Science Enhancement Programme

STUFF AND SUBSTANCE: TEN KEY PRACTICALS IN CHEMISTRY

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Innovations in practical work

STUFF AND SUBSTANCE:
TEN KEY PRACTICALS IN CHEMISTRY

The Science Enhancement Programme is a part of Gatsby Technical Education Projects. It is developing curriculum resources to support effective learning in science, and providing courses and professional development opportunities for science teachers. This booklet is part of the series 'Innovations in practical work', exploring ways in which low-cost and novel resources can be used in secondary science.

SEP
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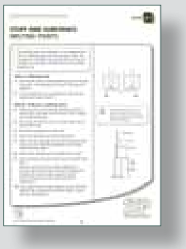

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www.sep.org.uk

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INTRODUCTION

Understanding the idea of a 'substance' is central to making sense of the variety of materials in the world and the way that they change. Research on pupils' understanding shows that they find many fundamental ideas in chemistry difficult, and this leads to problems in progression.

This booklet complements the CD-ROM 'Stuff and Substance' which was published by SEP a few years ago. 'Stuff and substance: ten key practicals in chemistry' looks at how practical work can be used to support the development of critical concepts in chemistry for secondary school students. The booklet provides links to the videos and animations in the 'Stuff and Substance' multimedia package, and how they can be used to develop the story.

These activities are intended for 11-14 year olds, but since older students often have misconceptions about these key ideas, the activities may also be useful at 14-16. The accompanying CD-ROM of e-resources may be purchased from Mindsets (formerly Middlesex University Teaching Resources). The e-resources are now also freely available online in the National STEM Centre eLibrary for use by teachers and students.

THE E-RESOURCES

The Stuff and Substance e-resources consist of a number of sections covering key ideas in basic chemistry. Each section contains text, videos, animations and questions for students, accompanied by notes for teachers.

Substances			
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B	Particle theory	O	A closer look at the change of state
C	The gas state	P	The gas state and pressure
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The e-resources are available for purchase on a CD-ROM from Mindsets (www.mindsetsonline.co.uk) and could be installed on a school network. They are also freely available online on the National STEM Centre eLibrary (http://stem.org.uk/cxtr).

This booklet makes references to a number of sections of the e-resources, and to specific videos and animations. There is a pdf file that can be downloaded from the SEP website that contains links to the e-resources on the National STEM Centre eLibrary for each of the activities to enable quick access to the materials.

SOURCES

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USING STUFF AND SUBSTANCE IN THE CLASSROOM: IDEAS AND SUGGESTIONS

The concept of a substance lies at the heart of understanding chemistry. For students, this idea is not innate, and cannot be left somehow to develop naturally. It is an abstract scientific idea that needs to be learned. Everyday thinking assigns identity to a sample of stuff by its *history* – where it comes from and what has happened to it – rather than its *here and now* properties. Thus the everyday view is quite different from the scientific view: chemistry sees the world in terms of *substances*.

This section gives an overview of how the *Stuff and Substance e-resources* can be used in the classroom alongside 10 key practical activities to teach about fundamental ideas in chemistry. In the margin, references are given to student activities – these resources and the accompanying teachers' notes can be found later in the booklet. There are also references in the margin to the relevant sections of *Stuff and Substance e-resources* where the ideas can be explored more fully.

DEVELOPING KEY IDEAS IN CHEMISTRY WITH STUDENTS

Traditional approaches to introductory chemistry often assume that the concept of a substance is 'obvious' and do not specify it as something to be taught. Instead, the introduction to the material world is structured around the notion of 'solids', 'liquids' and 'gases'. This can create difficulties for students. In this booklet, and the accompanying e-resources, the focus is on developing the concept of a *substance*. Key differences between the two approaches are:

Substances and states In the 'solids, liquids and gases' approach, students can take 'solids, liquids and gases' literally. They think these are three *different types of material* – as if they were different species. In particular, this leaves 'gases' as a mystery. It is essential that students understand that 'solid, liquid and gas' refer to *different states of a substance*. For example, water is not 'a liquid' – it just happens to be in the liquid state at room temperature. Under other conditions water can be in the solid or gas states.

The state of a substance depends on the conditions. Here, for example, water, iron and butane are not in their 'normal' states. 'Solids, liquids and gases' are not different types of material.

Mixtures The 'solids, liquids and gases' approach does not distinguish between substances and mixtures of substances. The messy behaviour of some mixtures, in contrast to the simpler behaviour of pure samples of substances, remains unexplained (e.g. melting chocolate compared to melting ice). Most of the materials that we meet in everyday life are mixtures of substances, and relatively few are just one substance. In the chemistry laboratory, to carry out meaningful experiments we usually need to use pure samples of substances rather than mixtures, and these substances are purchased from specialised suppliers of 'chemicals'.

Most everyday materials are mixtures of substances (left), though in the chemistry laboratory, pure samples of substances are often required (right).

Chemical change Students need to understand the concept of a substance if they are to understand the nature of chemical change. Without the concept of a substance, the 'solids, liquids and gas' approach puts emphasis on 'reversibility'. Thinking about whether a change is 'reversible' or 'irreversible' is not helpful to students in distinguishing a chemical change. Some chemical changes are easily reversible and others are not. The key point is to understand that *substances change into other substances.*

'Reversibility' is not a helpful indicator of chemical change. Burning a fuel and breaking a windscreen are both difficult to reverse, but only burning is a chemical change.

Particles If students learn about 'solids, liquids and gases' without the concept of a substance, their understanding of particle theory will be inhibited. It will not be clear to them that the 'basic' particles are particles of substances, or why different substances have different melting and boiling points (and hence have different states at room temperature). This reinforces the misconception of the existence of three kinds of particles (solid particles, liquid particles and gas particles) for three kinds of 'stuff'. With such misconceptions 'gases' will remain a mystery, and students will not be able to understand that substances in the gas state at room temperature are just as much substances as salt or iron. An emphasis on only the *movement* of particles *in* 'solids, liquids and gases' gives life to the misconception of 'particles' being embedded *in* the 'continuous material'.

Linking the concept of substance to ideas about particle theory is essential in developing students' understanding.

Composition When ideas of atoms are introduced, students can become confused if the distinction between the *substance* and the *atom* is not emphasised. When chemists say 'water is made of hydrogen and oxygen', they mean water particles are composed of hydrogen atoms and oxygen atoms. Water is not a mixture of the substances hydrogen and oxygen. Water is one substance in its own right. Water can be made by reacting the substances hydrogen and oxygen together – but it can also be made by reacting copper oxide with sulfuric acid.

Without distinguishing atoms from substances, 'water is made from hydrogen and oxygen' is an ambiguous statement: hydrogen cylinders (top left), oxygen cylinder (bottom left), water (top right) and a model of a water molecule (bottom right).

The *Stuff and Substance* approach puts the concept of a substance and a developing particle model centre stage. It addresses the ideas students need to develop to understand chemistry. The diagram on the following page shows a summary of the 10 practical activities in this booklet and how they relate to the flow of key ideas. These ideas are developed at both the macroscopic level (*observations*) and the particle model level (*explanations*). Arrows show the direction of travel, highlighting the interplay between observations and explanations.

Notice that some arrows move from the 'macroscopic level' to the 'particle model level' – in other words, the particle ideas are developed to explain phenomena. However, notice also that some arrows point in the other direction – in particular, the particle model is used to predict the possibility of the gas state (i.e. that 'gases' are substances) and to predict the possibility of chemical change.

Sections in the booklet and practical activities	**Observations (macroscopic level)**	**Explanations (particle model level)**
What is a substance? Melting points of wax, lead and common salt. (A1 Melting points)	Melting and well-defined melting points for different kinds of stuff: these are substances.	A 'basic' particle model explains the solid and liquid states and different melting points.
Predicting the gas state Injecting a drop of water into a very hot syringe. (A2 Predicting with the particle model)	A sample of a substance in the liquid state changing to the gas state. 'Gases' are substances.	The 'basic' model predicts the possibility of particles moving far apart on further heating.
Substances and mixtures of substances Comparing the melting behaviour of substances and mixtures of substances. (A3 Melting behaviour of materials)	Mixtures do not have well-defined melting and boiling points.	(The messy behaviour is not easily explained.)
Dissolving substances Recognising when substances in the solid or liquid states dissolve in water. (A4 Recognising dissolving)	When a substance dissolves in water (liquid) a clear colourless or coloured solution is formed.	Is explained by the 'basic' particle model.
Do 'gases' dissolve? Ammonia dissolving in a much smaller volume of water. (A5 Dissolving 'gases')	A solution of 'a gas' in water is no different to other solutions. Substances in solution do not have a state.	Is explained by the 'basic' particle model.
Evaporation Investigating evaporation and the factors which affect the rate of evaporation. (A6 Investigating evaporation)	Substances in the liquid state mix into the air at temperatures below boiling point.	Is explained by a 'basic' model plus ideas of energy distribution at a temperature.
Chemical change Stearin and sodium carbonate reacting together to give a new substance with a different melting point and solubility. (A7 What kind of change?)	Substances can change into other substances which have different properties.	A substance being defined by its atom structure predicts the possibility of rearrangement, i.e. creating new substances.
Reactions involving the gas state: combustion Magnesium reacting with a bag of oxygen. (A8 Magnesium and oxygen)	Some substances change into a new substance when heated in air. They react with the oxygen in the air.	Is explained by the rearrangement of atoms to give new atom structures.
Atoms and substances: rusting Showing that iron reacts with dissolved oxygen, not water, when it rusts. (A9 Investigating rusting)	A compound is a substance in its own right. It is not a mixture of the substances ('elements') it is made from.	Is explained by the distinction between individual atoms and the atom structures which define a substance.
Complex changes: a lighted candle Setting boiling wax alight and investigating glass wick candles. (A10 A lighted candle)	Some substances starting in the solid state have changed to the gas state before they react with oxygen in the air to give a flame and new substances.	A 'basic' particle model explains the change of state. Rearrangement of atoms explains the change to new substances.

A note about the terminology used: We have been careful only to use the word *substance* to mean *a substance*; the word *material* is used for any sort of *matter* or *stuff*. For example, water and orange juice are both *materials*, but only water is *a substance*. This distinction is fundamental to chemistry, and careful language is needed to express it, whatever the words used.

We have also not talked about *pure substances*. This is deliberate. Referring to a substance as pure can be misleading. The question of purity relates to a *sample of material*, not to the idea of a substance. Talking about 'pure substances' may suggest to students that some substances are pure and some are not pure, and that compounds are mixtures.

WHAT IS A SUBSTANCE?

What is meant by a substance? One way to explain this would be to say: 'A substance is a homogeneous sample of matter with definite physical and chemical properties, and a definite composition. Elements and compounds are substances.' However, this sophisticated definition only makes sense if one already understands what a substance is. An accessible first step is to use *melting behaviour* to recognise substances. Melting at a well-defined temperature indicates a *pure sample* of a substance and the value of the temperature identifies *which substance.*

Students do not expect the temperature of a sample to remain constant during melting. Not surprisingly, they think heating will always give a rise in temperature. Therefore, they expect the temperature to increase between the start and finish of melting. Some will think the sample size has an effect – the bigger the lump the higher the melting temperature. Although most students see solidifying on cooling as the reverse of melting, many think that this only happens at temperatures well below the melting temperature.

Students may meet these ideas in the classic 'cooling curve' experiment in which they measure the temperature change of a substance as it cools over time and solidifies – however, this involves a lot of ideas for students to understand, and they need to be introduced to these in stages. In the approach taken in this booklet, students start by gaining experiences of different substances melting at different temperatures. The idea of a melting point is introduced as 'when just hot enough to start melting'. The emphasis is on what is seen when a substance melts.

Classroom activities

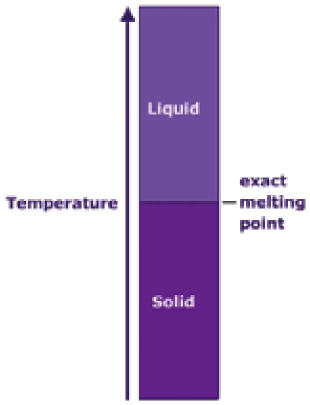
See Activity A1
Melting points (page 46)

Students will have seen wax melt with lighted candles, and they can be shown how a sample of candle wax will melt in hot water but not in cold. They can be asked to think about how hot the wax needs to be before it melts, and how they could find this out. One way of investigating this is to float a sample of wax on water and increase the temperature of the water until melting occurs. The investigation only makes sense if they appreciate that the melting point is *independent of the amount of wax.* This needs to be drawn out in class discussion, either before starting the activity or after allowing students to choose the quantity.

Candle wax melts in hot water but not in cold (left). The melting point can be found by heating a water bath with the wax floating in an aluminium foil ‘boat’ (right).

There are inaccuracies in this method, and students should consider how they could minimise these – for example, by using a small sample of wax and heating slowly to ensure that the temperature of the wax is as close as possible to the water temperature. Careful stirring ensures the thermometer is measuring the temperature of the water next to the wax. From this discussion, the *idea* of a melting point can be developed. If using candle wax, determine its melting point before the lesson and present this as the accurate value, say 64 °C. This is the temperature when wax is hot enough to melt. A piece of wax heated to 63 °C will not melt no matter how long it is kept at that temperature. Not even a little bit of it will melt until the temperature reaches 64 °C. Every bit of the wax will melt when its temperature reaches 64 °C, but it will take time for this to happen (which is why a small lump is better).

A substance has a well-defined melting point at which it changes from the solid state to the liquid state.



This diagram from the *Stuff and Substance e-resources* can be used to reinforce the idea of a melting point. Students can also be asked about solidifying – what would happen if liquid wax at 80 °C is allowed to cool? The liquid wax would start to solidify at 64 °C – though at this stage it would be acceptable to argue this will be when the temperature falls *just below* the melting point.

Students can be shown demonstrations of two substances with higher melting points – common salt (sodium chloride, 801 °C) and lead (327 °C). Some students may have seen lead melt; most students will not expect common salt to melt! Draw attention to the sharpness of the melting behaviour. Like the wax, both lead and common salt turn to a runny liquid on reaching melting point – there is a distinct change from solid to liquid, suggesting that they have well-defined melting points. A dramatic demonstration is to pour out the lead onto a slab of metal to cool it and then to pick up the lead ‘pancake’ immediately with tongs.

Sodium chloride melts at a high temperature (left). Molten lead being poured onto a slab of metal to cool it (right).

From this work on melting points, the key points that need to be emphasised with students are:

- A substance has a well-defined melting point: it changes straight to a runny liquid.
- Melting point is a 'switching temperature' between the solid and liquid *states* of a substance.
- 'Solid' and 'liquid' are two possible states for a substance.

Moving On

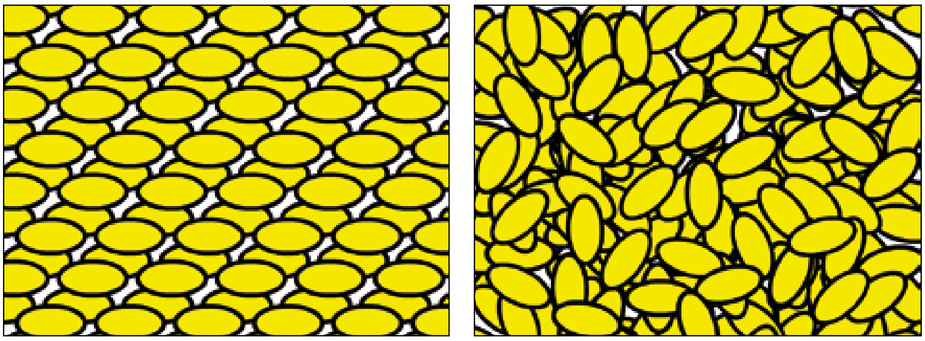
Section A: Melting and freezing
Section O: A closer look at change of state

As well as observing the changes in state in the laboratory, students can also view close-up videos of them and try some animations that consolidate the ideas (Section A of the e-resources). The working definition of *a substance* is consistent with the temperature remaining constant during change of state but does not make an issue of it. What happens at the melting point can be explored at greater depth later (Section O of the e-resources). Many students will want to think of melting and solidifying as taking place over a narrow temperature range.

