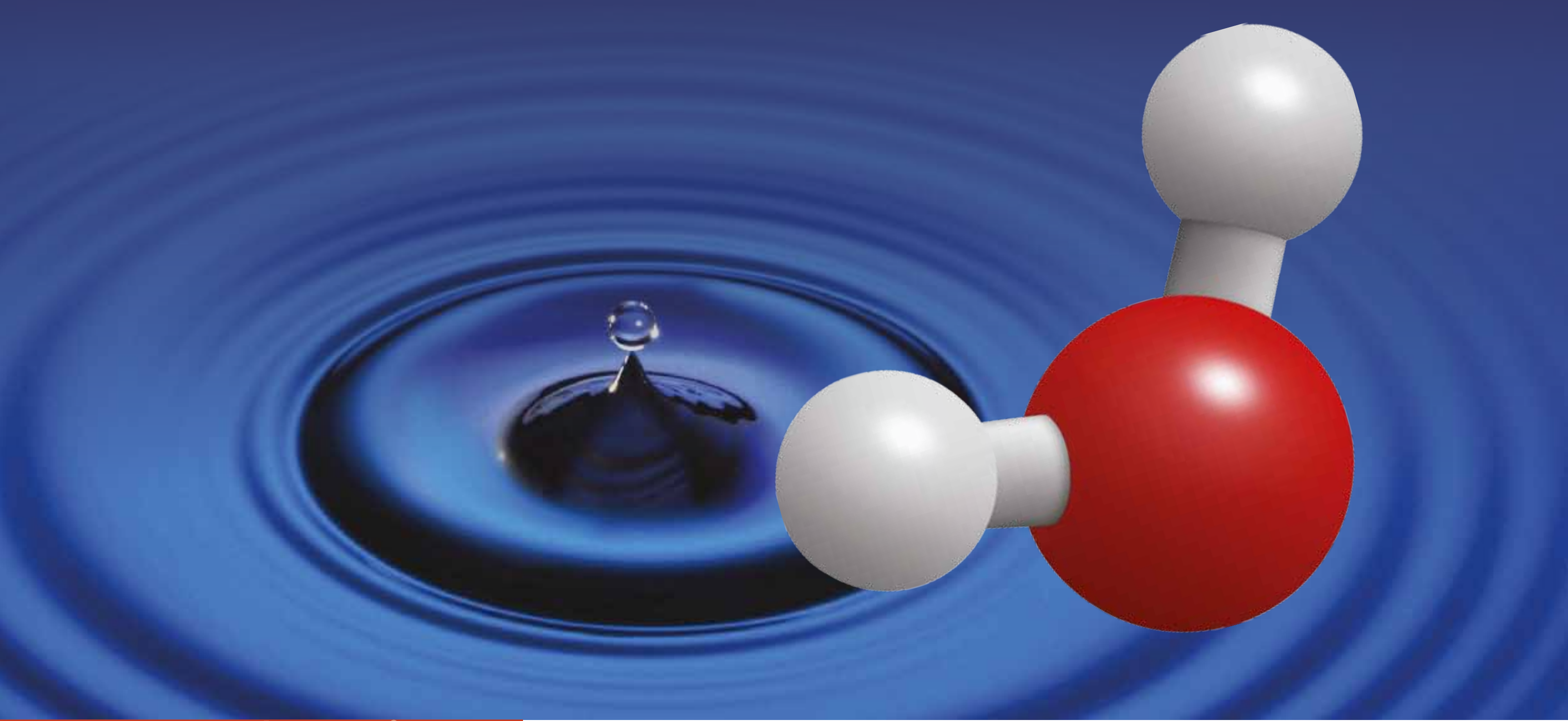
06 Chemical Bonds



Introduction

In previous chapters, students were introduced to elements, compounds, atoms, molecules, ions, the structure of atoms and chemical formulae. In this chapter, all these ideas are brought together in order to explain what holds the particles together in elements and compounds and the reason for their formulae. Different kinds of chemical bonds as well as the different structures in elements and compounds are discussed. Students are introduced to the different kinds of visual models to help them appreciate the structures of these substances.

Chapter Opener (page 83)

1. To open the chapter, the following questions could be discussed. Precise answers are not needed at this stage.

What is a chemical bond?

Answer: A chemical bond is a force that holds particles together.

How are atoms held together?

Answer: By forces of attraction between the atoms.

What kinds of bonds are there?

Answer: Refer to page 85 of the Textbook.

What kind of model do chemists use to visualise the bonding in molecules? What is the advantage and a limitation of this kind of model?

Answer: Ball-and-stick models. They show the bonding between the atoms in the molecule but do not show the actual shape of the molecule.

2. Carry out an 'Inquiry Preview.'

Learning Outcomes

After completing this chapter, the students should be able to:

- describe the formation of ionic bonds between metals and non-metals
- state that ionic materials contain a giant lattice in which ions are held together by electrostatic forces
- deduce the formulae and names of ionic compounds
- describe the formation of a covalent bond by the sharing of electrons
- describe, with the aid of diagrams, the formation of covalent bonds between non-metallic elements
- deduce the arrangement of electrons in covalent molecules
- state the kind of structures that substances with ionic and covalent bonding have
- compare the bonding and structures of diamond and graphite
- describe metals as a lattice of positive ions in a; sea of electrons
- define a metallic bond

Teaching pointers

6.1 What Holds Atoms Together? (page 84)

Stimulation

Show samples of the elements, compounds as well as the (space-filling) models shown in Figure 6.1 on page 84 of the Textbook. Introduce the idea of a chemical bond. Use the Skills Practice questions on page 95 of the Textbook to check students' understanding of key concepts to be learnt in this chapter. As part of the inquiry preview, get students to construct a list of questions based on Figure 6.1. Examples:

- Why do copper and sodium chloride form giant structures but not chlorine and water?
- Why does water have the formula H_2O?
- How do the two atoms in the chlorine molecule bond/join together?
- Why is the formula of the chlorine molecule Cl_2 and not, for example, Cl_3?

Students should attempt to answer their lists of questions as the chapter is being taught. This preview reinforces the importance of asking questions in science and aids in the learning of concepts.

1. Electrical conductivity is key evidence for the kinds of bonds present in substances. Although the syllabus does not require students to have this knowledge, it could still be mentioned to the class. Refer to the 'Notes for Teachers' below for a classification of substances according to their electrical conductivity and the types of bonding present in them.
2. The theory of chemical bonding was not proposed until the 20th Century, after the nuclear model of the atom and electronic structure of atoms were understood.

Skills Practice (page 85)

1. **(a)** **(i)** Copper. **(ii)** Chlorine and water. **(iii)** Sodium chloride.
   (b) **(i)** Sodium chloride. **(ii)** Chlorine and water. **(iii)** Copper.
2. The particles would not stay together.
3. **(a)** Sodium: 2.8.1 Chlorine: 2.8.7
   (b) Students *might* be able to suggest that to get a stable electronic structure, such as that of a noble gas, sodium atoms lose their outer electron while the outer shells of chlorine atoms gain one electron.

