The National Strategies
Secondary

Modelling matter: the nature of bonding

Science teaching unit

department for
children, schools and families

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Modelling matter: the nature of bonding

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Contents

Modelling matter: the nature of bonding

Background

This teaching sequence is designed for use at Key Stage 4. It links to the Secondary National Strategy Framework for Science yearly learning objectives and provides coverage of parts of the QCA Programme of Study for Science. The sequence extends the simple particle model of matter introduced in *Explaining change process using a simple particle model of matter* to enable pupils to explain a wider range of physical and chemical properties. The model introduced at Key Stage 3 did not provide any explanation for the mechanism of bonding, nor did it account for why some substances exist in simple atomic or molecular forms whereas others exist as giant structures. In this unit, a simple account of the electronic structure of atoms is introduced, and is used to explain ionic, covalent and metallic bonding. The nature of bonding is then related to key physical and chemical properties. Furthermore, the nature of modelling in science is treated explicitly so that pupils understand that although simple models can be powerful in generating explanations, it is sometimes necessary to use more complex models to explain a broader range of properties.

By the end of the unit, pupils should be able to use the model of electron configuration to explain ionic, covalent and metallic bonding, and relate bonding to simple physical and chemical properties. This aim is addressed through interactive teaching approaches where links between subject matter are explored and established through appropriate talk between teacher and pupils, and amongst pupils.

Teaching design principles

The design of this sequence is based upon a number of key principles. These are listed below:

Working on knowledge

The sequence involves:

- building explicitly upon the model of matter previously introduced;
- developing and learning how to use a model of bonding which is good enough to explain how compounds are formed;
- considering explicitly the differences between the two models of matter (Key Stage 3 and Key Stage 4), and the reasons for developing and using models in science.

Teaching approach

The sequence involves:

- introducing the need to extend the model used at Key Stage 3;
- using the new model to define ionic, covalent and metallic bonding.

Communicative approach

The sequence involves:

- using different communicative approaches between teacher and pupils according to different teaching purposes;
- providing opportunities for pupil-pupil talk, mainly in pairs.

How science works

This sequence involves:

- developing the general idea of a scientific model as a device for explaining or accounting for various properties of matter, including chemical bonding.

A key aspect of the teaching approach involves considering how models are used in science to explain the behaviour of the material world. In this unit, pupils consider the limitations of the model of matter introduced at Key Stage 3 for explaining chemical change, and are introduced to a more sophisticated model with broader explanatory power. During pupils' discussions, the teacher will need to spend time emphasising to pupils that they are developing a rather sophisticated model that was not fully elaborated until relatively recently in the history of science (i.e. in the early 20th century).

The development and use of models is considered in the Using models study guide.

Pupil curriculum starting points

Pupils will have been introduced to a simple model of the structure of matter at Key Stage 3, and will have used it to explain some physical properties of solids, liquids and gases. They will have also been introduced to a simple model of chemical change based upon the rearrangement of different kinds of atoms. However, a model to explain bonding was not introduced, and no explanation for the existence of simple atomic and molecular structures and giant structures was provided.

This unit assumes that pupils have been introduced to electron structure and are confident in the arrangements of the electrons for the first 20 elements in simple 'ring shaped' energy levels. If pupils have not been introduced to electron structure, this can be done in the second lesson, before Activity 2.3.

Modelling matter: the nature of bonding: Overview

Why does the model need extending?
review of model, group practical activity

Good enough model?
teacher-led exploration of limitations of existing model

Developing the model - ionic bonding:
teacher exposition and pupil exploration.

Developing the model - ionic bonding:
teacher exposition and pupil exploration.

Developing the model - metallic bonding:
exploration of limitations of models

Lesson 1: Why does the model need extending?

The lesson starts with a review of the particle model of solids, liquids and gases introduced at Key Stage 3. The limitations of this model are then explored by considering the properties of a range of solid compounds.

Activity 1.1: Revision of the model of solids, liquids and gases.

Teaching objectives

- To revise the particle model used at Key Stage 3.
- To encourage pupils to talk through their ideas about particle models, thereby motivating them to start thinking about the topic.
- To collect Assessment for Learning (AfL) baseline information about the pupils' understanding of content introduced at Key Stage 3.

Learning outcomes

By the end of this activity the pupils will be able to:

- recall and use the Key Stage 3 particle model;
- reflect on their understanding of the Key Stage 3 model and be ready to extend the model.

What to prepare

- Worksheet: Reminder of Key Stage 3 work - Particle models of solids, liquids and gases.

Mode of interaction

INTERACTIVE/AUTHORITATIVE
Through question and answer work, the teacher draws attention to particular features of pupils' models of solids, liquids and gases, re-wording and focusing as appropriate.

What happens during this activity

The teacher presents the class with examples of solids, liquids and gases and leads a discussion with the pupils to revise the particle model from their Key Stage 3 knowledge. They complete the drawings on the worksheet. It is important at this stage that the pupils remember and understand all of the features of the model, and that the teacher does not allow any incorrect features to remain unchallenged.