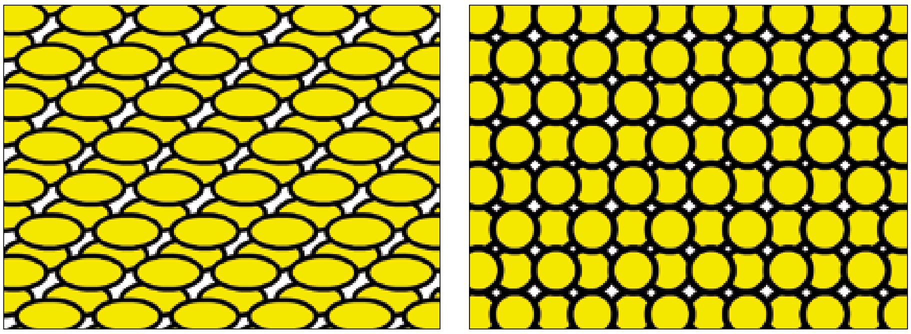
Section B: Particle theory

After the idea of a substance has been established, the next stage is to explain why a substance can exist in both the solid and liquid states and why different substances have different melting points. Students can now be introduced to a particle model that helps to explain these behaviours. Section B of the e-resources provides opportunities for this, and there are animations showing the movement of the particles in the solid and liquid states. Being able to interact with animations showing changes of state and the way that different substances are represented can be very helpful for students.

Still images from the animations in the e-resources: candle wax in solid state (left) and liquid state (right).



As well as showing the movement of the particles, the representations also indicate the 'grip' that particles have for each other: the thicker the line, the greater the grip and the higher the melting point.



Representations of candle wax in the solid state (left) and lead in the solid state (right). The lead particles are drawn with thicker lines to represent greater 'grip'.

The key ideas established through this work are:

- A sample of a substance is a collection of particles.
- There is nothing else except the particles.
- The particles of one substance are all the same.
- The particles hold on to each other – the 'ability to hold' or 'grip' is different for different substances.
- The particles are always moving in some way – they have energy of movement.
- Heating gives the particles more energy of movement – they are more energetic.

A crucial part of this model is the idea of particles having an 'ability to hold' or 'grip', with different strengths of hold explaining different melting points. Talking about the particles of a substance helps to establish the idea of a substance.

PREDICTING THE GAS STATE

Knowing how gases *behave* is one thing but understanding what gases *are* is another. The idea of 'a gas' being 'a substance' is not at all obvious, and historically was not established until the early eighteenth century. Thinking of gases as substances was an important precursor to Lavoisier's experiments with oxygen and his founding of modern chemistry. Many chemical reactions in school science involve gases as either reactants, products or both.

Intuitively, 'gases' are a mystery to students. They are far from thinking of 'gases' as being substances and most students don't even think gases have weight. For the particle model, the idea that the particles are the substance with most of the volume being 'nothing' is not conceptually easy. Without understanding that 'gases' are substances, just as much as those appearing in the solid or liquid states at room temperature, chemistry will not make sense.

The approach here is to assume that students don't know what 'gases' are and to use the particle model to *predict* the gas state. They can then be shown a demonstration in which they see a small sample of liquid water change to a much larger volume of clear colourless gas. Some students (if they know about 'what water is made of') may be distracted into thinking that the water separates into hydrogen and oxygen because these are 'gases'. It is better therefore that the idea of water in the gas state is established before students do work on the composition of water.

An important idea is that the state of a substance depends on the balance between 'ability to hold' and energy. One misconception is that the 'hold' of particles weakens as they gain energy. This is not the case – 'ability to hold' is a characteristic of the particles and *does not change* as the substance is heated. What changes is the energy the particles have to overcome the hold. Enough energy to partially overcome the hold gives the liquid state. Enough energy to completely overcome the hold gives the gas state.

Classroom activities

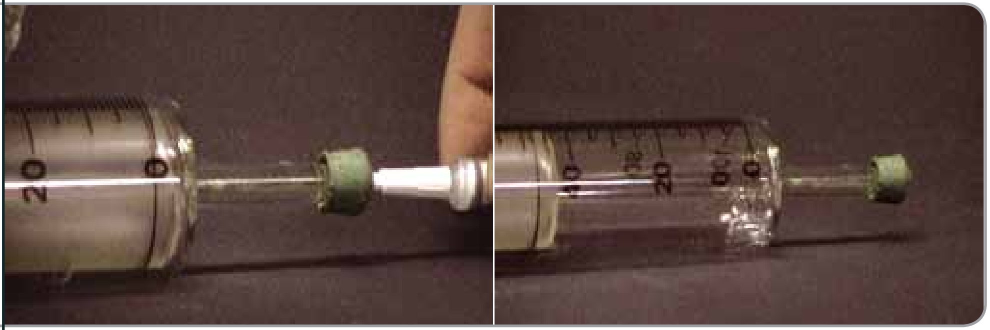
See Activity A2
Predicting with the particle model (page 48)

Students can begin by imagining what the particles would do if a drop of colourless liquid (like water or ethanol) is heated to higher and higher temperatures. They can be shown a drop of water being put inside a plastic bag, which is then sealed. Ask them to think about what might happen if the bag was heated, with explanations in terms of particles.

Students can be asked to imagine what would happen if a drop of water inside a sealed plastic bag is heated.

Depending on the class, some prompts may be appropriate (for example, remind them that during melting, the particles themselves do not change; only their energy and movement changes). Encourage detail. What will be seen? Allow groups to present their predictions without passing judgement, and note any misconceptions privately to pick up on later.

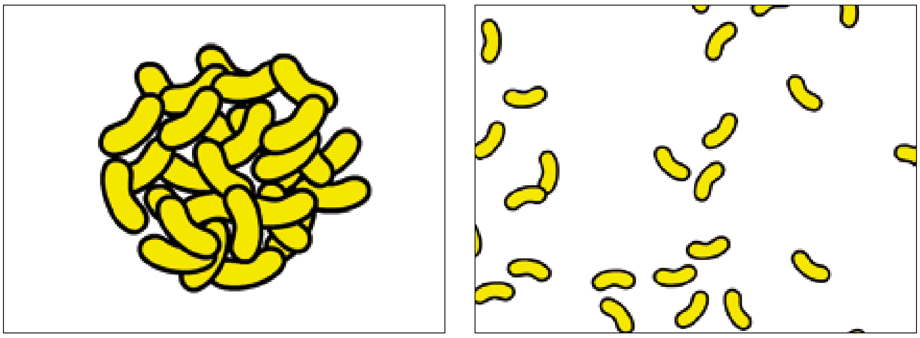
These predictions can now be put to the test. Students can observe a demonstration in which a drop of water is injected into a preheated gas syringe. Explain that the small amount of water will quickly heat up when it touches the hot glass. The plunger moves out quickly and then stops. Ensuing discussion will build on the group presentations. The key point is that inside the syringe looks like air, but only water was injected.



A drop of water being injected into a hot gas syringe (left). The plunger in the syringe moves out (right).

The simplest explanation is that the water particles have gained so much energy that they move far apart from each other. When particles move far apart we have the gas state. Inside the syringe is water in the gas state, which looks like other substances in the gas state, or like air. Drawing attention to the huge change in volume can lead to discussions on what is between the particles. If the particles are the substance water and nothing else is inside the syringe, between must be nothing – empty space. It can't be air because air is something – air particles.

To help with the discussions, students could look at the animation in the e-resources that shows what can happen when particles are given enough energy to move away from each other.



A group of particles representing the much larger number of particles in a real droplet (left). With enough energy the particles can move away from each other (right).

Some students may suggest that the particles expand, which is entirely consistent with the observations. This is not readily countered, other than saying we don't need to say they do. However, if the particles expand, we would have to explain why they expand. Saying the particles do not change and just move apart is a simpler model.

The syringe will cool and it is worth asking students to predict what will happen. If the demonstration is repeated, another possibility is to remove the rubber seal and eject the gas – a small puff of mist is seen.

Moving On

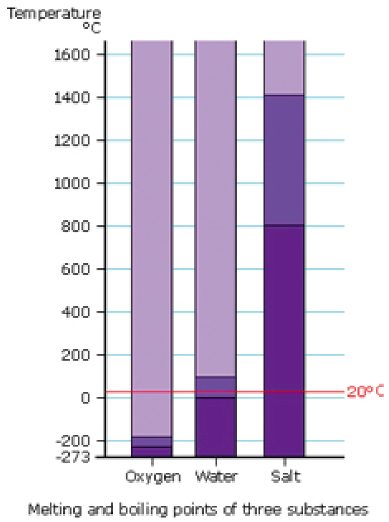
Section C:
The gas state

These ideas are extended in Section C of the e-resources to look at the process of boiling water, and at changes of state of other substances. A parallel can be drawn between the syringe experiment and the large bubbles which form at the bottom of a beaker of boiling water. A small amount of liquid water changes to the gas state which we see as the bubble. Inside, the bubbles are clear – just like inside the syringe. The mist seen above the beaker is where the water has condensed to form droplets of liquid water. It is important that students understand that the gas state is clear – if they can see something (like mist or smoke) it isn't a gas. Boiling point can then be defined as the temperature at which a substance changes from the liquid state to the gas state. Referring back to the syringe experiment, students could be asked about the temperatures. Why was the syringe heated to well over 100 °C? On cooling, when did drops of condensation form?

Section D:
Substances and the three states

More widely, what we commonly refer to as 'gases' can be understood as substances with boiling points below room temperature (Section D). 'Solids, liquids and gases' are not three separate kinds of matter. There are just substances with different melting and boiling points. 'Gases' having mass ought to follow from seeing the particles as the substance, and being no different to the solid and liquid states.

Melting and boiling points of three substances.



SUBSTANCES AND MIXTURES OF SUBSTANCES

Most everyday materials are mixtures of substances. Many are very complex mixtures. When investigating an unknown sample of stuff, the first question for the chemist is whether it is a substance or a mixture of substances. Properties, like melting behaviour, can reveal the difference – mixtures of substances do not have well-defined melting points. Generally, the behaviour of mixtures is much more complicated than substances.

Students are very familiar with mixing. If they know something has been made by mixing things, they will say it is a mixture – they use its 'history' to decide. But this can lead to difficulties. Compounds are not mixtures, but they may be formed by mixing substances together that react. Using *properties*, rather than '*history*', to distinguish mixtures is a completely new way of thinking, which will take getting used to.

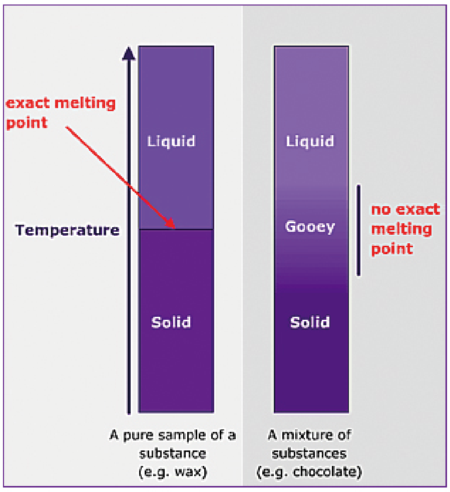
The approach taken here is to compare the melting of some 'unknown' materials, to illustrate the difference in behaviour between *substances* and *mixtures of substances*. This gives the opportunity to consolidate the idea of a melting point while taking things further. The emphasis is on recognising when something doesn't have a well-defined melting point.

Classroom activities

See Activity A3
Melting behaviour of materials (page 49)

Students can heat some 'unknown' materials, by placing a sample on a watch glass on top of a beaker of hot water. Suitable materials would be lauric acid (a substance with a relatively low melting point, 43 °C), and butter and chocolate (both mixtures of substances). In contrasting their behaviour, students should identify whether the material changes sharply from a solid to a liquid, or whether it goes 'gooey'. Thinking back to the way that a single substance behaves when it melts, students have the chance to work out the reason for the contrasting behaviours.

Chocolate is a mixture of substances and does not have a well-defined melting point.



The key point is that mixtures don't have well-defined melting points, and melting behaviour is a way of telling the difference between a substance and a mixture of substances. Most students will be familiar with the idea that chocolate and butter are mixtures without necessarily knowing all of the details. But the point is that we don't need to know where something came from to find out if it is a mixture.

Students should try to think of other materials which behave like wax and chocolate, respectively. From their earlier work, water, lead and common salt should spring to mind for wax. However, very few everyday materials are just one substance. Ice cream and road tar are similar to chocolate, but most everyday materials don't behave like chocolate when heated: wood, rubber, fabrics and foods don't melt when heated but undergo other kinds of changes (decomposition and combustion are dealt with later in this booklet). However, if something does melt and does have a well-defined melting point, then it is a substance.

Moving on

Section F:
Melting behaviour

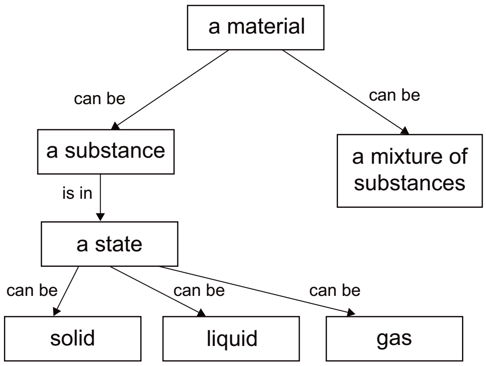
The idea of testing can be extended to boiling behaviour: a mixture does not have a well-defined boiling point (see Section F of the e-resources). Boiling a mixture of water/propanone (or water/ethanol) is a good demonstration. A thermometer placed in the boiling liquid will show an increasing temperature as the proportion of water to propanone (or ethanol) changes. Another example that is useful to discuss with students is air: they can see that it is also possible to have a mixture of substances in the *gas state*.

Section I:
Recognising dissolving

The idea of a state applies to a pure sample of a substance. Of course, some mixtures can have all the characteristics of a particular state, but many mixtures do not. Trying to classify all materials as either 'solids', 'liquids' or 'gases' is not an activity that is helpful or that makes sense. Many materials (such as jelly, toothpaste, foam, and so on) are difficult to classify because they are mixtures. (See '*Mixtures that are not solutions*' in Section I of the e-resources.) Wood is more compressible than the true solid state. It really only makes sense to talk about the three states of matter in relation to substances and not mixtures.

The concept map on the following page shows the ideas we have sought to establish. An understanding of the material world builds on this fundamental framework.

A concept map that summarises some of the key ideas introduced so far.



DISSOLVING SUBSTANCES

Liquid solutions play an important role in chemistry. Starting with pure samples of substances, solutions are known 'made up' mixtures (of a *solvent* and a *solute*). In school chemistry, the solvent is usually water. Before mixing, solutes can start in either the solid, liquid or gas states. Many chemical reactions involve at least one solution (e.g. acids). Making sense of observations requires thinking about the solubilities of the substances involved (e.g. formation of a precipitate or not). The first step to understanding solubility is to recognise when something dissolves. Here, the key criterion is the disappearance of the solute to give a *transparent* (*clear*) mixture.

The distinction between a suspension and a solution is a source of confusion for students. They will say powdered chalk dissolves on mixing with water because they see the powder spreading throughout, turning the water white. 'Mixing in all over' is being used as the criterion rather than *transparency* (*clearness*). Without properly understanding what a solution is, many students won't appreciate why a dissolved substance cannot be filtered out. Careful use of language needs to be encouraged: students tend to interchange 'melt' and 'dissolve' as words, although they can often tell the difference between heating one substance and mixing two together.

The approach differs from the dissolving experiments students are likely to have experienced in primary school in two important respects:

- The solutes are understood to be *substances*. There are no confusing mixtures where part dissolves and part does not.
- There are solutes in the *liquid state* as well as the solid state (and in the gas state too – see the next section *Do 'gases' dissolve*?).

