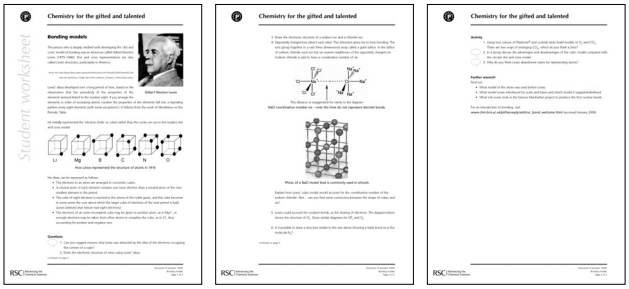
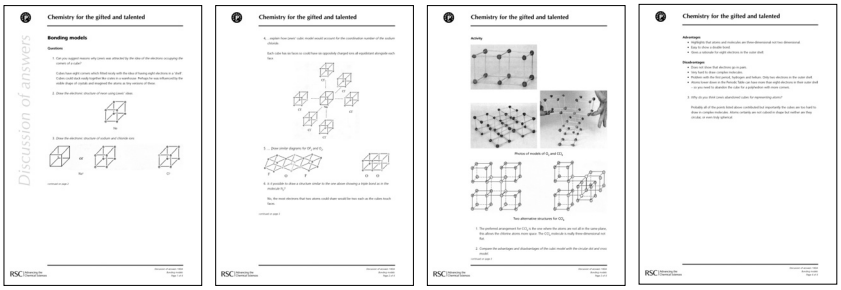
Bonding models



Student worksheet: CDROM index 10SW



Discussion of answers: CDROM index 10DA

Topics

How models are used in science, refining a model, geometry and coordination number and bond angles.

Level

Very able pre–16 or post–16 students.

Prior knowledge

Dot and cross diagrams and covalent and ionic bonding.

Rationale

Many students complain during their post-16 chemistry course that their teachers 'lied' to them in their pre–16 course. This is particularly true when revisiting atomic structure and bonding in post–16 courses. What the students are failing to appreciate (and perhaps we are failing to teach) is the nature of scientific models and how they are used in science. The general principle, that we use the simplest model available that works for the situation under consideration, escapes them. We refine or replace the model when it fails to explain or predict observed phenomena. A model should not be regarded as **truth** but as a useful systematic way of explaining or predicting events. Students may well be aware of an example of this in physics, that at low speeds Newtonian mechanics works fine but at speeds approaching the speed of light Einstein's special theory of relativity needs to be used.

Some students will develop the skill of holding alternative models together in their minds and choosing which to use based on the particular question – *eg* alternative models for the bonding in benzene or estimating the degree of ionic or covalent character in a bond by

Fajan's rules and electronegativity values.

This activity gets the students to think of the model they have been taught as a model rather than the truth.

Use

Teachers may need to explain to the students that the aim of the activity is to teach about the nature of models rather than giving them a new model of bonding which they will use afterwards. This could be used with a whole class or as a differentiated activity for part of a class.

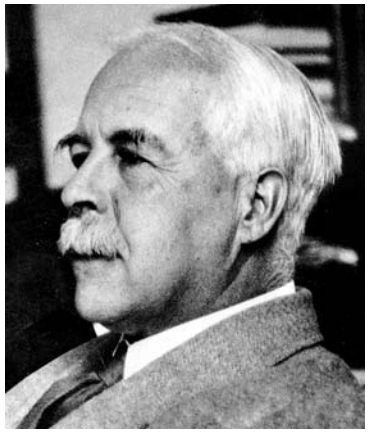
Each group will need some Plasticine® (preferably two colours) and several cocktail sticks.

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

When the students have completed the worksheet they should be given the *Discussion of answers* sheet. They could check their own work or conduct a peer review of the work of another student or group.

Student worksheet

Bonding models



Gilbert Newton Lewis

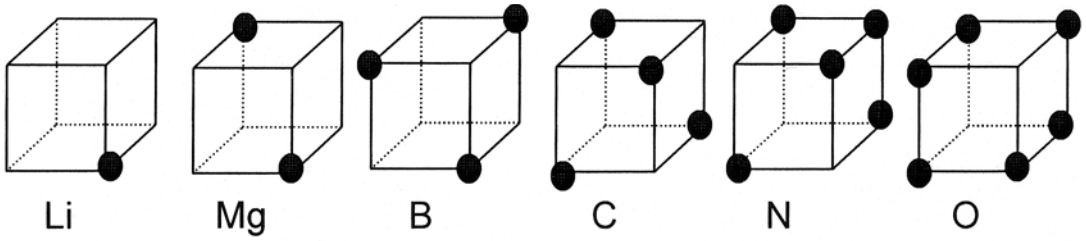
The person who is largely credited with developing the 'dot and cross' model of bonding was an American called Gilbert Newton Lewis (1875–1946). Dot and cross representations are also called Lewis structures, particularly in America.

