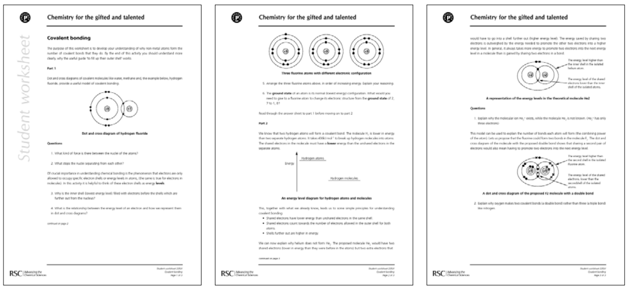
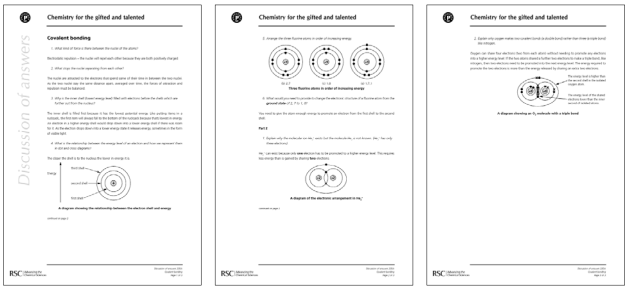
Covalent bonding



Student worksheet: CDROM index 22SW



Discussion of answers: CDROM index 22DA

Topics
Energetic stability and molecular orbitals.

Level
Able post-16 chemistry students or extremely able students aged 14–16 who have covered covalent bonding in their pre-16 course.

Prior knowledge
Dot and cross diagrams and electron energy levels or shells (2, 8, 8 *etc*).

Rationale
The over-reliance on 'to get a full outer shell' as the concept underpinning bonding has been identified in previous RSC publications[1]. This activity seeks to develop an understanding of covalent bonding in terms of energetic stability rather than full shells.

Use
This activity can be used as an introduction to the further study of covalent bonding in post-16 chemistry courses, perhaps instead of revisiting dot and cross diagrams. It can be done as a differentiated activity with gifted 14–16 year olds to extend their understanding and challenge their thinking.

The students should be given the worksheets and asked to work through part 1. They should then be given the *Discussion of answers* sheet so that they can clarify the points raised in part 1. They should then move on to part 2.

Note

A word of caution: the energy levels drawn in the molecules do not represent the shape of the orbits or orbitals (in the same way that they do not for atoms). They are simply a way of representing the energy level of the electrons. There may be some students who misunderstand this point.

This symbol means those questions are best tackled as a discussion if a group of students is doing this activity.

[1] K. Taber, *Chemical misconceptions – prevention, diagnosis and cure*, London: Royal Society of Chemistry, 2002.

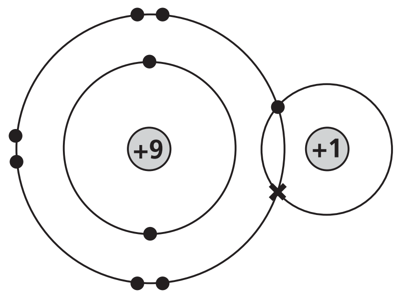
Student worksheet

Covalent bonding

The purpose of this worksheet is to develop your understanding of why non-metal atoms form the number of covalent bonds that they do. By the end of this activity you should understand more clearly why the useful guide 'to fill up their outer shell' works.

Part 1

Dot and cross diagrams of covalent molecules like water, methane and, the example below, hydrogen fluoride, provide a useful model of covalent bonding.



Dot and cross diagram of hydrogen fluoride

Questions

1. What kind of force is there between the nuclei of the atoms?

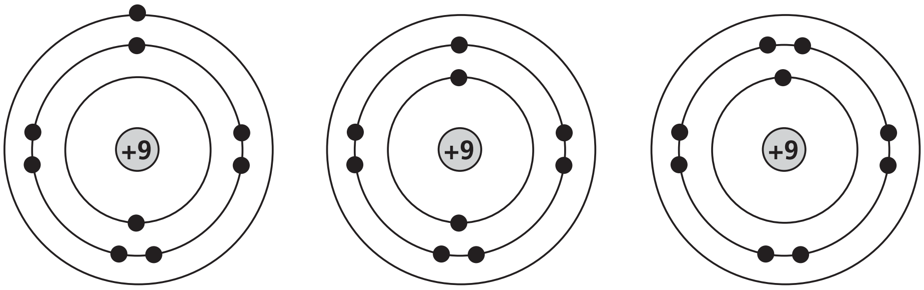
2. What stops the nuclei separating from each other?