Activity 1.2: The properties of ionic and covalent compounds

In this activity the pupils record their observations of the properties of different compounds.

Teaching objectives

- To develop a shared classification of compounds having divided them into two groups which have broadly similar properties.
- To encourage pupils to talk through their ideas about the properties of the compounds.

Learning outcomes

By the end of the activity, will be able to:

- recognise that solid compounds whose structure is currently represented in the same way, can have very different properties – and that these differences are not easily explained by the Key Stage 3 particle model.

What to prepare

- Worksheet: 'Compounds – observations'
- Risk assessment.

Mode of interaction

Pupils work in pairs to record their observations. The teacher then takes an INTERACTIVE/AUTHORITATIVE approach in building an agreed view of the properties of these compounds.

What happens during this activity

Pupils work around a collection of compounds with differing properties and address questions on a worksheet. The prompts on the worksheet guide pupils towards making clear distinctions between the properties.

At this stage pupils are asked to record their observations, but are not asked to consider why the compounds have these properties. Observations could be recorded on sticky notes so that the pupils can collate their findings about the compounds on large pieces of paper, for the discussion that follows.

The examples in the circus, and the rationale for choosing them, are as follows:

Examples	Rationale
DISSOLVING salt, copper sulfate, and wax in warm water	These three substances have been selected because, although they are all solids, their behaviour on mixing with water is different. This difference cannot be explained with the Key Stage 3 model of matter.
CONDUCTIVITY of copper sulfate, salt and sugar solutions.	These three substances have been selected because, although they are all solids and appear crystalline, their electrical conductivity when dissolved in water is different. This difference cannot be explained with the Key Stage 3 model of matter.
MELTING of wax, sugar and salt	These substances have been selected because although they are solids, their melting points are very different. This difference cannot be explained with the Key Stage 3 model of matter.
RESEARCH ACTIVITY of finding the melting and boiling points (if possible) of sugar, copper sulfate, wax, salt, water, hydrogen and chlorine – as well as the elemental composition of the compounds.	This activity provides further information about the sizable differences in the melting and boiling points of solids, which so far have been modelled in the same way.

These research activities take considerable time, so teachers may choose to allocate each of these activities to different groups of pupils.

During this activity pupils are encouraged to begin tentatively to group/classify substances and use opportunities to explain their grouping to others in order to develop their understanding of the differences between ionic (metal/non-metal bonding) and covalent compounds (non-metal/non-metal bonding). They could also be encouraged to look for anomalies, for example, graphite.

Finally, the teacher reviews the pupils' observations with them, and then helps them to sort the compounds into two groups:

- The first group of compounds (WAX, SUGAR) have low melting and boiling points, don't conduct electricity when in solution, don't dissolve in water and do not include atoms from metallic elements.
- The second group of compounds (COPPER SULFATE, SALT) have high melting and boiling points, conduct electricity when in solution, dissolve in water and contain atoms from metallic elements.

Reminder of Key Stage 3 work

Particle models of solids, liquids and gases

Complete this sheet by drawing the arrangements of the particles in solids, liquids and gases. Take care with the detail of your drawings.

Solids

Liquids

Gases

Compounds – observations

Safety notes need to be added by the teacher: precautions are needed during the heating of the solids (with the risk of spitting) and when using copper sulfate (which is hazardous). It is recommended that eye protection is worn.

Dissolving

We are going to find out whether four compounds will dissolve in water.

Take four small beakers of warm water. Add a *small spatula* of **salt** to the first beaker, and stir. [If you add too much you won't see the correct result!]

Does the salt dissolve? How can you tell? KEEP THE BEAKER AND ITS CONTENTS FOR THE NEXT EXPERIMENT!

Add a *small spatula* of **copper sulfate** to the second beaker, and stir.

Does the copper sulfate dissolve? How can you tell? KEEP THE BEAKER AND ITS CONTENTS FOR THE NEXT EXPERIMENT!

Add a *small spatula* of **wax** to the third beaker, and stir.

Does the wax dissolve? How can you tell? YOU CAN TIDY THIS APPARATUS AWAY: WE DON'T NEED IT AGAIN!

Add a *small spatula* of **sugar** to the fourth beaker, and stir.

Does the sugar dissolve? How can you tell? KEEP THE BEAKER AND ITS CONTENTS FOR THE NEXT EXPERIMENT!

Conductivity

We are now going to test whether the **salt solution**, the **copper sulfate solution** and the **sugar solution** conduct electricity.

Set up the circuit as your teacher shows you, and test whether the solution conducts electricity.

Delete as appropriate:

- Copper sulfate solution conducts electricity/ Copper sulfate solution does not conduct electricity
- Salt solution conducts electricity/ Salt solution does not conduct electricity
- Sugar solution conducts electricity/ Sugar solution does not conduct electricity

Melting

We are going to find out how easily **sugar**, **salt** and **wax** melt. The less time we heat them before they melt, the lower the boiling point. (We are not going to test how easy it is to melt copper sulfate for safety reasons.)

