Defence School of
Aeronautical Engineering

Aerosystems Engineer & Management Training School

Academic Principles Organisation

SCIENCE

BOOK 1

Matter

WARNING

These course notes are produced solely for the purpose of training. They are not subject to formal amendment action after issue and they must NOT be used for operating and maintaining the equipment described. Operation and maintenance of equipment is governed by the limitations and procedures laid down in the authorized publications and manuals which must be complied with for these purposes

ENABLING OBJECTIVE

SC1 Explain in basic terms the nature of matter.

KEY LEARNING POINTS

SC1.1 Explain the kinetic theory of matter.

SC1.2 Identify common engineering chemical elements by name and symbol.

SC1.3 Explain the three basic states of matter and the change of state of common substances.

SC1.4 Explain the three main bonds at molecular level.

SC1.5 Describe the nature of molecules found in metals and non-metals.

SC1.6 Explain the difference between heat and temperature

SC1.7 Explain the relationship between the common temperature scales.

SC1.8 Convert temperature values between the common temperature scales

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Exam

1 Question from SC1.1 to SC1.4
1 Question from SC1.5 to SC1.8

SC1.1 – EXPLAIN THE KINETIC THEORY OF MATTER

Kinetic theory of matter

1. This is based on the principle that all matter is made up of small particles and the only energy of a 'particle' is its movement (kinetic) energy. We also have to consider how the particle can interact with other particles in the vicinity. This 'kinetic theory' is then developed to describe the 'large scale' behaviour of matter from this microscopic description of energy in the system.

2. Kinetic or 'Movement' energy (KE) comes in three major forms:

- Linear (straight line) kinetic energy
- Angular (circular motion) kinetic energy.
- Vibrational (oscillatory) kinetic energy (about a 'fixed' point).

3. Linear kinetic energy is due to a body moving in a straight line. An example is, a car travelling along a straight road. The movement energy is measured in Joules (J).

4. Angular kinetic energy is related to movement energy by virtue of 'mass' moving on a circular path. We do not need to consider this for particles.

5. Vibrational kinetic energy is when particles are fixed together, such as in a solid, then the movement is limited to vibrational. This still gives us kinetic energy, but it is constantly changing between movement KE and stored energy (potential energy - PE) in the matter. This is important in the kinetic theory of matter because there will be vibrational movement even in a body that appears to be at rest.

Brownian motion

6. In 1827 the Scottish botanist Robert Brown noticed that pollen grains suspended in water moved about under the lens of a microscope, following a random zigzag path like the ones pictured below.

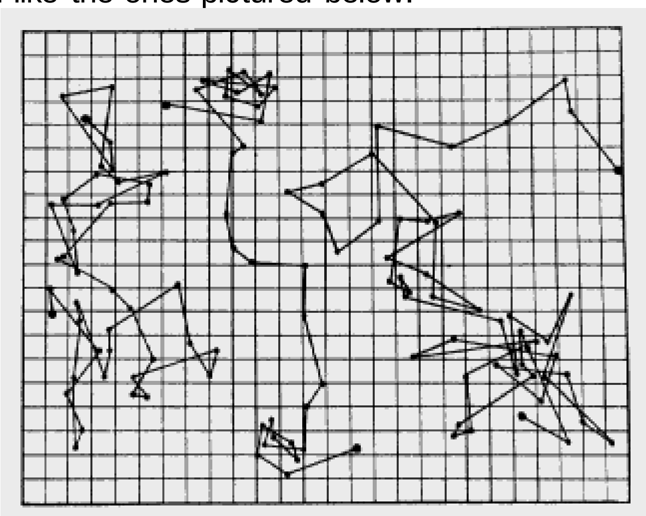


Figure 1 - Brownian motion

7. This "Brownian" movement was more rapid for smaller particles (we do not notice Brownian movement of cars, bricks, or people).

8. This process was thus explained: “In my way of thinking the phenomenon is a result of thermal molecular motion in the liquid environment (of the particles)."

9. This is indeed the case. A suspended particle is constantly and randomly bombarded from all sides by molecules of the liquid. If the particle is very small, the hits it takes from one side will be stronger than the bumps from other side, causing it to jump. These small random jumps are what make up Brownian motion. Small particles of smoke in a sealed box, observed under a microscope, show similar small random movements.

10. Brownian motion is good empirical evidence of the Kinetic theory of matter.

SC1.6 – EXPLAIN THE DIFFERENCE BETWEEN HEAT AND TEMPERATURE

Heat

11. Heat is a form of energy and is measured in Joules.

12. In the kinetic theory of matter, we only have to consider the kinetic energy of the particles. So, the heat in a body of matter is “the total kinetic energy of all the particles in that body”. This will be vibrational in a solid, linear in gases and a mixture of the two in the case of liquids.

13. The transfer of heat energy to and from a body would normally result in a change of temperature of the body.

Temperature

14. Temperature can be defined as the degree of hotness or coldness of a body. To compare it to the definition of heat above, it can therefore be defined as “the average kinetic energy of the particles in that body”.

15. The basic SI unit of temperature is the Kelvin.

16. It can however be measured under imperial units as degrees Celsius (°C), degrees Fahrenheit (°F).

17. Temperature is a way of comparing the ‘average’ KE of individual particles in a body. So, we are no longer interested in the total KE just the average KE of each particle that makes up the matter. Consider the simple systems depicted in Figure 2 below.

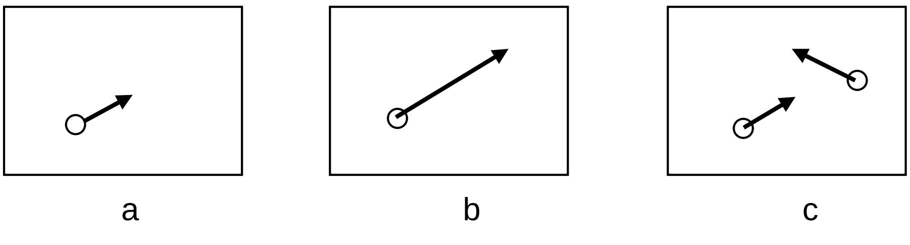


Figure 2 - Heat and temperature

18. In figure 2(a) above, we have a single particle moving at velocity *v*. We heat this system up to produce figure 2(b) where the particle is now moving faster. The heat content (total energy) has increased and so has the temperature (average energy per particle).

19. Now in figure 2(c) we have introduced an extra particle to the one in figure 2(a). Now the heat content has doubled because we have twice the total energy, but the temperature is the same because the average energy per particle is the same as figure 2(a).

20. Which of the following objects has the biggest heat content?

a. A ‘red hot’ needle
b. A cannon ball left out in the sun.

21. The needle clearly has the highest temperature – it radiates visibly. But which has the highest heat content? One test would be to use both to try and heat the same amount of water in a bucket (Figure 3 below). Whichever object causes the biggest change in temperature will have had the greatest heat content. If we were to try this, then the needle would barely change the temperature of the water. The cannon ball however, would warm the water noticeable. It is the cannon ball therefore that has the highest heat content.

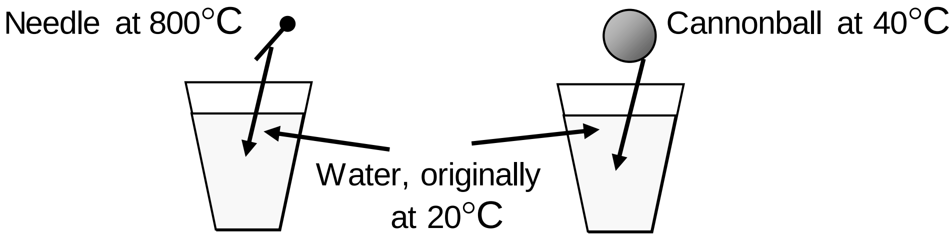


Figure 3 - Heating a bucket of water.

22. The needle will hardly heat the water in first bucket at all (maybe 20.1°C). In contrast the cannonball will heat the water in the second bucket noticeably. (This is because of its mass). Its temperature may be raised to 30°C.

