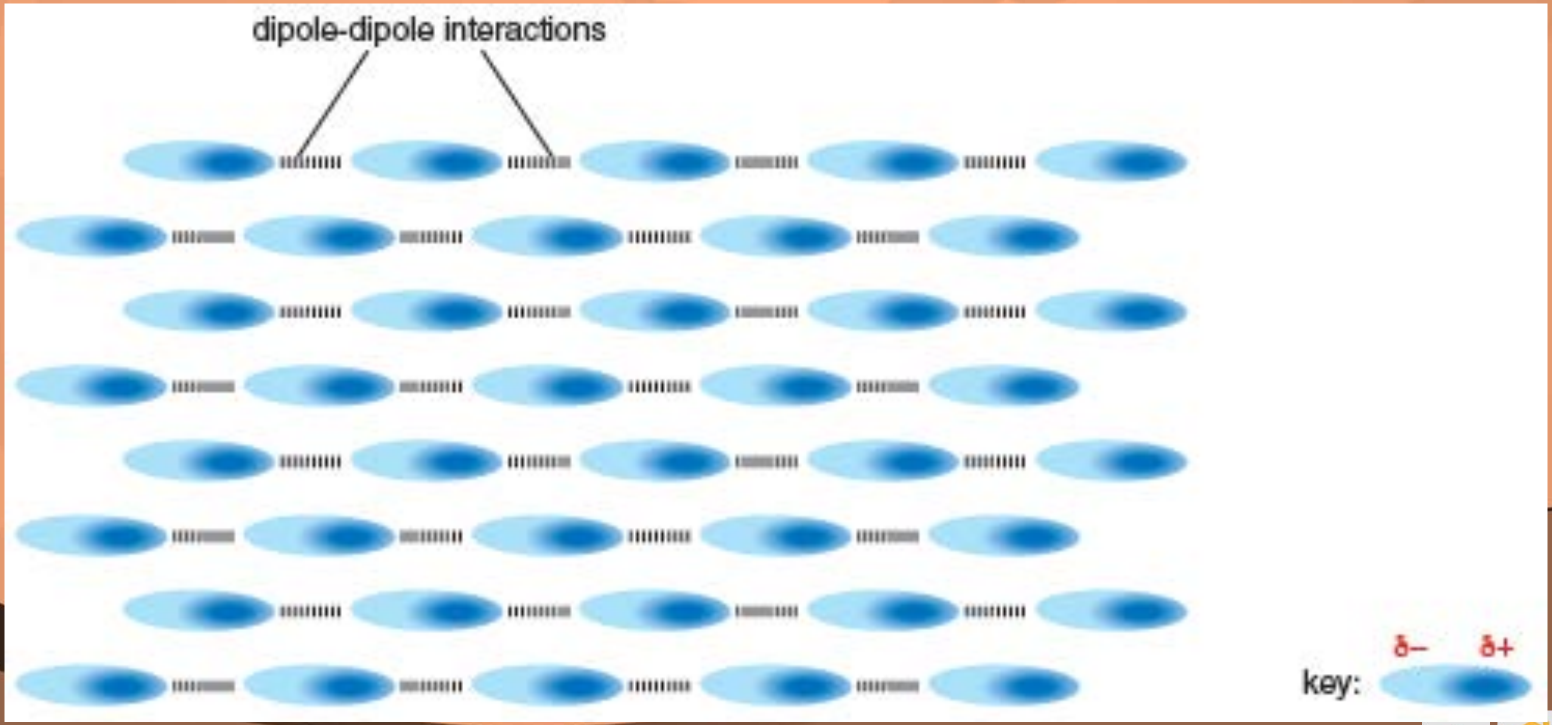
An illustration of the different parts of a molecule of a substance exhibiting liquid crystal behaviour



49.8 Liquid crystal phase (p.110)

The polar groups give rise to dipole-dipole interactions and promote the alignment of the molecules. Thus, the molecules order themselves quite naturally along their long axes.

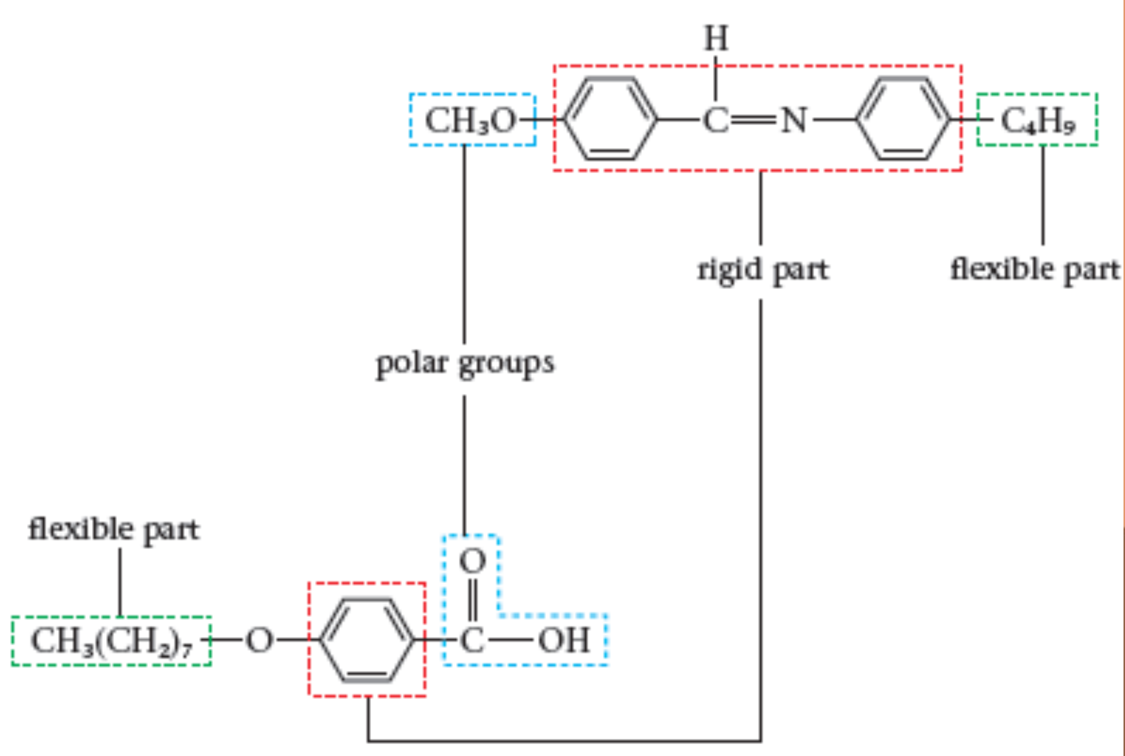
The polar groups give rise to dipole-dipole interactions and promote the alignment of the molecules



49.8 Liquid crystal phase (p.110)

Structures of molecules of two other substances that exhibit liquid crystal behaviour are shown below. The lengths of these molecules are much greater than their widths. The double bonds, including those in the benzene rings, add rigidity to the backbones of the molecules.

Molecular structures for two substances exhibiting liquid crystal behaviour



49.8 Liquid crystal phase (p.110)

Many substances that exhibit liquid crystal behavior contain molecules that

- Are rod-like, with a fairly rigid molecular backbone;
- Contain benzene rings; and
- Contain polar groups

49.9 Types of liquid crystal phase (p.114)

There are three main types of liquid crystal phase which can be identified by their different amounts of molecular order and positioning — the **nematic phase (向列相)**, the **smectic phase (近晶相)** and the **cholesteric phase (螺旋相)**.

In the nematic phase, the molecules are aligned in one direction but are free to drift around randomly, very much as in an ordinary liquid. Only the long axes of the molecules are parallel, and the ends are staggered at random intervals on the next page (a).

While pointing in the same direction as the molecules in the nematic phase, the molecules in the smectic phase tend to line themselves up into layers on the next page (b).

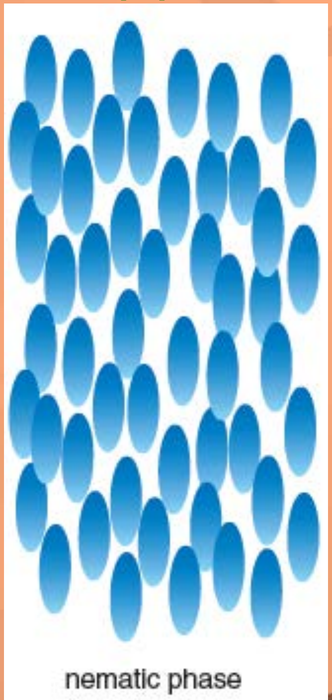
The cholesteric phase, also known as chiral nematic phase, arises when the molecules that make up the nematic phase are chiral.