Take three crucibles with lids. Put a spatula of sugar in the first, a spatula of salt in the second, and a small piece of wax in the third.

Set up the apparatus as in the photograph.

Andrew Lambert Photography / Science Photo Library.

Place the first crucible on the clay triangle. Heat from below with a Bunsen burner. Look to see if the sugar has melted every 30 seconds or so.

Repeat this procedure with the second crucible (salt).

Repeat with the third crucible (wax).

SO, WHICH OF THE SUBSTANCES HAVE HIGH MELTING POINTS? WHICH HAVE LOW MELTING POINTS?

Research activity

Use the Internet to find the melting and boiling point (if possible) for the following compounds. Also, see if you can find out the elements that each is made from, and note down if it contains any elements that are metals. (Hint: Carbon is not a metal!)

Compound	Melting point	Boiling point	Does it contain any atoms from elements that are metals?
Sucrose (this is the chemical name for one type of sugar)			
Copper sulfate			
Paraffin wax			
Sodium chloride (this is table salt)			

Summary of properties

Using your results, complete these groupings of the substances that you have worked with:

High melting point and boiling point	Low melting point and boiling point

Soluble in water	Insoluble in water

Conducted electricity in solution	Did not conduct electricity in solution

Contains both metal and non- metal elements	Only contains non-metal elements

Can you spot any patterns in your results?

Lesson 2: Good enough model?

Teaching 'story'

The pupils are introduced to the idea that their current particle model has limitations because it cannot explain all of the properties identified in the last lesson.

The teacher then explains that a model needs to be 'fit for purpose'. With the pupils now understanding more about scientific modelling, the idea of mobile, charged particles is introduced into the model.

The development and use of models is considered in the *Using Models* study guide.

Activity 2.1: Identifying specific limitations of the particle model

Teaching objective

- To guide pupils to recognise that the Key Stage 3 model that they have been using cannot explain conductivity and intermolecular bond strength.

Learning outcome

By the end of the activity, pupils will be able to:

- recognise that their existing model of the structure of matter has limitations;
- recognise that the model needs to be extended to explain a broader range of the properties of substances.

Mode of interaction

INTERACTIVE/AUTHORITATIVE
Through question and answer work, the teacher draws attention to particular limitations of the models in explaining the properties of the compounds.

What happens during this activity

The teacher goes through the properties of the two groups of compounds identified in the previous lesson. The teacher then asks the pupils whether the properties can be explained using the model that was developed at Key Stage 3, drawing the pupils' attention to the limitation of the model.

Activity 2.2: Choosing a model 'fit for purpose'

Teaching objectives

- To introduce the idea that a model should be 'fit for purpose'.
- To pose to the pupils the possibility that their Key Stage 3 model may need to be extended.

Learning outcomes

By the end of the activity pupils have begun to:

- understand the idea that a model should be 'fit for purpose';
- think that their original model may need to be extended.

Mode of interaction

INTERACTIVE/AUTHORITATIVE as the teacher talks through the analogies to illustrate the idea that models need to be fit for purpose.

What happens during this activity

This is a teacher-led presentation addressing the nature of modelling in science. The specific points to be emphasised are:

- models are much more than 'descriptions' or 'pictures' of things in the real world;
- rather, they are representations that emphasise particular features of the real world for particular purposes.

These points can be emphasised by drawing the following two analogies:

- The teacher selects a recent news story and compares how it is reported, for example, on 'The News at Ten', 'Newsround' and 'Sixty Seconds'. Each of these formats is 'fit for purpose'. It is possible to give a short, factual account which is appropriate for some people's needs. A more detailed approach is needed for other people's needs. *It is not the case that one version is 'right' and the other is 'wrong'* – the distinction is in focus and level of detail.

- The teacher describes the difference between taking a *photograph* of the laboratory apparatus used to boil a beaker of water, and drawing a diagram of the same apparatus. The diagram emphasises particular features and ignores others. This does not necessarily make the diagram *wrong* – a better way to look at it is that it is a model of the apparatus which is *better* at explaining some features than a photograph.

The teacher than explains that this can be the same with scientific models. Pupils are likely to accept that a photograph of atoms – if it were possible to take one – would not show things as they have been drawn in their science lessons. Although the current Key Stage 3 model can explain some features of solids, liquids and gases, and help to define and differentiate substances, elements, mixtures, compounds, physical and chemical changes, it cannot explain the properties of compounds considered so far in this lesson sequence. In order to do this the model needs to be extended.

Activity 2.3: Extending the model

Teaching objective

- To encourage pupils to talk through how specific features of an extended model of the nature of matter, i.e. charged particles, might explain some properties of matter, such as structure and dissolving.

Learning outcomes

By the end of the activity, pupils will be able to:

- explain how their existing model might be extended to address a broader range of properties of matter;
- explain how a model including charged particles might explain some features of the behaviour of matter, such as structure and dissolving.

What to prepare

- Worksheet: 'Just supposing…'

Mode of interaction

Pupils work in pairs with an INTERACTIVE/ DIALOGIC approach to consider the addition to the particle model and to explain the behaviour of sodium chloride.