SC1.3 – EXPLAIN THE THREE BASIC STATES OF MATTER AND THE CHANGE OF STATE OF COMMON SUBSTANCES

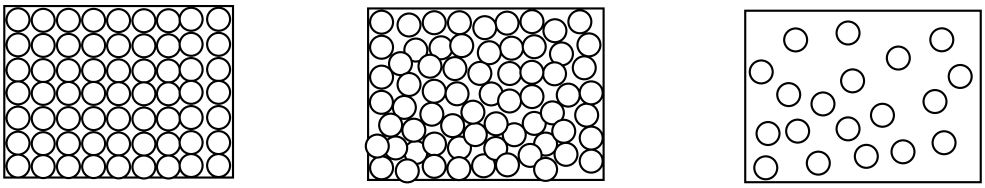
States of matter

23. Matter exists in a variety of forms called 'states', these three basic states are solids, liquids and gases.

24. A solid has a definite shape and volume. A liquid has a definite volume but will take up the shape of its container. A gas has no definite volume or shape – it will expand to take up the shape and volume of its container.

25. Any substance that can flow is called a fluid. Liquids and gases are therefore both fluids. The main difference between them is that liquids are considered to be incompressible whilst gases can be readily compressed. This is of great importance when considering the use of fluids in engineering components such as tyres, shock absorbers and hydraulic systems.

26. The difference between solids, liquids and gases can be explained in terms of molecular theory as illustrated in Figure 4 below.



a. Solid **b. Liquid** **c. Gas**

Figure 4 - Molecular Structure of Solids, Liquids and Gases

27. In a solid (figure 4a), the atoms or molecules are packed in very close together with very strong bonds between them giving the material a rigid, incompressible structure.

28. In a liquid (figure 4b), they are packed more loosely, weakening bonds allows the material to flow. There is still insufficient space between them, however, to allow for any significant compression.

29. In a gas (figure 4c), the atoms or molecules are widely spaced and in constant motion. The bonds are very weak allowing the gas to fill the available space and large amount of 'free' space allows a gas to be easily compressed.

Changes to states of matter

30. In general, matter passes between these states in a set manner. This is modelled by considering how increased energy is accommodated within the body of matter. In most cases the following description will apply.

31. Even in a solid the atoms or molecules are vibrating about a fixed point and because they are moving they possess a certain amount of energy known as internal energy. If the material is heated the internal energy increases and they vibrate more and more quickly and with a greater range of movement. This usually leads to an increase in size called thermal expansion.

32. Eventually the degree of vibration increases to a point where the internal energy becomes sufficient to 'overcome' the bonds between the atoms or molecules and the solid loses its rigid form to become a liquid. The heat has caused a change of state. Temporary bonds are continually formed and broken preventing the molecules from totally separating. Ice, for example, will melt to become water.

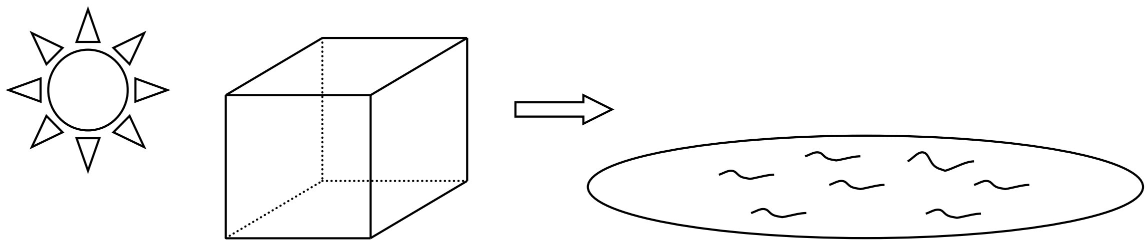


Figure 5 - A heated solid becomes liquid

33. Further heating will cause an even greater increase in internal energy, overcoming the bonds to the extent that a further change of state takes place and the liquid loses its form to become a gas. The bonds between molecules/molecules are fleeting and negligible. The gas molecules effectively move independently of each other hence the expansion to fill the container. Water for example will boil and become steam.

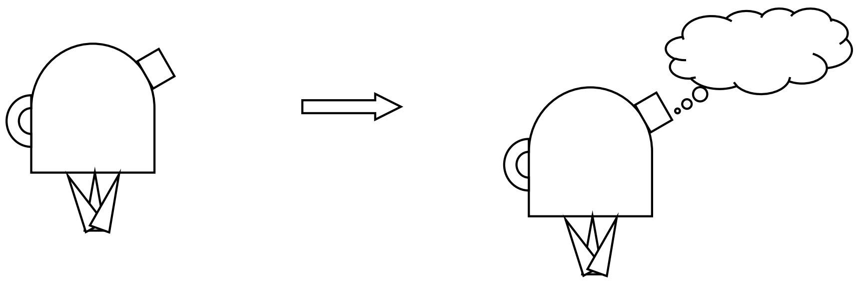


Figure 6 - A heated liquid becomes a gas

34. 'Evaporation' is the change of liquid to gas at any temperature. It is increased by either decreasing the pressure, an increase in surface area or increased ambient temperature or by air draughts over the surface.

35. Cooling the material will have the opposite effect. Large quantities of heat energy will be given up as the material changes state from gas to liquid and then to solid.

36. Some materials behave differently: Carbon dioxide (CO_2) for example goes straight from a solid state into a gas when it is heated at atmospheric pressure. Materials such as this are said to 'sublime'.

37. The different changes of state are listed below:

Change of state	Name
Solid to Liquid	Melting (or Fusion)
Liquid to Gas	Boiling (or Vaporisation)
Gas to Liquid	Condensing
Liquid to Solid	Freezing
Solid to Gas	Sublimation
Gas to Solid	Deposition (The opposite of sublimation)

Sensible and Latent heat

38. Consider the Phase diagram below showing the temperature of a pan of ice, being heated on a stove, over a period of time.

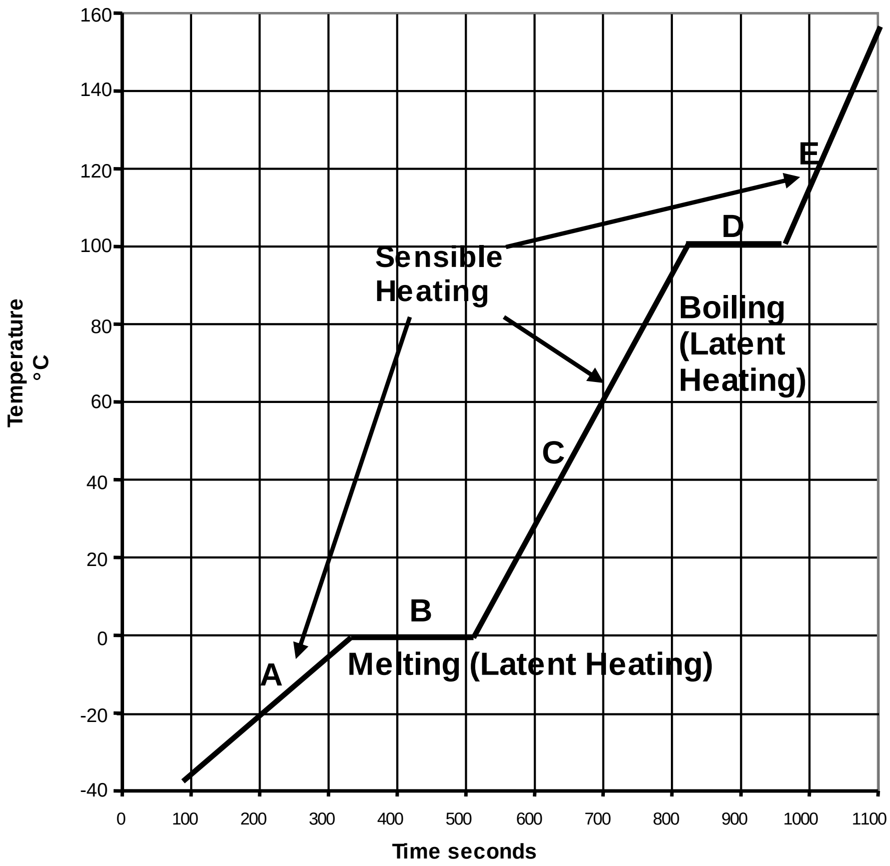


Figure 7 - Phase diagram for heating ice

39. At first, in section A the ice simply shows an increase of temperature over time, until 0°C is reached. Then, in section B of the graph, the temperature remains at a constant 0°C. This is when the ice begins to melt and becomes water. After this point the water temperature rises steadily along section C until a temperature of 100°C is reached, and the water starts to boil. Again, the temperature now remains

constant along portion D of the graph. When the water has all turned to steam, the temperature rises steadily along portion E. Cooling reverses the whole process.