Of crucial importance in understanding chemical bonding is the phenomenon that electrons are only allowed to occupy specific electron shells or energy levels in atoms, (the same is true for electrons in molecules). In this activity it is helpful to think of these electron shells as **energy levels**.

3. Why is the inner shell (lowest energy level) filled with electrons before the shells which are further out from the nucleus?

4. What is the relationship between the energy level of an electron and how we represent them in dot and cross diagrams?

continued on page 2



(a) 1,7,1 (b) 2,7 (c) 1,8

Three fluorine atoms with different electronic configurations

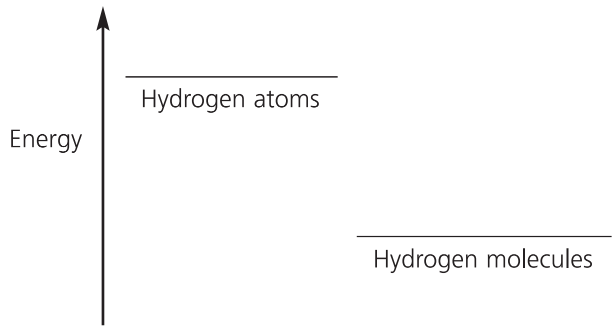
5. Arrange the three fluorine atoms above in order of increasing energy. Explain your reasoning.

6. The **ground state** of an atom is its normal (lowest energy) configuration. What would you need to give to a fluorine atom to change its electronic structure from the **ground state** of 2, 7 to 1, 8?

Read through the answer sheet to part 1 before moving on to part 2

Part 2

We know that two hydrogen atoms will form a covalent bond. The molecule H_2 is lower in energy than two separate hydrogen atoms. It takes 436kJ mol^{-1} to break up hydrogen molecules into atoms. The shared electrons in the molecule must have a **lower** energy than the unshared electrons in the separate atoms.



An energy level diagram for hydrogen atoms and molecules

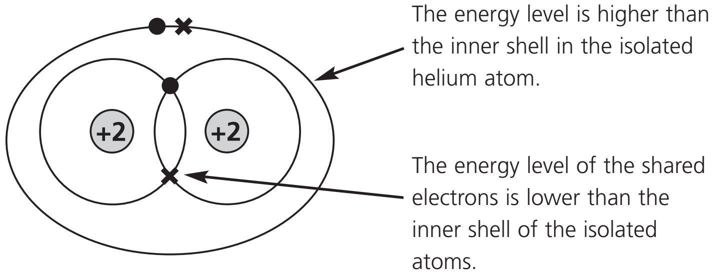
This, together with what we already know, leads us to some simple principles for understanding covalent bonding.

- Shared electrons have lower energy than unshared electrons in the same shell.
- Shared electrons count towards the number of electrons allowed in the outer shell for both atoms.
- Shells further out are higher in energy.

We can now explain why helium does not form He_2. The proposed molecule He_2 would have two shared electrons (lower in energy than they were before in the atoms) but two extra electrons that

continued on page 3

would have to go into a shell further out (higher energy level). The energy saved by sharing two electrons is outweighed by the energy needed to promote the other two electrons into a higher energy level. In general, it always takes more energy to *promote* two electrons into the next energy level in a molecule than is gained by sharing two electrons in a bond.

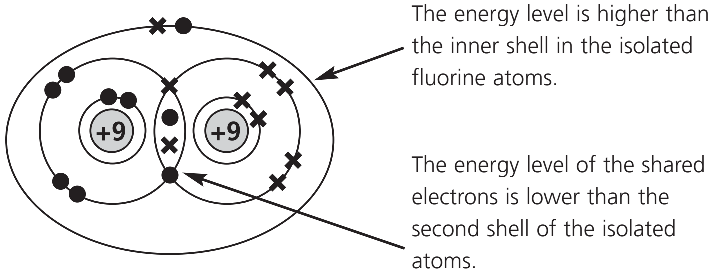


A representation of the energy levels in the theoretical molecule He_2

Questions

1. Explain why the molecular ion He_2^+ exists, while the molecule He_2 is not known. (He_2^+ has only three electrons.)

This model can be used to explain the number of bonds each atom will form (the combining power of the atom). Lets us propose that the fluorine could form two bonds in the molecule F_2. The dot and cross diagram of the molecule with the proposed double bond shows that sharing a second pair of electrons would also mean having to promote two electrons into the next energy level.



A dot and cross diagram of the proposed F_2 molecule with a double bond

2. Explain why oxygen makes two covalent bonds (a double bond) rather than three (a triple bond) like nitrogen.

Covalent bonding

1. *What kind of force is there between the nuclei of the atoms?*

Electrostatic repulsion – the nuclei will repel each other because they are both positively charged.