Notes for Teachers

Electrical conductivity and types of bonding

Conductors of electricity:

- Metals have metallic bonding (though this is not required in the Science: Chemistry syllabus).
- Electrolytes (substances that conduct electricity when in molten or aqueous solution) consist of ions and have ionic bonding.

Non-conductors of electricity:

These substances do not have ions; they have covalent bonding. They include:

- Non-metals
- Many compounds

Teaching pointers

6.2 How are Ionic Bonds Formed? (page 85)

1. Link this topic with the formation of ions in Chapter 4. Again, remind students that historically, the concept and the term 'ion' were used *before* electrons were discovered so how the charge on an ion arose was not understood.
2. Emphasise the basic idea that when chemical bonds are formed, atoms obtain the stable electronic structure of the noble gas nearest to them in the Periodic Table. In ionic bonding, this occurs by the transfer of electrons which was first suggested by Kossel and Lewis in 1916.
3. Teachers might demonstrate the burning of sodium in chlorine and get students to visualise the changes taking place as ionic bonds form. Heat a small piece of sodium in a deflagrating spoon and place it in a gas jar of chlorine gas as shown in the diagram below. A white solid of sodium chloride is formed.
4. Get students to draw the electronic structures for a variety of ionic compounds.
5. Show a model of the structure of sodium chloride (similar to Figure 6.5 on page 97 of the Textbook) and point out the rows of sodium and chloride ions. Emphasise the lack of any Na^+Cl^- pairs.
6. Chemistry in Society (page 87) discusses colours in gemstones produced by ions. Show the class examples of coloured solutions of compounds with the ions in Figure 6.6 such as chromium(III) sulfate (Cr^{3+} ions, green), iron(III) sulfate (Fe^{3+} ions, yellow/brown), iron(II) sulfate (Fe^{2+} ions, greenish) and copper(II) sulfate (Cu^{2+} ions, blue), This could serve as an introduction to the work on qualitative analysis studied in Chapter 18. See also the 'Notes for Teachers' on page 83.

Skills Practice (page 87)

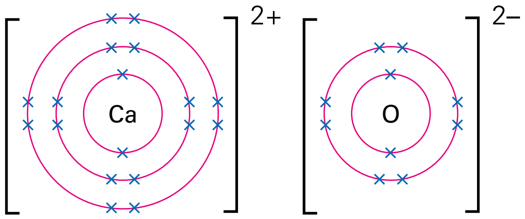
1. A sodium atom loses one electron to form a sodium ion, Na^+. One electron is transferred to a chlorine atom to form a chloride ion, Cl^-. One positive sodium ion and one negative chloride ion are attracted together by an electrostatic force. This force of attraction is the ionic bond.

2. Magnesium chloride and magnesium fluoride: Both have a similar formula MgX_2. The magnesium ion in both is Mg^{2+}. The fluoride ion and chloride ion both have a charge of 1–. The fluoride ion has only two electron shells compared with three for the chloride ion.

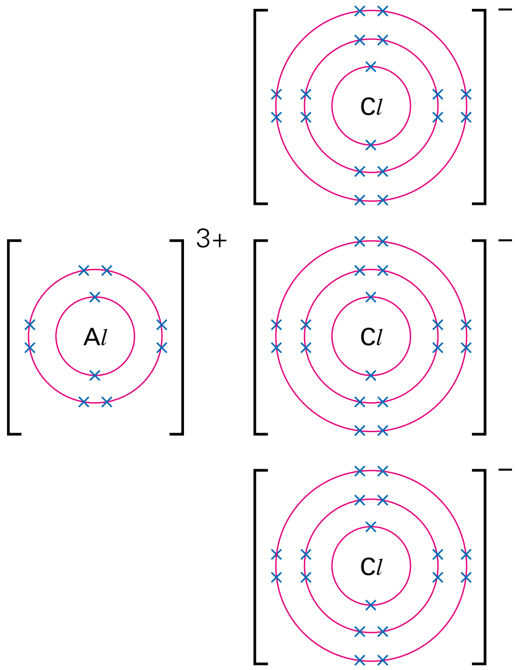
   Lithium fluoride and magnesium fluoride: Have the formulae LiF and MgF_2 respectively. The iodide ion is the same in both. The lithium ion has a charge of +1 compared with +2 for the magnesium ion.

3. The structure of sodium chloride consists of large numbers of ions, with the positive sodium ion and the negative chloride ion alternating with each other repeatedly throughout the structure. There are no Na^+Cl^- pairs.

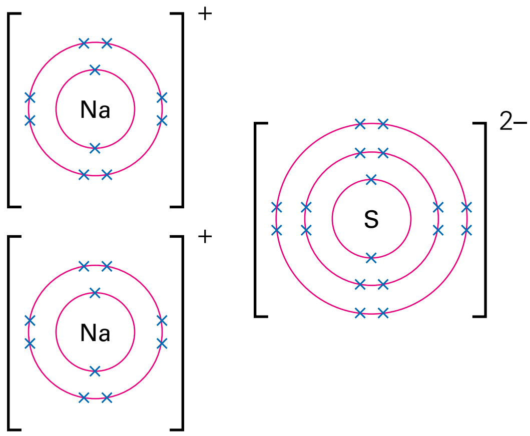
4. **(a)** Electron diagram of calcium oxide:



(b) Electron diagram of aluminium chloride:



(c) Electron diagram of sodium sulfide:



Notes for Teachers

Animations for ionic bonding
Animations of the formation of ionic bonds in compounds:

http://www.bbc.co.uk/schools/gcsebitesize/science/add_aqa_pre_2011/atomic/ionicrev4.shtml
http://www.visionlearning.com/library/module_viewer.php?mid=55

(Click on 'The reaction of sodium with chlorine')
http://www2.nl.edu/jste/bonds.htm

Aluminium oxide:
http://faculty.ucc.edu/chemistry-pankuch/AlO3/AlO3_Quest.dcr

Aluminium fluoride:
http://faculty.ucc.edu/chemistry-pankuch/AlF3/AlF3_Quest.dcr

Teaching pointers

Formulae and Names of Ionic Compounds (page 88)

1. Link the formation of simple ions with the gain or loss of outer shell electrons. However, for elements with proton number 20 and above in the Periodic Table, the electronic structures for these elements need not be shown. The names of simple negative ions end in *–ide*.
2. For polyatomic ions, students will have to accept the structures at this stage. Negative polyatomic ions containing oxygen usually end in *–ite* or *–ate*. The hydroxide ion is an exception to this rule.
3. Again, ensure that students can read and pronounce the names of ions correctly, For example, Cu^{2+} is pronounced as 'C-u-two-plus' or 'copper two plus' while $SO4^{2-}$ is 'S-O-4-two-minus'.
4. For the formulae and names of compounds, revise the notes on the naming of compounds in Section 4.3 on pages 56 of the Textbook.
5. As the writing of formulae can be difficult for many students, Additional Exercise 1 included in this Teacher's Resource File will help. It is a card game for writing formulae of ionic compounds given the names and vice versa. This simplifies the process of formula building, leading to a better grasp of the process. This game has been used in many schools and found to be extremely useful in helping students build ionic formulae quickly and correctly. It is preferable to the cross-multiplication rule, which is sometimes used; although this leads to correct answers, it is mechanical and does not produce understanding. The worksheet can be photocopied and distributed to the class. See also 'Notes for Teachers' below.