49.9 Types of liquid crystal phase (p.114)

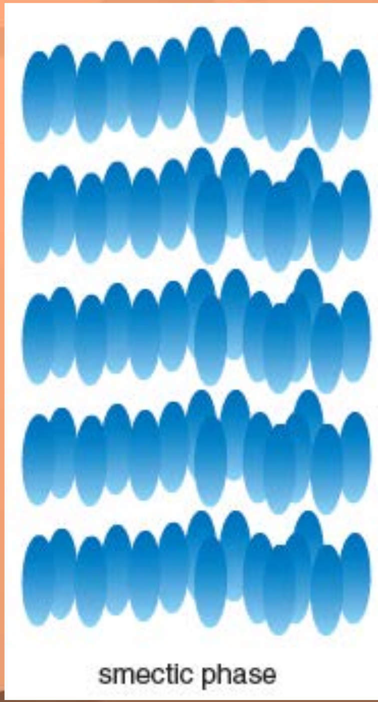
The figure (c) below shows the ordering of molecules in the cholesteric phase. The molecules are aligned in one direction as in the nematic phase, but they are arranged in layers with the molecules in each plane twisted slightly in relation to the molecules in the planes above and below, giving rise to a helical-like arrangement.

Arrangement of molecules in different phases

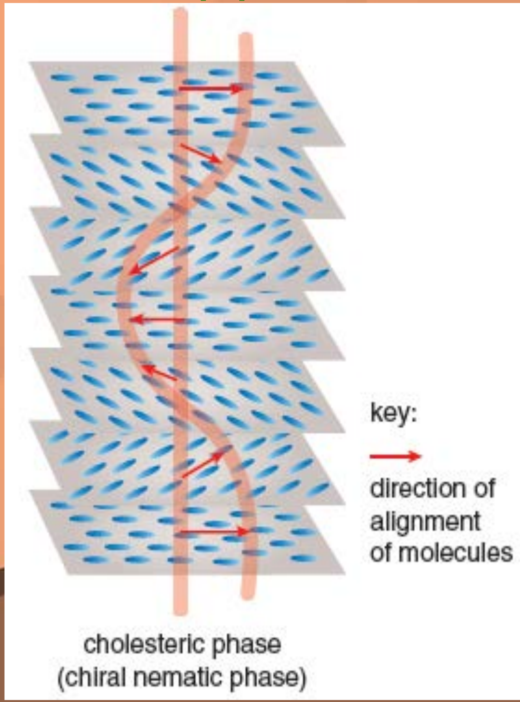
(a)



(b)

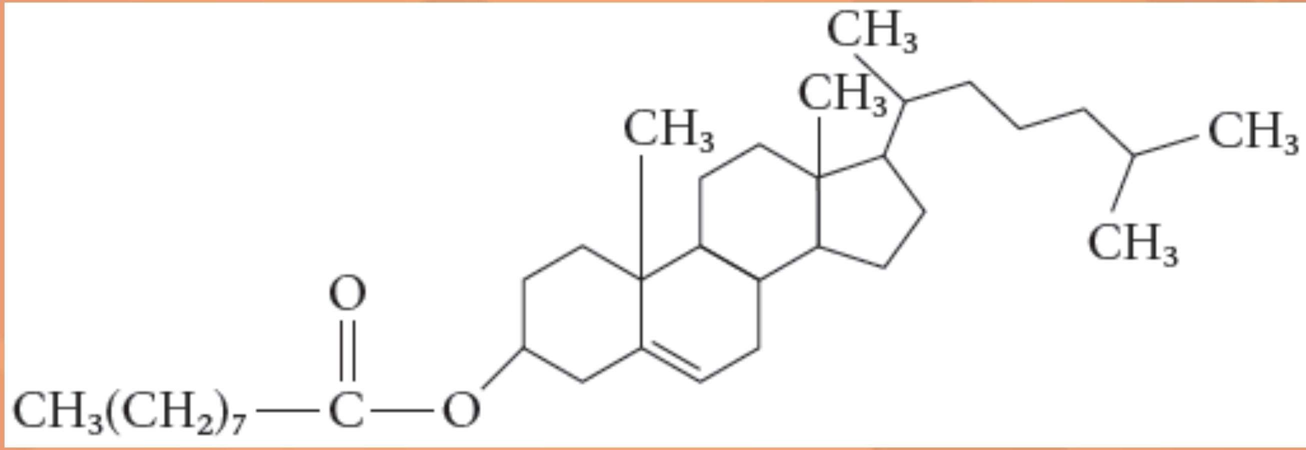


(c)



49.9 Types of liquid crystal phase (p.114)

The figure below shows the structure of a molecule of a substance that exhibits the cholesteric phase.



Molecule of a substance that exhibits the cholesteric phase

49.10 Basic working principle of one pixel in liquid crystal displays (p.115)

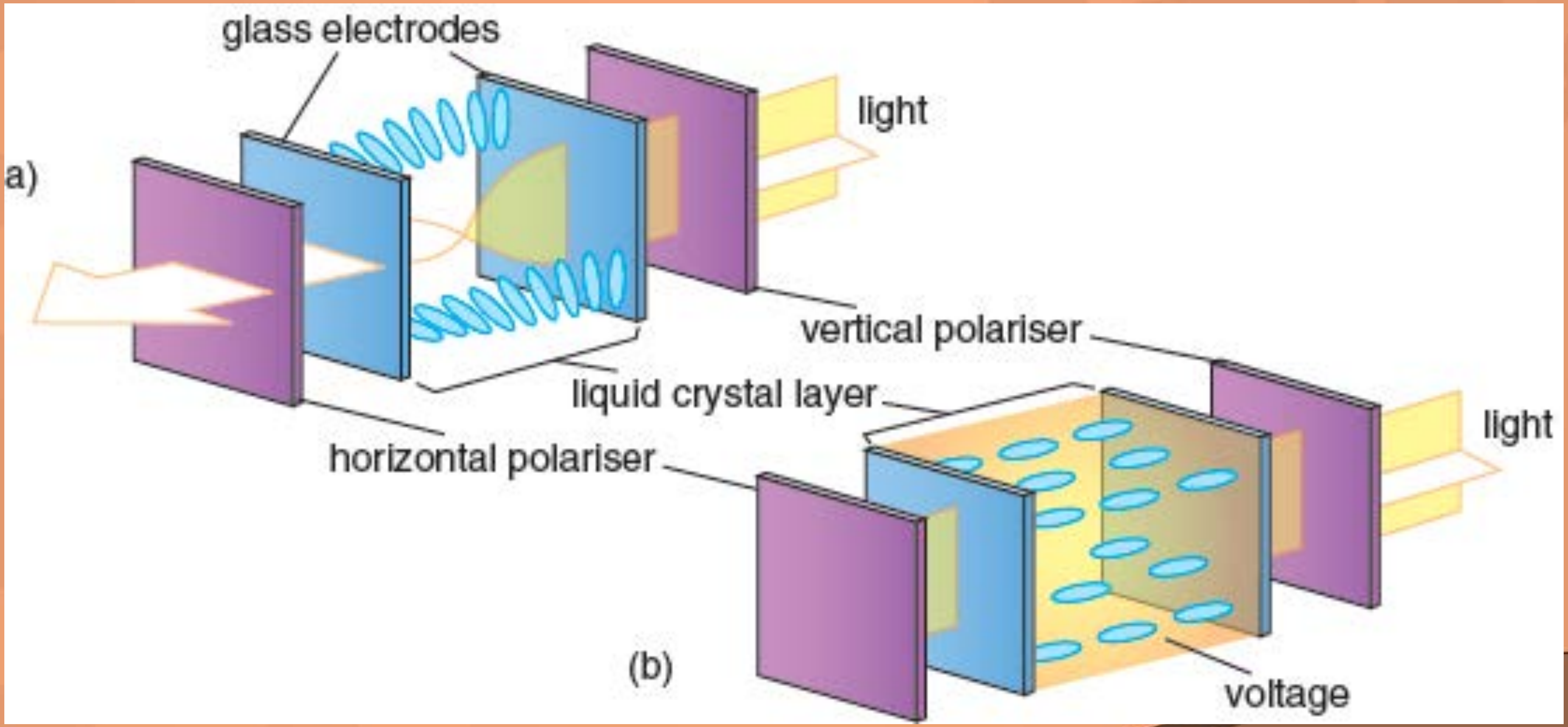
Liquid crystal displays come in a variety of designs but often a thin layer of cholesteric phase liquid crystals is placed between electrically conducting transparent glass electrodes (the conducting layer is indium tin oxide).

Pixels are the smallest building blocks of a display. The figure on the next page illustrates the basic working principle of one pixel in a liquid crystal display. Ordinary light passes through a vertical polariser that permits light waves vibrating in only the vertical plane to pass.

Examining the liquid crystal display of a disassembled watch
Ref.

49.10 Basic working principle of one pixel in liquid crystal displays (p.115)

Basic working principle of one pixel in a liquid crystal display



49.10 Basic working principle of one pixel in liquid crystal displays (p.115)

During the fabrication process, the liquid crystal molecules are orientated so that the molecules at the first glass electrode are orientated vertically and those at the second glass electrode horizontally. The orientation of the molecules in between the two electrodes varies systematically from vertical to horizontal, as shown in (a).

The polarised light is guided by the liquid crystal molecules. The plane of polarisation of the polarised light is rotated by 90° as it passes through the liquid crystal layer and is therefore in the correct orientation to pass through the horizontal polariser, giving a bright pixel.

49.10 Basic working principle of one pixel in liquid crystal displays (p.115)

When a voltage is applied, the liquid crystal molecules align with the electric field, as shown in (b). The polarised light passes through the liquid crystal layer without rotating the plane of polarisation of the polarised light. The polarised light is completely blocked by the second polariser, giving a black pixel.