DIALOGIC HOTSPOT

What happens in this activity

The teacher introduces the idea that particles can be charged and mobile, and that this can explain some of the properties observed earlier. Key points to introduce are that:

- there are two types of charge on particles – positive and negative;
- opposite charges attract.

The teacher then reminds pupils of the dissolving of salt (sodium chloride) and poses the question: What if sodium particles and chloride particles were oppositely charged? What if water particles had a charge? Pupils then work in groups to think about how this might help to explain the following questions:

- How come sodium chloride is a giant structure – with millions and millions of sodium and chloride particles in lines in all directions?

Target answer: Opposite charges attract. You can surround one sodium particle with at least 6 chloride particles, then surround each chloride particle with six sodium particles, resulting in a massive 3-dimensional structure.

- How come sodium chloride crystals break up when put into water?

Target answer: Charged particles in water touch the sodium and chloride particles and are attracted to them; this breaks down the crystal.

The teacher then draws together key features of pupils' models with the whole class.

Just supposing…

Just supposing…

- sodium particles and chloride particles were charged…
- …and they had opposite charges…which attracted one another…
- …and water particles also had a charge…

Could we explain the following things about sodium chloride?

- Sodium chloride is a SOLID, the sodium and chloride particles are BONDED together, and MANY MILLIONS OF PARTICLES are bonded together to make a crystal.
- Sodium chloride dissolves very easily when mixed with water.

Lesson 3: Developing the model – ionic bonding

Teaching 'story'

Pupils now have an understanding that their model of matter can be extended to include charged particles in order to address a wider range of properties of matter. The next step in the teaching story is to explain how these particles have become charged. Before the idea of electron transfer and sharing is introduced, electron structure is revised. If electron structure has not been taught previously, it will need to be taught fully as a substitute for activity 3.1.

Activity 3.1: Revision of electron configuration

Teaching objective:

- To revise electron configuration.

Learning outcomes

By the end of the activity, pupils will be able to:

- represent electron configuration confidently;
- recognise that electron configuration diagrams are models that are going to be used to explain some properties of atoms.

Mode of interaction

INTERACTIVE/AUTHORITATIVE
The teacher leads the revision, possibly through questions and answers, depending on how electron configuration has been taught previously.

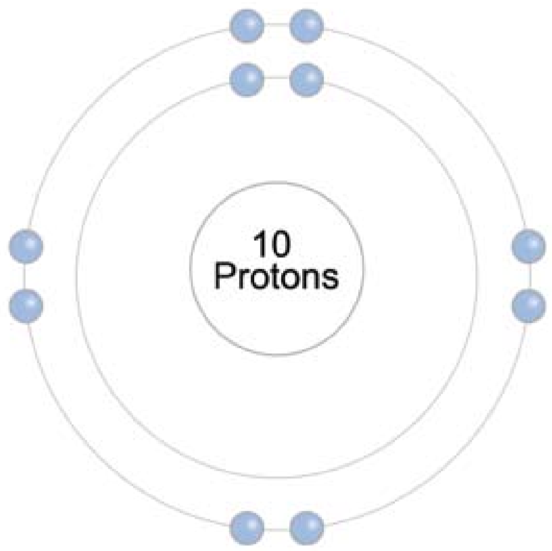
What happens in this activity

The electron configuration of the first 20 elements is revised. This is addressed in the traditional manner of circular representations of the energy levels as shown in other schemes of work or text books.

Key features to emphasise:

- This is a *model* to show a useful way of thinking about electrons. Those who study more chemistry and physics will encounter yet more sophisticated representations of electron structure, which can provide even more powerful explanations of properties.
- The 'dot and cross' notation often used in textbooks is widely assumed by pupils to indicate that electrons from different atoms are actually different; it is therefore necessary to emphasise that this is a *convenient representation* to show the origins of electrons, but *all electrons are the same*, no matter what atoms they are associated with.

The kind of representation of electron configuration to work towards is shown for neon:



Activity 3.2: How are the charged particles formed? Developing the model

Teaching objectives

- To use the model of electron configuration to explain the formation of positively and negatively charged ions.
- To explain how the existence of charged particles accounts for the structure of ionic compounds in the solid state.

Learning outcomes

By the end of the activity, pupils will be able to:

- explain how ions are formed by electron transfer;
- explain how the existence of charged particles accounts for ionic giant structures.