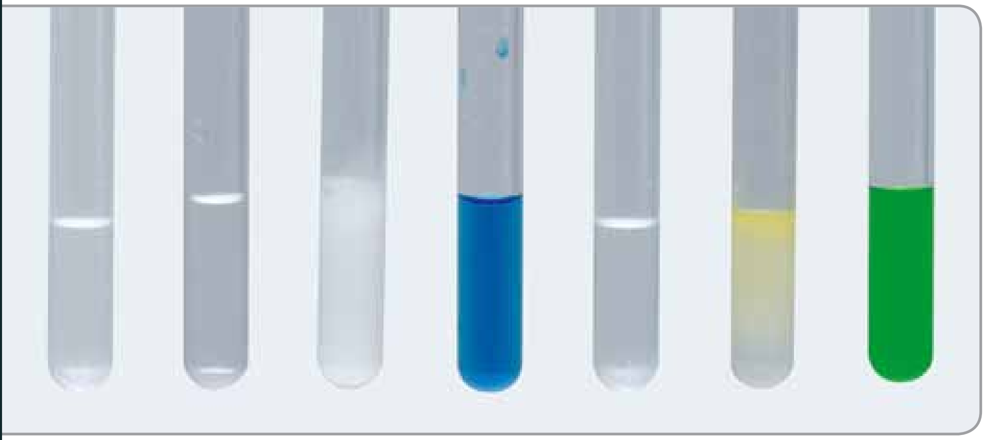
The emphasis is on establishing *transparency* (*clearness*) as the criterion for recognising dissolving, supported by the application of particle theory.

Classroom activities

See Activity A4
Recognising dissolving
(page 50)

Students can be given a range of 'unknown' substances to test and find out which dissolve in water. The unknowns are not categorised into 'solids' and 'liquids'. All are just substances that they add to water, stir and observe what happens; the only difference is the use of a spatula or a dropper.

Since the substances are not identified, students will have to rely on observations rather than any prior knowledge. The amount of substance to add is important and needs discussion. Students could be asked to think about what happens when more and more sugar is added to water; there comes a point when no more will dissolve. So, if this is going to be a good test of dissolving, only a small amount of substance should be added to plenty of water.



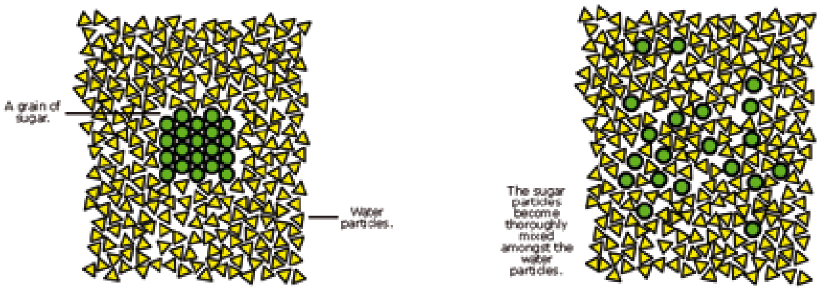
When testing for dissolving, students should try a range of substances, including some that are in the liquid state. Examples shown here are salt, sugar, chalk, copper sulfate, glycerine, olive oil, and green food colouring.

Working from the students' verdicts on the substances, the criterion for recognising dissolving can be formulated. A possible order for discussion is:

- *Salt, sugar and glycerine* Students are usually happy to say these dissolve.
- *Olive oil* Students generally say that this does not dissolve.
- *Copper sulfate and green food colouring* Opinion may be more divided, but many students may point out that even though it is coloured, the substances have 'disappeared' and no 'bits' can be seen. Dissolving gives a clear solution, either colourless or coloured.
- *Chalk* This is not clear – bits of the powdered chalk are still there, so it has not dissolved.

As supporting evidence, students can also try filtering two of the 'unknowns' (salt solution and chalk suspension).

After the practical activities, students can be asked to explain the observations with particle theory. This is a good opportunity to consolidate their particle model understanding. 'Bits' of a substance can be seen because each 'bit' consists of huge numbers of particles grouped together. When the particles separate and mix in with the water particles, the 'bits' disappear. Individual particles can't be seen, just like we can't see individual water particles – only the water as a whole. 'Bits' won't go through the gaps in filter paper, individual particles do.



Images from an animation sequence showing particle representations of dissolving: a grain of sugar in water (left) and after dissolving (right).

Section I: Recognising dissolving

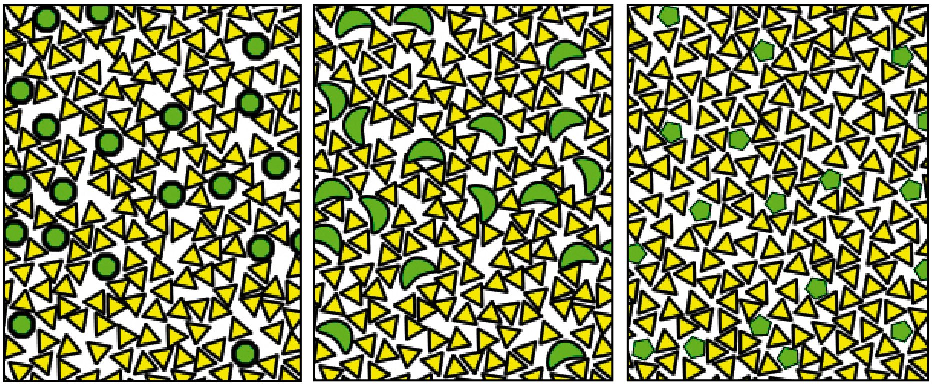
Section J: Solubility

Moving on

Students could look at animations showing what happens to the particles when two different substances – sugar and glycerine – dissolve in water (see Section I of the e-resources). They could also go on to look at the *amounts* of different substances that dissolve (see Section J of the e-resources). This includes a consideration of the range of solubilities, the effect of temperature on solubility, how crystals can be grown, and investigations involving solvents other than water.

DO 'GASES' DISSOLVE?

Solutions of 'gases' in water are no different from solutions where the solutes were in the solid or liquid state prior to mixing. In each case, individual solute particles are dispersed amongst the water particles. When dissolved, the solute does not have a state since individual particles do not have a state. For example, it would be wrong to say salt (sodium chloride) is liquid when in solution – this would imply it had melted! Equally, it makes no sense to say the salt is still solid. This is why, in the concept map on page 15, 'state' is only linked to 'substance' and not to 'mixture'.



Particle representations of solutions of three different substances in water: sugar, glycerine and ammonia. The solutions are similar even though the solutes were in different states (solid, liquid and gas) before mixing.

The solubilities of 'gases' range from high (e.g. hydrogen chloride, ammonia) to very low (e.g. hydrogen, methane). Oxygen is only slightly soluble in water, but even this small amount is important – respiration and rusting involve solutions containing oxygen. Some solutions are mixtures of substances that are separately in the solid, liquid and gas states. Crude oil is a complex mixture of this kind. Conversely, gases can come out of solution, in the same way that a precipitate can appear. A precipitate is a low-solubility substance emerging in the solid state during a chemical reaction; bubbles in a chemical reaction are a low-solubility substance (whose boiling point happens to be below room temperature) emerging in the gas state.

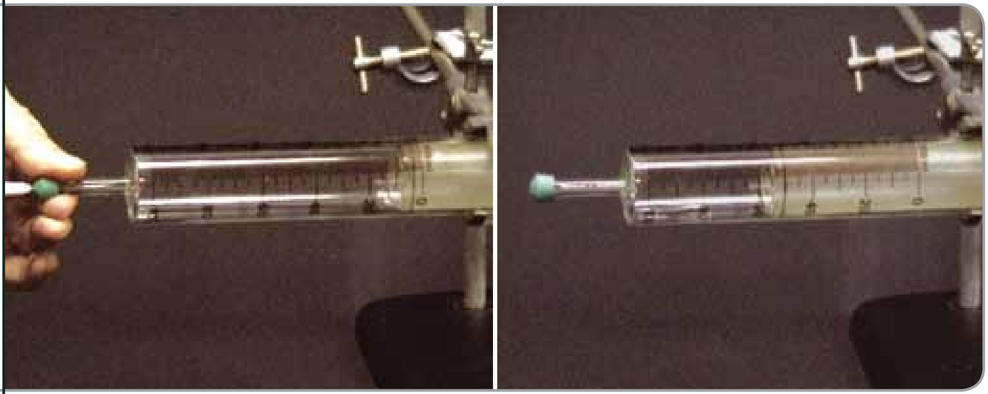
Students find the idea of 'gases' dissolving difficult. How can gas mix in with liquid? 'Gas' and 'liquid' appear to be incompatible. It seems much stranger than solid and liquid mixing together. Many of those thinking along particle lines are likely to imagine tiny gas bubbles dispersed amongst water particles. This is a good opportunity to emphasise that individual particles are not 'solid', 'liquid' or 'gas'.

The classic fountain experiment, using either ammonia or hydrogen chloride, is a spectacular demonstration of gases dissolving. However, with the gushing water it is not easy to appreciate just how large a volume of gas will dissolve in a small volume of water. If indicator is added, the colour change can be a distraction. The approach here gets down to the bare essentials. A small volume of water is injected into a gas syringe full of ammonia. This is followed by an investigation into the amount of carbon dioxide dissolved in carbonated water.

See Activity A5
Dissolving 'gases'
(page 51)

Classroom activities

This demonstration could be presented to students as a puzzle for them to solve. Tell them that ammonia is a substance which is in the gas state at room temperature. Show them a syringe of ammonia and then inject 1 cm^3 of water into it. The plunger moves in quickly initially, slowing until virtually all of the ammonia has dissolved. Then ask the students to try and explain what has happened using the particle theory.



Some water is introduced into a glass syringe filled with ammonia (left). The plunger starts to move as the ammonia dissolves in the water (right).

At first it seems quite remarkable that 100 cm^3 of ammonia will dissolve in 1 cm^3 of water. However, remind students about the drop of water injected into the hot syringe. The ammonia in the syringe would be no more than a drop if it were in the liquid state. A drop of ammonia dissolving in 1 cm^3 of water is not out of the ordinary. Class discussion will give you another opportunity to focus on the idea of the particles being the substance, and that for ammonia in the gas state there is nothing (space) between the particles. The idea of 'nothing between the particles' is a very demanding aspect of the particle theory for students. One student has been heard to exclaim 'where has all the nothing gone?'

Having established the solubility of ammonia, the fountain experiment would make a nice finale.

To consolidate the ideas, students can carry out an investigation to find out how much carbon dioxide is dissolved in carbonated water. You could start by opening a bottle of carbonated water and asking why bubbles emerge. Students need to appreciate that, originally, the carbon dioxide had been dissolved under high pressure. Once open, we can ask how much carbon dioxide remains dissolved. They will know that shaking encourages more carbon dioxide to escape (not all of the extra carbon dioxide dissolved at high pressure comes out at first). They probably won't realise that the solubility of carbon dioxide decreases with increasing temperature.

When a bottle of carbonated water is opened, bubbles of carbon dioxide appear (left). To find out how much carbon dioxide is dissolved, a measured volume in a boiling tube can be heated in a beaker of hot water (right).

There is plenty of scope here for thinking about the experimental method, so students could be encouraged to develop their own plan. If they are given a measured volume of carbonated water in a boiling tube fitted with a delivery tube, they can expel the gas by putting it in a hot water bath.

The main consideration then, is how to collect and measure the volume of carbon dioxide. The delivery tube can be connected to a squashed plastic bag using some sticky tape to make a gas tight connection. When all the carbon dioxide is collected, putting the inflated bag inside an appropriately sized beaker or measuring jug is a quick way of making a good estimate of the volume. Alternatively, the bung and delivery tube can be removed from the boiling tube and connected to a gas syringe. By squeezing the bag, the gas can be pushed into the syringe.

One way of collecting the carbon dioxide produced is to use a plastic bag. The volume can then be estimated by squashing the bag inside a measuring jug.

In discussions ask students to think about the accuracy of their results. Most likely they will have noticed that some carbon dioxide is lost on pouring the carbonated water from one container to another. There is also the gas lost on opening the bottle. On the other hand there could have been some air in the collecting bag to start with. Also, can we be sure that all of the carbon dioxide is out? Challenge them to come up with an improved method (e.g. the bottle could be opened inside a plastic bag).

Section K:
Separating mixtures

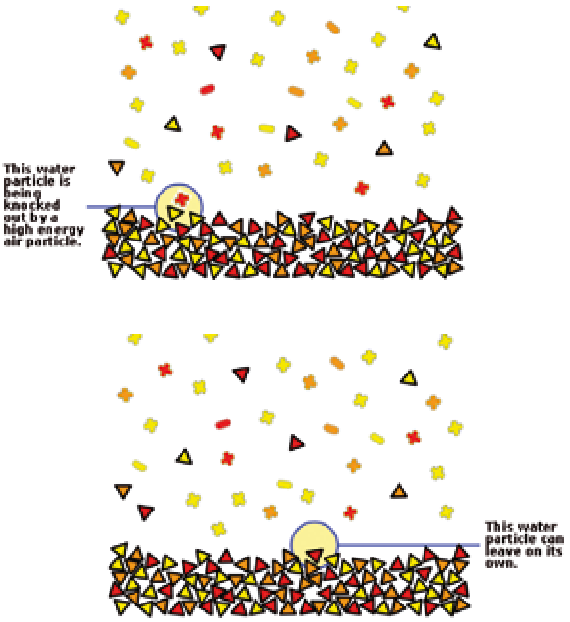
Moving on

Students do need to appreciate that some air is dissolved in water. Much aquatic life depends on this. When water is heated, the bubbles that first appear are of air that is being expelled from solution. Students will have seen that carbon dioxide is less soluble in warm water, and the same applies to other 'gases'. However, it is important to emphasise to students that the large bubbles in boiling water are not air but *water in the gas state*. These ideas are addressed in Section K3 of the Stuff and Substance e-resources.

EVAPORATION

Disappearing puddles and drying washing are very familiar events but how should we describe what is happening? Is water changing to the gas state? Yes, water particles separate from one another but this produces a *mixture* of water and air. Liquid water has *not* changed to a pure sample of water in the gas state – at atmospheric pressure we know water must be at 100 °C for this to happen. Water evaporating into the air is perhaps better viewed as a *mixing* phenomenon rather than a *change of state.* Explaining evaporation below boiling point requires further development of the particle model, looking at the distribution of energy amongst particles. Much can be done with the idea of high, medium and low energy particles (these are represented in the diagram below by red, orange and yellow respectively).

High energy water particles are able to escape the hold of the other water particles. High energy air particles collide and eject medium and low energy water particles. (Thus, energy is transferred from the air to the water due to the cooling effect from the loss of high energy water particles.) In time, all of the water evaporates.



Images from an animation sequence showing particle representations of evaporation: water particle being knocked out by high energy air particle (top) and high energy water particle leaving on its own (bottom).

The model easily accounts for the effects of surface area and temperature on the rate of evaporation. The action takes place at the surface, and with a larger surface area more can happen at once. At higher temperatures there are more high energy particles about. The effect of a breeze involves further ideas: water particles could return, so the actual rate of evaporation is the difference between the rate of leaving and rate of return. A breeze sweeps away water particles, thus reducing the rate of return. There is a direct parallel with the effect of stirring on the rate of dissolving.

With these new ideas our understanding of boiling deepens. Boiling is when there are enough high energy particles to form a body of gas with a pressure equal to the external pressure.

Many students do not appreciate that water will evaporate if left in an unheated cupboard. They think there must be a direct source of energy such as a radiator or the Sun. They are looking for a temperature gradient, although they wouldn't put it that way. Evaporated water going straight up to the clouds is also a common misconception. Thinking that evaporated water is present in the clear air all around is demanding.

More able students do try to reconcile evaporation with boiling. However, without ideas of energy distribution their thinking is limited. They reason that if the temperature must be 100 °C for water particles to separate, the particles cannot be properly separated on evaporation at lower temperatures. Therefore, they imagine evaporated water must be in tiny droplets, a kind of half-way state between liquid and gas. Some will think this is what is meant by 'water vapour'.