(page 88)

Mystery Clue

KI

Skills Practice (page 89)

1. E.g. Simple ions: Silver ion Ag^+, Zinc ion Zn^{2+}, Lead(II) ion Pb^{2+}, Chromium ion Cr^{3+}

   Polyatomic ions: Manganate(VII) ion MnO_4^-, hydrogencarbonate ion HCO_3^-, dichromate(VI) ion $Cr_2O_7^{2-}$
2. MgO, $CaCl_2$, Na_2O, Al_2O_3, $NaOH$, $Ca(OH)_2$, $Cu(NO_3)_2$, $Al_2(SO_4)_3$, $(NH_4)_2CO_3$
3. Potassium chloride, magnesium nitrate, iron(III) oxide, sodium carbonate, manganese(IV) oxide, ammonium chloride
4. (a) The symbols are reversed. $NaCl$
   (b) The subscripts are reversed. Al_2O_3
   (c) The '1' is not needed. $MgCl_2$
   (d) The brackets are not needed. Fe_2O_3
   (e) The subscripts are reversed. Cu_2O
   (f) The brackets are not needed. $CuSO_4$
   (g) Brackets are required. $Fe(NO_3)_3$
   (h) The brackets are misplaced and only one iron atom is required. $Fe(NO_3)_3$

Notes for Teachers

Colours of ions

Aqueous solutions of many ions are coloured. If one ion in a compound is coloured, the whole compound shows that colour. From the colour of a solution, we can often deduce the colours of its ions. For example, solutions of potassium chloride, potassium sulfate and potassium nitrate are all colourless, indicating that all the ions in these solutions are colourless. But potassium dichromate(VI) solution is orange. As the potassium ion is colourless, the orange colour must have come from the dichromate(VI) ion, $Cr_2O_7^{2-}(aq)$.

Cards for formula card game (Additional Exercise 1)

Refer to the end of this chapter for a set of ion cards for building ionic formulae. The cards can be photocopied and cut out to provide sets of models. Each group of students can have a set of cards which should be made available whenever students need to write formulae. The more able students will be able to move quickly from the models to the conventional methods while the less able students should have access to the cards for as long as is necessary. The rule for building a formula is simple; join the positive and negative ion cards together to form a rectangle.

Teaching pointers

6.3 How are Covalent Bonds Formed? (page 89)

1. Covalent bonding provides another good opportunity to discuss how scientific models or theories are modified. The ionic model for chemical bonding cannot account for substances that do not conduct electricity. For this, the covalent model of bonding is required.
2. In forming the covalent bond in a hydrogen molecule, hydrogen atoms end up with two outer shell electrons (as in helium). All other atoms in other covalent substances end up with eight outer shell electrons (as in the noble gas nearest to the atom in the Periodic Table).
3. Formulae such as H – H, O = O, etc, are actually structural formulae. However, there is no need to introduce this additional term at this stage. As each molecule is introduced, show a ball-and-stick model of its structure and discuss it.
4. Details about the structure of molecules such as the bond angles, lone pairs of electrons and molecular shape are not required at 'O' Level.
5. The idea of molecules being three-dimensional was suggested by Jacobus Henricus van't Hoff (see page 94). Van't Hoff was the first recipient of the Nobel Prize in Chemistry, in 1901. His research also provided strong evidence for the existence of molecules as distinct units of matter, confirming the idea first proposed by Avogadro many years earlier.
6. *Models in Chemistry*. In Activity 6.2B, students construct models of covalent molecules (as well as giant covalent structures from section 6.5 of the Textbook). The building of models is extremely instructive so it is best to carry out this activity *after* a discussion of the bonding and structures of the substances. Discuss also the use of both the ball-and-stick models and the space-filling models, together with their advantages and limitations.
7. It is a common misconception among students that covalent bonds (unlike ionic bonds) are weak. Ensure that students do not confuse covalent bonds, which are strong, with the weak forces between the molecules.

Skills Practice (page 91)

1. Two chlorine atoms share one electron each from their outer shells to obtain the stable electronic structure of the noble gas neon. A covalent bond is formed.
2. Both by gaining one electron (to form the chloride ion) or by sharing one electron, the chlorine ion obtains the stable noble gas electronic structure.
3. (a) Refer to Figure 5.11 on page 75.
   (b) (similar figure as for chlorine molecule in Figure 6.10 except '*Cl*' changed to 'F')
   (c) A single covalent bond.

Chemistry Inquiry (page 93)

Models for the Methane Molecule

Group Discussion

1. E.g. A model is a simplified description (using words, diagrams, physical models, mathematical equations). Models are used to help in understanding/explain observations/phenomena and to assist in making predictions.
2. Ball-and-stick models show clearly the number of bonds between each atom. However, they do not show the three-dimensional shape of a molecule very well. Space-filling models show the shape of a molecule, but do not show the bonds between the atoms.
3. Neither kind of model gives a complete picture of what a substance really look like. Because we cannot see atoms and molecules and do not know what they actually look like, we cannot say that one kind model is more correct than another kind.

Skills Practice (page 94)

1. (a) 'Dot and cross' diagram of ammonia:

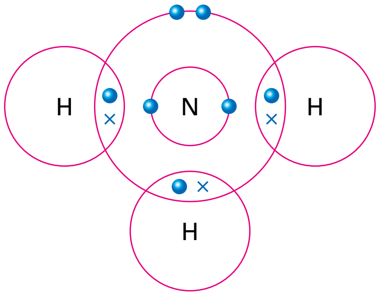
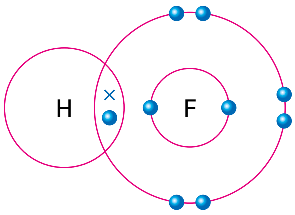


Figure 6.19

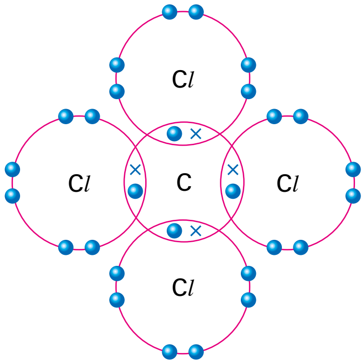
(b) NH_3

2. 'Dot and cross' diagram of hydrogen fluoride:



Formula: HF

3. (a) 'Dot and cross' diagram of tetrachloromethane (only outer shells shown):



(b) 'Tetra' means four and 'chloro' means chlorine. Tetrachloromethane is a methane molecule, CH_4, with the four hydrogen atoms replaced by four chlorine atoms.

4. (a) Covalent (b) Covalent (c) Ionic
(d) Covalent (e) Covalent

5. E.g. Bromine consists of Br_2 molecules. There are strong covalent bonds within the bromine molecules but only weak forces between the molecules. In liquid bromine, the molecules are packed close together but not in an orderly manner.