Mode of interaction

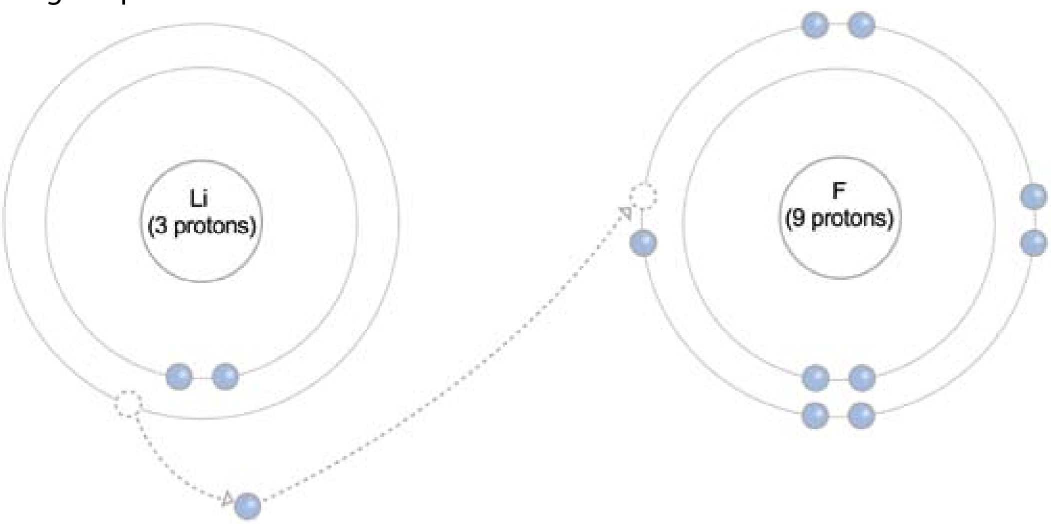
INTERACTIVE/AUTHORITATIVE: teacher-led presentation.

What happens in this activity

The teacher uses a diagrammatic representation of the electron configuration of lithium to show how a positive ion forms, and a diagrammatic representation of the electron configuration of fluorine to show how a negative ion (fluoride) forms. Pupils' attention is drawn to the nomenclature of the fluoride ion, and how this compares to other compounds that they have encountered (e.g. chlorides).

Note: Lithium fluoride has been used because of the simplicity of its electron configuration. Some teachers may prefer to use a more familiar compound, such as sodium chloride, which the pupils have already seen in this unit. This will require the teacher to address the issue of outer shell electrons.

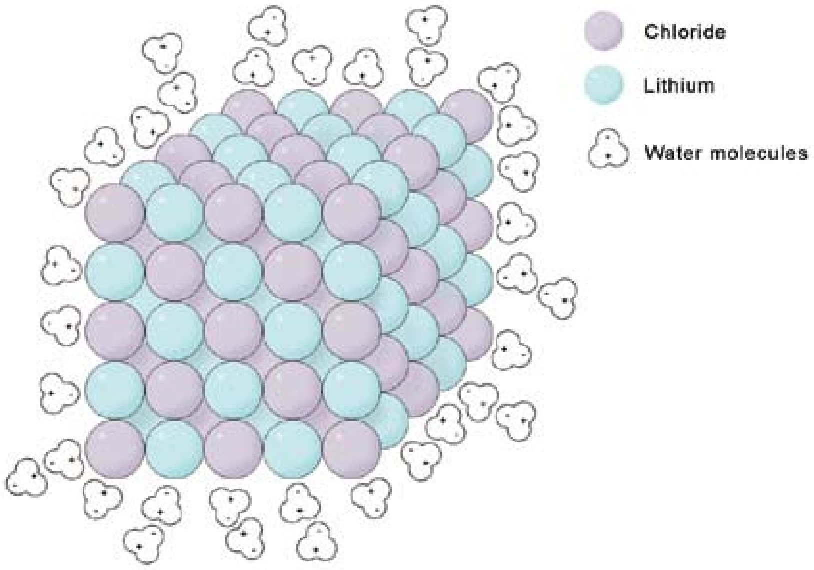
A target representation to work towards is shown:



The teacher then describes how, in compounds such as lithium fluoride, electrons transfer from atoms of one element to atoms of another element. This explains 'where the electrons go to' and 'where the electrons come from'. The teacher illustrates the 3-dimensional structure of lithium fluoride, showing how the attraction of charged particles explains why lithium fluoride is a giant structure.

The solubility of lithium chloride is explained in terms of charged particles being attracted to 'water particles', which have different charges at each end. A target representation is suggested below.

A piece of lithium chloride in water



> Note: In this unit, no attempt is made to address the size of charge on ions, or stoichiometry.

The pupils are then given a set of guidelines/rules which can be used to develop a quicker approach to working out the electronic structure of ions. They then use the rules to explore how potassium and chlorine form ions.

- Atoms loose or gain electrons so that they have a full outer shell of electrons. This is the most stable arrangement. (That is why the Noble gases – which have full outer shells of electrons – are very unreactive. They don't easily lose or gain electrons.)
- The more electrons that need to be lost or gained to get a full outer shell, the less likely an atom is to form ions.
- Atoms lose or gain as few electrons as possible when forming ions – beryllium loses 2 electrons rather than gaining 6, for example.
- Therefore, when ions form, usually a maximum of 3 electrons are lost or gained.

The sorts of probing questions the teacher might ask are:

Will the atom lose or gain electrons? How can you decide? (Get pupils to think about how many electrons are in the outer shell, and the easiest way to get a complete outer shell of electrons.)

Are there any other rules you could add to make it easier to decide whether an atom is likely to form ions, and what charge the ions are likely to have?

