# PROPERTIES USED TO IDENTIFY PURE SUBSTANCES

## COLOUR

Some substances have quite distinct colours. Examples are deep brown for liquid bromine, reddish brown for solid copper, pale blue for copper sulfate pentahydrate, yellow for sulfur, red for iron(III) oxide and deep purple for potassium permanganate.

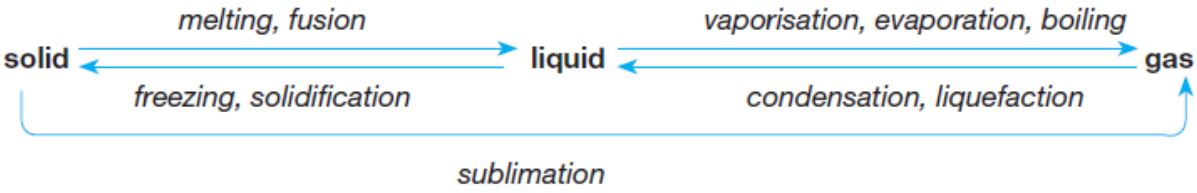
## PHYSICAL STATE AT ROOM TEMPERATURE

By physical state we mean whether the substance is a solid, liquid or gas.

Changes from solid to liquid to gas and vice versa are called changes of state.

**The three states of matter**

| Solid | Liquid | Gas |
|---|---|---|
| has a definite volume | has a definite volume | expands to fill the volume available to it |
| has a definite shape (bars or sheets of Al or Cu) or is made up of small pieces (crystals) that have definite shapes (sugar, salt, sand) | takes the shape of the container it is placed on | takes the shape of the container it is placed in |
| difficult to compress | difficult to compress | easily compressed |




## MELTING AND BOILING POINTS

The melting point of a solid is the lowest temperature at which the solid changes to a liquid.

If a solid is a pure substance, its melting point is quite sharp.
*an impure substance starts to melt at a lower temperature than does the pure substance.*

If the melting point is sharp and if it does not increase after submitting the solid to a further purification process, then we know that the substance is pure. The value of the melting point can be used as one piece of evidence for identifying the substance.

The reverse process of converting a liquid to a solid is called freezing. *The freezing point of a liquid is the same temperature as the melting point of the solid.* It is the *highest* temperature at which the liquid can be converted to a solid. A liquid can be converted back to a solid at any temperature below the freezing (melting) point.

**Boiling** is the process of converting a liquid to a vapour (gas) by heating the liquid until visible bubbles of vapour form throughout the whole bulk of the liquid and quickly rise to the surface. We call the lowest temperature at which this occurs the **boiling point**.

Pure substances have sharp boiling points.

Mixtures boil over a range of temperatures.

Boiling point can therefore be used as a test of purity. If a liquid has a sharp and constant boiling point, and if it does not change after putting the liquid through a further purification process, then the liquid is a pure substance and the value of the boiling point can be used to help identify the substance.

The process of *converting a gas (vapour) to a liquid is called* **condensation** or **liquefaction**. Condensation of a vapour back to a liquid can occur at any temperature less than or equal to the boiling point of the liquid.

## SAMPLE PROBLEM

Elements *A*, *B* and *C* have the following melting (m.p.) and boiling (b.p.) points.

Element *A*: m.p. = –71 °C, b.p. = –62 °C
Element *B*: m.p. = –39 °C, b.p. = –357 °C
Element *C*: m.p. = –2610 °C, b.p. = –5560 °C

Classify these elements as solid, liquid or gas at standard temperature and pressure.

Element *A* has both melting and boiling points below 25 °C so it is a gas at standard temperature and pressure. (This is the radioactive gas radon.)

Element *B* is a liquid at room temperature as its melting point is below 25 °C but its boiling point is above 25 °C. (This is the liquid metal mercury.)

Element *C* is a solid at room temperature as both its melting and boiling points are well above 25 °C. (This is the heavy metal molybdenum.)

## Exercises

**21** Melting and boiling points for some substances are shown in the table.

| Substance | Melting point (°C) | Boiling point (°C) | Substance | Melting point (°C) | Boiling point (°C) |
|---|---|---|---|---|---|
| sulfur | 114 | 444 | sulfur hexafluoride | –51 | –63 |
| gallium | 30 | 2400 | lead bromide | 373 | 914 |
| neon | –249 | –246 | magnesium | 650 | 1110 |
| bromine | –7 | 58 | phosphorus trichloride | –91 | 74 |
| carbon disulfide | –111 | 46 | carbon tetrabromide | 91 | 190 |
| hydrogen peroxide | –2 | 158 | sulfur dioxide | –73 | –10 |

**a** Which of these substances would be:
**I** solids **II** liquids at room temperature (20°C)?
**b** Arrange the solids in order of increasing melting point.
**c** Arrange the liquids in order of increasing boiling point.
**d** Which of these substances would *not* be solids at –60°C?