photo from http://dewey.library.upenn.edu/sceti/smith/scientist.cfm?PictureID=263&ScientistID=184

Used with permission of Edgar Fahs Smith Collection, University of Pennsylvania Library

Lewis' ideas developed over a long period of time, based on the observation that the periodicity of the properties of the elements seemed linked to the number eight. If you arrange the elements in order of increasing atomic number, the properties of the elements fall into a repeating pattern every eight elements (with some exceptions!). It follows from the work of Mendeleev on the Periodic Table.

He initially represented the 'electron shells' as cubes rather than the circles we use in the modern dot and cross model.



How Lewis represented the structure of atoms in 1916

His ideas can be expressed as follows.

- The electrons in an atom are arranged in concentric *cubes*.
- A neutral atom of each element contains one more electron than a neutral atom of the next smallest element in the period.
- The cube of eight electrons is reached in the atoms of the noble gases, and this cube becomes, in some sense, the core about which the larger cube of electrons of the next period is built. *(Lewis believed that helium had eight electrons).*
- The electrons of an outer, incomplete cube may be given to another atom, as in Mg^{2+}. Or enough electrons may be taken from other atoms to complete the cube, as in Cl^-, thus accounting for positive and negative ions.

Questions

1. Can you suggest reasons why Lewis was attracted by the idea of the electrons occupying the corners of a cube?

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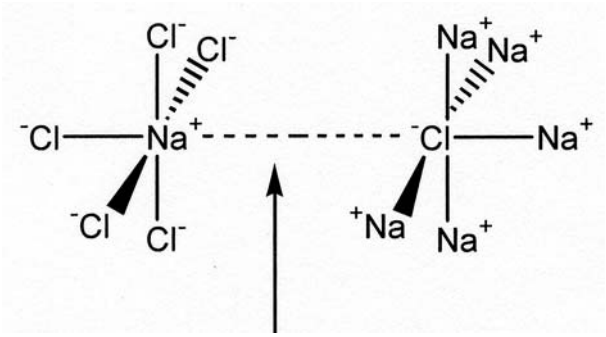
2. Draw the electronic structure of neon using Lewis' ideas.

3. Draw the electronic structure of a sodium ion and a chloride ion.

4. Oppositely charged ions attract each other. This attraction gives rise to ionic bonding. The ions group together in a vast three dimensional array called a giant lattice. In the lattice of sodium chloride each ion has six nearest neighbours of the oppositely charged ion. Sodium chloride is said to have a coordination number of six.



This distance is exaggerated for clarity in the diagram

NaCl coordination number six. Note: the lines do *not* represent discreet bonds.

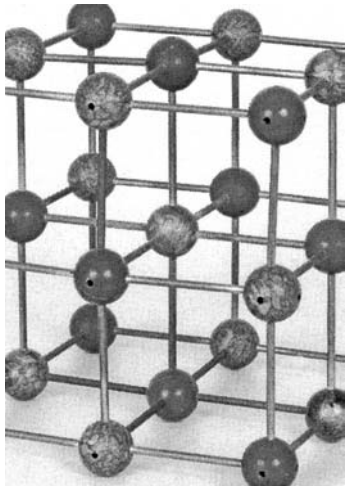


Photo of a NaCl model that is commonly used in schools

Explain how Lewis' cubic model would account for the coordination number of the sodium chloride. **Hint:** can you find some connection between the shape of cubes and six?

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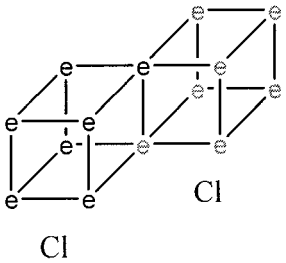
5. Lewis could account for covalent bonds as the sharing of electrons. The diagram below shows the structure of Cl_2. Draw similar diagrams for OF_2 and O_2.



6. Is it possible to draw a structure similar to the one above showing a triple bond as in the molecule N_2?

Activity

1. Using two colours of Plasticine® and cocktail sticks, build models of O_2 and CCl_4. There are two ways of arranging CCl_4 – which do you think is best?
2. In a group, discuss the advantages and disadvantages of the cubic model compared with the circular dot and cross model.
3. Why do you think Lewis abandoned cubes for representing atoms?

Further research

Find out:

- What model of the atom was used before Lewis.
- What model Lewis introduced for acids and bases and which model it supplanted/refined.
- What role Lewis took in the famous Manhattan project to produce the first nuclear bomb.