Lesson 4: Developing the model – covalent bonding

Teaching 'story'

Pupils are reminded that the charged particle model has so far only been used to explain the properties of one group of substances. Further extension of the model is required to explain the properties of the other group of substances (sugar and wax) identified in Lesson 1. Pupils are introduced to a second method of bond formation, namely electron sharing to form covalent compounds. Pupils consider how this explains the properties of other familiar substances.

Activity 4.1: How are the 'other' compounds formed?

Teaching objectives

- To introduce the existence of different types of bonding to explain the properties of different groups of substances.
- To develop a shared model of covalent bonding with pupils, and to show how this can be used to explain the structure of diatomic gaseous elements such as hydrogen, oxygen and chlorine.
- To collect Assessment for Learning (AfL) information about the pupils' thinking from their responses to the question and answer sessions.

Learning outcomes

By the end of the activity, pupils will be able to:

- recognise covalent bonding as involving electron sharing;
- explain how electron sharing results in a molecular structure, and contrast this with ionic bonding which results in a giant structure.

Mode of interaction

The teacher takes an INTERACTIVE/AUTHORITATIVE approach to introduce a model of covalent bonding as electron sharing.

Mode of interaction

Pupils work in pairs, using an INTERACTIVE / DIALOGIC approach, to consider the extension to the particles model.

What happens in this activity

Pupils are reminded of the substances they have looked at in Lessons 1 and 2 whose properties are not similar to lithium chloride (or sodium chloride).

Note: The examples presented in Lessons 1 and 2 actually include three groups:

- simple molecular structures (hydrogen, oxygen, chlorine);
- molecular giant structures (sucrose);
- polymers (wax).

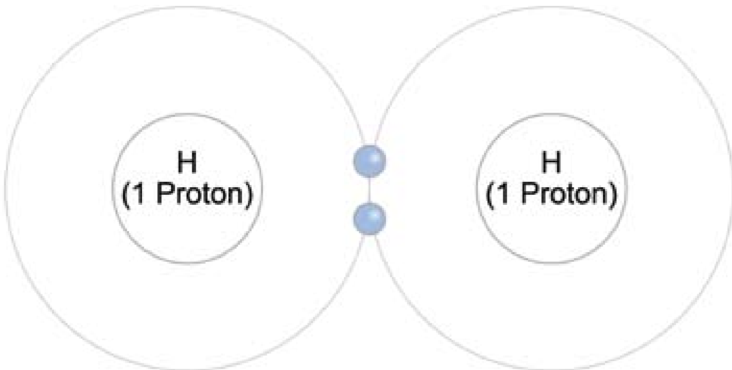
In this lesson, the focus will be on simple molecular structures for the sake of simplicity in addressing covalent bonding. There will be opportunities elsewhere in the Key Stage 4 curriculum to use the model to explain the bonding of molecular giant structures and polymers. However, teachers may want to be prepared to address pupils' questions about the properties of wax and sucrose. These could be explained in terms of the existence of weak bonds between molecules, explaining the low melting and boiling points.

The teacher poses a question:

How come the molecules in hydrogen gas are not touching, yet millions of lithium and chloride atoms are touching in solid lithium chloride?

Pairs of pupils could briefly discuss this question and the teacher takes feedback.

The teacher then proposes the model of electron sharing to form covalent bonds. Again, this is done using the traditional approach of the 'dot and cross' representation. A possible target representation of the H_2 molecule is shown below:



Pupils, working in pairs, are asked to explain the following properties of covalent compounds. Each question could be presented on the whiteboard, with pupils having the chance for quick discussions in pairs before responding:

- Why is the chemical formula for hydrogen gas 'H_2' and not just 'H'?
- Why are molecules of hydrogen gas not electrically charged?
- Why don't atoms of hydrogen bond together to form a crystal, like lithium fluoride?

Activity 4.2: Practising using the model.

Teaching objectives

- To allow the pupils to practise showing how covalent and ionic bonds are formed for simple compounds.
- To continue to link the type of bonding to properties.

Learning outcomes

By the end of the activity, pupils will be able to:

- use the extended particle model to show bonding, and link that to properties.

What to prepare

- Worksheet: 'Bonding and properties'.

Mode of interaction

INTERACTIVE/AUTHORITATIVE Pupils work in pairs focusing on the correct scientific models. The teacher circulates to probe pupils' understanding.

What happens during this activity

Working in small groups or pairs, pupils are given an example of ionic bonding to complete, and an example of covalent bonding. Pupils have to make statements about the properties of each compound, based upon its bonding.

The examples presented are sodium chloride (ionic) and chlorine gas (covalent). This activity could be extended to include the sharing of more than one pair of electrons and ions with a charge of more than 1.