A main problem with liquid crystal displays is that they only operate over the temperature range in which the molecules exist in the liquid crystal phase — extreme hot and cold temperatures will temporarily disable a liquid crystal display.

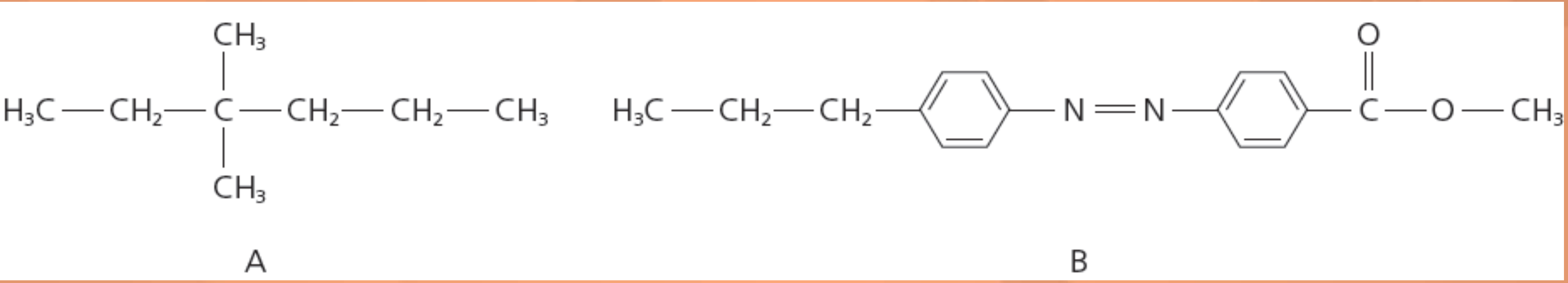
49.10 Basic working principle of one pixel in liquid crystal displays (p.115)

There is also an energy efficiency disadvantage of liquid crystal displays, as the light source is not polarised and the necessity of the polariser results in about half of the light not being used (it is simply absorbed by the polariser). Furthermore, it is necessary to have the backlight continuously on, which results in light leakage (not perfect polariser / liquid crystal cell) and hence limited contrast. This explains why other technologies are still being researched.

49.10 Basic working principle of one pixel in liquid crystal displays (p.115)

Practice 49.3

1. Explain which of the following compounds, A or B, would exhibit liquid crystal behaviour.



2. Liquid crystals can have various phases — the nematic phase, the smectic phase and the cholesteric phase.

a) Describe the similarity in molecular arrangement of the three phases.

b) Suggest the difference between the nematic phase and the smectic phase.

49.10 Basic working principle of one pixel in liquid crystal displays (p.115)

Practice 49.3 (continued)

1

- Compound A is not long and rigid, and contains no polar groups, so it would not exhibit liquid crystal behaviour.
- Compound B has two benzene rings linked through a multiply bond unit, and it contains polar groups.
- The combination of a long, rigid shape and polar groups makes compound B exhibiting liquid crystal behaviour.

2 a) The molecules are aligned in one direction.

b) The molecules in the smectic phase tend to line themselves up into layers while those in the nematic phase do not.

49.11 Nanomaterials (p.117)

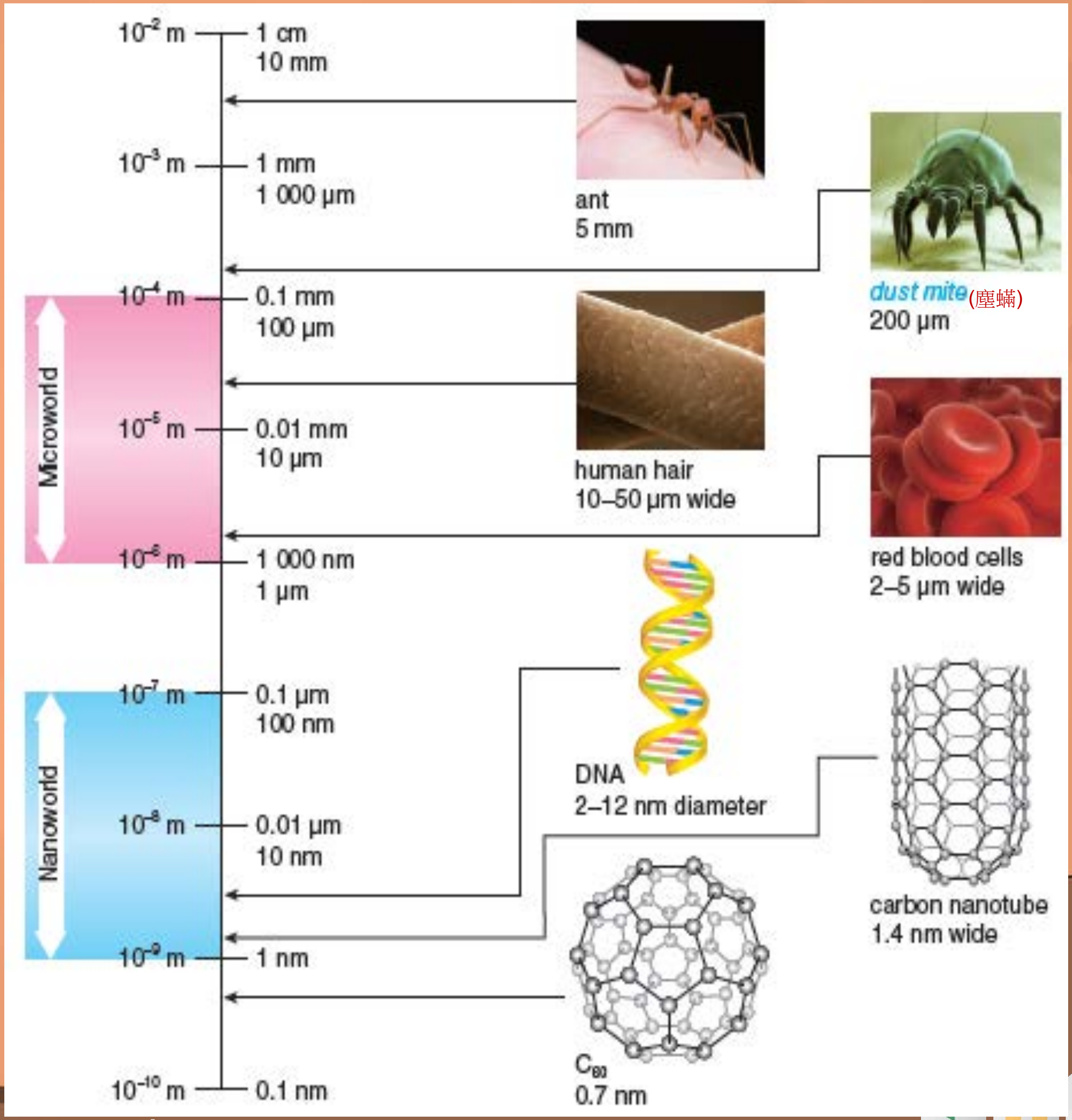
Nanomaterials are organic or inorganic materials where at least one dimension (height, length or depth) is less than 100 nanometres. A nanometre is a billionth of a metre or 0.000 000 001 m. You can write this as 1×10^{-9} m.

The chart shown on the next page provides a comparison of various objects to help you begin to envision exactly how small a nanometer is. It starts with objects that can be seen by the unaided eye, such as an ant, at the top and goes to objects about a nanometre or less in size, such as buckminsterfullerene (C_{60}).

49.11 Nanomaterials (p.117)

Objects in microscale and nanoscale

Nanomaterials can be nanoscale in one dimension (e.g. surface films), two dimensions (e.g. wires), or three dimensions (e.g. particles).

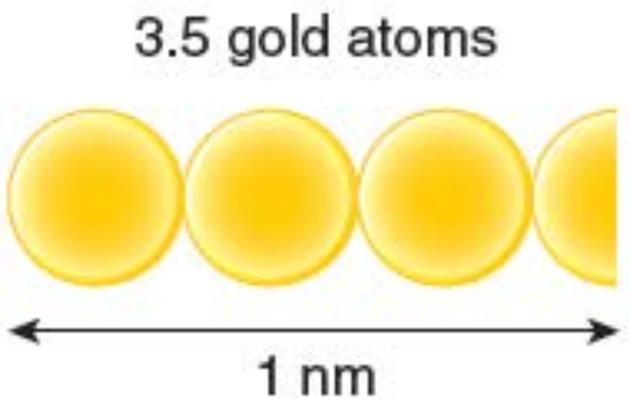


49.12 What gives nanoparticles their useful properties? (p.118)

Conventional materials have grain size anywhere from 100 μm to 1 mm and more. These consist of huge numbers of atoms.

Materials that belong to the nanoscale are made of clusters of atoms or molecules, not single atoms. For example, 3.5 atoms of gold (the figure below) or 8 hydrogen atoms lined up in a row are one nanometer long.