**22** A small portion of a white solid was slowly heated. It started to melt at 88°C but had not completely changed to liquid until 93°C. The rest of the white solid was then put through a purification procedure. A small portion of the 'purified' solid melted sharply at 91°C. A further 'purification' did not change the melting point. Was the original white solid pure or not? Why? Was the final white solid pure? Why? Use Table 1.7 or the one in Exercise 21 to identify the solid.

Answers:

**21** **a** **i** sulfur, gallium, lead bromide, magnesium, carbon tetrabromide
**ii** bromine, carbon disulfide, hydrogen peroxide, phosphorus trichloride
**b** gallium, sulfur, carbon tetrabromide, lead bromide, magnesium
**c** carbon disulfide, bromine, phosphorus trichloride, hydrogen peroxide
**d** neon, carbon disulfide, phosphorus trichloride, sulfur dioxide

**22** no; did not have a sharp melting point; yes; had a sharp melting point which did not change after further purification; carbon tetrabromide.

# DENSITY

**Density** is defined as mass per unit volume.

Common units for density are grams per millilitre, g/mL, or kilograms per cubic metre, $kg/m^3$.

Density of a liquid can be determined by measuring the mass of a known volume of the liquid, for example from a pipette. For a geometrically shaped piece of a solid, density can be determined by measuring the dimensions of the solid, calculating its volume, then measuring its mass. In each case:

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

**TABLE 1.7 Melting and boiling points and densities for some common substances**

| Substance | Melting point (°C) | Boiling point (°C) | Density (g/mL[a]) | Substance | Melting point (°C) | Boiling (°C) | Density (g/mL[a]) |
|---|---|---|---|---|---|---|---|
| aluminium | 660 | 2450 | 2.7 | ethanol | –114 | 78 | 0.79 |
| copper | 1083 | 2600 | 9.0 | ethyl acetate | –84 | 77 | 0.90 |
| zinc | 420 | 610 | 7.1 | ethylene glycol | –16 | 198 | 1.11 |
| lead | 327 | 1740 | 11.4 | acetic acid | 16.7 | 118 | 1.04 |
| mercury | –39 | 357 | 13.6 | chloroform | –64 | 62 | 1.48 |
| sulfur | 114 | 444 | 2.0 | hexane | –95 | 69 | 0.66 |
| phosphorus | 44 | 280 | 1.8 | oxygen | –219 | –183 | |
| carbon (graphite) | 3730 | 4830 | 2.3 | nitrogen | –210 | –196 | |
| sodium | 98 | 892 | 0.97 | hydrogen | –259 | –253 | |
| water | 0.0 | 100.0 | 1.00 | | | | |

[a] *at 25°C*

## Exercises

**23** Calculate the density of:

- **a** a block of aluminium measuring 0.50 cm × 1.20 cm × 0.80 cm which has a mass of 1.30 g
- **b** 5.0 mL chloroform which has a mass of 7.40 g
- **c** a cylinder of zinc, 3.0 mm in diameter and 3.0 cm long, which has a mass of 1.506 g

**24** Using density values from Table 1.7, calculate the mass of:

- **a** 5.0 mL ethanol
- **b** a cube of copper having a side of 0.80 cm
- **c** 25.0 mL hexane

**25** Using density values from Table 1.7, determine what volumes of the following substances would have the following masses:

**a** 10 g chloroform **b** 25 g ethylene glycol **c** 250 g copper

Answers:

**23** **a** 2.71 g/mL **b** 1.5 g/mL **c** 7.1 g/mL

**24** **a** 4.0 g (3.95 rounded to two significant figures because of 5.0 and 0.79)

**b** 4.6 g

**c** 17 g (16.5 rounded to two significant figures because of 0.66)

**25** **a** 6.8 mL **b** 23 mL **c** 28 mL

***• explain the relationship between the reactivity of an element and the likelihood of it existing as an uncombined element***

## ELEMENTS OCCURRING ON EARTH AS FREE ELEMENTS

Oxygen and nitrogen occur as uncombined elements in the atmosphere. By mass the atmosphere (excluding water vapour) is 21% oxygen and 78% nitrogen. Most of the remaining 1% of the atmosphere is argon, with trace amounts of He, Ne, Kr, Xe and Rn.

Other elements that occur in some places as uncombined elements are sulfur and the metals, gold, silver and platinum (and to a small extent copper).

## WHY MOST ELEMENTS ON EARTH OCCUR AS COMPOUNDS

- Sodium, potassium, calcium, magnesium, fluorine and chlorine which are all very reactive elements are never found as free elements.

- Copper and sulphur which have moderate reactivity do exist naturally in some locations as uncombined elements, although they are more commonly found as compounds.
- Gold, Platinum, and the noble gases such as argon and helium, which are extremely unreactive, occur naturally as uncombined elements.

Activity series of some common metals

| Most active | | | | | | | | | | | Least active |
|---|---|---|---|---|---|---|---|---|---|---|---|
| K | Na | Ca | Mg | Al | Zn | Fe | Pb | Cu | Hg | Ag | Au |

***• classify elements as metals, non-metals and semi-metals according to their physical properties***

## METALS AND NON-METALS

**Metals** are elements which:

- are solids at room temperature
- have a shiny or lustrous appearance
- are good conductors of heat and electricity
- are malleable (able to be rolled into sheets) and ductile (able to be drawn into wires).