Some common questions asked by pupils, and possible responses, are presented below:

Possible question	Potential response
How do atoms 'know' to lose an electron?	It is very difficult to give a satisfactory explanation at this level. It is usual to describe atoms being stable when they have a complete outer shell of electrons. The atom doesn't know to lose an electron. It is just more stable for it to exist with a full outer shell of electrons, so it does. The notion of stability can be explained in terms of the arrangement having 'low energy'.
Why do some atoms lose electrons while others share electrons?	Again, it is hard to give a completely satisfactory explanation. However, pupils have seen that chlorine can exist in both ionic and covalently bonded structures. This shows that a given atom can attain its stable structure with a complete outer shell of electrons in more than one way. Examples like carbon dioxide and sodium chloride can be used to explain why some substances form ionic bonds while others form covalent bonds. Carbon has to lose or gain 4 electrons to form ions, and we saw in the last lesson that atoms rarely loose or gain more than 3 electrons. However, by sharing electrons, it is possible for both carbon and oxygen atoms to have full outer shells. Sodium and chlorine only have to lose or gain one electron, and therefore form ionic bonds.
How do atoms 'know' how many electrons to lose?	This is best answered in terms of stability. Atoms are more stable with complete outer shells of electrons, so they lose or gain the number of electrons that results in the most stable state.

Bonding and properties

You are going to draw diagrams to show the bonding in two compounds, and consider how this explains the properties of each compound.

1. Sodium chloride (ionic bonding)

Draw an electron diagram for a *sodium atom*.
(Hint: it has 11 protons and 11 electrons. The electrons are arranged in 3 shells.)

- How many electrons does the sodium atom have to lose or gain to get a complete outer shell of electrons?
- Draw an electron diagram for a *charged sodium ion*. What is the charge on the ion?

Draw an electron diagram for a *chlorine atom*.
(Hint: it has 17 protons and 17 electrons. The electrons are arranged in 3 shells.)

- How many electrons does the sodium atom have to lose or gain to get a complete outer shell of electrons?
- Draw an electron diagram for a *charged chloride ion*. What is the charge on the ion?

Solid sodium chloride exists as salt crystals. Explain how the ionic bonding helps us to understand why sodium chloride is made of crystals.

Sodium chloride crystals dissolve easily in water. Explain how the ionic bonding helps us to understand why they dissolve in water.

Sodium chloride has a high melting point. What does this tell us about the strength of the ionic bonds in sodium chloride?

2. Chlorine gas (covalent bonding)

You have already drawn an electron diagram for a chlorine atom in the last section.

- How many electrons does the chlorine atom need to *share* with another atom in order to have a full outer shell of electrons?

Draw an electron diagram for a chlorine atom but *only showing the outer shell of electrons*. This is how people normally draw electron diagrams to explain bonding. It is simpler to ignore the inner shells of electrons because they are not involved in bonding.

Draw an electron diagram for a chlorine molecule. (Hint: the formula for a chlorine molecule is Cl_2, so you will need to draw two chlorine atoms, each sharing one electron.)

Chlorine is a gas. Explain how our model of the bonding in chlorine helps us to understand why chlorine exists as a gas, rather than as a crystal structure.

Lesson 5: Developing the model – metallic bonding

Teaching 'story'

The pupils are introduced to the properties of metals. Through discussion, pupils are made aware that these properties cannot be explained in terms of ionic or covalent bonding. A simple model of metallic bonding is introduced and used to explain some properties of metals.

Activity 5.1: The properties of metals.

Teaching objectives

- To develop a shared view of the properties of metals.
- To develop a shared understanding of the need for a new model of bonding for metals, and some features that the model should include.

Learning outcomes

By the end of the activity, pupils will be able to:

- recognise key properties of metals;
- explain that the existing models of ionic and covalent bonding are inadequate to explain the properties of metals;
- recognise that the model of bonding in metals should address the strength, flexibility and conductivity of metals.

Mode of interaction

Pupils work in groups to discuss their ideas with an INTERACTIVE / DIALOGIC approach. The teacher probes pupils' developing thinking.

DIALOGIC HOTSPOT

What to prepare

- Worksheet: 'Metals – what's going on?'

What happens during this activity

This activity begins with a demonstration by the teacher to establish some key properties of metals. As properties such as conductivity are likely to be familiar to pupils, little time is spent demonstrating this property. However, some teachers may choose to allocate time for the pupils to carry out practical work to test conductivity.

Three metals are chosen as examples: copper, iron and zinc.

- The teacher demonstrates their conductivity.
- Their flexibility is then demonstrated, and contrasted with the brittleness of ionic solids such as sodium chloride.
- The teacher should also remind pupils that solutions of ionic compounds conduct electricity. However, pupils may not know that in solid form, ionic compounds *do not conduct electricity*. This should be demonstrated.
- Finally, a sample of each metal is held in the Bunsen burner flame to show that metals have a high melting point.