Intuitively, students readily accept the effects of surface area and temperature on the rate of evaporation. A breeze is more problematic. Many associate a breeze with cooling and reason that a lower temperature will reduce the rate of evaporation. They do not appreciate that the cooling is due to the increased rate of evaporation in the first place.

In the teaching approach taken here, standard practical activities are used but the emphasis is on viewing evaporation more as a mixing phenomenon than a change of state. The particle model is developed to explain evaporation and the factors affecting the rate of evaporation.

Classroom activities

See Activity A6
Investigating evaporation
(page 52)

Before looking at the factors affecting the rate of evaporation, it is useful to spend a little time looking at the phenomenon itself. Monitoring a dish of water kept in a suitable cupboard will show that evaporation takes place without the direct agency of the Sun or a radiator. By using two containers of different diameters with the same volume of water, the effects of surface area can be explored.

Water will evaporate faster from the container with the larger surface area. This will happen even if the containers are left inside a dark cupboard – they do not need to be exposed to the Sun.

At one level we can explain evaporation by saying the water particles have left the dish, but how can this happen at room temperature? After all, previously we said water particles moved apart at 100 °C. Students can be told that the particle model needs further development in order to explain this.

They can be introduced to the idea of energy distribution, with different colours representing particles of different energies as in the diagrams above (see Section G of the Stuff and Substance e-resources). It is worth emphasising that individual particles do not have a temperature (just like they do not have a state).

With some groups of students you may not wish to introduce ideas of energy distribution. You could just talk about air particles knocking out water particles. This is enough to make a distinction from boiling and establish that a mixture of separated water and air particles is formed. This simpler model can also account for the factors affecting the rate of evaporation.

Students can then go on to look at some of the other factors that affect the rate of evaporation. There are a number of different ways that this could be done – for example, by putting drops of water or ethanol on pieces of filter paper and seeing how fast they evaporate. Comparing the loss of water and ethanol shows that other substances in the liquid state evaporate and that rates are different. Many students may be tempted to suggest ethanol particles have more energy rather than a weaker hold as the reason for the faster rate. With a weaker hold, medium energy ethanol particles can also escape.

For the investigations into the effects of temperature and a breeze, students will most likely anticipate the results (although the breeze is not so straightforward). The focus therefore is on using the particle model to explain the observations. (See Section R1 of the Stuff and Substance e-resources for the factors affecting evaporation.)

Moving on

Section G:
Evaporation of water
Section H:
Condensation of water

Section G4 of the Stuff and Substance e-resources summarises the contrast between *boiling* and *evaporation below boiling point.* Condensation of water (on cooling a mixture of water and air) is addressed in Section H1. Students can find the appearance of water droplets on cold objects something of a mystery. Accounting for water is difficult if they don't think of water as being present in clear air. The preceding work on evaporation should make this more believable.

The work on dissolving, boiling and evaporation forms a basis for later work in many areas, for example looking at how solutions can be separated by distillation (K2) and a particle interpretation of the water cycle (K4). At a more advanced level, some students may go on to look at the dependence of boiling point on pressure (P2) and at the factors that affect the rate of dissolving using ideas of energy distribution (S1). Section O takes a closer look at temperature and energy changes during changes of state.

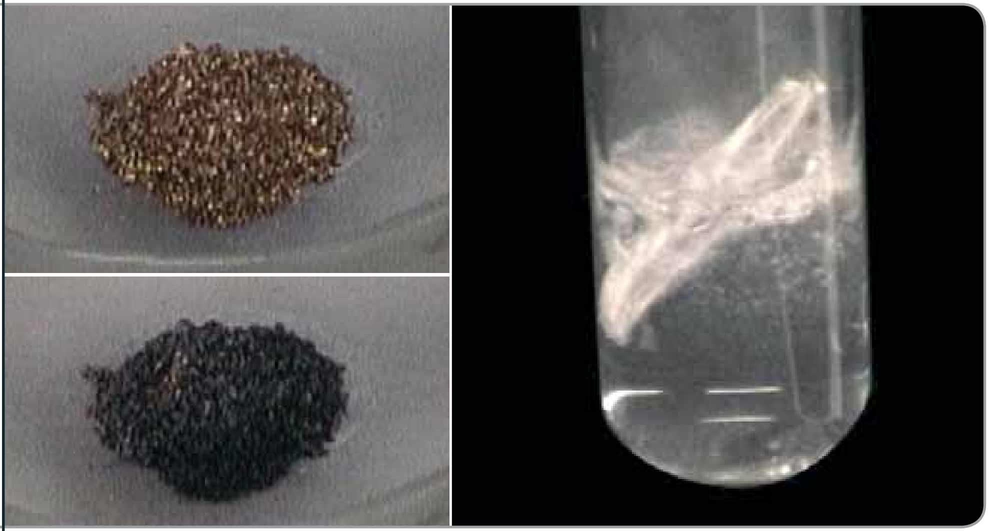
CHEMICAL CHANGE

For the chemist it is easy to take chemical change for granted. After all, this is what chemistry is all about – making new substances. However, 'substances changing into other substances' contradicts an intuitive sense of *conservation*. Where have the old substances gone and where have the new substances come from?

The mystery is explained by ideas of *atoms*. A particle of a substance is defined by a specific combination of atoms (the atom structure). In a chemical change the atoms re-arrange, hence the old substances cease to exist and new ones are created. *Atoms* are conserved but not the *substances*.

Many students do not think in terms of chemical change. Some common ideas are:

- The 'product' is a *mixture* of the 'reactants' – not a new substance in its own right. For example, copper oxide (a black powder produced when copper is heated in air) is a mixture of two substances, copper and oxygen. Or the black powder is still copper but in a different form.
- The 'product' already existed in one of the reactants and *separated out.* For example, bubbles in the reaction between magnesium and acid solution are a gas coming out of the metal. Here, few will think of the 'gas' as being a substance, let alone a new one being created.



Students may not think in terms of new substances being formed during a chemical change. When copper (top left) is heated in air, copper oxide is produced (bottom left). When magnesium is added to acid solution, hydrogen and another substance in solution are produced (right).

To introduce students to the idea of chemical change, the approach here is to avoid reactions involving bubbles, flames, bangs, colours and smells that can be distracting to students (these can follow later). Instead a relatively unspectacular example of chemical change is chosen, leading to a discussion that something other than changes of state, mixing or separating is involved. Ideas of atoms are introduced and used to predict chemical change as *something that can happen.*

See Activity A7
What kind of change?
(page 54)

Classroom activities

The approach starts with the reaction between melted stearin (stearic acid) and hot sodium carbonate solution. Rather than present this as an example of a chemical reaction, it is better to introduce it to students as just a set of instructions to follow. The idea of chemical change can come later when they think about what they have observed.

Students make their own solution of sodium carbonate so they know it is soluble. Adding hot sodium carbonate solution to melted stearin results in the appearance of a white 'solid'. Invite discussion about what has happened. Could the white 'solid' be stearin? No, its melting point is higher. Could it be sodium carbonate? No, sodium carbonate is quite soluble, this is quite insoluble. Some students might suggest a mixture of stearin and sodium carbonate. Ask how to test for a mixture. Hopefully some will suggest melting behaviour. Tell students that it has a well-defined melting point (unfortunately not actually true in this case since sodium stearate decomposes before reaching its melting point).

When stearin reacts with sodium carbonate solution, a new substance (sodium stearate) is produced (left). This new substance has properties different from those of the reactants, for example it forms a lather when shaken with hot water (right).

We are forced to conclude that we have a new substance. As further evidence, students can shake a small amount of the white solid with hot distilled water. This produces a lather, and neither stearin nor sodium carbonate does this. Say that when a new substance is formed we call this a chemical change. You may wish to explain that the white solid is a kind of soap, like the substances copper and lead are kinds of metal.

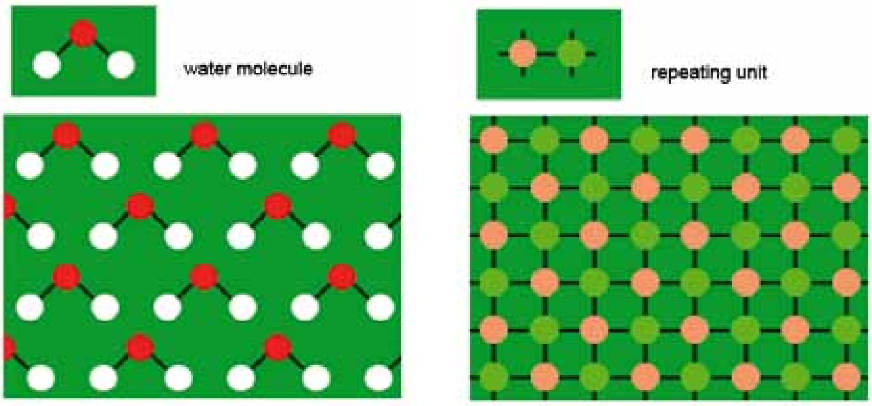
Your students are likely to find these events very strange and this might be worth acknowledging. They will probably not believe that substances can change into other substances. Explain that to understand how chemical change can happen we need to develop the particle theory further.

Moving on

There are two sections of the Stuff and Substance e-resources that are designed to support students' understanding of the phenomenon of chemical change: Section L (Structures) and Section M (Substances changing).

Section L: Structures

Section L (Structures) introduces the idea of atoms in relation to the concept of a substance. From the start, *molecular structures* and *giant structures* are considered. For molecular structures (e.g. water), the particles are the *individual molecules*. For giant structures (e.g. sodium chloride), we can think of the particles as being the *repeating unit* that gives the pattern. The molecule or repeating unit defines the substance. The structure of a substance has a big influence on its melting point. In general, molecular structures have lower melting points than giant structures, and the melting point of molecular structures decreases with the number of atoms per molecule. Substances with small molecules tend to be in the gas state at room temperature.

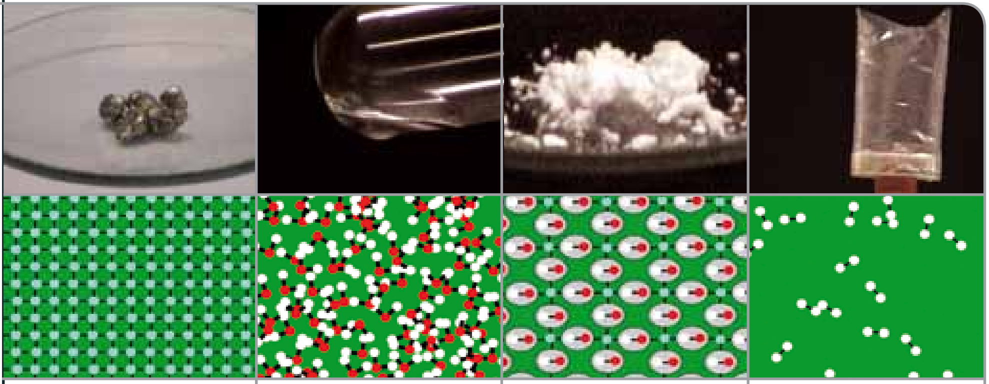


Ice has a molecular structure, and the particles are the individual water molecules (left). Sodium chloride has a giant structure, and we can think of the sodium chloride particles as being the repeating unit that gives the pattern (right). Ideas of ions can be introduced later when bonding is addressed.

Section L goes on to consider the more complex giant structures of substances like calcium carbonate. Many of the chemical changes that students come across in the early years at secondary school involve giant structures, so it is important that these are considered in order to explain the chemical changes they meet. Finally, the section makes the distinction between substances with particles made of one type of atom (*elementary substances*, usually shortened to *elements*) and substances made of two or more types of atom (*compound substances*, usually shortened to *compounds*).

Section M:
Substances changing

In Section M (Substances changing), these ideas are used to predict the *possibility* of chemical change. There are interactive animations that help students understand how a chemical reaction involves the re-arrangement of atoms. Two examples of chemical changes follow, and students are encouraged to explain the observations in terms of atom structures (sections M2 and M3). The first example involves two substances in the gas state (ammonia and hydrogen chloride) changing to one substance in the solid state (ammonium chloride). The second example looks at the reaction between calcium and water. By using a small volume of water, the calcium hydroxide produced is seen as a white powder, and hydrogen is collected in a plastic bag.



calcium | water | calcium hydroxide | hydrogen

Calcium reacts with water to form calcium hydroxide and hydrogen. The top row shows photographs of these substances, and the bottom row shows representations of their atom structures.

Section M of the e-resources also looks at the reaction between magnesium and oxygen, and this is now discussed in the following section of this booklet.

REACTIONS INVOLVING THE GAS STATE: COMBUSTION

Lavoisier's oxygen theory of combustion opened the door to modern chemistry. Before then, the phlogiston theory held sway. Phlogiston was 'something' which escaped into the air during combustion. Gaining 'something' (oxygen) from the air was an about-turn. Such opposing interpretations of the same event remind us that theory is not obvious.

The spectacular reaction between magnesium and oxygen to produce magnesium oxide is a common practical in school science. Understanding this reaction challenges students because the idea of chemical change is difficult, and also because it involves a reactant in the gas state. Students who are unsure about the gas state may think of magnesium reacting 'to' the oxygen – the white powder produced being magnesium but in a different 'form'. Others may think something has been lost from the magnesium. And those who can conceive of oxygen joining magnesium may believe that there is simply a mixture of two substances (magnesium and oxygen) rather than a new substance in its own right.

The mass of the white powder produced is greater than that of the magnesium, but this evidence is not so straightforward to interpret. Students may have notions that powders are lighter than lumps and that 'gases' exert no weight or even make things lighter.

Classroom activities

See Activity A8
Magnesium and oxygen
(page 55)

A good starting point is to demonstrate what happens when a strip of magnesium is heated: it produces a bright white flame and some white powder is left. Explain that magnesium is an elementary substance and ask students to think about what they have observed. Has the magnesium melted? Clearly not. What could the resulting white stuff be? (Don't call it magnesium oxide yet.) Is this still magnesium? How could we find out if the white stuff is one substance or a mixture of substances? They may suggest looking at melting points – tell them that the melting point of the white solid is well-defined at 2852 °C and that if magnesium is heated away from the air it melts at 649 °C. So, the white stuff is a new substance – there has been a chemical change.

Perhaps another substance is involved in the change? What about the air – which substances are present? Oxygen should arise as a likely candidate. Ask students what happens to the oxygen? Does it combine with magnesium to make the white powder?

Section M:
Substances changing

The Stuff and Substance e-resources include a video of a good way of illustrating this. It shows a bag of oxygen attached to a horizontal boiling tube containing magnesium ribbon and air. This makes the reaction with oxygen more apparent, since the bag crumples as the reaction proceeds. Before showing the video, encourage the students to predict what will happen when the magnesium is heated.

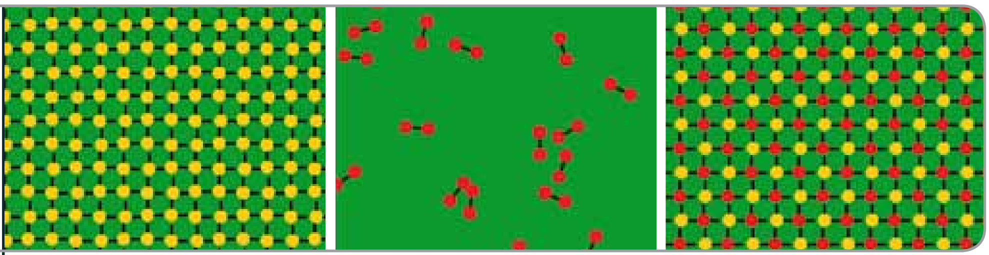
Magnesium in a boiling tube attached to a bag of oxygen is heated (left); as the magnesium reacts with the oxygen, the plastic bag crumples (right).

On heating, there is enough oxygen in the tube to start a reaction and further oxygen from the bag pushes in. Once the reaction gets going, the Bunsen can be removed and the bag is seen to collapse as the magnesium continues to react.