Most other elements are called **non-metals**.

Non-metals are elements which:

- Are solids, liquids or gases.
- Are generally dull.
- Are poor conductors of heat and electricity.
- Are not malleable or ductile.

Boron, silicon, germanium, arsenic, antimony and tellurium do not fall clearly into either category. They are called semi-metals.

Physical properties of metals, semi-metals and non-metals

| Group | metals | semi-metals | non-metals |
|---|---|---|---|
| Appearance | lustrous | low sheen | dull |
| Electrical conductivity | high | low (semi-conductors) | nil (insulators) |
| Thermal conductivity | high | high | low (insulators) |
| Malleability and ductility | high | moderate | nil (brittle) |
| Density | generally high | intermediate | low |
| Boiling point | generally high | very high | low |
| Strength | high | variable | low |
| Examples | sodium, magnesium, iron, chromium, zinc, platinum, gold, mercury, lutetium | boron, silicon, germanium, arsenic, antimony, tellurium, astatine | hydrogen, helium, carbon, nitrogen, oxygen, fluorine, neon, phosphorus |

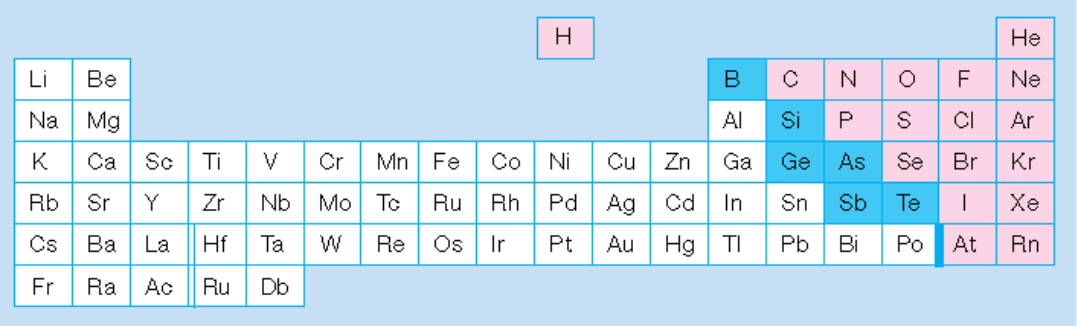
• ***account for the uses of metals and non-metals in terms of their physical properties***

Uses and properties of some elements

| Element | Use | Property related to use |
|---|---|---|
| Metals | | |
| copper | electrical wiring | ductility; high electrical conductivity |
| iron | structural building materials | high tensile strength |
| zinc | galvanising of iron | high reactivity allows it to preferentially corrode and protect the iron |
| gold | ornaments, jewellery | lustre; highly unreactive |
| Aluminium | aircrafts | Low density |
| Tungsten | Filaments in electric bulbs | High melting point |
| Non-metals | | |
| argon | atmosphere for welding and metallurgy | inert |
| helium | meteorological balloons | low density |
| Carbon as graphite | Electrode in common dry cells (batteries)<br>Dry lubricants | Electrical conductivity<br><br>Slippery nature |
| Carbon as diamond | Jewellery<br>As a cutting tool | Scatters light effectively<br>Extremely hard |
| Liquid nitrogen | Cooling agent | Low freezing and boiling point |
| Semi-metals | | |
| silicon | computer chips, transistors | semi-conductor |

***• process information from secondary sources and use the periodic table to present information about the classification of elements as:***
***– metals, non-metals and semi-metals***
***– solids, liquids and gases at 25 °C and normal atmospheric pressure.***

# Metals and non-metals in the Periodic Table




# Physical states of the elements

Of the naturally occurring elements, at room temperature:

- *two* are liquids: mercury and bromine
- *eleven* are gases: oxygen, nitrogen, hydrogen, helium, neon, argon, krypton, xenon, radon, fluorine and chlorine. All of these are colourless except fluorine which is pale yellow and chlorine which is greenish yellow.
- the rest are solids.

## Exercises

**29** Which of the elements A, B, C, D, E in the table below would you class as metals? Give your reasons.

| Element | Melting point (°C) | Relative electrical conductivity[a] |
|---|---|---|
| iron | 1540 | 100 |
| sulfur | 113 | <0.01 |
| A | 50 | 50 |
| B | 10 | 0.04 |
| C | 800 | 0.02 |
| D | 1450 | 140 |
| E | 3400 | 200 |

[a] *Relative to iron arbitrarily set at 100.*

***30 a** Give the names of *five* metals that are used in your home and state a use for each. Which property makes the metal particularly suitable for that use and why?

**b** List *four* items of jewellery that you or your family own and that are made of predominantly pure elements. Name the elements. Which properties make these elements particularly suitable for jewellery?

**c** Name *six* compounds that are purchased as virtually pure compounds for use in the home. State what each is used for.

Answers:

**29** *A*, *D*, *E*; they all have significant electrical conductivity