40. When we put heat energy into a body we would normally expect the temperature to rise steadily. This happens during portions A, C and E. We call this process Sensible heating.

41. For the other portions of the graphs we are still putting heat energy in at a constant rate but there is no measurable change in temperature. This is because the state of the material is changing. The energy is being used to change the internal 'structure' and the form in which the KE of particles is located. Because there is no change in temperature this is termed Latent (hidden) heating.

42. Each type of material will require a certain amount of heat energy to completely change a given mass of solid into liquid (see Figure 6 Section B). To compare different materials, the energy required per kg is quoted and is called the material's "Specific Latent heat of fusion".

43. Likewise, each type of material will require a certain amount of heat energy to completely change a given mass of liquid into gas (see Figure 6 Section D). To compare, the energy required per kg is quoted and is called the material's "Specific Latent heat of vaporisation". Some examples of Latent heat values are given in the Table below:

Material	Chemical Symbol	Latent Heat of Fusion (J/kg)	Latent Heat of Vaporisation (J/kg)
Aluminium	Al	386 790	10 800 000
Lead	Pb	26 204	862 000
Tin	Sn	61 116	2 497 000
Iron	Fe	267 000	6 095 000
Ice / water	H_2O	336 000	2 260 000
Silicon	Si	1 650 000	13 700 000

Latent heats of various materials

44. Comparing the values above, the amount of energy each material takes to cause them to melt and/or boil will vary widely. Silicon for example requires 63 times the energy to melt it compared to the same mass of lead.

Example:

45. Four kilograms of lead is heated until it just begins to melt. How much energy is required to totally melt this quantity of lead?

(Latent heat of fusion of lead is 26204 J/kg from table above.)

Answer: 4 kg x 26 204 J/kg = 104 816 J = 104.8 kJ

Exercise 1

1. Define the term heat.

2. Define temperature.

3. Draw a phase diagram of heating a bucket of ice from -10 °C to 110 °C. Label the various phases as sensible or latent, name the phases and the phase changes.

4. Use the values in the para 43 above (or formula sheet), to answer the following:

   a. How much energy is required to convert 25 kg of ice into water (assume the ice is at 0°C)?

   b. Determine the amount of energy required to boil 0.75 kg of water liquid into vapour (assume the water is at 100 °C)?

   c. How many kg of steam will be produced if 5 MJ of heat energy is put into a large urn of water at 100°C?

SC1.2 – IDENTIFY COMMON ENGINEERING CHEMICAL ELEMENTS BY NAME AND CHEMICAL SYMBOL

Chemical elements

46. Elements are chemical components that cannot be broken down into simpler blocks (without involving nuclear processes). Page 33 shows a list of all naturally occurring elements plus some exotic materials that are found only in the laboratory. The 'periodic table' shown on page 31 shows all the elements in a layout where elements in a given column behave in a similar fashion (reference to page 31 is made below in paras 47 to 53).

47. Elements in the first column (column 1) are called the Alkali metals (hydrogen is a slight anomaly here). These are extremely reactive metals that get more reactive as we go down the column.

48. The last column (column 18 – 'dark green') comprises the inert (or 'noble') gases. These only react under very special circumstances in normal use they perform no chemical reactions. Argon for example, is used in arc welding to prevent the oxidisation that would occur in air.

49. The second to last column (column 17) is called the halogens. These are very reactive substances where the most reactive (fluorine, F) is at the top this time

50. The 'blue' colours signify metals. These are characterised by their ability to be shaped; cast, machined, hardened etc. They are generally good conductors of heat and electricity and form a very important source of material in engineering.

51. Non-metals, shown in 'light green', are in the main used in compound form i.e. with other elements. Silicon dioxide (SiO_2) for example is the main constituent of glass. The gas nitrogen (N_2) is important because it is so abundant in our atmosphere and it is relatively 'inert' (does not react).

52. Carbon is exceptionally important chemically. It is so prolific in the way in which it can react that it has its own branch of chemistry called 'organic' chemistry. This is almost as big as all other chemistry combined. Living systems make use of organic chemistry. All of our current aviation fuel is carbon based. Carbon itself is used in the form of the composite 'carbon fibre' which is very lightweight and strong.

53. The 'metalloid' grouping shown in 'pink' is an important grouping. These elements show some properties similar to metals, however they also show behaviour peculiar to their grouping. They all (in the right conditions) will form materials called 'semi-conductors'. These can conduct electricity under some circumstances but be insulators if we change those circumstances. This gives us the ability to build electronic switches, logic gates, processors etc. Practically all of modern electronic systems are based on these devices.

54. For more information on any particular element in the periodic table search on-line for interactive periodic tables. Most can then be accessible by clicking on any element name for full details and properties.

55. We are going to consider twelve elements in detail that are considered important to aerospace engineering. These are the descriptions from the site mentioned above.

Aluminium (Al). It is a silvery white reactive metal, which is usually covered by a tenacious oxide coating. It is the most common metallic element in the earth's crust. The metal has good thermal properties and is malleable and ductile. Aluminium and its alloys are widely used for various applications including aircraft assemblies and engine parts.

Beryllium (Be): Beryllium is a light and lustrous metal. It is resistant to attack by air or water, even at elevated temperatures (red heat). Beryllium is non-magnetic, is a good thermal conductor and is used as an alloying addition to copper or nickel, the alloys having excellent thermal, mechanical and electrical properties; in addition, when alloyed with nickel, the resultant Be/Ni alloy has the highest coefficient for secondary electron emission. Applications for pure beryllium include its use as windows in X-ray tubes and as a source of neutrons when bombarded with alpha particles. Beryllium and its compounds are highly toxic.

Carbon (C): Carbon occurs naturally in two allotropic forms, namely graphite and diamond; the discovery in 1985 of fullerenes (or buckyballs and nano-tubes) has increased the number of allotropic forms of this element. The study of carbon and its organic compounds is the basis of organic chemistry.
The applications for carbon include its use as an alloying element with iron in the manufacture of steel, its use as brushes in electrical generators and motors, the use of colloidal graphite or carbon to coat surfaces (e.g. glass), in electrical assemblies to absorb microwaves, and the use of high purity carbon (graphite) in nuclear reactors to moderate neutrons.
Diamond has unique properties, being the hardest natural material with excellent corrosion resistance and thermal transfer. Industrial diamond is used in rock drilling equipment and abrasive materials.
Carbon is a fundamental part of all life, it being a prime constituent of DNA. On average, the human body contains approximately 16 kg of carbon in one form or another.

Copper (Cu): Copper is a reddish coloured metal, which is malleable and ductile. It has excellent thermal and electrical conductivities and good corrosion resistance. The element is inert to non-oxidising acids but reacts with oxidising agents. In air, it will weather to produce the characteristic green patina of the carbonate.
Pure copper has an electrical conductivity second only to that of silver and hence its main application is in the electrical industry. Copper is also the basis of many important alloys (e.g. brass, bronze and aluminium bronze) and has been traditionally considered to be one of the coinage metals, along with silver and gold, but being more common, is the least valued. It is one of the first metals ever to have been worked by man and is thought to have been mined for more than 5000 years.

Iron (Fe): One of the most abundant metals, iron is probably one of the most important, being used on the largest scale of any metal. Its production in the blast furnace is well documented. When pure, iron is a lustrous white metal, which is soft and very workable. However, it is reactive and easily forms a coating of rust in the presence of moist air. Iron is soluble in dilute acids.
Depending upon the temperature, pure iron can exist in three forms. Iron is the basis for many types of steel, the properties being achieved by the alloying of iron with carbon, nickel, chromium and other elements in varying proportions which results in materials with vastly differing mechanical and physical properties.
Iron is also an essential element for all life forms, the average human body containing 4 g of the element. The majority of iron in the body is present within haemoglobin important for the transportation of oxygen by red blood cells.