Notes for Teachers

Formulae and names for simple covalent compounds

Unlike ionic compounds, the formulae of some covalent substances *cannot* be easily predicted. For example, besides forming carbon dioxide, CO_2, carbon and oxygen can also form carbon monoxide, CO. Also, hydrogen and oxygen can form hydrogen peroxide, H_2O_2, as well as water, H_2O. At this stage, students are not able to work out formulae such as CO and H_2O_2.

Also, unlike ionic compounds, the names of many simple covalent substances *cannot* be deduced from their formulae as these compounds have *common* names. For example, the names *methane* and *ammonia* cannot be deduced from their formulae. For such compounds, students will have to memorise the names.

Other covalent substances have *systematic* names, that is, names that can be deduced from their formulae (and vice versa). For example, CO_2 is named carbon dioxide as the molecule has one carbon atom and two oxygen atoms. Another example is carbon tetrachloride which has the formula, CCl_4, as it has one carbon atom and four chlorine atoms. The advantage of systematic names is that the names of the substances can be deduced from their formulae and vice versa. In Section 7 of the Textbook, students will become familiar with the systematic names of organic compounds.

IT Link

Page for atomic structure and bonding — revise, activities, tests:
http://www.bbc.co.uk/schools/gcsebitesize/science/add_aqa_pre_2011/atomic/

Examples of dot and cross models for bonding in covalent molecules:
http://www.bbc.co.uk/schools/gcsebitesize/science/add_aqa_pre_2011/atomic/covalentrev3.shtml
http://www.bbc.co.uk/schools/gcsebitesize/science/add_aqa_pre_2011/atomic/covalentrev4.shtml

Examples of dot and cross models for bonding in covalent molecules and animation for bonding in carbon dioxide:
http://www.bbc.co.uk/schools/gcsebitesize/science/add_gateway_pre_2011/periodictable/covalentbondingrev2.shtml

Covalent bonding activity:
http://www.bbc.co.uk/schools/gcsebitesize/science/add_gateway_pre_2011/periodictable/covalentbond.shtml

Formation of covalent bonds in water:
http://www.absorblearning.com/media/item.action?quick=su
http://www.youtube.com/watch?v=0UAMbP8r9VU

Hydrogen chloride:
http://www.bbc.co.uk/schools/gcsebitesize/science/add_ocr_pre_2011/atmosphere_hydrosphere/airmolecularrev4.shtml

Hydrogen:
http://www2.nl.edu/jste/bonds.htm

Teaching pointers

6.4 What Do Giant Molecular Structures Look Like? (page 95)

1. Giant molecular structures are also known as giant covalent structures as all the bonds in the giant structures are covalent. Refer to Skills Practice Question 1.
2. Giant covalent structures, such as diamond, silicon, quartz (silicon dioxide) and graphite, consist of non-metals.
3. Ensure that students can draw the 'dot and cross' diagrams for diamond, silicon dioxide and graphite without referring to their textbooks.
4. Carry out Activity 6.3C in the Theory Workbook to get students to construct ball-and-stick models of diamond, quartz (silicon dioxide) and graphite.

(page 95)

Mystery Clue

The chemical formula of uranium dioxide is UO_2. The structure and bonding are the same as for SiO_2 in Figure 6.20. There are many single U–O bonds.

Skills Practice (page 96)

1. (a) They are called giant atomic structures as the structures are made of *atoms* joined to other *atoms* in a giant structure. They are called giant molecular structures as many atoms are joined to form one large *molecule*.
   (b) All are appropriate.
2. Silicon.
3. (a) Diamond is a single large molecule with a giant covalent structure. It consists of single covalent bonds between the carbon atoms and each carbon atom is bonded to 4 other carbon atoms.

   Chlorine is a small molecule with a simple molecular structure. It consists of single covalent bonds between pairs of chlorine atoms.
   (b) Silicon dioxide is a single large molecule with the silicon and oxygen atoms in the ratio of 1 : 2. It has a giant covalent structure and there are single covalent bonds between the silicon and oxygen atoms. Carbon dioxide has a simple molecular structure and there is a double bond between a carbon and two oxygen atoms.

Notes for Teachers

Quartz
Quartz contains about 0.000 1% by mass of free gold and is a major source of the metal. Quartz is also the base mineral in the gemstone, amethyst.

Teaching pointers

6.5 How are Metallic Bonds Formed? (page 96)

1. Metals exist as crystals in the solid state. This was first shown using X-ray diffraction.
2. Get students to view the animations of the structure of a metal and of metallic bonding. Examples of websites are given in the 'Notes for Teachers' below. This will give them a good visualisation of the structure and of the behaviour of the delocalised electrons in a metal.

3. To end the discussion on chemical bonds, the class could carry out Additional Exercise 3 on Linus Pauling. The notes and worksheet can be photocopied and distributed to the class. Pauling made a great contribution to our understanding of the nature of the chemical bond, and in particular, the covalent bond. Question 4 could be used as a group or class discussion, either after students have answered the question or instead of this.

Skills Practice (page 97)

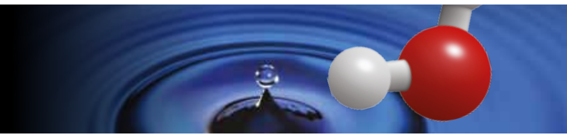
1. Just as the sea consists of many water molecules that are free to move, a metal consists of many free/delocalised electrons that are free to move.
2. **(a)** Two.
   (b) The two electrons in the outer shell.
   (c) The 18 electrons in the inner three shells.
3. In both, the particles are arranged in three-dimensional structures. Both structures consist of ions. Both have outer shell electrons that are detached from the atoms. In metals, the outer shell electrons move freely within the structure. In ionic compounds, the outer shell electrons from metals are transferred to the non-metal part of the compound. Metals consist of one kind of ion; ionic compounds consist of two kinds. In metals, the bonds are between the free electrons and the positive ions; in ionic compounds, the bonds are between the positive and negative ions.

Notes for Teachers

Animation on metallic bonding
There are a number of website animations that students can view on metallic bonding. Here are just three of them:

http://www.youtube.com/watch?v=c4udBSZfLHY
http://www.drkstreet.com/resources/metallic-bonding-animation.swf
http://cd1.edb.hkedcity.net/cd/science/chemistry/resource/animations/metallic_bond/metallic.html

06 Chapter Review



Self-Management

Misconception Analysis (page 97)

1. **False** Both ionic and covalent bonds are strong. They are strong to hold the atoms together. However, the forces *between* molecules are weak.

2. **False** Figure 6.28 shows that magnesium chloride has covalent bonds when in fact, it should have ionic bonds. The ions should be drawn such that they do not touch or overlap with each other.

3. **False** Sodium chloride has a giant ionic structure consisting of many sodium and chloride ions. There are no individual $NaCl$ units/molecules in the structure.

4. **False** The formula, $MgNO_{32}$, suggests incorrectly that there are 32 oxygen atoms. The correct formula is $Mg(NO_3)_2$ which has 6 oxygen atoms.

5. **False** The strong forces are *within* the Cl_2 molecules; there are only weak forces *between* the molecules.

6. **False** Compounds such as CH_4 and NH_3 do have simple molecular structures. But other compounds such as silicon dioxide, SiO_2, have a giant covalent structure.