Three and a half gold atoms lined up in a row equal to 1 nm (assuming a covalent radius of 0.144 nm each)



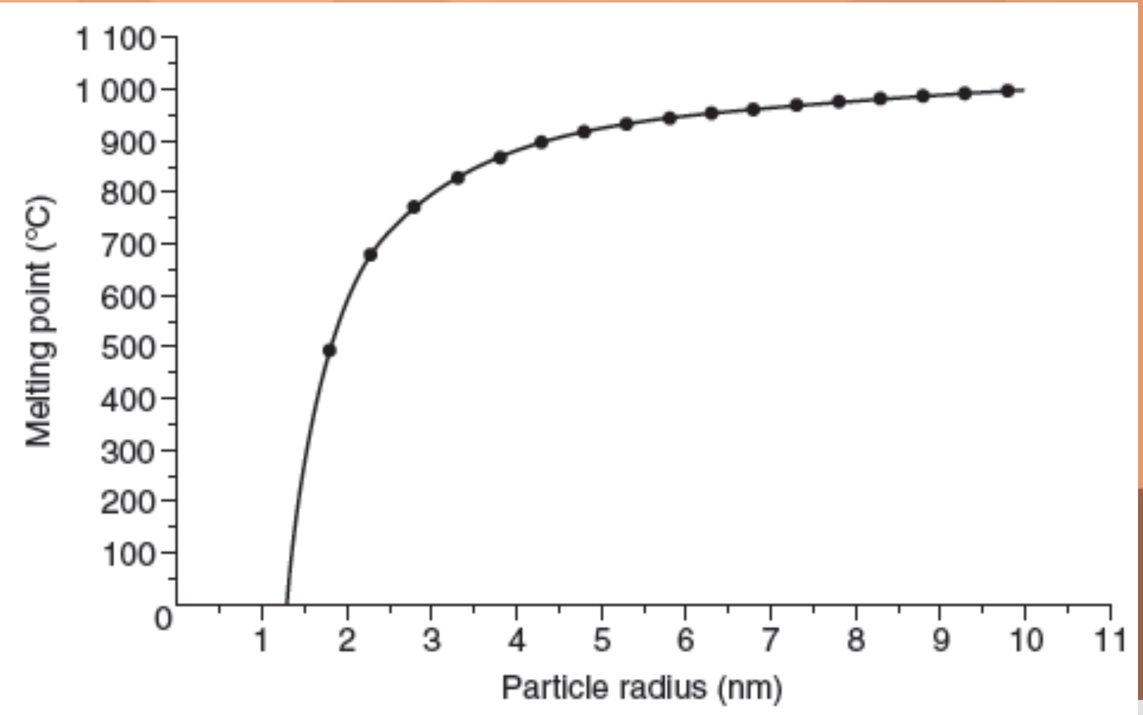
49.12 What gives nanoparticles their useful properties? (p.118)

The physical properties of a substance (melting point, boiling point, electrical conductivity, etc.) are determined by studying a pure sample in quantities big enough to be measured under normal laboratory conditions. One mole of water contains 6.02×10^{23} molecules. Hence when the boiling point of one mole of water is determined, the value obtained represents an average value based on the behaviour of billions and billions of molecules of water. You may assume that the result should be the same for any size of group of water molecules. This is not correct for many materials — as the size of the material is reduced, and the nanoscale region is reached, it is possible that the same material will display totally different properties.

49.12 What gives nanoparticles their useful properties? (p.118)

The figure below shows the relationship between particle radius and melting point of gold nanoparticles. As you can see, the melting point of gold nanoparticles can be even lower than room temperature when the size decreases to less than 1.4 nm.

A graph showing the relationship between particle radius and melting point of gold nanoparticles

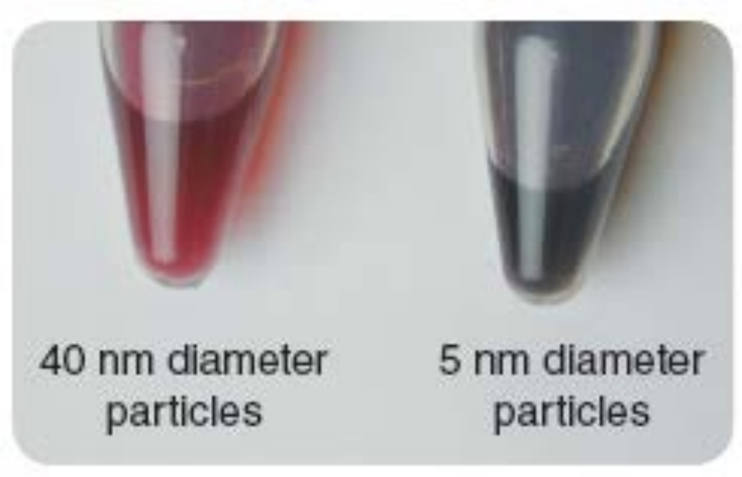


49.12 What gives nanoparticles their useful properties? (p.118)

Large pieces of gold look shiny and golden. However, when gold particles get very, very small, they look different because they interact differently with visible light.

The figure below is a photograph of two samples containing gold nanoparticles of different diameters. At small sizes (such as 40 nm), gold nanoparticles have a red colour. The nanoparticles become brown as their size is reduced further still.

Two samples containing gold nanoparticles of different diameters

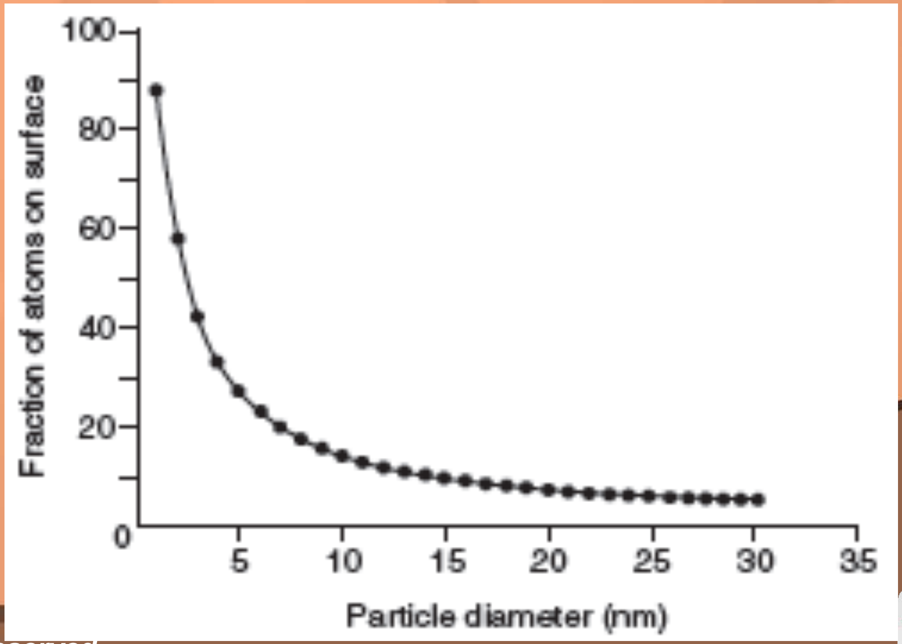


49.12 What gives nanoparticles their useful properties? (p.118)

The main reason why nanoparticles have different properties from large pieces of the same material is that the nanoparticles have a much larger surface area to volume ratio. This means that a much higher fraction of the atoms or molecules are on the surface.

The figure below shows how the fraction of atoms on surface changes with particle diameter.

A graph showing how the fraction of atoms on surface changes with particle diameter



49.12 What gives nanoparticles their useful properties? (p.118)

This has a profound effect on reactions that occur at the surface such as catalysis, and reactions that, to be initiated, require the adsorption of certain chemical species at the material's surface.

49.13 Uses of nanomaterials (p.120)

Many sunblock lotions contain zinc oxide to block out harmful ultraviolet radiation from the sun. In traditional sunblocks, the large particles of zinc oxide used also reflect visible light, giving the sunblocks a white appearance.

Now many sunblocks use nanoparticles of zinc oxide. They still block out ultraviolet radiation, but they do not reflect visible light. Hence these sunblocks are transparent and more appealing to customers.

Nanoparticles of zinc oxide are smaller than the wavelength of visible light. Hence visible light is able to pass through the particles.

Synthesising silver nanoparticles *Ref.*

49.13 Uses of nanomaterials (p.120)

Bulk silver metal is very unreactive. However, nanoparticles of silver can kill bacteria. Clothes manufacturers incorporate silver nanoparticles into some clothes to kill bacteria and prevent smells.

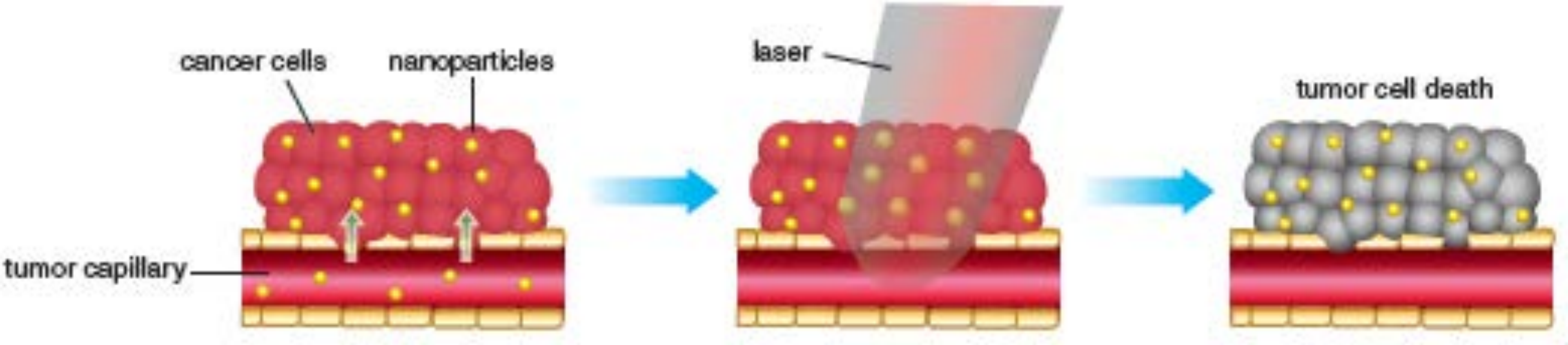
Socks with nanoparticles of silver

49.13 Uses of nanomaterials (p.120)

A recent development in cancer treatment involves gold nanoparticles. Researchers have found that the tiny gold particles can be injected and absorbed by tumours. Tumours have thin, leaky blood vessels with holes large enough for the gold nanoparticles to pass into.