Lead (Pb): Lead is a soft, malleable and ductile metal. The main source of the metal being the ore "galena" Lead oxidises readily in moist air, is stable to oxygen and water, but dissolves in nitric acid. It is a poor electrical and thermal conductor but has reasonable corrosion resistance. Applications for this metal are wide and varied; for example, its relative imperviousness to radiation makes it ideal as radiation shielding material for use with X-ray equipment. Lead is also used in ceramic glazes, batteries and as a prime constituent of soft solders. However, its use is now ‘discouraged’ as lead is now known to be detrimental to health, particularly to that of children.

Magnesium (Mg): Magnesium is a brilliant white metal, which is relatively soft. As a powder, magnesium is extremely reactive, but as a solid it oxidises slowly in air and reacts slowly in water.
Applications of magnesium include its use as a deoxidiser for copper, brass and nickel alloys and it is also added to several aluminium base alloys. It is the basis of strong, light alloys used in the aircraft and automobile industries (e.g. in engine assemblies). Alloys with zirconium and thorium have also been investigated for their use in aircraft manufacture.

Silicon (Si): After carbon, silicon is the most abundant element on earth, it is generally present as a silicate, these being found in many rocks, clays and soils. Silicon is obtained by reducing silica (sand, SiO_2), with carbon. Silicon exists in two allotropic forms; brown silicon is a powder, whereas crystalline (metallic) silicon is grey and it is the latter, which is more widely used. Bulk silicon is un-reactive towards oxygen, water, acids, but is soluble in hot alkalis.
Silicon has many applications in various industries; for example, ultra-high purity silicon is used in the semiconductor industry as a result of its ‘semiconducting’ properties. Silicon is also used as an alloying element in the manufacture of certain alloys (e.g. ferrosilicon, an alloy of iron and silicon which is used to introduce silicon into steel and cast iron). It is also used in the manufacture of glass.

Titanium (Ti): Titanium is a hard, lustrous, silvery metal. It is a relatively abundant element. It forms a protective oxide coating and, hence, resists corrosion, although powdered metal burns in air. Titanium tends to be inert at low temperatures but will combine with various reagents at high temperatures.
Titanium and its alloys are characterised by their lightness, strength and corrosion resistance and are used widely in aerospace applications. In addition, these properties also make the material suitable for medical applications (e.g. replacement

hip joints). Titanium dioxide, TiO_2 is used as a white pigment in paints and plastics as it provides great opacity. The same material is also used in the manufacture of heat resisting and durable glass, the TiO_2 replacing certain proportions of the soda. Titanium carbide is used to manufacture cemented carbides.

Oxygen (O): Oxygen gas is colourless, odourless, and tasteless. The liquid and solid forms are a pale blue colour and are strongly paramagnetic. Oxygen supports combustion, combines with most elements, and is a component of hundreds of thousands of organic compounds. Ozone (O_3), a highly active compound is formed by the action of an electrical discharge or ultraviolet light on oxygen.

It is the third most abundant element found in the sun and the earth, and it plays a part in the carbon-nitrogen cycle. Excited oxygen yields the bright red and yellow-green colours of the Aurora. Oxygen enrichment of steel blast furnaces accounts for the greatest use of the gas. Large quantities are used in making synthesis gas for ammonia, methanol, and ethylene oxide. It is also used as ‘bleach’, for oxidizing oils, for oxy-acetylene welding, and for determining carbon content of steel and organic compounds. Plants and animals require oxygen for respiration. Hospitals frequently prescribe oxygen for patients. Approximately two thirds of the human body and nine tenths of the mass of water is oxygen.

Hydrogen (H): Hydrogen is the most abundant element in the universe. The heavier elements were made from hydrogen in processes within stars. Hydrogen is a colourless, odourless, combustible gas. It is so light and diffusive that un-combined hydrogen can escape from the atmosphere.

Hydrogen is important in the proton-proton reaction and carbon-nitrogen cycle. Liquid hydrogen is used in cryogenics and in the study of superconductivity. Great quantities are used for the fixation of nitrogen from the air in the Haber ammonia process. Hydrogen is use in welding, for the hydrogenation of fats and oils, in methanol production. Other applications include producing rocket fuel, filling balloons, making fuel cells, producing hydrochloric acid, and reducing metallic ores. Deuterium is used as a moderator to slow down neutrons and as a tracer. Tritium is used in the production of the hydrogen (fusion) bomb. Tritium is also used in making luminous paints and as a tracer. (See ‘isotopes’ in paragraph 62, below.)

Nitrogen (N): Nitrogen gas is colourless, odourless, and relatively inert. Liquid nitrogen is also colourless and odourless and is similar in appearance to water. Nitrogen compounds are found in foods, fertilizers, poisons, and explosives. Nitrogen gas is used as a blanketing medium during the production of electronic components. Nitrogen is also used in annealing stainless steels and other steel products. Liquid nitrogen is used as a refrigerant. Although nitrogen gas is fairly inert, soil bacteria can 'fix' nitrogen into a usable form, which plants and animals can then utilize. Nitrogen is a component of all proteins. Nitrogen is responsible for the orange-red, blue-green, blue-violet, and deep violet colours of the aurora (*northern lights*).

Nitrogen gas (N_2) makes up 78.1% of the volume of the Earth’s air. Nitrogen is found in all living organisms. Ammonia (NH_3), an important commercial nitrogen compound, is often the starting compound for many other nitrogen compounds.

SC1.4 – EXPLAIN THE THREE MAIN BONDS AT MOLECULAR LEVEL

Atoms and molecules

56. We have already defined atoms as the smallest amount of an element that can exist. The name atom comes from the Greek word atom meaning indivisible.

57. A molecule is any group of atoms bonded together. They can be comprised of one or many elements. Molecules formed from a single element are still referred to as 'elemental'. If the molecule comprises of many elements, then it is referred to as a compound. Some simple compounds are shown in figure 8 below.

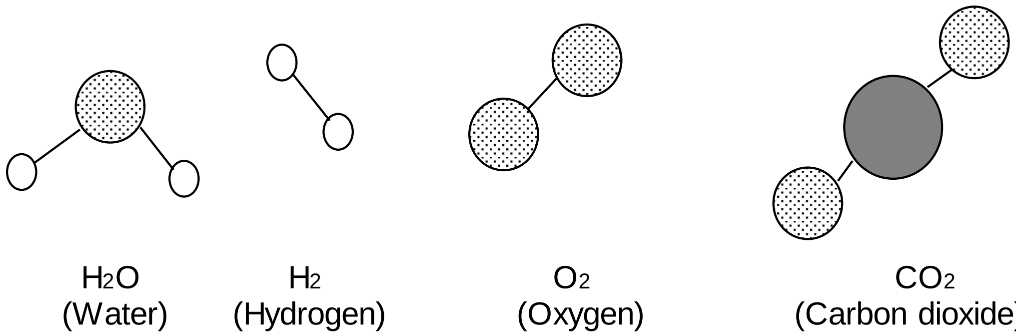


Figure 8 - Examples of simple molecules

Note: compounds are not to be confused with mixtures. Mixtures are not chemically bound together for example salt and pepper can form a mixture but salt itself is a compound.

58. We will look at the Bohr model (figure 9 below) and utilise it to help us understand the behaviour of different elements and compounds. This model describes atoms as formed from three different particle types: protons, neutrons and electrons. Protons have a positive electrical charge. Neutrons have no charge (they are neutral) and electrons have a negative electrical charge.

59. The Nucleus is the central region of any atom and is comprised of a very small volume in which the protons and neutrons reside. The Neutrons can be thought of as 'glue' that sticks protons together. (Normally electrically positive particles such as protons would repel one another.) This central region is where 99.9% of all of the mass of the atom is placed. Neutrons and protons have the same mass. Electrons have approximately 1/1000 of this mass.