7. **False** Silicon dioxide is a giant covalent/molecular structure consisting of many silicon and oxygen atoms.

8. **False** A metal is made of atoms. The atoms are held together by *metallic* bonds which consist of the attraction between a lattice of positive ions and a 'sea of electrons' around the positive ions. In ionic bonding, two different kinds of ions (one positive and the other negative) attract each other.

Structured Questions (pages 98–100)

1. (a) 'Dot and cross' diagram of the ions in sodium fluoride:

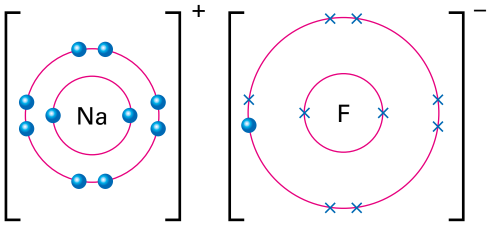
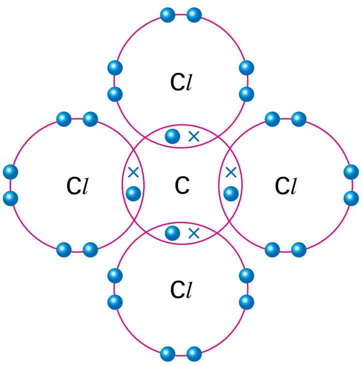


Figure 6.28

(b) NaF
(c) (i) They have the same electronic structures.
(ii) They have different proton numbers and different ionic charges (sodium ion has a charge of +1 while fluoride ion has a charge of –1).
(d) Yes

2. (a) 'Dot and cross' diagram of tetrachloromethane:



(b) CCl_4
(c) Covalent bonding
(d) It has a simple molecular structure. Each discrete unit of the compound is a molecule with just four atoms.
(e) Possible answers: The skill of elaborating is used and it helps to link Figure 6.30 to the formula and the type of bonding and structure. The skill of inferring enables answers to be obtained from the given information and previous knowledge.

3. (a)

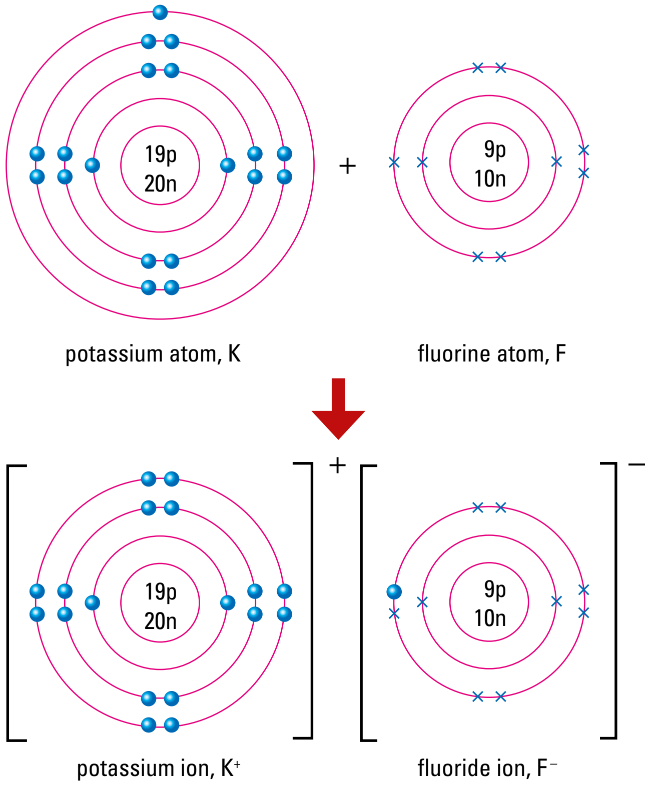


Figure 6.30

(b) KF (or K^+F^-)
(c) The compound has ionic bonding as it consists of (positive) potassium ions and (negative) fluoride ions.
(d)

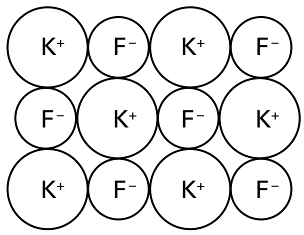


Figure 6.31

4. (a) Covalent bonds (since they are both non-metals)
(b) 'Dot and cross' diagram:

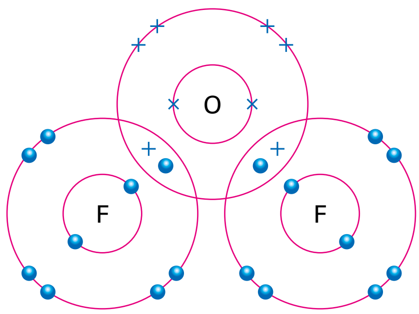
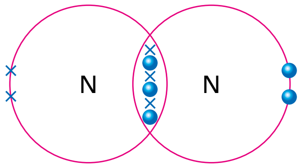


Figure 6.32

5. (a) 'Dot and cross' diagram of N_2 molecule:



(b) Triple bonds

6. (a) Electrons are shared between atoms.
(b) The outer shell of aluminium has only 6 electrons. (Atoms usually have 8 valence electrons.)
(c) Since aluminium is a metal and hydrogen is a non-metal, the bonds in this compound should be ionic and not covalent.

Note: Discuss question 6 with the class. Here is a suggestion as to how the discussion may be carried out.

(a) There are 2 types of bonding. In ionic bonding, electrons are transferred and the ions produced are separate. In covalent bonding, shells overlap and electrons are shared.

What kind of bonding does Figure 6.34 show?
(Answer: covalent bonding)

(b) Think about all the covalent bonds in the molecules you have studied so far, such as H_2, H_2O and CH_4.

How many electrons are there in the outer shells of each atom (i.e. in the shells that overlap)?
(Answer: 2 or 8)

What do you notice about the number of valence electrons of each atom in Figure 6.27?
(Answer: Hydrogen has 2 valence electrons while aluminium has only 6. This is unusual.)

(c) *What type of bonds do you find in compounds of metals and non-metals?*
(Answer: Ionic bonds)

So, what is unusual about aluminium hydride?
(Answer: It is a compound made up of a metal and a non-metal and yet it has covalent bonds.)

Conclusion:
There are exceptions to the 'rules' about bonding. (The study of these exceptions is in the 'A' Level syllabus.)

7. (a)

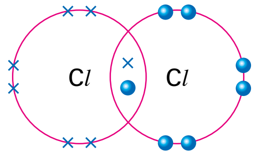
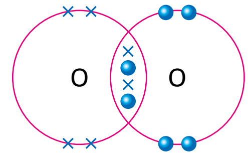
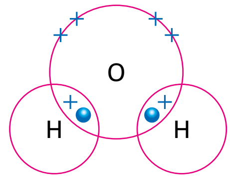
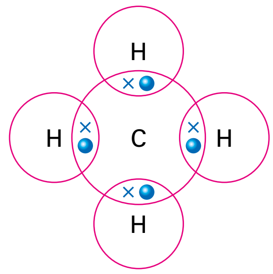
Substance	Formula	Electron diagram (outer shells only)
chlorine gas	Cl_2	
oxygen gas	O_2	
water	H_2O	
methane gas	CH_4	

Table 6.1

(b) Water and methane are compounds. Each consists of more than one kind of element joined together.
(c) There are 4 C–H single covalent bonds in a methane molecule.