Pupils then work in small groups to discuss answers to the questions posed on the worksheet 'Metals – what's going on?' The questions focus attention on the relationship between the properties of ionic and covalent compounds and their bonding and ask pupils to identify why the models of ionic and covalent bonding do not explain the properties of metals. The rationale for the questions on the sheet is as follows:

Question area	Rationale
Questions that contrast the brittleness of crystalline solids and the flexibility of metals, but recognise that both metals and crystalline solids are strong.	Ionic bonds must be strong due to the high melting point of ionic solids, but ionic solids are brittle and metals are not. Pupils are asked what would happen if a plane of charged sodium and a plane of chloride particles were to slide against one another. The answer enables them to appreciate that similarly charged sodium and chloride particles would repel each other. Furthermore, metals contain just one kind of atom. Metals cannot therefore have ionic bonding.
Questions that contrast the electrical conductivity of ionic solids, solutions of ionic compounds and metals.	In ionic solids no charged particles are free to move and carry current. In solutions of ionic compounds the ions are free to carry current. What charged particles might be free to carry current in solid metals?
Questions about covalently bonded substances.	The only covalently bonded compounds to be addressed in this unit exist as simple molecules. On this basis, pupils should be able to dismiss the notion that the atoms in metals are bonded covalently.

Finally, the teacher reviews the pupils' explanations in a plenary session. The class is led to an agreed view that a new model of bonding for metals is needed which can explain:

- the flexibility of metals – the model must explain why metals do not snap so easily when bent;
- the conductivity of metals – the model must include charged particles that are free to carry electric current;
- the fact that metals are solids with high melting points – the model must include strong bonds between atoms.

Activity 5.2: Teacher presentation: bonding in metals

Teaching objective

- To present a simple model of metallic bonding that can explain the strength, flexibility and conductivity of metals.

Learning outcomes

By the end of the activity, pupils will be able to:

- explain the flexibility, conductivity and strength of metals in terms of a simple model of metallic bonding.

Mode of interaction

INTERACTIVE/AUTHORITATIVE
The teacher presents the model of metallic bonding, relating it to the properties of metals, and contrasting it with the models of ionic and covalent bonding.

What happens during this activity

The teacher makes a presentation about metallic bonding. Key features of the model, and how they relate to the properties of metals, are summarised below:

Feature of model	How it relates to the properties of metals
Electrons in the outer shells of each metal atom are free to move between atoms.	These electrons are shared between large groups of atoms – explaining the strength of metals.
Electrons in the outer shells of each metal atom are free to move between atoms.	These electrons are charged and free to move, which explains why metals are good conductors of electricity.
The electrons are shared between large groups of atoms.	This explains why metals are solids.
Metals consist of just one type of atom, and the atoms do not carry a charge.	Atoms can therefore slide over each other, staying tightly joined together, without any repulsion of oppositely-charged atoms.

Executive desk toys, which have a magnetic base and lots of small pieces of metal that can be sculpted into different shapes, can be used to model the atoms in metals and explain why metals can be stretched and beaten into different shapes (i.e. the properties of ductility and malleability).

Metals – what's going on?

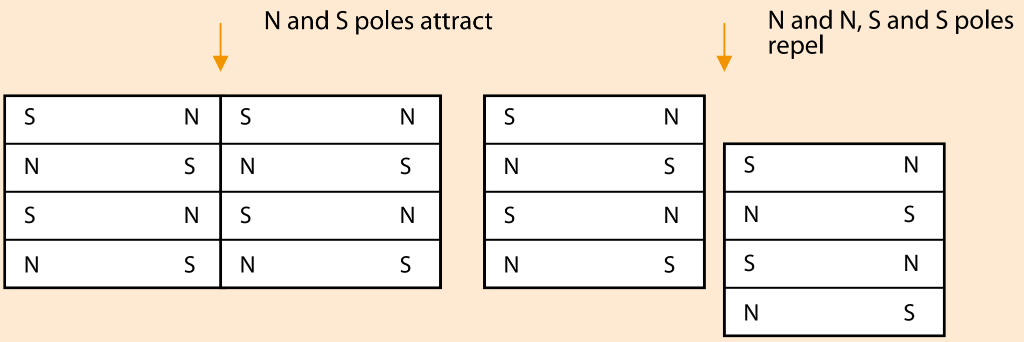
Jot down your answers to the questions in the spaces as you work through this series of questions.

Metals are solids. Most of the covalently-bonded substances that you have seen are gases.

How can we tell that the atoms in metals aren't held together by covalent bonds?

How do we know that the bonds between atoms in metals are *strong*? How do we know that the bonds between the atoms in ionic compounds like sodium chloride are *strong*?

Can you think of a reason why ionic compounds like sodium chloride are brittle? Hint: think what would happen if two layers of atoms in a sodium chloride crystal slid along each other. Think what would happen if we tried to slide the two rows of magnets along each other in the diagram below:



Do you think that the atoms in metals can have ionic bonding?

Metals conduct electricity. Ionic compounds *do not conduct electricity* in their solid form, but *conduct electricity when in solution*.

Think back to your models of the structure of solid ionic compounds like sodium chloride, and solutions of sodium chloride: **what could be carrying the electric current in the solution, and why isn't it free to move in the solid?**

Do you think that the atoms in metals can have ionic bonding?

Acknowledgements

Page 11, Photograph of *Oxidation of magnesium*. Andrew Lambert Photography / Science Photo Library. Used with kind permission.

Audience: Science subject leaders, teachers of science and higher level teaching assistants.

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