60. Outside of the nucleus is where the electrons are located in orbits called shells. The important thing about shells is they only hold a fixed number of electrons and that they like to be either totally full or completely empty. The shells from inner to outer can accommodate 2, 8, 18, 32 ($2n^2$) electrons respectively. Materials that have completely full shells are inert, meaning they do not react easily with any other atom.

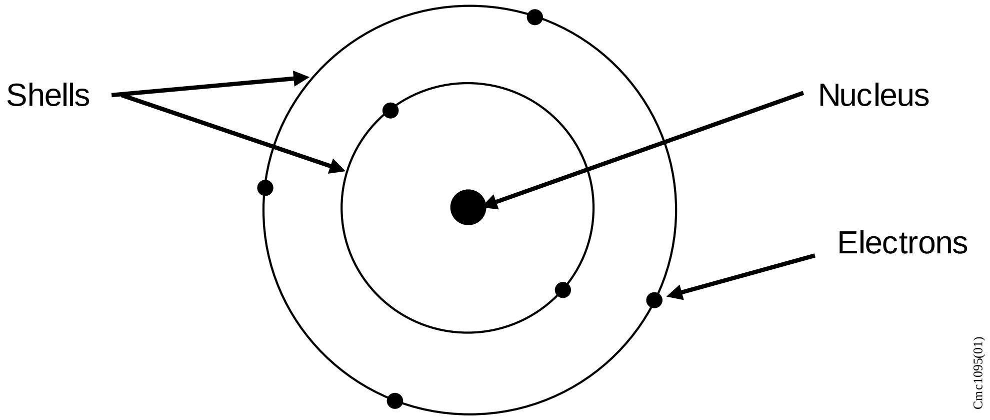


Figure 9 - Bohr model of a carbon atom

61. The nature of any atom is determined by its number of protons. Hydrogen (H) at the top left-hand corner of the periodic table has the simplest atom possible; one proton, and one electron. The outer shell has space for two electrons and therefore is not full. This means hydrogen will be reactive and not inert.

62. Atoms with the same number of protons but different numbers of neutrons are called isotopes. Chemically they react in a similar way. It is only in processes where the mass is important will any difference be seen. Three isotopes of hydrogen atoms exist. These all have a single proton, but deuterium has a neutron in the nucleus too, and tritium has a single proton and two neutrons. These isotopes of hydrogen are important in nuclear weapons and potentially in future nuclear energy production via fusion. (We will not consider isotopes further.)

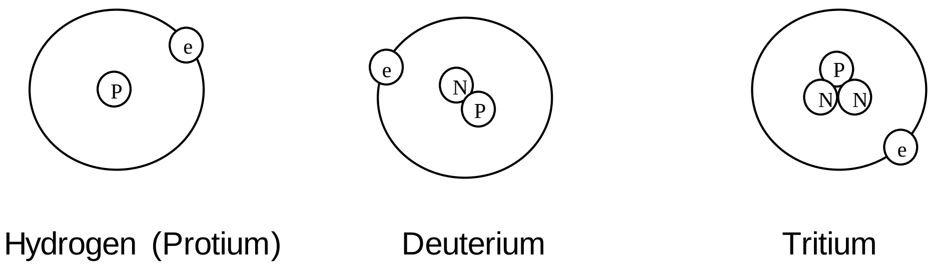


Figure 10 - Three isotopes of Hydrogen

63. When any outer shell is incomplete, chemistry seeks a way in which the outer shell can somehow be considered as full or empty. In the case of hydrogen, a solution whereby electrons are 'shared' exists. In this situation, sometimes one of the atoms has both electrons and the other has none and periodically they swap roles. This sharing of electrons is called a covalent bond. The atoms have to stay close to each other for this to work. (Overall this system is now 'electro-valently' like an inert gas – hydrogen gas is however still dangerously reactive!)

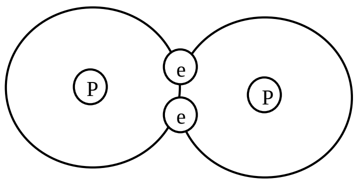


Figure 11 - A molecule of Hydrogen (H_2)

64. Any electron in an incomplete shell is called a valence electron. All chemicals try to combine with the valence electrons from other atoms to fill (or empty) the outer shell. This tells us is that the whole of chemistry is determined by the outer electron shell. Any chemicals with a similar number of outer 'shell' holes will behave in a similar fashion chemically. This is why columns in the periodic table behave similarly chemically.

65. The next most complicated atom is helium (He). This comprises normally of a nucleus of two protons and two neutrons surrounded by a shell containing 2 electrons. Helium has a complete outer shell and is therefore inert.

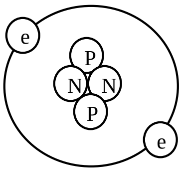


Figure 12 - An atom of Helium (He)

66. The next atom is lithium (Li). Ignoring isotopes, lithium comprises three protons, three electrons and four neutrons. The outer shell has seven holes.

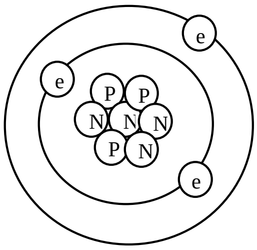


Figure 13 - An atom of Lithium (Li)

67. Lithium would need to share electrons with seven other lithium atoms to fill the outer shell. This is effectively what happens in metallic lithium. But when lithium reacts with other elements it finds it easier to give away its outer valence electron than to try and fill the gaps. When Lithium reacts with elements that have one valence hole in their outer shell it will lose the valence electron rather than sharing. When valence electrons totally move from one atom to another they form ionic bonds. An atom that loses electrons becomes a positive ion. Atoms that gain electrons become negative ions.

68. Fluorine is the simplest chemical (after hydrogen) that has an outer shell with one whole available. For fluorine (and other halogens,) it is easier to grab a valence electron from another atom than it is to share electrons covalently. It will then form a negative ion.

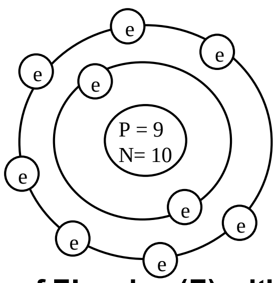


Figure 14 - An atom of Fluorine (F) with one valence 'gap'.

69. Reaction between lithium and fluorine results in the lithium losing electrons and becoming positive ions and the fluorine atoms gaining electrons and becoming negative ions. Both then have achieved the principle of having totally full or totally empty outer shells.

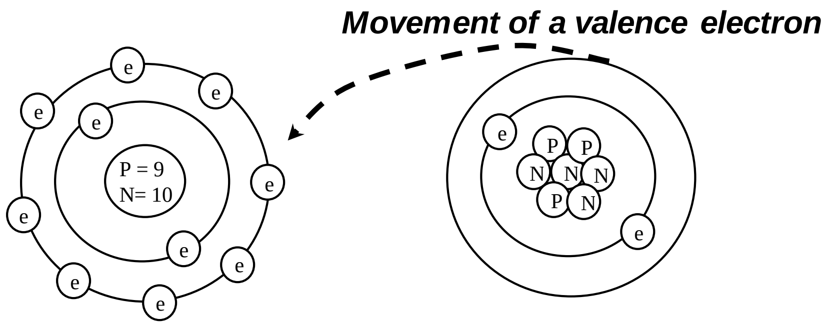


Figure 15 - Ions of F^- and Li^+

70. These ions then organise themselves on electrostatic principles because they are charged bodies. The electrostatic rule is that opposites attract and like charges repel one another. In the case of lithium and fluorine the form a 3-D cubic lattice like so:

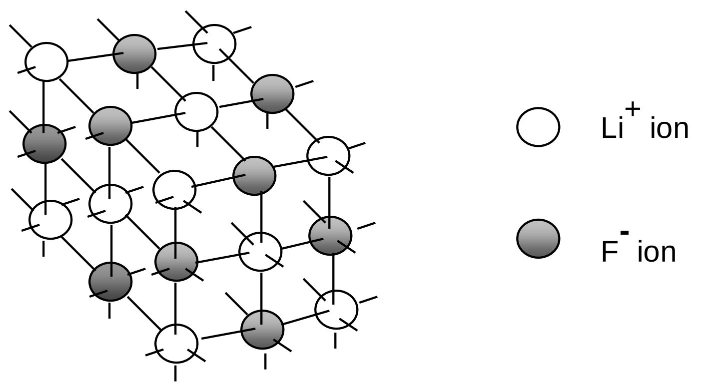


Figure 16 - Lattice structure of Lithium Fluoride (Li F)

71. In the crystalline structure indicated above, the atoms are bonded together ionically. Ionic bonds are not as strong as covalent sharing of electrons. Ionic bonding still constitutes strong bonds. In general, a single covalent bond is always stronger that a single ionic bond.