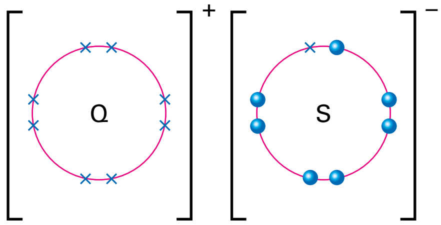
8. (a) Ga^{3+}
(b) (i) $GaCl_3$
(ii) Ga_2O_3

9. (a) **R**
(b) **P** can *only* form bonds by losing its one valence electron to form P^+. **Q**, with 4 valence electrons, would need to gain 4 electrons to form the $\mathbf{Q}^{4-}$ ion or lose all the 4 outer shell electrons to form the $\mathbf{Q}^{4+}$ ion . As this is not possible, **P** cannot combine with **Q**.
(c)

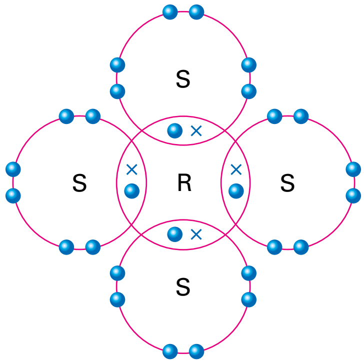
Compound formed between	Type of bond	Formula of compound
P and **R**	Ionic bond	P_2R
Q and **R**	Covalent bond	QR_2
Calcium and **R**	Ionic bond	CaR

10. (a) (i) Q and S (ii) R and S
(b) Electron diagram for:

QS



RS_4



11. (a) To visualise the structure of molecules which are too small to be seen and to help in the understanding of the bonding and shape of molecule.
(b) (i) The model on the left in Figure 6.35 is a ball-and-stick model. (ii) It shows clearly the number of bonds between each atom. (iii) But it does not show the three-dimensional shape of the molecule.
(i) The model on the right in Figure 6.35 is a space-filling model. (ii) It shows the shape of the molecule. (iii) But it does not show the bonds between the atoms.

Free Response Questions (page 100)

For these questions, different responses are possible. Here are examples of how the questions could be answered:

1. Some atoms gain and lose electrons to obtain a noble gas electronic structure. In doing so, these atoms form ions. For example, a sodium atom loses its single outer shell electron to form a sodium ion, Na^+, with the same electronic configuration as neon, that is, 2.8. The outer shell of a chlorine atom gains one electron to form the chloride ion, Cl^-, with the same electronic configuration as argon, that is, 2.8.8. Other atoms share electrons to obtain noble gas electronic structures. For example, in the oxygen molecule, O_2, each oxygen atom shares two electrons in the outer shell to obtain the electronic configuration of 2.8 which is the same as that of neon.

2. In giant ionic structures, there is a three-dimensional array of positive and negative ions held together by ionic bonds. An example is sodium chloride which consists of Na^+ and Cl^- ions.

In giant covalent structures, atoms are held together by covalent bonds in a giant three-dimensional structure. An example of an element with a giant covalent structure is diamond (carbon) which has a giant structure of carbon atoms. A compound with a giant covalent structure is quartz/silicon dioxide which consists of silicon and oxygen atoms.

In simple molecular structures, there are covalent bonds between the atoms in the molecules. Examples include chlorine, Cl^-, which is an element and carbon dioxide, CO_2, which is a compound.

3. Both ionic and covalent bonding depends on a knowledge of electronic structure (number of outer shell electrons), the stable electronic structures of noble gases and the electrical conductivity of substances.

Ionic bonding also builds on the concept of electron transfer to form ions with stable electronic structures and the electrostatic attraction between ions. Covalent bonding also builds on the concept of electron sharing to give stable structures.

Extension (page 100)

1. The molecular modelling program can be downloaded free from the Internet (see Web 6.3), though you may be required to register before doing so. The program is rather sophisticated and you will need to be familiar with it.

The structures are drawn on one page but are viewed on another. Using the original structure of the molecule, different kinds of models such as the ball-and-stick models and space-filling models can be obtained. The colours used for the atoms can be changed.

This program also comes with a library of apparatus such as glassware and heating apparatus, enabling laboratory apparatus to be drawn.

2. Web 6.4 in the Textbook describes a card game in which chemical formulae are matched with their names. You will have to prepare the cards given on the website.

Additional Teaching Material

Additional Exercise 1: A Card Game for Ionic Compounds

Objective

To write chemical formulae of ionic compounds given the names and vice versa

Competencies

CIT: sound reasoning (*analysing, inferring*); creativity (*visualising, generating formulae*)

Learning through games

Games can be a fun way to learn. For example, there are games in which you create a city while thinking about things such as pollution and energy needs. In this activity, you will play a game to write the chemical formulae for ionic compounds.

How to play the game

Your teacher will give you a set of cards representing common anions and cations. Each card has the formula and the name of the ion written on it.

To get a correct chemical formula, join the shapes together to form a rectangle. The formula can then be read or copied from the cards. For example, to find the formula of copper(II) chloride, a complete rectangle is formed by joining one copper(II) ion card and two chloride ion cards (Figure 1). Hence the formula of copper(II) chloride is $CuCl_2$.