At this point, the white stuff can be identified as magnesium oxide. Ask students what evidence there is that magnesium oxide has a high melting point (2852 °C, as noted earlier). Clearly, the temperature during the reaction is very high and yet the magnesium oxide emerges in the solid state. What does this suggest about the structure of magnesium oxide? It will have a giant structure. Magnesium itself has a relatively high melting point and also has a giant structure.

The chemical change can then be interpreted in terms of atoms (using animations from section M4 of the e-resources).

Representations of the atom structures of magnesium, oxygen and magnesium oxide.



This can lead to a discussion with the students about how they might expect the mass of magnesium oxide to compare with that of the magnesium. To consolidate their understanding, they could then do a standard class practical in which magnesium is heated in a crucible with lid in order to measure the change in mass.

Section M:
Substances changing

Moving on

Throughout section M of the e-resources, word equations are used. Initially these equations are given, but later they become drag-and-drop exercises of increasing sophistication. The later parts of section M consider other types of chemical reaction, including reactions taking place in solution and thermal decomposition.

- An example of a reaction in solution is given in section M5: solutions of potassium iodide and lead nitrate are made and then mixed. Lead iodide is produced as a precipitate and filtered out, and potassium nitrate is recovered from the filtrate by evaporating the water. In this way, all reactants and products are seen and the change is interpreted in terms of atom structures.
- The thermal decomposition of copper carbonate to give copper oxide and carbon dioxide is discussed in section M6. This is intended to challenge the idea that chemical change always involves two or more substances reacting together. It is also intended to show that copper oxide can be made in two different ways (thermal decomposition of copper carbonate, or heating copper in oxygen). Many students think that the identity of a substance is defined by its history – the example of copper oxide counters the idea that if you start with different substances you must end up with different substances.

ATOMS AND SUBSTANCES: RUSTING

Rusting has a complex mechanism. An electrochemical reaction produces iron(II) hydroxide which is then oxidised to hydrated iron(III) oxide; i.e. rust. Both of these processes use oxygen dissolved in water. Therefore, at an introductory level, we can say iron reacts with dissolved oxygen. Understanding the meaning of 'dissolved oxygen' rests on the distinction between *atoms* and *substances*. Iron reacts with the *substance oxygen* (O_2 molecules) and not with the *atoms of oxygen* within the water molecules.

Again, like all chemical changes, students will not readily conceive of rust as a new substance in its own right. Part of the problem is a lack of distinction between atoms and substances – without this, the difference between compounds and mixtures cannot be appreciated. For example, water may be seen, mistakenly, as a mixture of *two substances* ('hydrogen' and 'oxygen') rather than one substance made of *two different kinds of atom.*

There are standard school science experiments that aim to establish the need for both oxygen and water (liquid state) for rusting to occur. In the approach taken here, the purpose of looking at rusting is not so much to learn about rusting itself, but to underline the difference between atoms and substances.

Classroom activities

See Activity A9
Investigating rusting
(page 56)

Two key experiments on rusting can help students to understand these ideas. In the first experiment, iron wool is immersed in a sealed test tube full of water, and left for a few days. Over this period it can be seen to rust. More iron wool is then added and left for a few days, but this does not rust. In the second experiment, damp iron wool left to rust in an upturned test tube of air over water is shown to use up about 20% of the air.

The first piece of iron wool added to the test tube rusts (left) but the second piece added later does not. 'Something' in the water has been used up.

Iron uses up about 20% of the air when it rusts (right), suggesting the 'something' it reacts with is oxygen.

In the first experiment, the additional iron shows that the rusting had stopped for the original iron. Students are likely to suggest that all of 'something' is used up when the first lot of iron rusts, which is why the extra iron does not rust.

The second experiment indicates what the 'something' might be. Students have the opportunity to link their knowledge of air composition to the fact that the level stops rising when about 20% of the volume has gone. 'Oxygen' should emerge as the contender.

For the first experiment students may say that 'the oxygen in the water' is used up. However, exactly what is meant by 'oxygen in the water' needs careful unpacking. Many will be thinking of the oxygen that goes to make up water itself – the oxygen in water molecules. To counter this, note the abundance of water – there is still plenty left so why should the reaction stop? Returning to the second experiment, emphasise the substance oxygen that is in the air and which reacts with the iron is O_2 molecules.

So, in the first experiment, were there O_2 molecules in the water? Well yes, some oxygen molecules could be 'mixed in' (i.e. dissolved) amongst the water molecules. Molecular models of water and oxygen could be used to represent dissolved oxygen.

In conclusion you could point out the need to dampen the iron wool with liquid water in the second experiment, and that other experiments show that iron will not rust in dry air or even pure oxygen (gas state). Rusting is a special reaction of iron which only takes place with dissolved oxygen. Hot iron will react directly with oxygen to give a black oxide, not rust.

COMPLEX CHANGES: A LIGHTED CANDLE

A lighted candle is a familiar sight, but it is difficult to think of a phenomenon that places a greater demand on students' understanding of substances:

- Wax changes from the solid through liquid to the gas state, whereupon it mixes with air – itself a mixture of substances already in the gas state.
- At the high temperature, wax and oxygen change into water and carbon dioxide. The change releases energy which maintains the process while both wax and oxygen are supplied in sufficient amounts.
- Both products emerge in a gaseous mixture, but one condenses to the liquid state on cooling if contained in sufficient concentration.
- Soot arising from incomplete combustion, emerging in the solid state, adds to the complexity.

Many students think that it is only the *wick* of a candle that burns. They may believe that *wax* is used in a candle because it does *not* burn, and is there to slow down the burning of the wick by gradually melting. Water coming out of the flame seems a strange notion when water is associated with putting out fire. Tests can show the presence of water (condensation) and carbon dioxide in a container placed over a flame – but these are often interpreted as water and carbon dioxide that were already in the air, and not new substances created by the flame. Most students do appreciate that oxygen is needed to keep a candle alight, but may not be sure how, or what becomes of it.

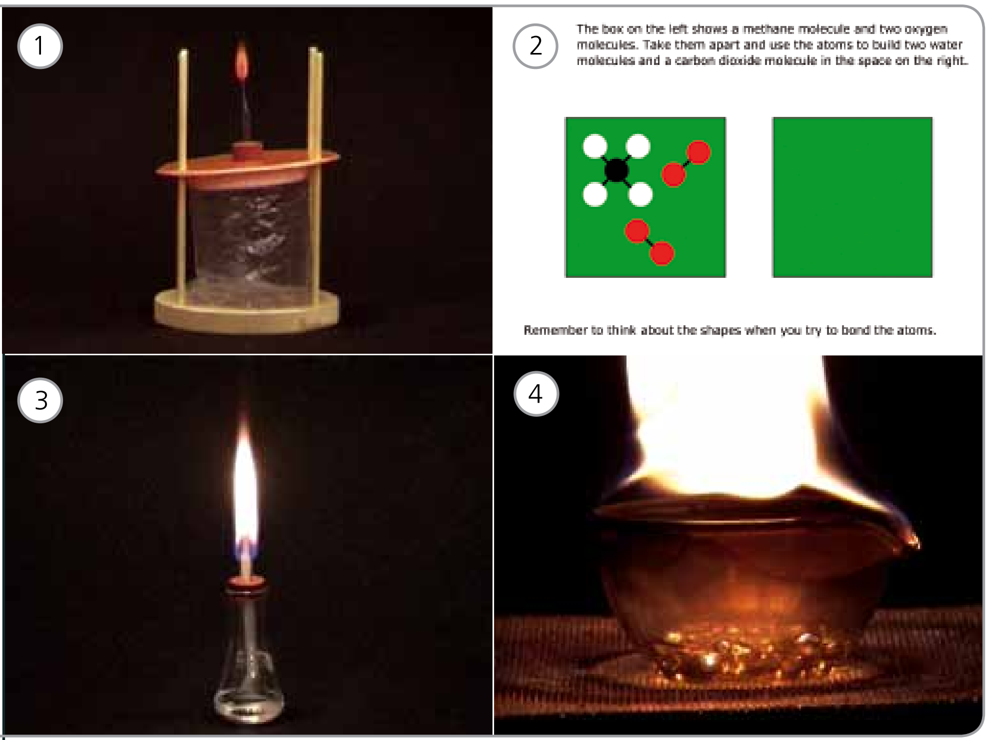
Indeed, on observing a lighted candle, it does look as if the wick is burning to produce the flame, and all the wax seems to do is melt. Understanding what is really happening to the wax and how it reacts with oxygen in the air requires an explanation that draws upon all of the ideas we have developed so far about substances.

Classroom activities

The Stuff and Substance e-resources build up to a candle flame by looking at flames of increasing complexity (sections V1 to V3):

Section V:
Fire

- The approach starts with the simple case of burning hydrogen and the creation of water.
- Methane and oxygen changing to water and carbon dioxide is next.
- Propanone then illustrates a substance in the liquid state where enough evaporates into the air to make a mixture which can be set alight. A glass wick is introduced as a means of controlling the reaction.
- Finally, oleic acid shows a substance in the liquid state which needs to be boiling before it sets alight; a glass wick can be used to boil a little at a time.



The box on the left shows a methane molecule and two oxygen molecules. Take them apart and use the atoms to build two water molecules and a carbon dioxide molecule in the space on the right.

Remember to think about the shapes when you try to bond the atoms.

A progression of ideas about combustion and flames:

1) hydrogen burning in air

2) atom structures of the reactants and products for methane burning

3) a substance in the liquid state (propanone) burning using a glass wool wick

4) a substance in the liquid state (oleic acid) being heated before it burns.

The stage is set for looking at the combustion of wax, which initially is in the solid state. A good place to start is to ask students to observe a lighted candle (with a string wick). Ask them what they think the flame is. Why are candles made of wax? Can wax be set alight?

See Activity A10
A lighted candle
(page 57)

Three experiments are chosen to help to answer these questions. Firstly, boiling wax is set alight. Secondly, candles with glass wool wicks are shown to burn perfectly well. Finally, the products from the candle flame are shown to be carbon dioxide and water.

The first experiment is a demonstration showing that wax can be heated until it boils and can then be set alight. Before lighting the wax, it is worth noting the clear bubbles in the boiling wax and the mist/smoke overhead – similar to boiling water. Wax in the gas state is clear (like any substance in the gas state), and the mist/smoke is where some wax has condensed to small droplets.

Now ask students to reconsider the candle flame. Is it just the wick that burns to give the flame? A length of string takes seconds to burn, so how can a candle last for hours? Is wax burning to give the flame? The string wick does burn, but glass wool can be used for the wick instead of string – glass does not set alight!

A conventional candle and a candle with a glass wool wick (left); lighting the white ‘smoke’ from a candle after it has been blown out (right).

A class discussion can lead students into understanding that in a glass wick candle, the liquid wax is soaked up the wick. On blowing out their candle, they will see a plume of 'white smoke' coming from the wick for a short while. This is condensed wax, and can be lit again with a flame – students will enjoy this trick of relighting the candle from the 'smoke', and a flame can jump several centimetres down to the wick.

Students can then observe what happens when they cover a burning candle with a beaker, and can test for the presence of water that has condensed on the beaker (using cobalt chloride paper) and carbon dioxide (using limewater).

A beaker is placed over a lighted candle in order to identify the products of combustion (water and carbon dioxide).

This should be familiar behaviour if students have already learned something about the nature of flames (for example, using the examples from the e-resources described above). Emphasise to students that condensation forms because the flame gives out lots of water and a high concentration builds up in the beaker; when the beaker is lifted off, the water quickly evaporates because the concentration falls.

After the experiments, students should use the atom structures of wax and oxygen to explain the change to water and carbon dioxide (see section V4 of the e-resources). As in the previous section in this booklet, the distinction between *atoms* and *substances* should be made clearly when discussing the reactions.

Students may have a tendency to talk, for example, in terms of 'the carbon in the wax reacting with oxygen' or 'the hydrogen in the wax'. Such expressions do not differentiate between atoms and substances, and are consistent with the notion of wax being a mixture of two substances – 'hydrogen' and 'carbon'. The chemical reaction is between wax and oxygen, and this involves the breaking of bonds between atoms and the making of new bonds to give new atom structures (substances). Chemical reactions take place between substances – not atoms.

Section V:
Fire

Moving on

Glass wick candles show that the flame is a reaction between wax and oxygen; this is essentially the same for a string wick candle. However, something does happen to a string wick, and understanding this requires further ideas. Section V5 of the e-resources goes on to consider other aspects of combustion, such as the reaction of carbon and oxygen (which does not give a flame), incomplete combustion, and the role of soot in producing light. The distinction between thermal decomposition and combustion is discussed in Section V6, by considering what happens when sugar, wood and string are heated in air.

CONCLUSION

The ideas and suggestions presented in this booklet aim to show that *Stuff and Substance* represents a new and attractive approach to introducing the science of chemistry. There are many ideas for students to learn if they are to really understand chemistry and it is important to address these ideas in a step-by-step coherent progression. More traditional approaches, starting with complex phenomena such as burning candles or the reactions of acids, can simply overload students with too much all at once. Not surprisingly, faced with the seemingly unfathomable, many students give up. In our experience, students show high levels of engagement in the *Stuff and Substance* approach, because developing a deep understanding is rewarding and motivating. Of course, it will take time for the ideas to become established and students will progress at different rates. However, the approach can lead to a significant overall improvement in students' understanding of and attitudes towards chemistry. Moreover, developing these key ideas with students in the early years of the secondary school will provide a very sound basis for further study.

STUDENT ACTIVITIES

STUFF AND SUBSTANCE:
TEN KEY PRACTICALS IN CHEMISTRY

Teachers' notes

The student materials consist of ten key practical activities that are intended to be used with 11-14 year old students, but could also be useful with an older age range. The activities have been selected using the insights gained from research and effective classroom practice to develop understanding of the concept of a substance and of particle theory.

Activities A1 – A3: These activities are concerned with establishing the nature of substances and mixtures. A key problem is that students take 'solids, liquids and gases' literally. They think these are three different types of material. The activities involve:

- Melting, the solid and liquid states – establishing the nature of a substance
- Boiling – establishing the difficult idea of the gas state
- Mixtures – differences in melting behaviour of substances and mixtures of substances.

Activities A4 – A6: These activities focus on the formation of mixtures. The traditional 'solids, liquids and gases' approach often does not distinguish between substances and mixtures of substances. This leads to a number of difficulties, for example in understanding the differences between boiling and evaporation. The activities involve:

- Dissolving – substances in the solid and liquid states
- Dissolving – substances in the gas state
- Evaporation – water mixing into the air.

Activities A7 – A10: These are concerned with establishing the concept of a chemical reaction, the role of gases in reactions and the nature of combustion. The activities involve:

- Chemical reactions – changes that involve the production of new substances
- Combustion – reactions that involve substances in the gas state
- Rusting – establishing the differences between atoms and substances
- Complex changes – a lighted candle.

An overview of the activities

The activities are:

• **Activity A1**	Melting points
• **Activity A2**	Predicting with the particle model
• **Activity A3**	Melting behaviour of materials
• **Activity A4**	Recognising dissolving
• **Activity A5**	Dissolving 'gases'
• **Activity A6**	Investigating evaporation
• **Activity A7**	What kind of change?
• **Activity A8**	Magnesium and oxygen
• **Activity A9**	Investigating rusting
• **Activity A10**	A lighted candle

The e-resources

In addition to the practical activities, there are references in the following teachers' notes to the *Stuff & Substance e-resources*. These resources are available as a CD-ROM and online. See page 2 of this booklet for further details about the e-resources.

Activity A1: Melting points

Students experimentally determine the melting point of wax, and observe the melting of sodium chloride and lead (see also page 7 of this booklet 'What is a substance?').

LEARNING OBJECTIVES

Students will:

- carry out a procedure to determine the melting point of wax and consider the limitations of its accuracy
- explain how a substance can be recognised by a well-defined melting point between its solid and liquid states.

NOTES

CAUTION Be aware that the glassware could get quite hot and cause scalds. If liquid wax gets on the skin, it can solidify and still cause thermal burns. Lead is toxic, and should be heated in a well-ventilated room.