Note: The structure illustrated above is the same as that formed by sodium and chlorine when they react. This forms sodium chloride (Na Cl), which is table salt.

Note: the strength is measured by how much energy it takes to break the bond or how 'elastic' the material is.

SC1.5 – DESCRIBE THE NATURE OF MOLECULES FOUND IN METALS AND NON-METALS

Metals & non-metals

72. In certain materials some of the valence electrons are effectively shared by being able to move easily from atom to atom. These are called free electrons. This occurs in some organic chemicals but most noticeable it occurs in metals where the electrons can be thought of as a cloud of negative charge that can float between the positive ions. Metallic bonds are easy to form and therefore easy to break. Metallic bonding is weaker than ionic bonding.

73. Any material that has free electrons will conduct electricity (and heat) well. Therefore, metals are good conductors. The pure form of carbon known as graphite also has free electrons. It too is a relatively good conductor of electricity and heat. In electrical conduction it is the movement of charge (in this case electrons) that constitutes an electrical current.

74. In the case of heat, it is the kinetic theory that again explains the ability of materials with free electrons to conduct so much better than non-metals (i.e. materials with no free electrons). The transfer of heat in the kinetic model is simply the transfer of KE of individual particles. In the case of metals (& other materials containing free electrons) it is the free electrons that are the particles moving KE through the materials structure. They do this by collision with other electrons and with the positive ion lattice, which in turn vibrates more and hence has a higher temperature. Because free electrons can move freely into the structure and because the structure can interact with free electrons further within the interior of the lattice, that heat can flow very effectively through the material.

75. Metals: These are characterised generally by the following features:

a. High strength, (resistance to breakage under tension or compression),

b. High stiffness, (resistance to deformation under torque, shear or bending)

c. High ductility, (ability to be stretched without breakage)

d. Ease of working, (ability to be shaped by simple processes such as presses, turning, drilling, milling (machining), forging, welding, cutting etc)

e. Good conductor of heat and electrical current

76. Materials that do not possess free electrons are generally non-metals. They will be poor conductors of heat and electricity and are classed as insulators.

Note: all materials, even insulators such as plastic, rubber and air can be made to conduct if subjected to a large enough voltage. This is called ‘electrical breakdown’ in the case of an insulator.

Exercise 2

1. Name the chemical elements that have the following symbols:

Al		Fe		Si	
Be		Pb		Ti	
Cu		Mg		H	

2. Explain the term Brownian motion. Why does this support the Kinetic theory of matter?

3. Draw an atom of Helium, that has the atomic number 2 and an atomic mass of 4. Show the nucleus, number of protons and neutrons, electron shells. Explain why this atom does not easily form molecules.

4. Describe the process of covalent bonding and give an example of a molecule that has covalent bonds.

5. Describe ionic bonding and give an example of a molecule that has ionic bonding.

6. Describe metallic bonding.

7. List the characteristic properties a metal.

8. Why do metals show good electrical and thermal conduction?

9. Why are many non-metals insulators?

SC1.7 – EXPLAIN THE RELATIONSHIP BETWEEN THE COMMON TEMPERATURE SCALES
SC1.8 – CONVERT TEMPERATURE VALUES BETWEEN THE COMMON TEMPERATURE SCALES

Temperature scales

77. The SI unit of temperature is Kelvin; however, temperature can also be measured in degrees Celsius (°C) or degrees Fahrenheit (°F).

78. Kelvin is a temperature scale based on absolute zero temperature.

79. Absolute zero temperature is the lowest possible temperature where nothing could be colder and no heat energy (or kinetic energy) remains in a substance. Absolute zero is the point at which there is a complete cessation of any molecular movement and is defined as being precisely 0 K and corresponds to −273.15 °C. This is a condition that has not yet been achieved.

80. Absolute Temperature is the temperature measured from absolute zero. To show the relationship between the Kelvin temperature scale and the Celsius scale refer to Figure 17.

Note that 1 °C = 1 K

81. Absolute temperature in Kelvin can be calculated using the following relationship:

$$K = °C + 273.15$$

82. Kelvin and Celsius temperature scales are compared in Figure 17 below.

83. °C (Celsius) relates to the Celsius temperature scale (previously known as the centigrade scale). It is defined by two fixed points of temperature, namely the melting point of pure water (0°C) and the boiling point of pure water (100 °C), measured at normal atmospheric pressure (1.013 bar).

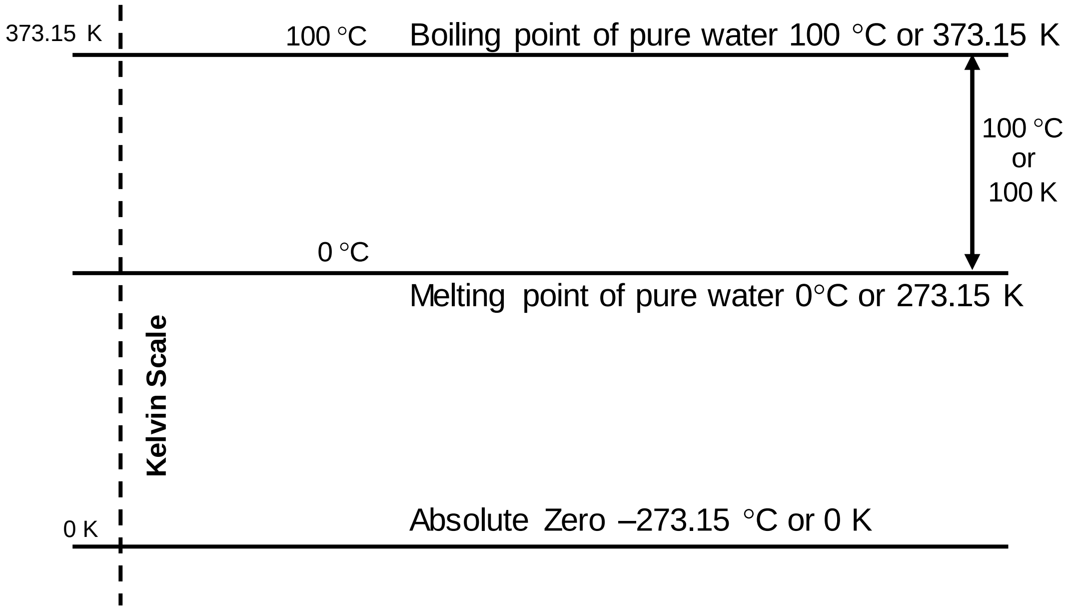


Figure 17 - Comparison of Kelvin and Celsius temperature scales

84. °F (Fahrenheit) relates to the Fahrenheit temperature scale. It is defined by two fixed points of temperature, namely the melting point of pure water (32 °F) and the boiling point of pure water (212 °F), measured at normal atmospheric pressure (note 180 divisions as opposed to 100 for °C).

Note that the Fahrenheit scale has 180 divisions between the fixed points and the Celsius has 100 divisions, giving a ratio of 180 to 100, which simplifies to ratio of 9 to 5.