However, they cannot get into healthy blood vessels. When a laser is directed at the tumour, energy is transferred to the gold nanoparticles and they warm up quickly. The temperature of the tumour increases enough to change the properties of its proteins but barely warms the surrounding tissue. This destroys the tumour cells without damaging healthy cells on the next page.

49.13 Uses of nanomaterials (p.120)



Schematic representation of nanoparticle-based photothermal therapy for cancer treatment

49.13 Uses of nanomaterials (p.120)

There is potential to use the gold nanocages to carry cancer-fighting drugs to the tumour at the same time. The carbon nanocages can also be used to deliver drugs in the body. Incredibly strong, yet light, nanotubes are already being used to reinforce materials. The new materials are finding uses in sport, such as making very strong but light tennis racquets.

A nanocatalyst is a substance with catalytic properties that has at least one nanoscale dimension. A nanocatalyst has a large surface area to volume ratio. This increases the activity of the catalyst since there is more surface to interact with the reactants.

49.14 Are nanomaterials safe? (p.123)

Nanomaterials, particularly nanoparticles, are being incorporated into a wide range of consumer products to improve functionality and performance. The prevalent use of nanoparticles, particularly in textiles, surface coatings and personal-care products, means that they are likely to enter the environment via domestic and industrial waste water.

To assess the potential risks associated with the introduction of nanomaterials into the environment, it is crucial to understand their effects on our health and environment. When making decisions about different uses of nanomaterials, the benefits and risks must be balanced.

Key terms (p.124)

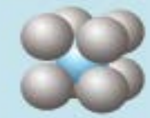
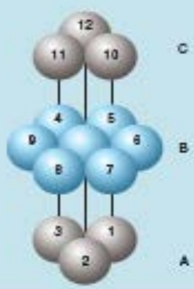
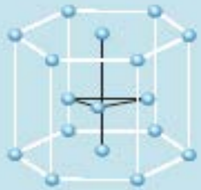
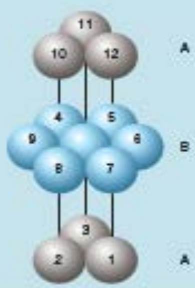
Hexagonal close-packing	六方緊密裝填	**Cubic close-packing**	立方緊密裝填
coordination number	配位數	body-centred cubic packing	體心立體裝填
unit cell	晶胞	face-centred cubic	面心立方
alloy	合金	brass	黃銅
bronze	青銅	solder	焊錫
duralumin	硬鋁	substitutional alloy	取代合金
interstitial alloy	間隙合金	liquid crystal phase	液晶相
nematic phase	向列相	smectic phase	近晶相
cholesteric phase	螺旋相		

Summary (P.125)

1) A pure metal is a crystalline solid with positive metal ions packed closely together in a repeating pattern in a sea of electrons.

Summary (P.125)

2) The following table summarises the information about the different types of metallic crystal structures.

Structure	Unit cell	Number of particles per unit cell	Coordination number
Body-centred cubic		2	8 
Cubic close-packed		4	12 
Hexagonal close-packed		6	12 

Summary (P.125)

3) An alloy is typically a mixture of metals or a mixture of a metal and a non-metal, usually carbon but sometimes phosphorus.

4) Compared with the pure metals from which it is made, an alloy
a) is harder and stronger;
b) is less malleable and ductile;
c) is more corrosion resistant;
d) has a lower melting points.

5) Liquid crystal phase has properties intermediate between those of the solid and liquid phases.

Summary (P.125)

6 Many substances that exhibit liquid crystal behaviour contain molecules that
- are rod-like, with a fairly rigid molecular backbone;
- contain benzene rings; and
- contain polar groups.

7 The table below summarises the arrangements of molecules in the three phases of liquid crystals.

Nematic phase	Smectic phase	Cholesteric phase
the molecules are aligned in one direction	the molecules are aligned in one direction and line up into layers	the molecules are aligned in one direction and arranged in layers with the molecules in each plane twisted slightly in relation to the molecules in the planes above and below

Summary (P.125)

8 a) Nanomaterials are organic or inorganic materials where at least one dimension (height, length or depth) is less than 100 nm (1 nm = 10^{-9} m).

b) Nanomaterials can be used in sunblock lotions, cancer treatment and as catalysts.

Unit Exercise (p.127)

Note: Questions are rated according to ascending level of difficulty (from 1 to 5):

 **question targeted at level 3 and above;**

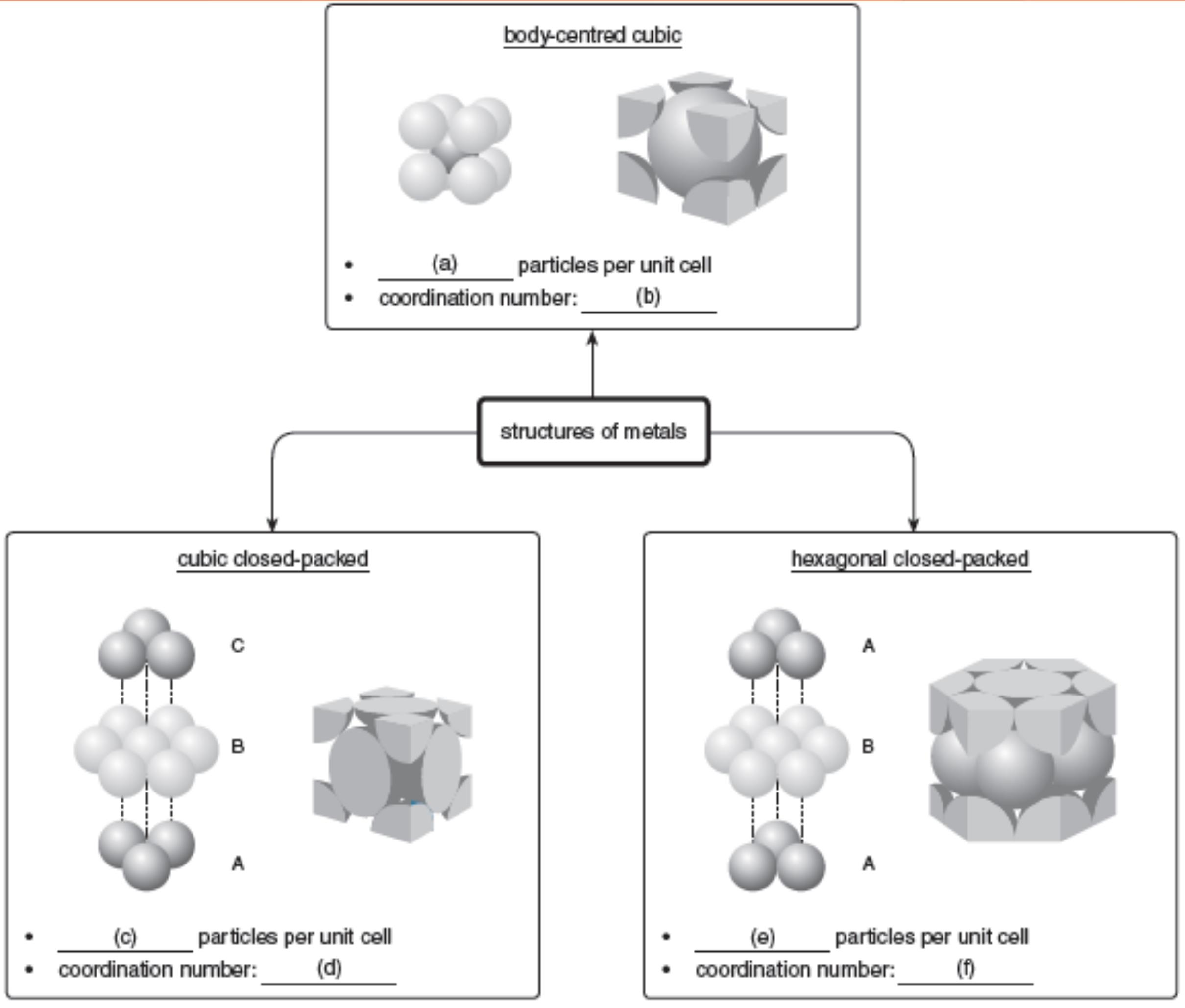
 **question targeted at level 4 and above;**

 **question targeted at level 5.**

Unit Exercise (p.127)

PART I KNOWLEDGE AND UNDERSTANDING

1 Complete the following concept map.

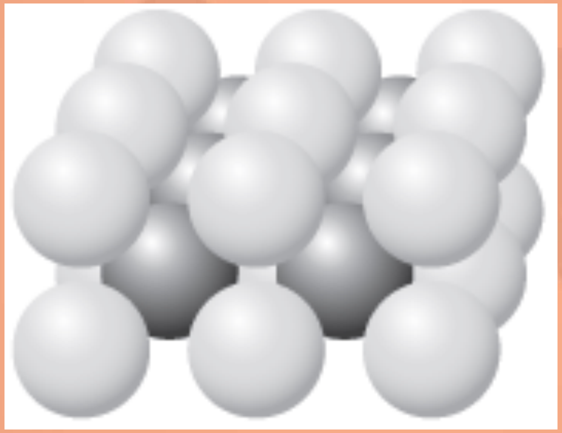


a) 2
b) 8
c) 4
d) 12
e) 6
f) 12

Unit Exercise (p.127)

PART II MULTIPLE CHOICE QUESTIONS

Directions: Questions 2 and 3 refer to the packing of atoms in a metal crystal shown below.