In Tasks A and B, it is important for students to realise that the lump will only melt when it is hot enough. The key idea being established here is that a substance has a clearly defined melting point. In fact, candle wax is not a single substance, but since the range over which it melts is reasonably small, it is suitable for this experiment and its familiarity is an advantage. You do not need to tell students that it is a mixture. It is advisable to determine a melting point for your particular wax beforehand. If you wanted to use a single substance you could use stearic acid (stearin), melting point 70 °C. Stearic acid is normally supplied in flakes too small to be handled individually and it is advisable to convert these to lumps by melting, solidifying and cutting.

If allowed to choose, most students will go for large lumps and this causes problems. Using a very small piece of wax is best since a small piece heats up quickly and it is easy to spot when it melts.

Aluminium foil can be fashioned easily into small milk bottle top sized floating rafts to hold the wax. A wooden block with a shallow hole and a rod could be used to stamp out boats from foil. The boats are not essential, but the melting is more obvious and it does allow the wax to be easily retrieved. If time allows, students could try repeating the measurement with the same sample after it has cooled down.

For Task C, large rock salt crystals should be selected and should be washed and dried before use. If small grains of salt are used, poor conduction through the sample makes melting difficult to achieve. The melting point of sodium chloride is 801 °C.

Each flame is at the same temperature and three flames are not hotter than one flame. However, the hotter something is compared to its surroundings, the faster it cools, so we need to supply energy quickly to heat the tube to high temperatures. If you have insufficient gas taps for 3 Bunsen burners, you could use 2 Bunsens and a blow torch.

While the sodium chloride is melting you could ask students about similarities and differences between this and ice melting – in each a solid is turning to a liquid, but unlike ice, the solid sodium chloride sinks. Water is exceptional amongst substances in that in the solid state it is less dense than the liquid.

In Task D, ventilate the room well by opening windows when the lead is being heated. You should wear thick gloves and eye protection. This works best if the lump of lead is not too flat, so that it is clear that the shape changes as it melts. The melting point of lead is 327 °C.

RESOURCES NEEDED

For Task A (demonstration):

- 2 boiling tubes containing samples of candle wax
- 2 beakers, 250 cm^3
- Kettle.

For Task B, each group will need:

- Small piece of candle wax
- Aluminium foil for boat
- Beaker (250 cm^3)
- Thermometer, -10 - 110 °C
- Bunsen burner, tripod, gauze and mat
- Access to wooden block with shallow hole and rod to make milk top sized foil boats.

For Task C (demonstration):

- Rock salt crystals
- 3 Bunsen burners and heatproof mat
- Clamp stand, bosshead and clamp
- Spatula
- Eye protection.

For Task D (demonstration):

- Lump of lead (e.g. piece of old lead piping)
- Crucible
- Bunsen burner, tripod, pipeclay triangle and heatproof mat
- Sheet of metal
- Tongs
- Thermal gloves
- Eye protection.

USEFUL SOURCES

CLEAPSS Hazcards 56 (Lead metal, lead carbonate, oxides and sulfide).

USING THE E-RESOURCES

There are animations showing melting, and how this relates to particle theory that students could use. There are also vidoes of melting lead and salt. It is better to demonstrate salt and lead melting, but you could show them the videos instead. Even if they have seen these being demonstrated, the videos are useful so that they can see what is happening close up. (See page 2 of this booklet for details of the e-resources.)

Activity A2: Predicting with the particle model

Students observe a demonstration to show that liquid water can be changed into gaseous water. Water in the gas state looks like air but is still the substance water (see also page 10 of this booklet 'Predicting the gas state').

LEARNING OBJECTIVES

Students will:

- understand that substances are made of particles that do not change even when the state changes
- understand that the gas state is a third possible state for a substance
- use the particle model to explain why the same amount of substance can occupy such a large volume in the gas state.

NOTES

CAUTION Be aware that the glassware is 150 °C and could cause burns. Wear thermal gloves when handling the hot glass syringe. The hypodermic needle can penetrate the skin and when not in use should have a cap on the end to prevent accidental skin breakage. The movement of the plunger should not be restricted by string or other means. It must be able to come out if too much gas is produced.

Note that Task A is a 'thought experiment' and the plastic bag is chosen as a container as being something that is familiar to students before introducing them to the use of the glass syringe. A plastic bag is not suitable for carrying out the experiment in reality.

For Task B, the gas syringe should be left in an oven at 150 °C to get to the required temperature. Before the demonstration, it is a good idea to show students the set-up with a second cold syringe – so they will know what will be pulled out of the oven. Avoid calling it a *gas* syringe, as this will give them a clue – in the student sheet it is referred to as a glass syringe. Quickly take the syringe out of the oven and lie it on a heatproof mat. Use thermal gloves to protect your skin when handling the hot gas syringe. Inject a drop of water (0.05 cm^3) into the syringe. The final volume of gas is very sensitive to the amount of water injected. Ideally, the volume of gas will be around 100 cm^3. If too much water is injected, excess gas escapes quite safely as soon as the plunger breaks contact with the barrel. There is time, but you will need to be reasonably quick with the injection, before the syringe cools down too much. Practicing the demonstration is recommended.

You may wish to extend this demonstration by asking students to predict what would happen to the gas syringe if it was allowed to cool. The water would condense and the volume would reduce, and the plunger would move back into the gas syringe. You could allow the syringe to cool over the course of the lesson and view it as part of a plenary. (NB Air can be drawn into the syringe through the pierced cap and the plunger may not return fully.) With more able students you may wish to get them to think about air pressure, by asking why the plunger stops at a particular volume and what pushes the plunger in when the water changes back to the liquid state.

In Task C it is important to emphasise that the particles have more energy in the gas state but have not changed in any other way. The increase in volume is because the particles have moved apart, with lots of empty space between them, but the particles themselves do not get bigger. This should be reflected in the students' diagrams.

RESOURCES NEEDED

- Plastic bag, beaker of water and dropper
- Glass gas syringe, 100 cm^3, fitted with a rubber cap
- Plastic syringe, 1 cm^3 (or smaller), fitted with a hypodermic needle
- Thermostatically controlled oven
- Heatproof mat
- Water in a beaker
- Thermal gloves
- If available, one or more cold gas syringes that students can be shown prior to the demonstration.

USING THE E-RESOURCES

The animation showing a particle representation of a drop of water being heated is an important one for students to see. There is a video of this experiment which is useful to show what is happening close up. (See page 2 of this booklet for details of the e-resources.)

Activity A3: Melting behaviour of materials

Students compare the different melting behaviours of a substance and a mixture of substances (see also page 13 of this booklet 'Substances and mixtures of substances').

LEARNING OBJECTIVES

Students will:

- experimentally compare the melting behaviour of a substance and a mixture of substances
- appreciate that a mixture does not have a well-defined melting point.

NOTES

CAUTION Be aware that the glassware could get quite hot and cause scolds. Students need to take care when pouring hot water from the kettle.

The three unknowns that students are asked to compare are chocolate (A), lauric acid (B) and butter (C).

Lauric acid is supplied as flakes. To produce the small cubes required for the activity, melt the flakes, pour in a mould and leave to cool before cutting. Since lauric acid is a substance, it has a well-defined melting point (43 °C).

Chocolate does not have a melting point. Typically chocolate will start to soften at about 34 °C. It requires a much higher temperature for chocolate to be runny. Chocolate does not seem to have a well-defined melting point; it becomes a gooey liquid rather than being a runny liquid. This is because chocolate is a mixture of substances. Melting chocolate is a very complex event and we would caution against any attempt to give a detailed explanation.

The student sheet refers to the use of a watch glass; alternatively, copper sheet could be used as a better thermal conductor. Depending on how quickly the students do each material, they may need to put in fresh hot water between each run.

RESOURCES NEEDED

Each group will need:

- Small cubes (approximately 5 mm each side) of the following, labelled A, B and C:
  - A chocolate
  - B lauric acid
  - C butter
- Beaker, 250 cm^3
- 3 watch glasses (or copper sheet)
- Spatula
- Kettle
- Eye protection.

USING THE E-RESOURCES

There is a video showing a comparison of wax and chocolate melting. There are also animations that show how substances and mixtures also show differences in their boiling behaviour. (See page 2 of this booklet for details of the e-resources.)

Activity A4: Recognising dissolving

Students investigate to see which substances can dissolve in water (see also page 15 of this booklet 'Dissolving substances').

LEARNING OBJECTIVES

Students will:

- investigate to see which substances can dissolve in water
- identify clearness/transparency as the key criterion for recognising dissolving
- understand that a solute can be a substance in a solid or liquid state
- use ideas from the particle model to explain how a solute dissolves in a solvent.

NOTES

CAUTION Copper sulfate is harmful. Wear eye protection and wash hands at the end of the experiment.

The substances should be supplied to students in containers labelled A – G. There is no need to name the substances. You may wish to direct students to use *small* quantities, or allow students free choice in amounts and then draw attention to the problems of adding too much – as many will!

Sugar (A), salt (B), copper sulfate (C), glycerine (E) and green food colouring (F) all dissolve in water. Chalk (D) and olive oil (G) do not dissolve.

Olive oil is a mixture of substances but behaves as one substance as none of the mixture dissolves. Green food colouring is actually a solution itself.

For Task B, make sure that the filter paper is fine enough to filter out all of the chalk. You may wish students to complete this task before discussing how to recognise dissolving.

In Task C, it is important that students understand that a 'grain' or 'blob' would contain millions of particles, but we can only show a small number in our diagrams.

Similarly, the diagrams should show the particles spreading out over time due to collisions. Therefore dissolving results in clear solutions because there are too few particles of solute grouped together for us to be able to see them. Encourage students to use key terms such as solvent, solute and solution.

RESOURCES NEEDED

Each group will need:

- Samples of the following labelled A – G:
    - A sugar
    - B common salt (sodium chloride)
    - C copper sulfate (labelled 'HARMFUL')
    - D chalk powder
    - E glycerine
    - F green food colouring
    - G olive oil (or colourless baby oil)
- 7 test tubes
- Test tube rack
- Spatula
- Dropping pipette
- Glass stirring rod
- Water.

USEFUL SOURCES

CLEAPSS Hazcards 27C (Copper salts: sulfates(VI)).

USING THE E-RESOURCES

There are animations that show particle representations of sugar and glycerine dissolving in water. There are also videos that can be used as extension showing crystallisation (as the reverse process) and solvents other than water. (See page 2 of this booklet for details of the e-resources.)

Activity A5: Dissolving 'gases'

Students observe a teacher demonstration of ammonia dissolving into water. Students then investigate the volume of carbon dioxide dissolved in carbonated water (see also page 17 of this booklet 'Do 'gases' dissolve?').

LEARNING OBJECTIVES

Students will:

- appreciate that substances in the gas state can also dissolve in water
- consolidate their understanding of the particle model for the gas state and the explanation for dissolving
- develop their understanding of experimental method and accuracy.

NOTES

CAUTION Ammonia is toxic. Fill the syringe in a fume cupboard. Be careful with the hypodermic needle as this can break the skin. When not in use, ensure that a protective cap is put over the needle.

For Task A, you may wish to have a gas syringe that has been filled prior to the lesson. Flush out a few times to make sure the syringe contains just ammonia. The loaded syringe could be put in the holder and stand, then left in the fume cupboard.

In Task B, the instructions for the investigation are open-ended. You may wish to be more prescriptive depending on the class. For example, give the volume of carbonated water to use and a strong steer for the method.

For the carbonated water, you could pour water out of a large bottle of mineral water, or you could carbonate distilled water using a soda stream as part of a demonstration before students start the investigation.

The student sheet shows a boiling tube with the carbonated water. Alternatively you could use a conical flask with about 50 cm^3 of carbonated water, which will give a bigger volume that is easier to measure.

Plastic bags could come pre-attached to rubber tubing if you think students will have difficulty doing this for themselves. A plastic connector could be used to connect the two pieces of rubber tubing.

Simply squashing the bag containing carbon dioxide into a beaker or measuring jug is an easy way of estimating the volume (any liquid carried into the bag can then be measured separately and subtracted from the volume). If available, a gas syringe can be used to give a more accurate measurement. The bag can be detached from the boiling tube, connected to the syringe and the bag squeezed to push the gas into the syringe.

RESOURCES NEEDED

For Task A (demonstration):

- Ammonia gas
- Glass gas syringe, 100 cm^3, with cap
- Gas syringe holder and stand
- Plastic syringe, 1 cm^3, fitted with a hypodermic needle
- Water
- Eye protection.

For Task B (demonstration):

- Bottle of carbonated water.

For Task B, each group will need to be able to choose from the following:

- Access to carbonated water
- Measuring cylinders, 10, 25, 50 and 100 cm^3
- Boiling tubes
- Conical flasks
- Bung with a rubber delivery tube, to fit either boiling tube or conical flask
- Beakers, 250 and 500 cm^3 (for hot water bath)
- Plastic beakers and jugs of various sizes with graduations for measuring gas in plastic bag
- Gas syringes if available, with holders
- Extra rubber tubing
- Kettle
- Clear plastic bags of assorted sizes (thin gauge flexible bags are best, e.g. sandwich bags)
- Sticky tape
- Clamp and stand.

USEFUL SOURCES

CLEAPSS Hazcards 5 (Ammonia gas).

USING THE E-RESOURCES

There is an animation showing a particle representation of a substance in the gas state dissolving in water. The section makes the point using diagrams that once dissolved, a solute no longer has a state. There is also a video showing the reverse process – air bubbles being formed in heated rainwater. (See page 2 of this booklet for details of the e-resources.)

Activity A6: Investigating evaporation

Students investigate factors that affect evaporation (see also page 20 of this booklet 'Evaporation').

LEARNING OBJECTIVES

Students will:

- identify how different substances evaporate at different rates under the same conditions
- investigate to see how surface area, temperature and breeze affects rate of evaporation
- use ideas from the particle model to explain how a substance in the liquid state evaporates.

NOTES

CAUTION Ethanol (IDA) is highly flammable and should be kept away from naked flames. Use in a well-ventilated laboratory.

The suggested tasks make qualitative comparisons. They could be adapted to include mass measurements if desired (perhaps using metal bottle tops to hold the substances instead of filter paper).

From Task A, students should conclude that evaporation does not require direct heat from a radiator or the Sun and that the rate of evaporation increases with a larger surface area.

For Tasks B, C and D you could use filter paper, kitchen towel, or fabric (including quick drying fabric). Only a few drops are needed just to make the paper or fabric damp; it should not be 'soaking wet'. (This would be particularly important if masses were being measured since a residue will be left on the balance pan.)

Students should conclude that ethanol evaporates faster than water, and that evaporation happens fastest at a warm temperature and with a breeze.

RESOURCES NEEDED

For Task A (demonstration):

- Measuring cylinder, 10 cm^3
- Petri dish
- Water.

For Tasks B, C and D, each group will need:

- Ethanol (IDA)
- Water
- 6 squares of filter paper / fabric (3 cm x 3 cm)
- 2 watch glasses
- 2 dropping pipettes
- Tweezers
- Stopclock
- Access to 'washing line' (2 clamp stands, bossheads and clamps, with length of string and paperclips)
- Access to a heat lamp
- Access to a desk fan or hand held fan
- Eye protection.

USEFUL SOURCES

CLEAPSS Hazcards 40A (Ethanol (IDA)).

USING THE E-RESOURCES

There are particle animations and resources to help explain evaporation and the factors which affect the rate of evaporation. There is also an animation that draws the important distinction between boiling and evaporation (below the boiling point). There is also a video showing the reverse process – condensation of water on a cold metal block. (See page 2 of this booklet for details of the e-resources.)

Activity A7: What kind of change?

Students investigate the reaction between stearic acid (stearin) and sodium carbonate to make sodium stearate (see also page 22 of this booklet 'Chemical change').

LEARNING OBJECTIVES

Students will:

- complete a chemical reaction
- contrast the properties of reactants and products in a chemical reaction.

NOTES

CAUTION: Sodium carbonate is an irritant and eye protection should be worn. Stearin (we suggest using stearin as a simpler name for stearic acid) and sodium stearate are both low hazard. Hot water can cause scalding.