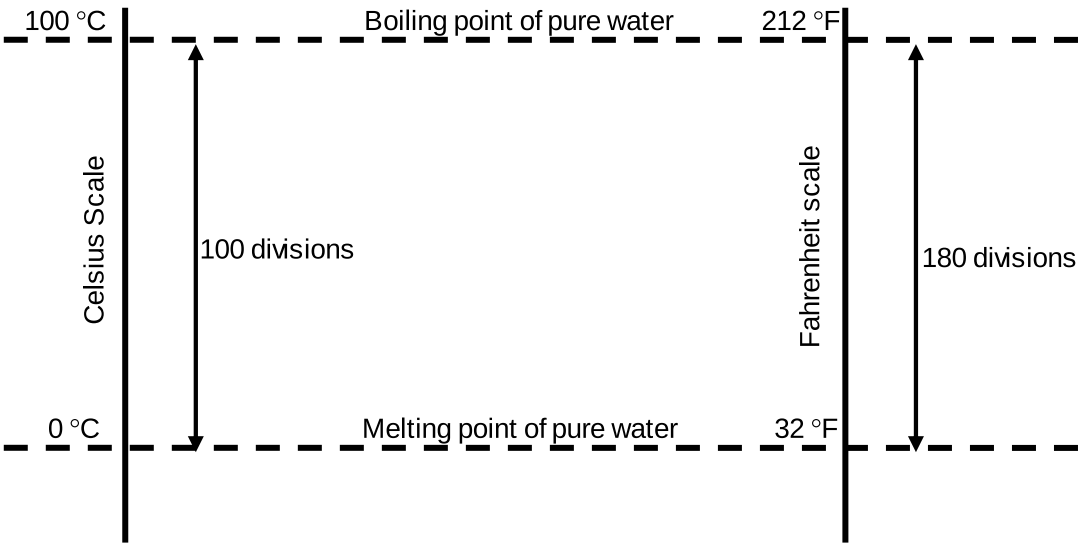


Figure 18 - Comparison of Celsius and Fahrenheit temperature scales

85. This relationship allows us to develop the following formulae that will facilitate the conversion between the two temperature scales.

$$°F = \left(°C \times \frac{9}{5}\right) + 32$$

$$°C = (°F - 32) \times \frac{5}{9}$$

Examples:

86. Convert 32 °C to °F

$$°F = \left(°C \times \frac{9}{5}\right) + 32$$

$$°F = \left(32 \times \frac{9}{5}\right) + 32 = 89.6°F$$

87. Convert 150 °F to °C

$$°C = (°F - 32) \times \frac{5}{9}$$

$$°C = (150 - 32) \times \frac{5}{9} = 65.6°C$$

Note: In an examination you will be given these formulae.

Example:

88. Convert 74 °C to Kelvin

$$K = °C + 273.15$$

$$= 74 + 273.15 = 347.15\ K$$

89. A handy conversion chart for temperature conversions is given in Table 4 below.

To find	From	Formula
Fahrenheit	Celsius	$°F = \left(°C \times \frac{9}{5}\right) + 32$
Celsius	Fahrenheit	$°C = (°F - 32) \times \frac{5}{9}$
Kelvin	Celsius	$K = °C + 273.15$
Celsius	Kelvin	$°C = K - 273.15$

Table 4 - Temperature conversion formulas

Exercise 3

1. Explain the difference between temperature and heat.

2. A Celsius thermometer changes its value by +5 ^{0}C over a period of 1 hour. What would the change be in Kelvin?

3. Convert the following temperatures to Fahrenheit

   a. 34 ^{0}C   b. 247 ^{0}C   c. 1 550 ^{0}C

4. Convert the following temperature to Celsius

   a. 87 ^{0}F   b. 540 ^{0}F   c. 2 300 ^{0}F

5. Convert the following temperatures to Kelvin

   a. 35 ^{0}C   b. 112 ^{0}C   c. 333 ^{0}F

6. Convert the following temperatures to Fahrenheit

   a. 293 K   b. 533 K

MATTER CONSOLIDATION

1. Briefly explain the term ‘matter’.

2. What type of matter has its molecules widely spaced and has very weak force of attraction?

3. In the space below, define as clearly as possible the term ‘Sensible Heat’

4. Name the two Latent Heat energies that occur as matter changes state and define one of them in the space below.

5. What is the SI unit for Latent Heat of Fusion?

6. Name the particles that make up an atom and state their charge.

7. What is an Isotope?

8. In your own words describe a Covalent bond.

9. In your own word describe an Ionic bond.

10. How does metallic bonding differ from covalent and ionic bonding?

11. Describe Brownian motion.

12. Match the following elements on the left with its chemical symbols:

Lead	Ti
Aluminium	Fe
Copper	Ni
Iron	C
Silicon	Pb
Carbon	Cu
Titanium	Al
Zinc	Si
Tin	Sn
Nickel	Zn

Answers to Exercises

Exercise 1 p10

1. Total kinetic energy of all the particles in a body.

2. Average kinetic energy of particles in a body, or degree of hotness or coldness of a body.

3. See handout p 8

4. a 8,4 MJ
   b 1.69 MJ
   c 2.21 kg

Exercise 2 p20

1.

Aluminium	Iron	Silicon
Beryllium	Lead	Titanium
Copper	Magnesium	Hydrogen

2. Random motion of small particles due to collisions caused by thermal molecular motion. Theory is all matter is constantly in motion.

3. See handout – 2 electrons in outer shell = full valence shell therefore inert.

4. Sharing electrons in valance shell so each thinks full and more stable.

   e.g. Hydrogen.

5. Electrostatic bond where free electron in 1 element “donates” to fill valence shell of another element each now bonded and stabilised. e.g. Lithium fluoride.

6. Clouds of negative charged electrons floating between positive ions.

7. High strength, stiffness and ductility. Easy to work. Conductor.

8. Due to movement of free electrons.

9. Due to lack of free electrons.

Exercise 3 p24

1. Temperature is the degree of hotness or coldness and is the average KE of a body. Heat is a form of energy and is the total KE of a body.

2. 5 Kelvin.

3.	a.	93.2 ^{0}F	b.	476.6 ^{0}F	c.	2 822 ^{0}F
4.	a.	30.56 ^{0}C	b.	282.22 ^{0}C	c.	1 260 ^{0}C
5.	a.	308.15 K	b.	385.15 K	c.	440.37 K
6.	a.	67.73 ^{0}F	b.	499.73 ^{0}F		

Answers to Matter Consolidation

1	Objects that take up space and have mass are called matter
2	A Gas
3	Heat added to body and its temperature increases
4	Latent heat of Fusion / Vaporisation. See handout p9
5	J/kg
6	Neutron no charge; Proton +ve; Electron -ve
7	Atoms with same number of protons but different neutrons
8	Sharing of electrons between 2 atoms
9	Electrostatic attraction
10	Weakest bond where sea of electrons shared temporarily
11	Random motion of pollen/smoke due to thermal molecule motion
12	See handout pages 11-14

SCIENCE DEFINITIONS

Book 1 – Matter

Atom	The smallest amount of any element
Electron	Negative charge - Orbit in shells (Max 2-8-18-32)
Valence Shell	Outermost shell
Valence Electron	Electron in valence shell
Proton	Positive charge - Part of the nucleus
Atomic Number	Number of protons
Neutrons	No charge - Part of the nucleus
Nucleus	Centre of an atom - Contains protons and neutrons
Positive Ion	Atom with less electrons than a standard atom
Negative Ion	Atom with more electrons than a standard atom
Isotope	Has more, or less, neutrons than a standard atom of that element
Molecule	2 or more atoms bonded together - Can be same or different elements
Compound	2 or more elements chemically bonded
Mixture	2 or more substances mixed together but not chemically bonded
Covalent Bond	Sharing of valence electrons – Strongest bond
Ionic Bond	Metal gives away an electron – Non-metal gains an electron – Electrostatic bond.
Metallic Bond	Many free electrons - Weakest of the 3 bonds
Features of Metals	Strength, Workability, Stiffness, Ductility - Good conductors
Kinetic Theory of Matter	Above absolute zero, all particles have kinetic energy (KE)
Kinetic Molecular Motion	Vibrational in solids - Linear in gases
Brownian Motion	Molecules within a fluid colliding with small particles causing random jerky motion. A good demonstration of the kinetic theory of matter