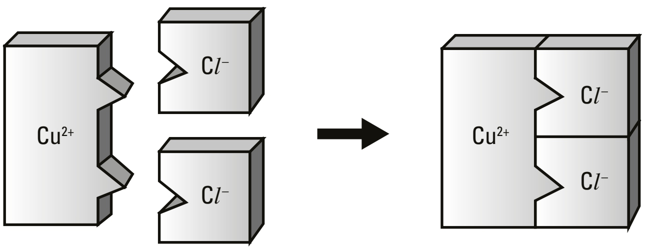


Figure 1 Forming the formula for copper(II) chloide

1. Now use the cards to work out the chemical formulae of the following ionic compounds.

(a) potassium chloride ____________

(b) zinc chloride ____________

(c) copper(II) oxide ____________

(d) potassium sulfate ____________

(e) potassium manganate(VII) ____________

(f) sodium hydrogencarbonate ____________

(g) potassium dichromate(VI) ____________

(h) magnesium hydroxide ____________

(i) iron(II) sulfide ____________

(j) sodium sulfite ____________

(k) iron(III) oxide ____________

(l) iron(II) nitrate ____________

(m) ammonium nitrate ____________

(n) iron(III) sulfate ____________

(o) ammonium sulfate ____________

2. Name the compounds with the following formulae.

(a) KI ______________________

(b) K_3PO_4 ______________________

(c) $AgNO_3$ ______________________

(d) Al_2O_3 ______________________

(e) $HgCl_2$ ______________________

(f) $(NH_4)_2Cr_2O_7$ ______________________

(g) $Ca(NO_3)_2$ ______________________

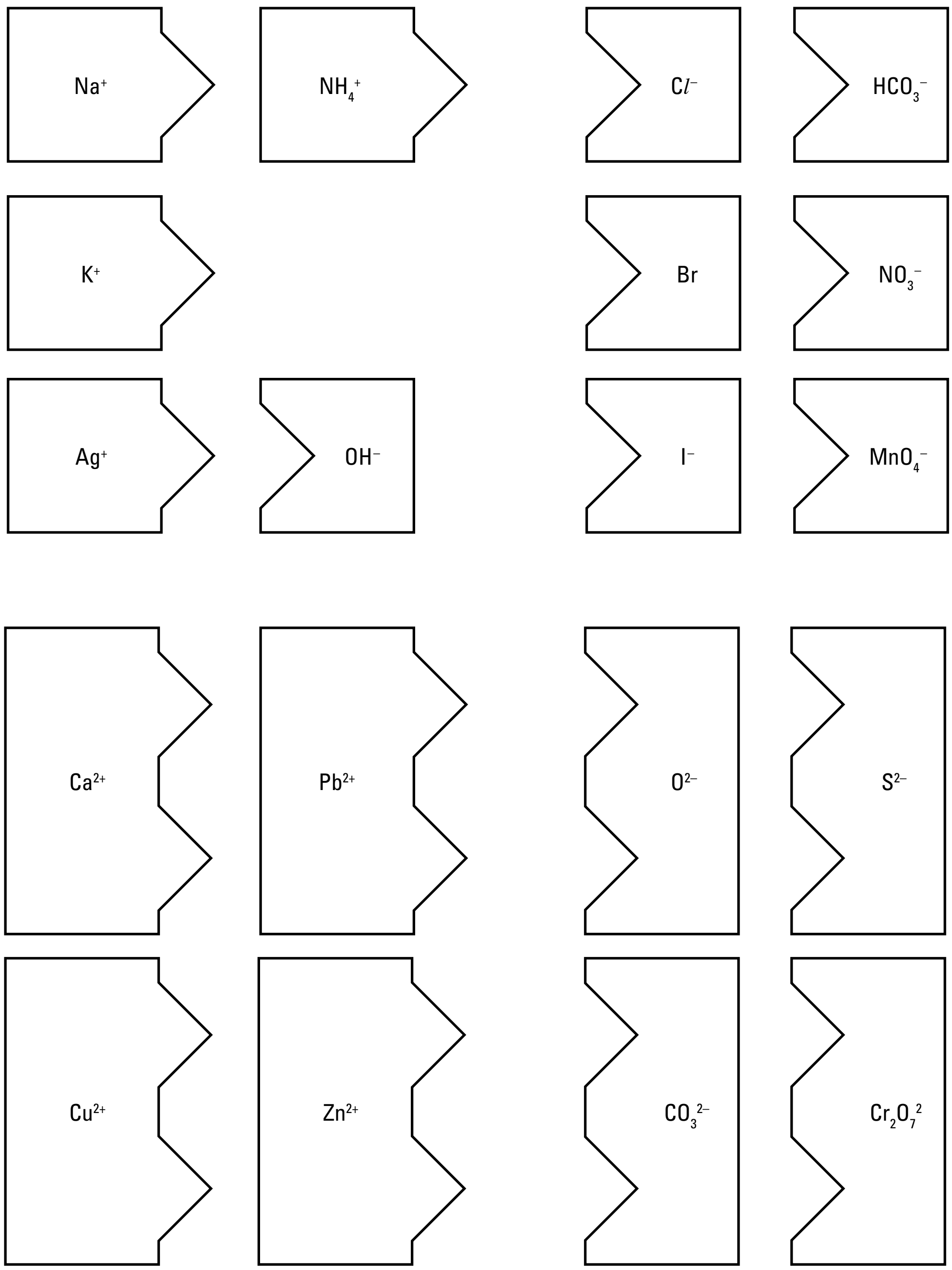
(h) $Cr_2(SO_4)_3$ ______________________

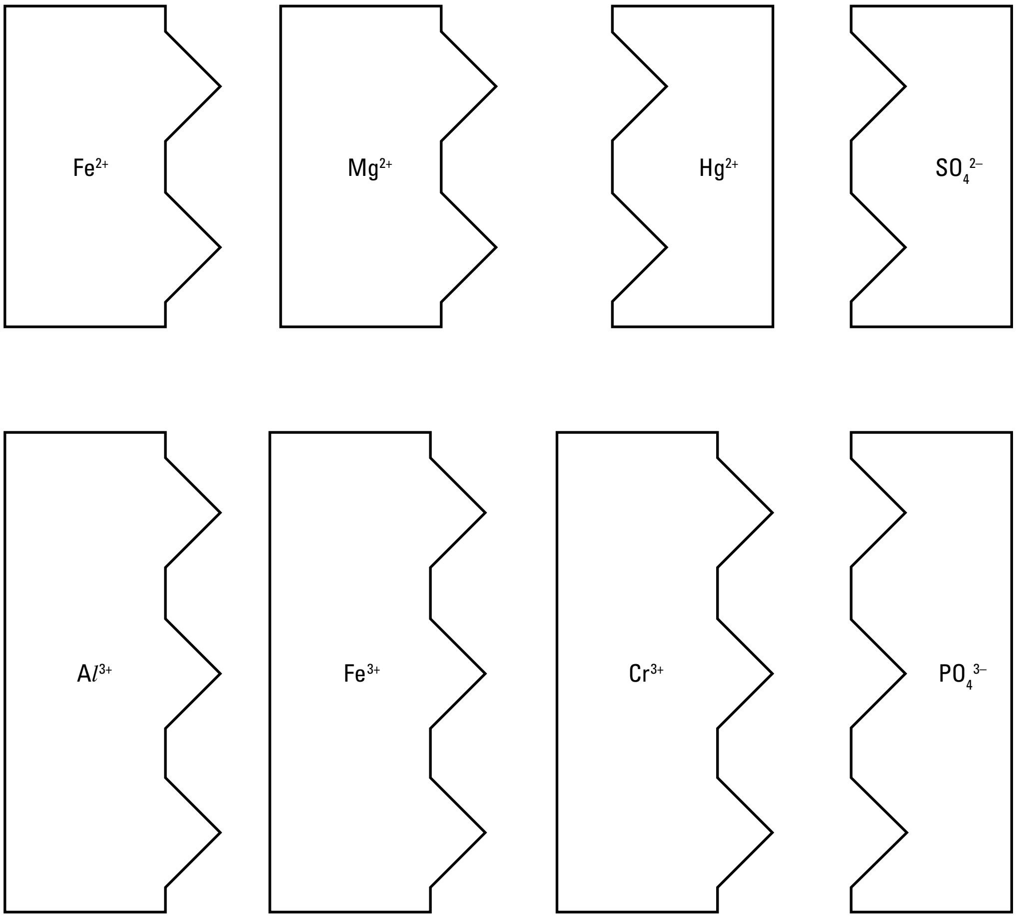
3. With or without the cards, work out the formulae and names of six or more other ionic compounds.