In Task A, students are making a salt which is also a type of soap by the following reaction:

sodium carbonate + stearic acid
→ sodium stearate + carbon dioxide + water

However, the details of the reaction are not important. The key point is the emergence of a new substance which has different properties to stearin and sodium carbonate in terms of melting point and solubility.

In Task B, students contrast the lathering properties of the two reactants and the visible white product.

Students should find only the sodium stearate will produce a foam or lather. Sodium stearate is very insoluble in cold water and the solubility does not increase enough to produce a lather until the temperature is above 50 °C.

Best results are at temperatures above 70 °C when the solubility increases markedly. However, at temperatures of 70 °C and higher, pressure builds up on shaking the test tubes which could cause the liquids to spray. Therefore, the student experiment is limited to a temperature of 60 °C. If results are not convincing enough, you may wish to demonstrate the test at higher temperatures.

RESOURCES NEEDED

Each group will need:

- Stearic acid (stearin) (LOW HAZARD)
- Sodium carbonate (IRRITANT)
- Distilled water
- Beaker, 250 cm^3
- Measuring cylinder, 10 cm^3
- 2 boiling tubes
- Bung to fit boiling tube
- 3 test tubes
- 3 bungs to fit test tubes
- Test tube rack
- Spatula
- Spirit thermometer, -10 – 110 °C
- Hot plate
- Access to tap water
- Access to a kettle
- Eye protection.

USEFUL SOURCES

CLEAPSS Hazcards 95 (Sodium and potassium salts (3)).

USING THE E-RESOURCES

Videos of two other illustrations of chemical change are given in the e-resources (the reaction of ammonia and hydrogen chloride) and the reaction of calcium and water). (See page 2 of this booklet for details of the e-resources.)

Activity A8: Magnesium and oxygen

Students investigate how magnesium reacts with oxygen (see also page 25 of this booklet 'Reactions involving the gas state: combustion').

LEARNING OBJECTIVES

Students will:

- investigate the reaction between magnesium and oxygen
- use the particle model to explain their observations.

NOTES

Task A is a demonstration of what happens when magnesium ribbon is burnt in air. Use safety screens for this demonstration and ensure that students do not look directly at the flame. They should observe the reaction through blue glass or Polaroid filters (or even partially-opened fingers in front of the eyes). Hold the magnesium ribbon with a pair of tongs in a blue Bunsen flame and then remove it from the flame when it starts to burn.

The reaction demonstrated in the video in Task B involves the use of a plastic bag as a container for the oxygen in order to show how the oxygen is used up in the reaction. Note, however, that the use of plastic bags as a means of manipulating gases is a novel technique that has been developed for the videos in the Stuff and Substance e-resources. While offering a convenient means for handling gases, there are potential safety issues: if a bag accidentally comes into contact with a flame or if a bag splits, for example. Note that published model (general) risk assessments do not exist for these techniques.

In Task C, students should find that there is a mass increase as oxygen from the air combines with the magnesium to make magnesium oxide. However this needs to be done carefully, and in particular students need to avoid the product escaping when they raise the lid to let in air.

RESOURCES NEEDED

For Task A (demonstration):

- Magnesium ribbon, 5 cm length
- Tongs
- Bunsen burner and heatproof mat
- Safety screens
- Eye protection
- Blue glass or Polaroid filters for students.

For Task B (video clip):

- Computer with interactive whiteboard or data projector
- Stuff and Substance e-resources (section M4.1).

For Task C, each group will need:

- Magnesium ribbon
- Crucible and lid
- Tongs
- Tripod and pipeclay triangle
- Bunsen burner and heatproof mat
- Access to top pan balance
- Eye protection.

USEFUL SOURCES

CLEAPSS Hazcards 59A (Magnesium) and 69 (Oxygen); Laboratory handbook 13.2.2.

USING THE E-RESOURCES

Section M4 of the e-resources looks at the reaction between magnesium and oxygen. As well as the video that is shown in Task B, the resources also include exercises on the structures of the substances involved, the word equation for the change and a comparison with what happens when copper is heated in air. (See page 2 of this booklet for details of the e-resources.)

Activity A9: Investigating rusting

Students investigate how oxygen affects rusting (see also page 27 of this booklet ‘Atoms and substances: rusting’).

LEARNING OBJECTIVES

Students will:

- investigate the effect on rusting when dissolved oxygen has been removed from water by previous rusting
- measure the amount of air used in rusting
- use ideas of atoms and substances to explain their observations.

NOTES

In Task A, students are reacting all the dissolved oxygen with the first piece of iron wool. When the second piece is added, there is no dissolved oxygen left and therefore no further reaction. Students should be careful when adding the second piece of iron wool not to agitate the water too much as this would add more oxygen.

The second test tube is set up to prove that the second piece of iron wool is not ‘special’ and could still rust. It may be easier to insert an iron nail rather than a second piece of iron wool to reduce the chance of agitation. However, it is important to stress that both iron wool and the nail are just forms of iron; they are the same substance not something different.

Once the second amount of iron has been added it is sufficient to leave for just one extra day to prove than no new rusting will occur, however the set up can be left longer with no additional rusting taking place.

Rusting is a complex process, and in fact as well as dissolved oxygen, water is also involved as a reactant. However, this refinement in the explanation of rusting is more appropriate for advanced study.

In Task B, students should observe that the water level will rise in the test tube as the oxygen reacts with the iron. Students may be able to measure and discover that 1/5th of the test tube has been ‘flooded’ with water. This corresponds to the proportion of dry air that is oxygen.

RESOURCES NEEDED

Each group will need:

- Iron wool
- Water
- 3 test tubes with 2 bungs
- Test tube rack
- Permanent marker
- Beaker, 100 cm^3
- Clamp stand, bosshead and clamp.

Activity A10: A lighted candle

Students investigate the combustion of candle wax (see also page 29 of this booklet 'Complex changes: a lighted candle').

LEARNING OBJECTIVES

Students will:

- observe that boiling wax can be set alight
- investigate the role of the wick in a lighted candle
- test the products created in a candle flame and write a word equation.

NOTES

CAUTION Boiling wax is near to 400 °C. When demonstrating this in Task A, take extreme care not to get it on your skin as it could cause a severe burn. Have a safety screen between the demonstration and the students. All students should be wearing eye protection. If a reasonably small amount of wax is used, it can be allowed to burn out quite safely. Should you wish to put the flame out use a set of tongs to pick up a gauze mat and lower it onto the evaporating basin to smother the flame. Do not spray water onto the hot wax.

In Task A, the boiling wax will not usually combust until a flame (lighted splint) is put above the boiling wax. Just above the liquid is a combustible mix of wax molecules mixed with air. However, sometimes it will spontaneously combust – especially if the Bunsen flame is large. Therefore you should use a modest flame.

For Task B, the glass wick candles need to be made up prior to the lesson (though you could demonstrate to students how one is made during the lesson):

1. Cut a candle into 2 cm lengths without breaking the string wick (so it resembles a necklace) and then pull the pieces of wax from the string.

2. Using disposable gloves, roll glass wool into strings (3 cm long), drip molten wax onto the lengths and re-roll as the wax solidifies to give straight 'stiff' strings.

3. Take a piece of wax from (1) and insert a glass wick into the hole left by the string. If necessary, enlarge the hole with a drill. Trim the wick to size.

4. Bed the glass wick in by setting the candle alight for a few seconds.

Students should conclude that the wick allows control over the combustion of the wax. The wax at the base of the wick is melting and the liquid wax travels up the wick where it starts to boil. The wax molecules mix with the air and there is a reaction between the wax and oxygen. The flame is the visible energy being released by the chemical reaction.

In Task C, it is better to use a short candle to avoid the build up of soot on the beaker.

You may wish to extend students by giving them the atom structures for wax and oxygen and ask students to explain how carbon dioxide and water are formed.

RESOURCES NEEDED

For Task A (demonstration):

- Candle wax cut into a cube
- 2 wooden splints
- Matches
- Evaporating dish
- Tripod and pipeclay triangle
- Bunsen burner and heatproof mat
- Safety screens
- Eye protection.

For Tasks B and C, each group will need:

- Short candle (< 2 cm) with the string wick replaced by glass wool
- Limewater
- Cobalt chloride paper (toxic)
- 2 wooden splints
- Matches
- Glass beaker, 250 cm^3
- Bunsen burner and heatproof mat
- Dropping pipette
- Plastic lid to cover beaker
- Eye protection.

USING THE E-RESOURCES

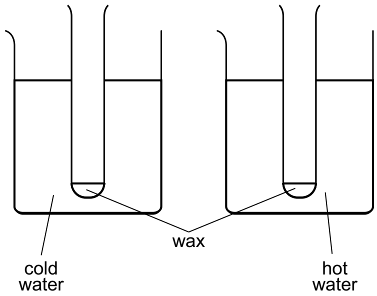
Section C3.3 of the e-resources also has a video of wax boiling in a long test-tube showing a clear space between the boiling wax and mist of condensed wax above. (See page 2 of this booklet for details of the e-resources.)

STUFF AND SUBSTANCE:
MELTING POINTS

The melting point of a substance is the temperature at which a substance gets just hot enough to melt. You are going to investigate the melting point of wax, and will look at some other substances that melt at higher temperatures.

Task A Melting wax

1. Your teacher will put tubes containing wax into hot and cold water. What happens to the wax? Why does this happen?
2. Can you think how you could find out how hot wax needs to be before it melts?

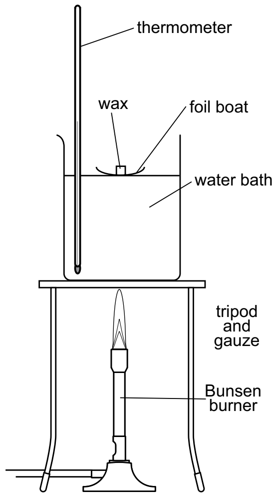


Task B Finding a melting point

3. Make your own water bath by half filling a 250 cm^3 beaker with cold water from the kettle. Put the beaker on a tripod and gauze.
4. Put a piece of solid wax into a foil boat. Float the foil boat on the water.
5. Record the temperature of the water.
6. Heat the water bath with the Bunsen burner.
7. Watch the wax carefully, and turn off the Bunsen when it starts to melt. Note the temperature of the water. Does all the wax melt?
8. What is your estimate of the melting point of wax?
9. How could you make your results more accurate? Think about:

   Does the size of the lump make any difference?
   Are the wax and the water at the same temperature?
   Is it better to heat the water quickly or slowly?
   Where in the water do you want to know the temperature?
10. If you used a more accurate method, do you think your value for the melting point would be higher or lower than your first attempt?

⚠ *The beaker may get hot and could scald. Liquid wax on the skin can solidify and cause burns. Wear eye protection.*



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STUFF & SUBSTANCE:

MELTING POINTS

Task C Melting sodium chloride

11. Do you think that salt (sodium chloride) melts? Your teacher will demonstrate an experiment to find out.

12. Put two or three large crystals of sodium chloride into a boiling tube, and clamp securely at an angle.

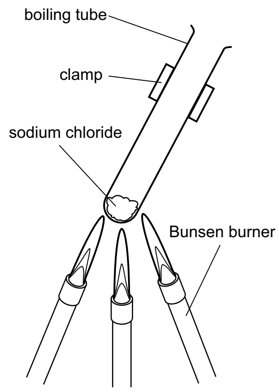
13. Set up three Bunsen burners, so that all of the flames overlap on the bottom of the boiling tube. Heat the tube with blue flames.

14. What can you see happening?

15. Why do you think we are using three Bunsen burners?

16. How can you tell that the sodium chloride has melted?

The equipment will get very hot and could cause burns. Wear eye protection.



Task D Melting lead

17. Do you think that lead will melt when heated? Your teacher will demonstrate an experiment to find out.

18. Set up a Bunsen burner, tripod and pipeclay triangle, and put a sample of lead into a crucible.

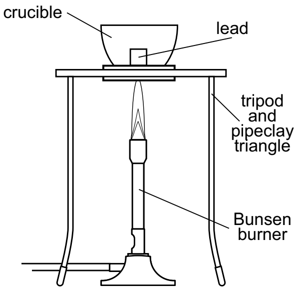
19. Using a blue Bunsen flame, heat the lead.

20. How can you tell that the lead has melted?

21. Once the lead has melted, turn off the Bunsen burner. Using tongs, pour the contents of the crucible onto a large flat piece of metal. Still using tongs, pick up the 'pancake'.

22. What do you observe? Why do you think this is happening?

The equipment will get very hot and could cause burns. Wear eye protection and thick gloves. Open the windows to provide ventilation.



Task E Comparing wax, sodium chloride and lead

23. Think about what happens when wax, sodium chloride and lead are heated. In what way are they similar? In what way are they different?

STUFF AND SUBSTANCE: PREDICTING WITH THE PARTICLE MODEL

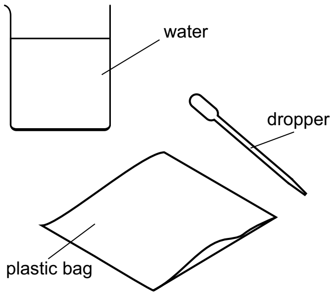
Substances are made of particles:

- close together, vibrating - the solid state
- close together, moving around - the liquid state.

You are going to use the particle model to make predictions about how substances behave.

Task A Predicting

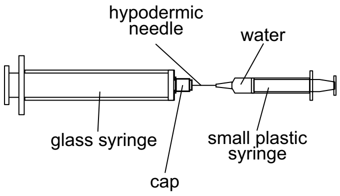
1. Imagine that a plastic bag is squeezed flat and then a drop of water is put inside it. The plastic bag is then sealed with a clip and heated. What might happen to the water inside? What will you see? Think about the particles. Draw a poster to show your ideas.



Task B Observing

2. In this task, your teacher will use a glass syringe that has been heated to 150 °C. The plunger of the syringe has been pushed all the way in and there is a cap on the end. What is inside the glass syringe?
3. A small plastic syringe with a hypodermic needle is then filled with water.
4. Your teacher will inject a drop of water (0.05 cm^3) into the hot glass syringe. What happens? How does this match your predictions?
5. What is inside the syringe?

⚠ *The glass syringe is hot and could cause burns. Wear thermal gloves. Ensure the plunger does not fly out. The hypodermic needle is sharp and could break the skin.*



Task C Particles

6. Use the ideas of the *particle model* to draw a labelled diagram of this experiment to explain the results:
   - Why did the volumes inside the syringes change?
   - Have the individual particles changed?
   - Which substance is in the syringe?
   - What is between the particles?
   - What state is the water in?

Particle model

- A sample of a substance is a collection of particles.
- There is nothing else except the particles.
- The particles of one substance are all the same.
- The particles hold on to each other – the 'ability to hold' is different for different substances.
- The particles are always moving in some way – they have energy of movement.
- Heating gives the particles more energy of movement – they are more energetic.

Science Enhancement Programme

STUFF AND SUBSTANCE:
MELTING BEHAVIOUR OF MATERIALS

Different materials melt in different ways. A material could be just *one* substance or *more than one* substance mixed together. You are going to do an investigation to compare the melting behaviour of different materials.

1. You will need samples of three different materials (A, B and C). Note that we are using the word 'material' here to mean any kind of 'stuff' – we are not using it in the everyday sense of a cloth or fabric.

When some materials are heated they show a well-defined change from solid to liquid; others go through a 'gooey' stage and don't show a sharp change. You need to identify the kind of change for each sample.

2. Make a water bath by half-filling a 250 cm^3 beaker with hot water from the kettle.

3. Put a watch glass on top of the beaker.

4. Put a small sample of the first material (sample A) on the watch glass, and observe what happens to it.

5. Touch the sample with a spatula. What do you notice? Is it changing sharply from solid to liquid or does it go 'gooey'? Fill in a table like the one shown.

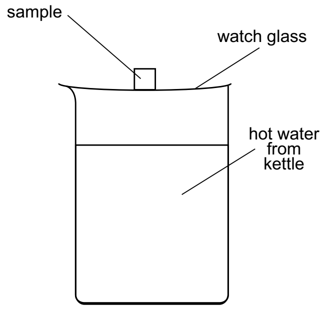
6. Now repeat for the other samples (B and C).