Sublimation	Solid to Gas or Vapour - Dry Ice
Deposition	Gas or Vapour to Solid - Haw Frost
Latent Heating	Change of state - no change of temperature
Sensible Heating	Change of temperature - no change of state
Latent Heat of Fusion	Heat energy (J) required to melt 1 kg of a substance
Latent Heat of Vaporisation	Heat energy (J) required to vaporise 1 kg of a substance
Heat	Form of energy (J) - Total KE of all the particles in a body
Temperature	Hotness or coldness of a body - Average KE of all the particles in a body Measured in Kelvin

Periodic Table of the Elements

Atomic Number → 5 10.811 ← Atomic Mass
B ← Symbol
Element Name → Boron

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 1.0079 H Hydrogen																	2 4.0026 He Helium
2	3 6.941 Li Lithium	4 9.0122 Be Beryllium											5 10.811 B Boron	6 12.011 C Carbon	7 14.007 N Nitrogen	8 15.999 O Oxygen	9 18.998 F Fluorine	10 20.180 Ne Neon
3	11 22.99 Na Sodium	12 4.305 Mg Magnesium											13 26.982 Al Aluminium	14 28.086 Si Silicon	15 30.974 P Phosphorus	16 32.065 S Sulphur	17 35.453 Cl Chlorine	18 39.948 Ar Argon
4	19 39.098 K Potassium	20 40.078 Ca Calcium	21 44.956 Sc Scandium	22 47.867 Ti Titanium	23 50.942 V Vanadium	24 51.996 Cr Chromium	25 54.938 Mn Manganese	26 55.845 Fe Iron	27 58.933 Co Cobalt	28 58.693 Ni Nickel	29 63.546 Cu Copper	30 65.39 Zn Zinc	31 69.723 Ga Gallium	32 72.64 Ge Germanium	33 74.922 As Arsenic	34 78.96 Se Selenium	35 79.904 Br Bromine	36 83.80 Kr Krypton
5	37 85.468 Rb Rubidium	38 87.62 Sr Strontium	39 88.906 Y Yttrium	40 91.224 Zr Zirconium	41 92.906 Nb Niobium	42 95.94 Mo Molybdenum	43 98 Tc Technetium	44 101.07 Ru Ruthenium	45 102.91 Rh Rhodium	46 106.42 Pd Palladium	47 107.87 Ag Silver	48 112.41 Cd Cadmium	49 114.82 In Indium	50 118.71 Sn Tin	51 121.76 Sb Antimony	52 127.60 Te Tellurium	53 126.90 I Iodine	54 131.29 Xe Xenon
6	55 132.91 Cs Caesium	56 137.33 Ba Barium	57_71 La–Lu Lanthanide	72 178.49 Hf Hafnium	73 180.95 Ta Tantalum	74 183.84 W Tungsten	75 186.21 Re Rhenium	76 190.23 Os Osmium	77 192.22 Ir Iridium	78 195.08 Pt Platinum	79 196.97 Au Gold	80 200.59 Hg Mercury	81 204.38 Tl Thallium	82 207.2 Pb Lead	83 208.98 Bi Bismuth	84 209 Po Polonium	85 210 At Astatine	86 222 Rn Radon
7	87 223 Fr Francium	88 226 Ra Radium	89_103 Ac—Lr Actinide	104 261 Rf Rutherfordium	105 262 Db Dubnium	106 266 Sg Seaborgium	107 264 Bh Bohrium	108 277 Hs Hassium	109 278 Mt Meitnerium	110 281 Ds Darmstatium	111 282 Rg Roentgenium	112 285 Cn Copernicium	113 286 Nh Nihonium	114 289 Fl Flerovium	115 290 Mc Moscovium	116 293 Lv Livermorium	117 294 Ts Tenessine	118 294 Og Ogenesson

Lanthanide

57 138.91 La Lanthanium	58 140.12 Ce Cerium	59 140.91 Pr Praseodymium	60 144.24 Nd Neodymium	61 145 Pm Promethium	62 150.36 Sm Samarium	63 151.96 Eu Europium	64 157.25 Gd Gadolinium	65 158.93 Tb Terbium	66 162.50 Dy Dysprosium	67 164.93 Ho Holmium	68 167.26 Er Erbium	69 168.93 Tm Thalium	70 173.04 Yb Ytterbium	71 174.97 Lu Lutetium

Actinide

89 227 Ac Actinium	90 232.04 Th Thorium	91 231.04 Pa Protactium	92 238.03 U Uranium	93 237 Np Neptunium	94 244 Pu Plutonium	95 243 Am Americium	96 247 Cm Curium	97 247 Bk Berkelium	98 251 Cf Californium	99 252 Es Einsteinium	100 257 Fm Fermium	101 258 Md Mendlevium	102 259 No Nobelium	103 262 Lr Lawrencium

Atomic Number	Name	Symbol	Atomic Number	Name	Symbol	Atomic Number	Name	Symbol
1	**Hydrogen**	**H**	46	Palladium	Pd	91	Protactinium	Pa
2	Helium	He	47	Silver	Ag	92	Uranium	U
3	Lithium	Li	48	Cadmium	Cd	93	Neptunium	Np
4	**Beryllium**	**Be**	49	Indium	In	94	Plutonium	Pu
5	Boron	B	50	Tin	Sn	95	Americium	Am
6	**Carbon**	**C**	51	Antimony	Sb	96	Curium	Cm
7	**Nitrogen**	**N**	52	Tellurium	Te	97	Berkelium	Bk
8	**Oxygen**	**O**	53	Iodine	I	98	Californium	Cf
9	Fluorine	F	54	Xenon	Xe	99	Einsteinium	Es
10	Neon	Ne	55	Caesium	Cs	100	Fermium	Fm
11	Sodium	Na	56	Barium	Ba	101	Mendelevium	Md
12	**Magnesium**	**Mg**	57	Lanthanum	La	102	Nobelium	No
13	**Aluminium**	**Al**	58	Cerium	Ce	103	Lawrencium	Lr
14	**Silicon**	**Si**	59	Praseodymium	Pr	104	Rutherfordium	Rf
15	Phosphorus	P	60	Neodymium	Nd	105	Dubnium	Db
16	Sulphur	S	61	Promethium	Pm	106	Seaborgium	Sg
17	Chlorine	Cl	62	Samarium	Sm	107	Bohrium	Bh
18	Argon	Ar	63	Europium	Eu	108	Hassium	Hs
19	Potassium	K	64	Gadolinium	Gd	109	Meitnerium	Mt
20	Calcium	Ca	65	Terbium	Tb	110	Darmstadtium	Ds
21	Scandium	Sc	66	Dysprosium	Dy	111	Roentgenium	Rg
22	**Titanium**	**Ti**	67	Holmium	Ho	112	Copernicium	Cn
23	Vanadium	V	68	Erbium	Er	113	Nihonium	Nh
24	Chromium	Cr	69	Thulium	Tm	114	Flerovium	Fl
25	Manganese	Mn	70	Ytterbium	Yb	115	Moscovium	Mc
26	**Iron**	**Fe**	71	Lutetium	Lu	116	Livermorium	Lv
27	Cobalt	Co	72	Hafnium	Hf	117	Tennessine	Ts
28	Nickel	Ni	73	Tantalum	Ta	118	Oganesson	Og
29	**Copper**	**Cu**	74	Tungsten	W			
30	Zinc	Zn	75	Rhenium	Re			
31	Gallium	Ga	76	Osmium	Os			
32	Germanium	Ge	77	Iridium	Ir			
33	Arsenic	As	78	Platinum	Pt			
34	Selenium	Se	79	Gold	Au			
35	Bromine	Br	80	Mercury	Hg			
36	Krypton	Kr	81	Thallium	Tl			
37	Rubidium	Rb	**82**	**Lead**	**Pb**			
38	Strontium	Sr	83	Bismuth	Bi			
39	Yttrium	Y	84	Polonium	Po			
40	Zirconium	Zr	85	Astatine	At			
41	Niobium	Nb	86	Radon	Rn			
42	Molybdenum	Mo	87	Francium	Fr			
43	Technetium	Tc	88	Radium	Ra			
44	Ruthenium	Ru	89	Actinium	Ac			
45	Rhodium	Rh	90	Thorium	Th			

Note: you are expected to know the elements highlighted in bold for examination purposes.