2 What is the name of the structure?

A Body-centred cubic structure

B Cubic close-packed structure

C Face-centred cubic structure

D Hexagonal close-packed structure

Answer: A

Unit Exercise (p.127)

3 What is the coordination number of each atom in the structure?

A 4

B 6

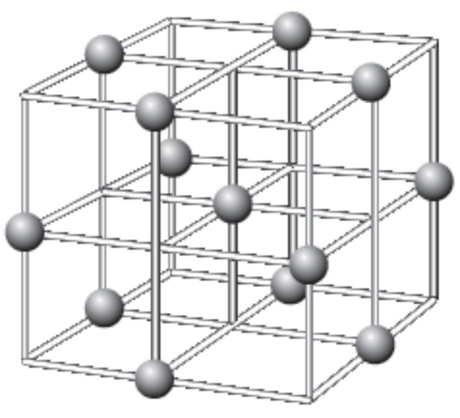
C 8

D 12

Answer: C

Unit Exercise (p.127)

Directions: Questions 4 and 5 refer to the unit cell of copper crystal shown below.



4 What is the coordination number of each copper atom?

A 4

B 6

C 8

D 12

Answer: D

Unit Exercise (p.127)

5 What is the number of copper atoms in the unit cell?

A 2

B 4

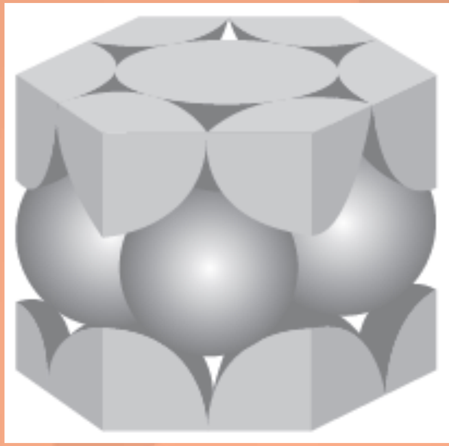
C 6

D 8

Answer: B

Unit Exercise (p.127)

Directions: Questions 6 and 7 refer to the unit cell of magnesium crystal shown below.



6 What is the number of magnesium atoms in the unit cell?

A 2

B 4

C 6

D 8

Answer: C

Unit Exercise (p.127)

7 What is the coordination number of each magnesium atom?

A 4

B 6

C 8

D 12

Answer: D

Unit Exercise (p.127)

8 Which of the following applications of silver nanoparticles are often used?

A Anti-bacterial agent

B Catalyst

C Electric wiring

D Jewellery

Answer: A

Unit Exercise (p.127)

9 Which of the following statements about duralumin are correct?

(1) It contains manganese.

(2) It is more corrosion resistant than pure aluminium.

(3) It is used to make ten-dollar coins.

A (1) and (2) only

B (1) and (3) only

C (2) and (3) only

D (1), (2) and (3)

Answer: A

(1) Duralumin contains 95% aluminium, 3% copper, 1% magnesium and 1% manganese.

(3) Duralumin is used in aircraft and spacecraft.

Unit Exercise (p.127)

10 Which of the following statements about the molecules in a liquid crystal phase is / are correct?

(1) They have some degree of transitional freedom.
(2) They always have sphere shapes.
(3) They must be chiral.

A (1) only
B (2) only
C (1) and (3) only
D (2) and (3) only

Answer: A

(2) Many substances that exhibit liquid crystal behaviour contain molecules that are rod-like.

Unit Exercise (p.127)

PART III STRUCTURED QUESTIONS

11 The table gives information about some alloys.

Alloy	Constituents	Use
Brass		
Bronze	copper and tin	statues
Solder		joining metals
Stainless steel		cutlery

a) i) What are the constituents of brass?
ii) Suggest ONE use of brass.

a) i) Copper and zinc (1)
ii) Any one of the following:
- Water taps (1)
- Musical instruments (1)
- Decorative items (1)

Unit Exercise (p.127)

11 (Continued)

b) i) What are constituents of solder?
ii) Explain why the melting point of solder is lower than those of its constituents.

b) i) Lead and tin (1)
ii) The melting point of a solid is very much dependent on its structure. A solid with particles regularly packed has a higher melting point than one with particles packed less regularly. (1)
The particles of different sizes in solder make their arrangement less regular than particles in a pure metal. (1)
Thus, the melting point of solder is lower than those of its constituents.

Unit Exercise (p.127)

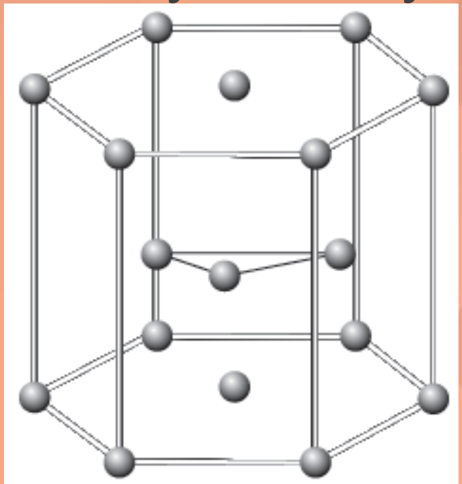
11 (Continued)

c) With reference to the elements introduced into iron for producing stainless steel, explain why stainless steel is suitable for making cutlery.

c) Introducing chromium into iron makes iron more corrosion resistant. (1)

Unit Exercise (p.127)

12 The unit cell of beryllium crystal is shown below.



a) Explain the meaning of the term ‘unit cell’.

The unit cell is the smallest repeating entity which, by repeated translation in three dimensions, builds up the whole structure. (1)

b) Name the type of packing. Hexagonal close-packed (1)

c) State the coordination number of a beryllium atom. 12 (1)

Unit Exercise (p.127)

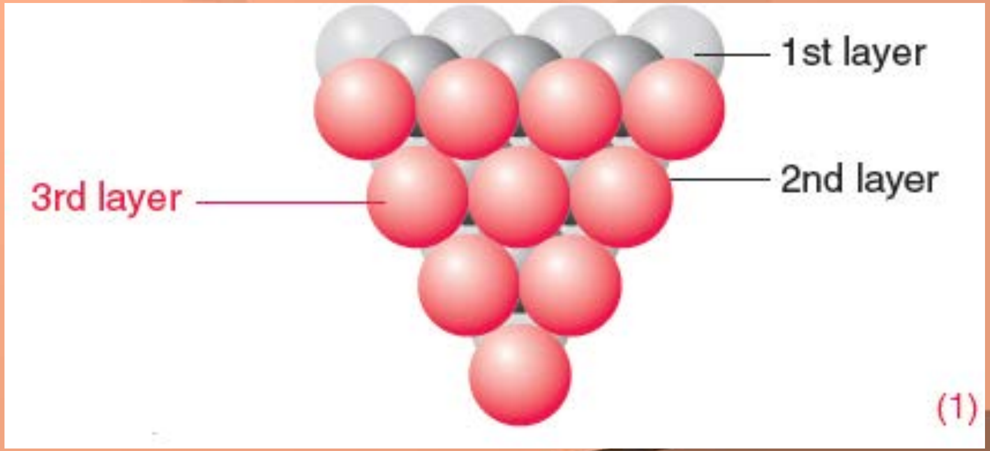
12 (Continued)

d) Deduce the number of beryllium atoms in the unit cell.

Number of beryllium atoms in unit cell

$= 12 \times \frac{1}{6} + 2 \times \frac{1}{2} + 3 = 6$ (1)

e) The diagram below shows the first and second layers of atoms in beryllium crystal.