2. *What stops the nuclei separating from each other?*

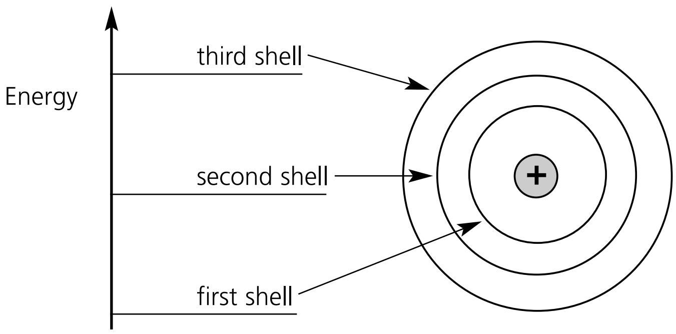
The nuclei are attracted to the electrons that spend some of their time in between the two nuclei. As the two nuclei stay the same distance apart, averaged over time, the forces of attraction and repulsion must be balanced.

3. *Why is the inner shell (lowest energy level) filled with electrons before the shells which are further out from the nucleus?*

The inner shell is filled first because it has the lowest potential energy. Like putting items in a rucksack, the first item will always fall to the bottom of the rucksack because that's lowest in energy. An electron in a higher energy shell would drop down into a lower energy shell if there was room for it. As the electron drops down into a lower energy state it releases energy, sometimes in the form of visible light.

4. *What is the relationship between the energy level of an electron and how we represent them in dot and cross diagrams?*

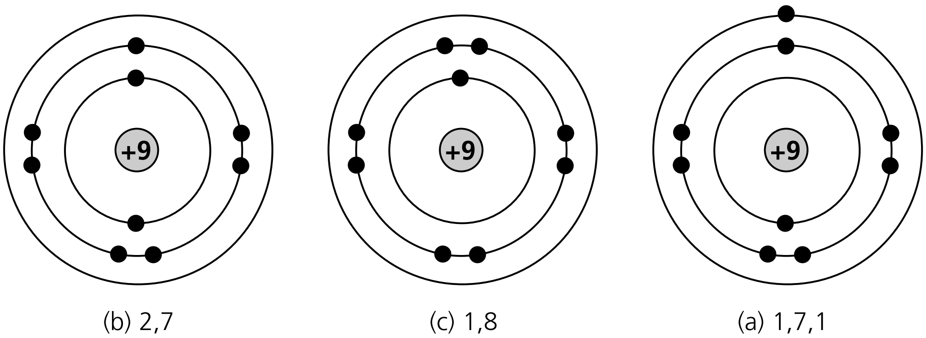
The closer the shell is to the nucleus, the lower in energy it is.



A diagram showing the relationship between the electron shell and energy

continued on page 2

5. *Arrange the three fluorine atoms in order of increasing energy.*



Three fluorine atoms in order of increasing energy

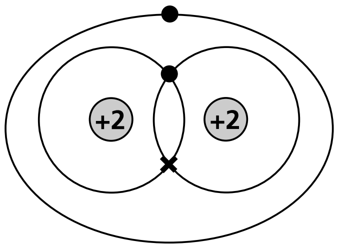
6. *What would you need to provide to change the electronic structure of a fluorine atom from the* ***ground state*** *of 2, 7 to 1, 8?*

You need to give the atom enough energy to promote an electron from the first shell to the second shell.

Part 2

1. *Explain why the molecular ion He_2^+ exists but the molecule He_2 is not known. (He_2^+ has only three electrons.)*

He_2^+ can exist because only **one** electron has to be promoted to a higher energy level. This requires less energy than is gained by sharing **two** electrons.

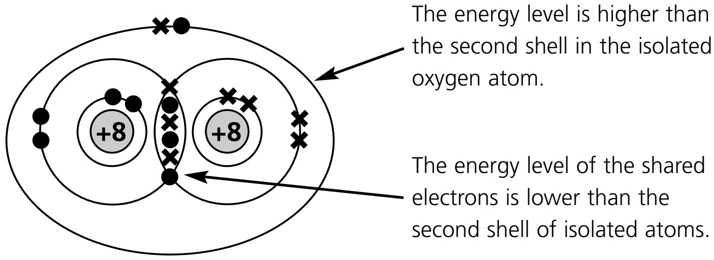


A diagram of the electronic arrangement in He_2^+

continued on page 3

2. *Explain why oxygen makes two covalent bonds (a double bond) rather than three (a triple bond) like nitrogen.*

Oxygen can share four electrons (two from each atom) without needing to promote any electrons into a higher energy level. If the two atoms shared a further two electrons to make a triple bond, like nitrogen, then two electrons need to be promoted into the next energy level. The energy required to promote the two electrons is more than the energy released by sharing an extra two electrons.



A diagram showing an O_2 molecule with a triple bond