For an introduction to bonding, visit:
www.chm.bris.ac.uk/pt/harvey/gcse/struc_bond_welcome.html (accessed January 2006).

Discussion of answers

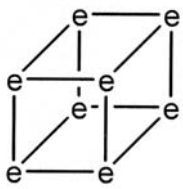
Bonding models

Questions

1. *Can you suggest reasons why Lewis was attracted by the idea of the electrons occupying the corners of a cube?*

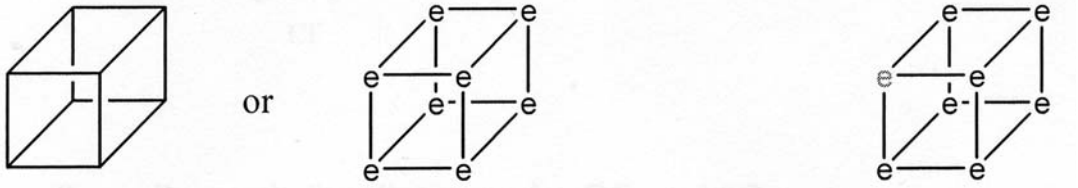
   Cubes have eight corners which fitted nicely with the idea of having eight electrons in a 'shell'. Cubes could stack easily together like crates in a warehouse. Perhaps he was influenced by the visible shape of crystals and imagined the atoms as tiny versions of these.

2. *Draw the electronic structure of neon using Lewis' ideas.*



Ne

3. *Draw the electronic structure of sodium and chloride ions.*



Na^+ Cl^-

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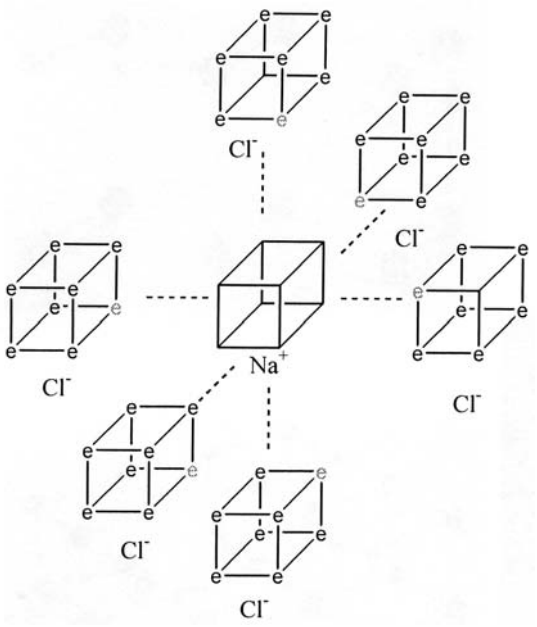
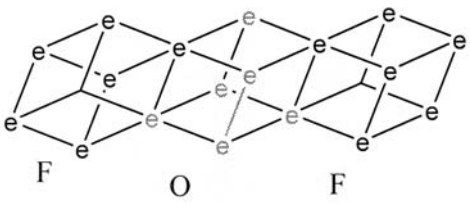
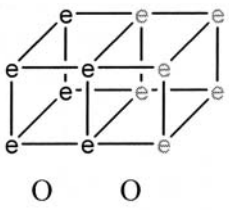
4. *Explain how Lewis' cubic model would account for the coordination number of the sodium chloride.*

   Each cube has six faces so could have six oppositely charged ions all equidistant alongside each face.



5. *... Draw similar diagrams for OF_2 and O_2.*





6. *Is it possible to draw a structure similar to the one above showing a triple bond as in the molecule N_2?*

   No, the most electrons that two atoms could share would be two each as the cubes touch faces.