____

____

Cards for Ionic Formula Building Game




Fe^{2+}
Mg^{2+}
Hg^{2+}
SO_4^{2-}
Al^{3+}
Fe^{3+}
Cr^{3+}
PO_4^{3-}

Additional Teaching Material

Additional Exercise 2: Bonding and Structure — Key Concepts

Complete the table for the types of bonding and structure of elements and compounds.

	Type of structure	Type of particle	Type of bond	Example
Elements (non-metals)	simple molecular			
				carbon (diamond)
Compounds			ionic	
		molecules		
	giant covalent			

Additional Teaching Material

Additional Exercise 3: Case Study: A Famous Chemist — Linus Pauling

Objective

- To appreciate the contribution to chemistry by one famous chemist

Competencies

CLGAC: global awareness (*contribution of scientists; ethical issues in science*); social awareness

CIT: sound reasoning (*predicting, analysing, inferring, explaining, comparing*); creativity (*using physical models*)

ICS: openness (*willingness to receive, explore and respond to other ideas and perspectives*); management of information (*locating and using information to gain understanding*)

Linus Pauling was an American chemist (Figure 1). He was famous for his work on chemical bonding. In 1954, he was awarded the Nobel Prize in Chemistry for this work (Figure 2).

Pauling's interest in chemistry began when he was in high school. A friend had a small chemistry laboratory in his bedroom, and the experiments they did inspired him to become a chemist. He failed to take some required American history courses because of this interest in chemistry and hence, did not qualify for his high school diploma. The school awarded him the diploma 45 years later, only after he had won two Nobel Prizes!

In his work on chemical bonding, Pauling studied the electronic structure of atoms, and how atoms formed molecules. For part of this work, he travelled to Europe to study under Niels Bohr in Copenhagen. Pauling was also interested in how the properties of substances are related to their structure and type of bonding. He later became interested in the structure of protein molecules, such as haemoglobin. This work paved the way for the discovery of the structure of DNA.

After World War II, Pauling became a peace activist and spoke out about the dangers of nuclear weapons (Figure 3). For this, he received the Nobel Peace Prize in 1962, becoming the only person to receive the Nobel Prize in more than one field. Later in life, he became interested in alternative medicine and claimed that large doses of Vitamin C could prevent colds and cancer! Most scientists, however, do not accept these claims.

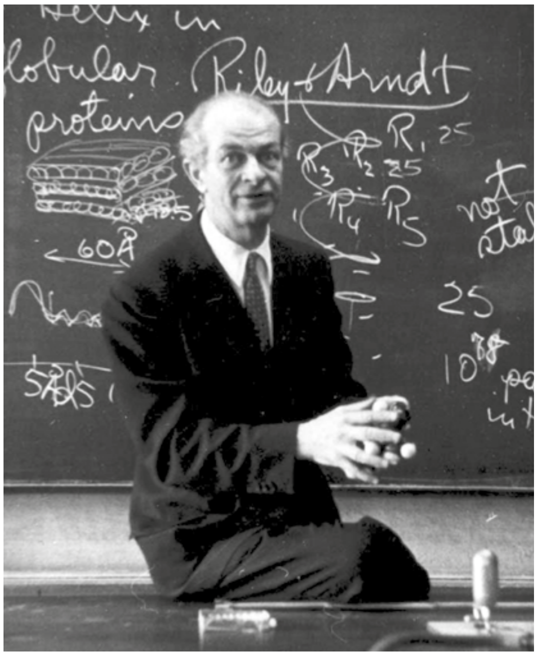


Figure 1 Linus Pauling (1901–1994)

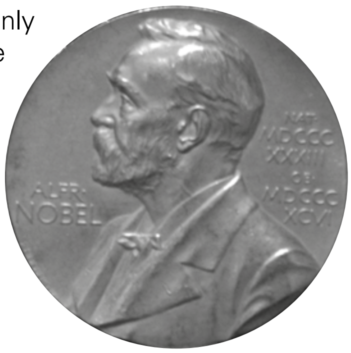


Figure 2 The Nobel Prize medal

Figure 3 A nuclear explosion causes great destruction.

Carry out an information search to answer the following questions. You may use textbooks, the library or the Internet.

1. Which country awards the Nobel Prize for
(a) chemistry, and
(b) peace?

(a) ____________________

(b) ____________________

2. Name a few other winners of Nobel Prize in Chemistry, the years they received it and the work they received it for.

____

____

____

____

3. Vitamin C is important in our diet.

(a) Why is it needed?

____

____

____

(b) List some foods that are sources of the vitamin.

____

____

4. Should scientists get involved in areas outside of science, as Pauling did? List some points 'for' and 'against'. Then give your opinion and list your reasons.

____

____

____

____

____

____

____

* For the complete list of Nobel Prize winners in Chemistry, refer to the following website:
http://nobelprize.org/chemistry/laureates/index.html

Answers

Additional Exercise 1:

1. (a) KCl (b) $ZnCl_2$
(c) CuO (d) K_2SO_4
(e) $KMnO_4$ (f) $NaHCO_3$
(g) $K_2Cr_2O_7$ (h) $Mg(OH)_2$
(i) FeS (j) Na_2SO_3
(k) Fe_2O_3 (l) $Fe(NO_3)_2$
(m) NH_4NO_3 (n) $Fe_2(SO_4)_3$
(o) $(NH_4)_2SO_4$

2. (a) potassium iodide
(b) potassium phosphate
(c) silver nitrate
(d) aluminium oxide
(e) mercury(II) chloride
(f) ammonium dichromate(VI)
(g) calcium nitrate
(h) chromium(III) sulfate

Additional Exercise 2:

	Type of structure	Type of particle	Type of bond	Example
Elements (non-metals)	simple molecular	molecules	covalent	hydrogen
	giant covalent	atoms	covalent	carbon (diamond)
Compounds	giant ionic	ions	ionic	sodium chloride
	simple molecular	molecules	covalent	water
	giant covalent	atoms	covalent	silicon dioxide

Additional Exercise 3:

1. (a) Sweden
(b) Norway
(c) silver nitrate
(d) aluminium oxide
(e) mercury(II) chloride
(f) ammonium dichromate(VI)
(g) calcium nitrate
(h) chromium(III) sulfate

2. *E.g. 1908: Ernest Rutherford (1871–1937) for the chemistry of radioactive substances.

1911: Madam Curie (1867–1934) for the discovery of the elements, radium and polonium.

1918: Fritz Haber (1868–1934) for the formation of ammonia from nitrogen and hydrogen.

1983: Henry Taube (1915–2005) for his work on redox reactions involving electron transfer.

3. (a) Vitamin C is needed for healthy skin, gums and teeth and some protection from colds. A deficiency of Vitamin C leads to scurvy (a gum disease, less common nowadays).
(b) E.g. Oranges, lemons, tomatoes, green vegetables

4. E.g. For: Scientists, like all people, are allowed to have opinions./Scientists are intelligent and may have good opinions./The area outside of science may be related to the scientific work scientists do.

Against: People may believe what a (famous) scientist says, even if it is wrong./The scientist may have no more knowledge of the area than anyone else./The scientist should just concentrate on his scientific work and leave other areas to experts in those areas.

Blank