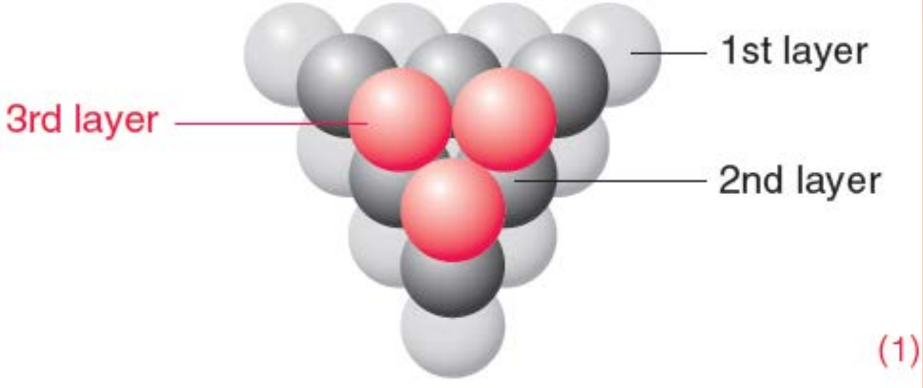


Draw a third layer of atoms on the diagram to show the stacking pattern.

Unit Exercise (p.127)

13 Atoms in silver crystal adopts a 'ABCABC' stacking pattern.

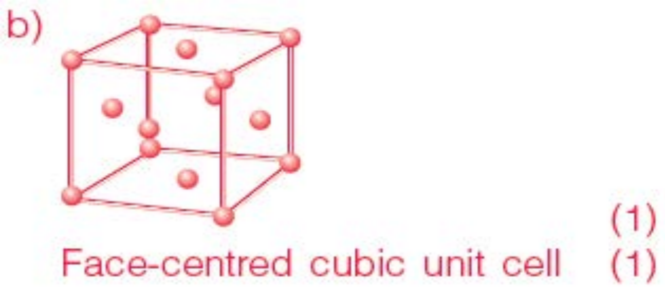
a) The diagram below shows the first and second layers of atoms in silver crystal.



Draw a third layer of atoms on the diagram to show the 'ABCABC' stacking pattern.

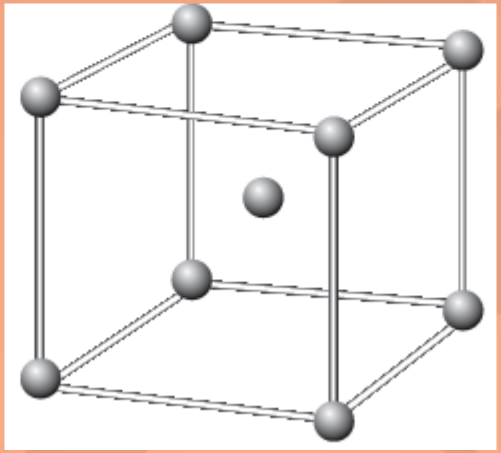
b) Sketch the unit cell of silver. Name the unit cell.

c) What is the coordination number of a silver atom? 12 (1)



Unit Exercise (p.127)

14 The diagram below shows a unit cell of rubidium (Rb) at room temperature.



a) Name this type of crystal structure.

b) Calculate the number of rubidium atoms in the unit cell.

a) Body-centred cubic structure (1)

b) Number of rubidium atoms in unit cell = $8 \times \frac{1}{8} + 1 = 2$ (1)

Unit Exercise (p.127)

14 (Continued)

c) The density of a substance is its mass to volume ratio. Given that the density of rubidium is 1.53 g cm^{-3}, calculate the edge length of the unit cell of rubidium.
(Relative atomic mass: Rb = 85.5; Avogadro constant = 6.02 x 10^{23} mol^{-1})

c) Density of rubidium = $\frac{\text{mass of unit cell}}{\text{volume of unit cell}}$

Volume of unit cell = $\frac{2\times\frac{85.5\text{ g mol}^{-1}}{6.02\times10^{23}\text{ mol}^{-1}}}{1.53\text{ g cm}^{-3}}$

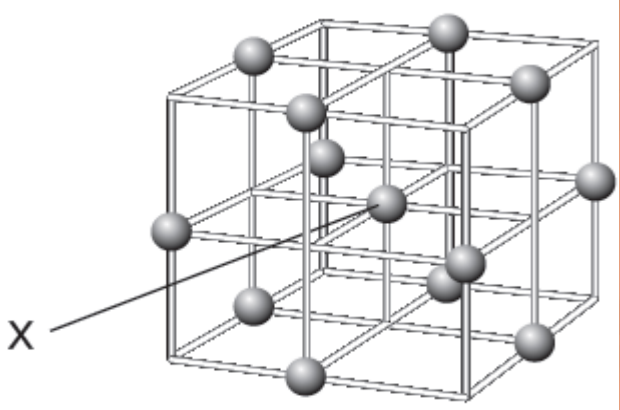
= 1.86 x 10^{-22} cm^3 (1)

Edge length of unit cell = $\sqrt[3]{1.86\times10^{-22}}$ cm

= 5.71 x 10^{-8} cm (1)

Unit Exercise (p.127)

15 Gold is a precious metal. The diagram below shows a unit cell of gold crystal.



a) Name this type of crystal structure.

b) Calculate the number of gold atoms in the unit cell.

c) What is the coordination number of the gold atom labelled 'X'?

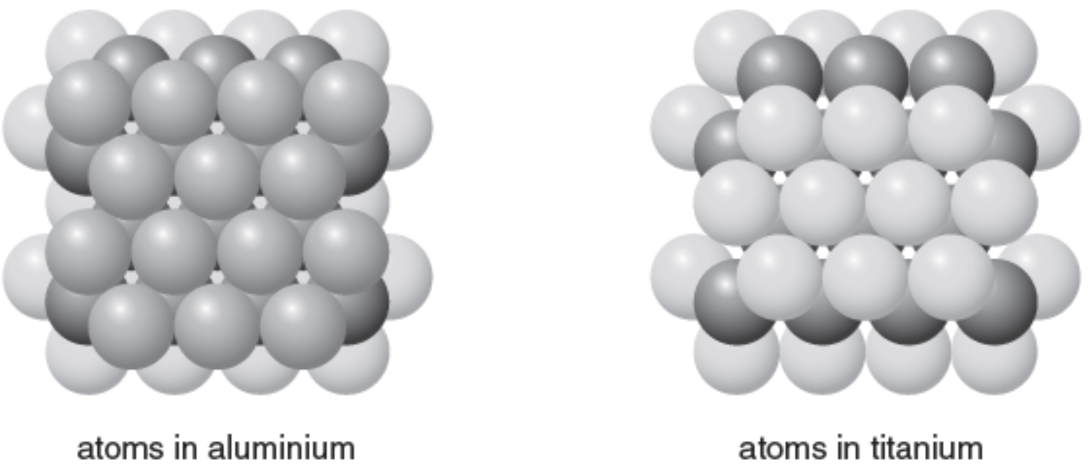
d) A sample of 18-carat gold is composed of 75% gold, 15% silver and 10% copper. Explain, from scientific point of view, the advantage of using this sample of 18-carat gold over using pure gold in making jewellery embedded with diamonds.

e) Gold nanoparticles of various size exhibit different colours. Suggest one example of using gold nanoparticles in architecture.

(HKDSE, Paper 2, 2016, 2(b))

Unit Exercise (p.127)

16 The packing of atoms in aluminium and titanium are shown below.



a) State ONE similarity and ONE difference between the packing of aluminium crystal and that of titanium crystal.

a) Similarity: coordination number (12) / close-packed structure (1)

Difference:

- aluminium — ABC type packing (1)
- titanium — AB type packing (1)

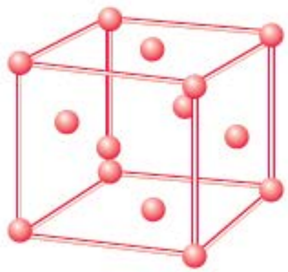
Unit Exercise (p.127)

16 (Continued)

b) Sketch unit cells of aluminium and titanium.

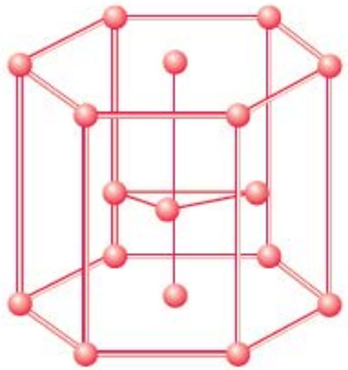
c) Name each unit cell sketched in (b).

b) & c) aluminium



(1) Face-centred cubic unit cell (1)

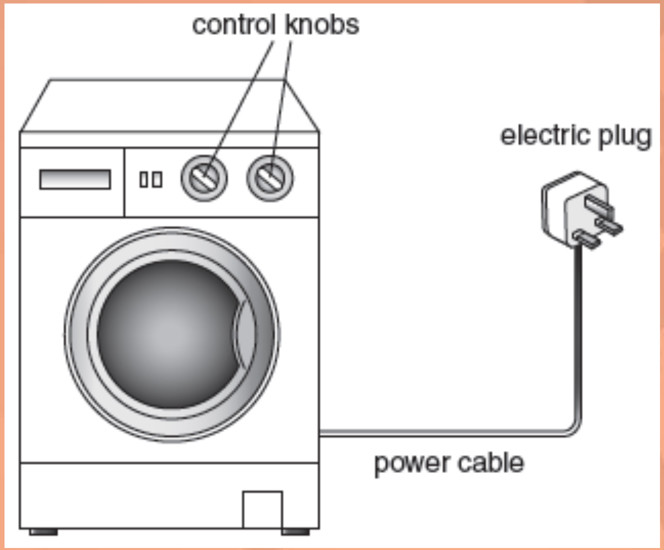
titanium



(1) Unit cell of hexagonal close-packed structure (1)

Unit Exercise (p.127)

17) A washing machine is shown below.