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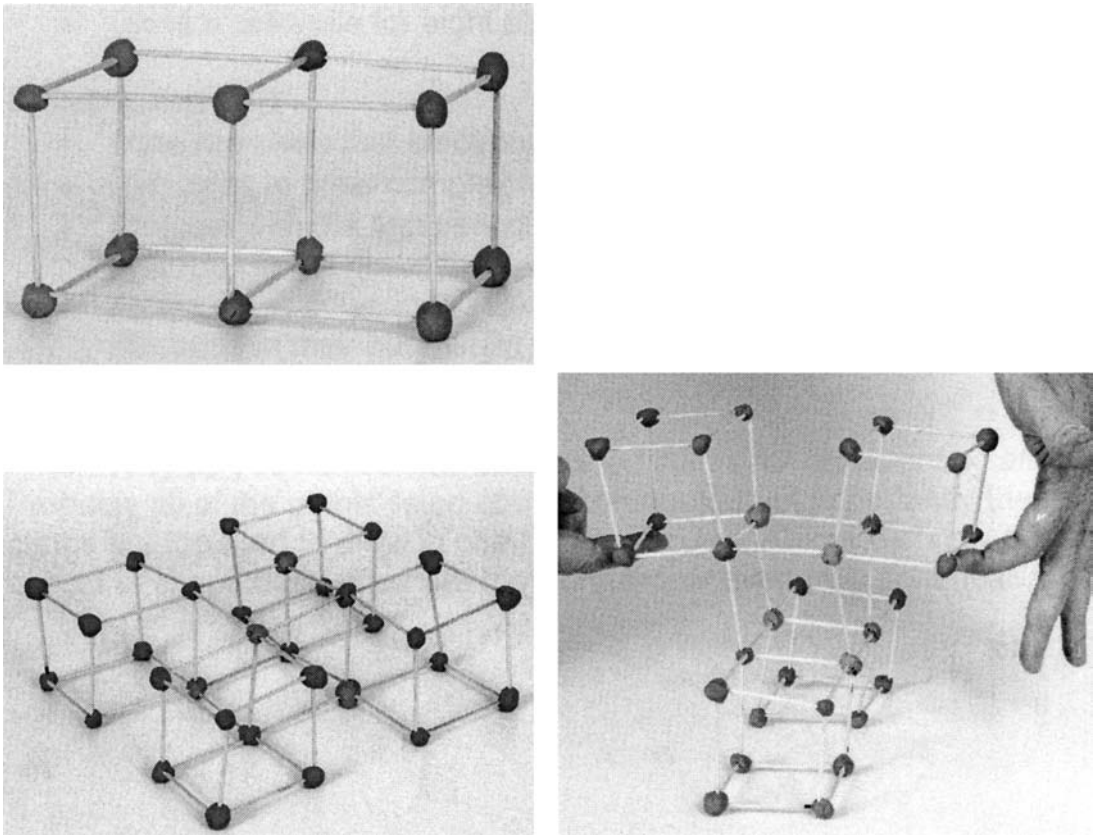
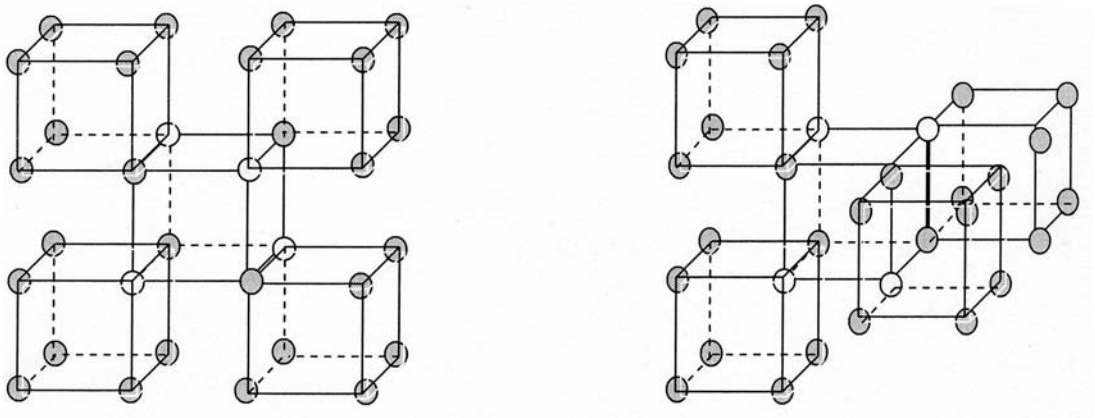
Activity



Photos of models of O_2 and CCl_4



Two alternative structures for CCl_4

1. The preferred arrangement for CCl_4 is the one where the atoms are not all in the same plane as this allows the chlorine atoms more space. The CCl_4 molecule is really three dimensional not flat.

2. *Compare the advantages and disadvantages of the cubic model with the circular dot and cross model.*

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Advantages

- Highlights that atoms and molecules are three dimensional not two dimensional.
- Easy to show a double bond.
- Gives a rationale for eight electrons in the outer shell.

Disadvantages

- Does not show that electrons go in pairs.
- Very hard to draw complex molecules.
- Problem with the first period, hydrogen and helium. Only two electrons in the outer shell.
- Atoms lower down in the Periodic Table can have more than eight electrons in their outer shell – so you need to abandon the cube for a polyhedron with more corners.

3. *Why do you think Lewis abandoned cubes for representing atoms?*

   Probably all of the points listed above contributed but importantly the cubes are too hard to draw in complex molecules. Atoms are certainly not cuboid in shape, but neither are they circular, or even truly spherical.