The table shows some materials used in making the washing machine, and their properties.

Material	Density (g cm^{-3})	Relative strength
Aluminium	2.7	80
Low carbon steel	7.8	690
Copper	8.9	215
Urea-methanal	1.2	70
Brass	8.4	500

Unit Exercise (p.127)

17 (Continued)

a) Using the information in the table and your knowledge of materials, select the most appropriate material to use for the following parts of the washing machine. Explain your choice in each case.

i) The connecting wire from the motor to the electric plug

ii) The control knobs

a) i) Copper

Any one of the following:

- Good electrical conductivity (1)
- Ductile (1)
- Corrosion resistant (1)

ii) Urea-methanal

Any one of the following:

- Good strength (1)
- Low cost (1)
- Easily moulded (1)
- Easily coloured (1)

Unit Exercise (p.127)

17 (Continued)

b) Brass is an alloy of copper and zinc.
Explain why the strength of copper can be improved by alloying it with zinc.

b) In brass, the introduction of particles of different sizes into the structure of copper causes distortion of the regular arrangement of particles in copper. (1)
Relative motion between the layers of particles is hindered. (1)

Unit Exercise (p.127)

18 a) Sketch a unit cell for each of the following metallic crystal structures:

i) Cubic close-packed structure

ii) Body-centred cubic structure

b) State TWO structural features of the molecules of the substances that exhibit liquid crystal behaviour.

c) Classify the following plastics into thermoplastics and thermosetting plastics:

polyvinyl chloride, polystyrene, urea-methanal

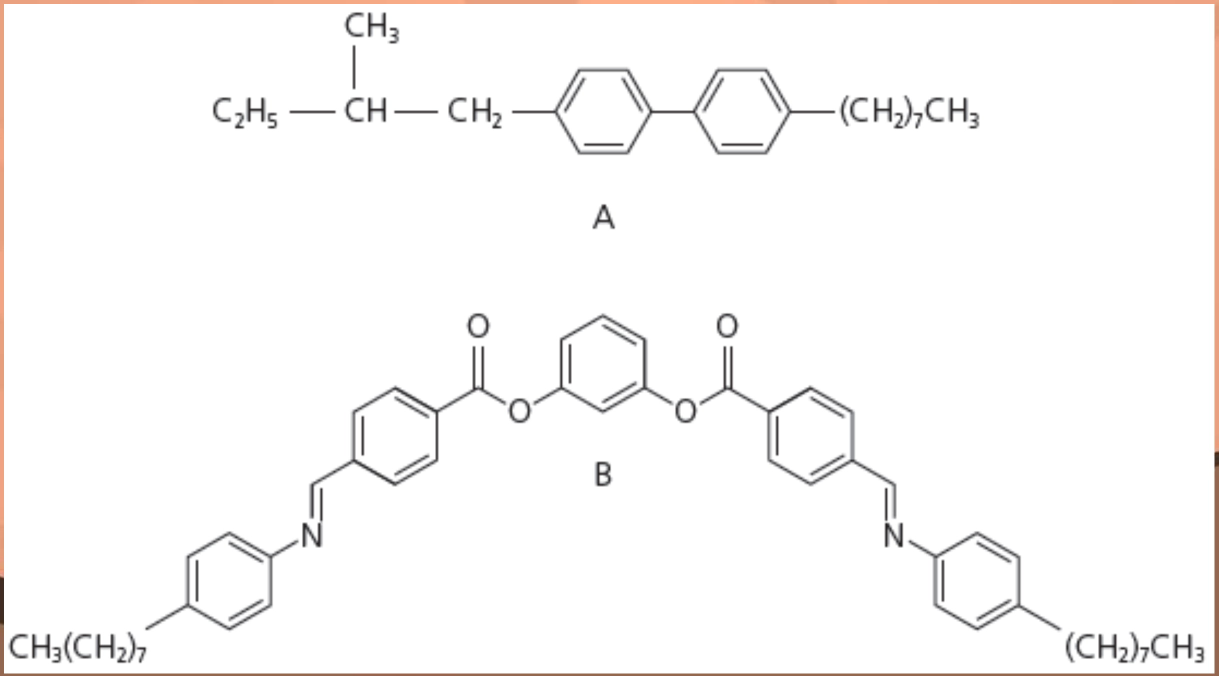
(HKDSE, Paper 2, 2014, 2(a))

Unit Exercise (p.127)

19 Liquid crystals are widely used in making visual displays. Liquid crystals can have various phases in their structures.

a) Compare the nematic phase and the smectic phase of liquid crystals.

b) Explain which of the following compounds, A or B, would form cholesteric phase liquid crystals.



Unit Exercise (p.127)

19 (Continued)

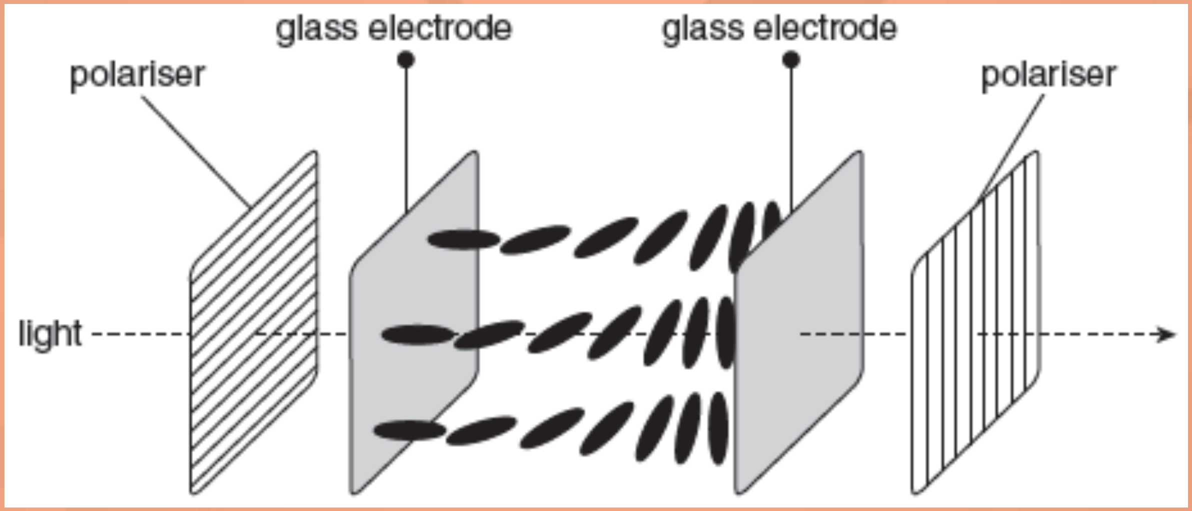
c) Suggest why liquid crystals would lose the liquid crystal properties at very low temperatures.

d) Organic Light Emitting Diode (OLED) can emit light when an electric current passes through. OLED can also be used in making visual displays. Explain why the power efficiency of liquid crystal displays is considered to be lower than that of OLED displays.

(HKDSE, Paper 2, 2013, 2(c))

Unit Exercise (p.127)

20 The following diagram shows the arrangement of certain liquid crystal molecules between the glass electrodes of one pixel in a liquid crystal display when no voltage is applied.



Unit Exercise (p.127)

20 (Continued)

a) Name the relevant liquid crystal phase. Explain your answer.

b) A voltage is applied to the liquid crystal layer.

i) Draw a diagram to show the expected arrangement of the liquid crystal molecules.

ii) Would the pixel appear bright or dark? Explain your answer.

c) Explain why the liquid crystal display could not operate beyond a certain high temperature.

(HKDSE, Paper 2, 2018, 2(b))

Unit Exercise (p.127)

21 Nanoparticles of cobalt oxide can be used as catalysts in the production of hydrogen from water.

a) How does the size of a nanoparticle compare with the size of an atom?

A nanoparticle is larger. (1)

b) Suggest ONE reason why 1 g of cobalt oxide nanoparticles is a better catalyst than 1 g of cobalt oxide powder.

Nanoparticles have larger surface area. (1)

(AQA GCSE (Higher Tier), Additional Science Chemistry, Unit C2, Jun. 2016, 3(c))

Unit Exercise (p.127)

22 Read the article about the use of nanoparticles in sunblock lotions.

Sunblock lotions

Many sunblock lotions use nanoparticles. These lotions are very good at absorbing radiation, especially ultraviolet radiation.

Some sunblock lotions contain nanoparticles of titanium(IV) oxide. Normal-sized particles of titanium(IV) oxide are safe to put on the skin. For this reason, some chemical companies have assumed that nanoparticles of titanium(IV) oxide are also safe.

a) Explain the meaning of the term 'nanomaterial'.

a) Nanomaterials are organic or inorganic materials where at least one dimension (height, length or depth) is less than 100 nanometres. (1)

Unit Exercise (p.127)

b) Explain why some scientists worry about effects of using nanoparticles in sunblock lotions.

b) Any one of the following:

- Nanoparticles show properties different from larger particles of the same material. (1)
- May be harmful / harmful effects have not been fully investigated. (1)
- May have long-term effects / difficult to establish long-term effects. (1)