7. What might be the reason for their different behaviours?

8. Can you think of other materials that change from solid to runny liquid when heated? Can you think of other materials that go 'gooey' when heated?

9. In terms of *particles*, what is the difference between a substance and a mixture?

⚠ *Take care when using hot water. The beaker and watch glass will get hot and could scold. Wear eye protection.*



Sample	Observations
A	
B	
C	

STUFF AND SUBSTANCE: RECOGNISING DISSOLVING

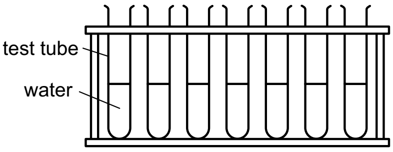
When some substances are added to water they are said to dissolve. How do we decide when something dissolves?

You are going to investigate which substances can dissolve in water.

⚠ *Substance C is harmful. Wear eye protection. Wash hands after the experiment.*

Task A Which substances dissolve?

1. You need 7 samples of substances (labelled A - G) and 7 test tubes. Half-fill each test-tube with water and place them in a test tube rack.



2. Choose one of the substances. Add a small amount to a test tube:
   - for a sample in the *solid state*, add a quarter of a spatula
   - for a sample in the *liquid state*, add three drops using a dropping pipette.
3. Use a glass rod to stir the mixture. What do you observe?
4. Does the substance dissolve? What did you see that made you decide? Record your results in a table like the one shown.
5. Repeat for the other 6 substances.

Sample	Observations	Does it dissolve
A		
B		
C		
D		
E		
F		
G		

Task B Filtering

6. Pour the mixture of water with B through filter paper. What do you observe?
7. Pour the mixture of water with D through filter paper. What do you observe?

Task C Particles and dissolving

8. Use the ideas of the *particle model* to explain what happens when a substance dissolves in water. Also explain why a dissolved substance cannot be filtered out. Make a cartoon to show your ideas.

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STUFF AND SUBSTANCE: DISSOLVING 'GASES'

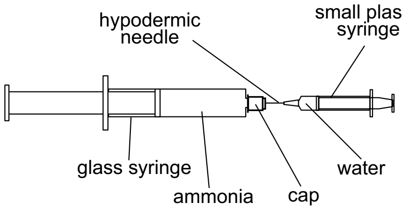
Ammonia is a substance in the gas state at room temperature. You are going to see what happens when it mixes with water.

Carbonated water is a solution of carbon dioxide in water. You are going to find out how much carbon dioxide is in a bottle of carbonated water.

⚠ *Ammonia is toxic. Use in a well-ventilated room or fume cupboard.*

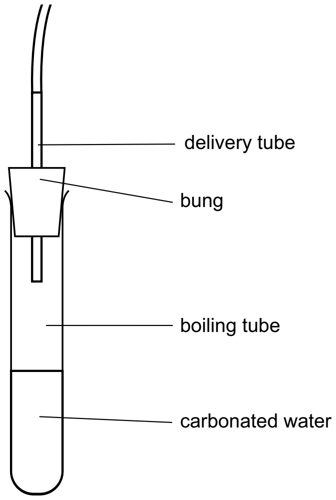
Task A Ammonia and water

1. In this demonstration, your teacher will use a glass syringe that contains 100 cm^3 ammonia. Using a syringe with a hypodermic needle, 1 cm^3 of water is injected into the glass syringe.
2. What do you observe? Can you explain what has happened? Use the ideas of the *particle model.*



Task B How much carbon dioxide is in a bottle of carbonated water?

3. Your teacher will open a bottle of carbonated water. Why do you think that bubbles appear?
4. You will now investigate how much carbon dioxide remains dissolved in the water. You need to think about how you will get the carbon dioxide to come out, how to collect it and how to measure its volume. Some hints:
    - shaking the solution gets more carbon dioxide to come out
    - carbon dioxide is much less soluble at higher temperatures
    - you can make a gas tight connection between a pipe and a plastic bag with sticky tape
    - the bag could be put inside something to see how much volume it takes up.



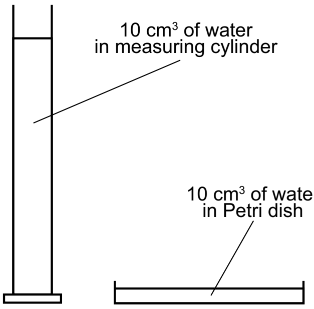
5. How accurate is your value for the volume of carbon dioxide? Could you improve your method? (Think of where you might have lost some carbon dioxide. Could you have gained any air somewhere? Is there a better way of measuring the volume?)
6. Could you also find out how much carbon dioxide escapes when the bottle is first opened?

STUFF AND SUBSTANCE: INVESTIGATING EVAPORATION

When water is left in an open container, it slowly disappears – this process is called *evaporation*. In this activity you will investigate some of the factors that affect the rate of evaporation, and explain your results in terms of the particle model.

Task A What effect does surface area have on evaporation?

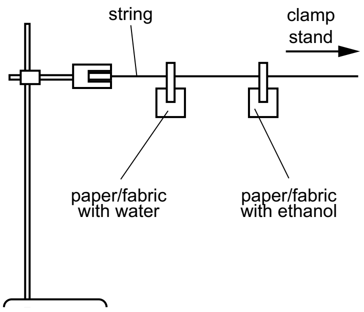
1. Put 10 cm^3 of water into a measuring cylinder. Put 10 cm^3 of water into a Petri dish.
2. Put the containers in the corner of a room or in a cupboard and leave for several days.
3. What happens to the volumes of water? How do the rates of evaporation compare? How does surface area affect evaporation?



Task B Comparing evaporation of different substances

4. Using a pencil, label a piece of filter paper or fabric (approximately 3 cm x 3 cm) with the word ‘water’, and add your name. Put it on a watch glass, and add 3 drops of water with a dropping pipette.
5. Repeat with a second piece of filter paper (or fabric) using ethanol.
6. Hang the two pieces on a ‘washing line’ (a string stretched between two clamp stands) using paper clips and observe them for a few minutes. Does one appear to ‘dry’ more quickly?
7. Which substance evaporated faster?

⚠ *Ethanol (IDA) is highly flammable and harmful through inhalation. Keep away from naked flames and use in a well-ventilated laboratory. Wear eye protection.*



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STUFF & SUBSTANCE:

INVESTIGATING EVAPORATION

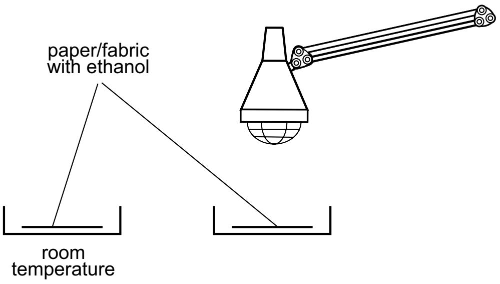
Task C What effect does temperature have on evaporation?

8. Use two pieces of filter paper (or fabric) as before. Label one 'cool' and the other 'warm'. Add 3 drops of ethanol to each.

9. Put one in a dish at room temperature and the other under a heat lamp. Observe them for a few minutes. Does one appear to 'dry' more quickly?

10. What effect did the temperature have on evaporation?

⚠ *Ethanol (IDA) is highly flammable and harmful through inhalation. Keep away from naked flames and use in a well-ventilated laboratory. Wear eye protection.*

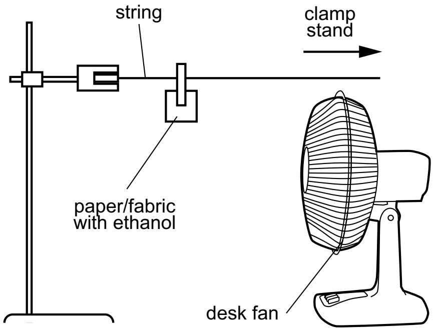


Task D What effect does a breeze have on evaporation?

11. Use two pieces of filter paper (or fabric) as before. Label one 'no breeze' and the other 'with breeze'. Add 3 drops of ethanol to each.

12. Put one on a 'washing line' with no breeze, and the other on a 'washing line' next to a desk fan. Observe them for a few minutes. Does one appear to 'dry' more quickly?

13. What effect did the breeze have on evaporation?



Task E Particles

14. Use the ideas of the *particle model* to explain how the rate of evaporation is affected by:

- the substance used
- the surface area
- the temperature
- movement of the air over the surface.

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STUFF AND SUBSTANCE:
WHAT KIND OF CHANGE?

You have seen substances change state and you have seen substances mix with each other. These are not the only things that can happen with substances. Substances can also change into other substances.

Task A Mixing stearin and sodium carbonate

1. Half fill a 250 cm^3 beaker with hot water from the kettle (above 80 °C) to make a hot water bath. Use a thermometer to monitor the temperature of the water bath. You may need to use a hot plate to make sure it remains above 80 °C.

2. Add 0.5 g of anhydrous sodium carbonate to 5 cm^3 of distilled water in a boiling tube. Put a bung in the top of the boiling tube and shake to dissolve the powder. Once the solution has been made, remove the bung and put the boiling tube into the hot water bath.

3. Add 0.4 g of stearin to a second boiling tube and put into the hot water bath. Watch the stearin melt.

4. Leave for five more minutes (to make sure the sodium carbonate solution is above 80 °C), remove both boiling tubes from the hot water bath and place in a test tube rack. Carefully add the hot sodium carbonate solution to the liquid stearin. What do you observe straight away?

5. What happens on cooling? Why can't the white stuff be stearin? Why can't the white stuff be sodium carbonate?

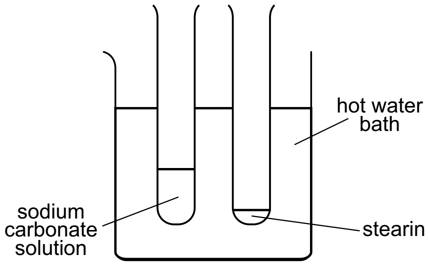
Task B Comparing the different substances

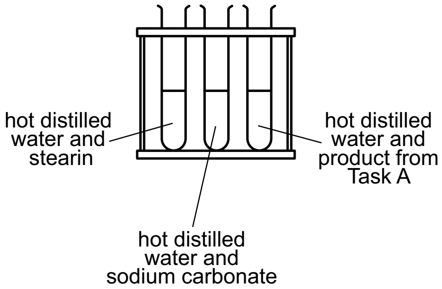
6. Half fill three test tubes with hot distilled water (between 50 °C and 60 °C).

7. In the first test tube add about a quarter of a spatula of stearin, in the second put about a quarter of a spatula of sodium carbonate and in the final test tube add about a quarter of a spatula of the white solid made in Task A.

8. Place bungs in the top of each test tube and shake. What do you observe?

⚠ *Be aware that hot water can cause scalds. Sodium carbonate is an irritant, wear eye protection.*





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STUFF AND SUBSTANCE:
MAGNESIUM AND OXYGEN

For many chemical reactions the substances have to be hot to react with each other. You are going to investigate the reaction between magnesium and oxygen.

Task A Heating magnesium in air

1. Your teacher will demonstrate what happens when magnesium ribbon is heated in air. What can you see happening?

Task B Reacting magnesium with oxygen

2. Your teacher will show you a video in which magnesium is placed in a test tube attached to a bag of pure oxygen. The magnesium is then heated. What do you predict will happen to the magnesium and the bag of oxygen?

3. Observe carefully. What can you see happening?

4. Can you use the ideas of particles to explain your observations?

Task C Measuring the change in mass

5. Take a piece of magnesium and curl it into a corkscrew shape. Put the magnesium into a crucible and replace the lid. Note the starting mass of the magnesium, crucible and lid.

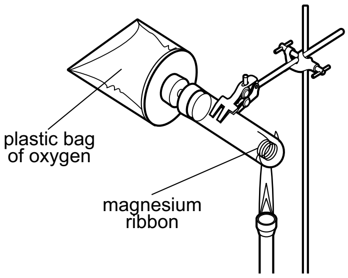
6. Set up a Bunsen burner with a tripod and pipeclay triangle. Put the filled crucible on the pipeclay triangle. Strongly heat the crucible. Every few moments, use a pair on tongs and gently lift the lid slightly. Why is this necessary?

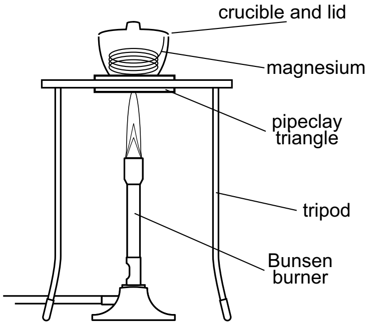
7. When you no longer get a white flash, turn off the Bunsen burner and allow the equipment to cool.

8. Measure the mass of the cold crucible, lid and its contents. What has happened to the mass?

9. Use the particle model to explain your observation.

⚠ *Magnesium is highly flammable. Do not look directly at the burning magnesium. Blue glass or Polaroid glass should be used to shield the eyes.*





Science Enhancement Programme

STUFF AND SUBSTANCE: INVESTIGATING RUSTING

Rusting is a chemical change involving iron. When rusting happens objects made of iron lose their structural strength. You are going to investigate what is needed to make iron rust.

⚠ *Iron wool can be prickly. Wear protective gloves and avoid direct contact with the skin.*

Carry out the two tasks below and try to come up with an explanation which connects all of your observations. Use the ideas of atoms and substances in your explanations.

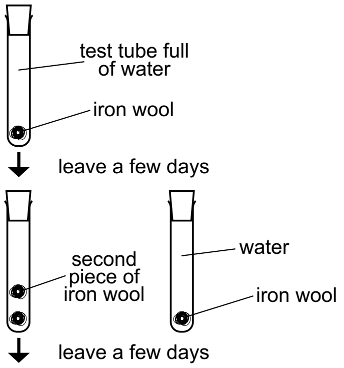
Task A Qualitative observation

1. Take a small piece of iron wool and put it into a test tube. Fill the test tube to the brim with tap water and seal with a bung. Put the test tube in a rack and leave for three days.

2. After three days, what do you observe?

3. Put a second piece of iron wool in this test tube and seal again with a bung. Be careful not to lose any water so you don't trap any air. Also prepare a second test tube as in step 1. Leave both test tubes for one more day.

4. After one more day what do you observe? How do the test tubes compare?

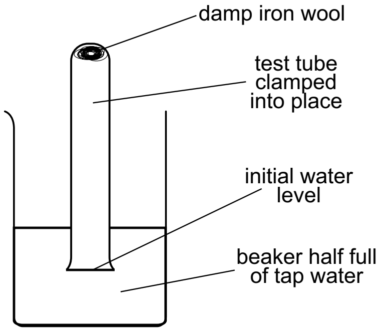


Task B Quantitative observation

5. Rinse some iron wool so that it is damp. Push the iron wool to the bottom of a test tube so it doesn't fall out when the tube is turned upside down.

6. Half fill a 100 cm^3 beaker with tap water. Clamp the test tube upside down so that the brim is submerged into the water by about 2 cm.

7. Leave for one week, noting the level periodically (every day if possible). What do you observe?



Science Enhancement Programme

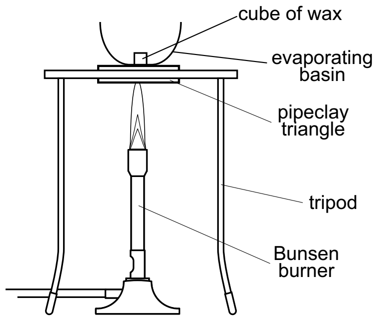
STUFF AND SUBSTANCE:
A LIGHTED CANDLE

Candle wax is a substance made from hydrogen and carbon atoms. A flame is a reaction between two substances in the gas state which gives out a lot of energy. You are going to investigate a candle flame.

⚠ *Boiling wax is* very hot. Take care not to get it on your skin as it could cause a severe burn. If you need to put out the wax use tongs to pick up a gauze mat and lower it onto the basin to smother the flame. *Do not spray water onto the hot wax.*

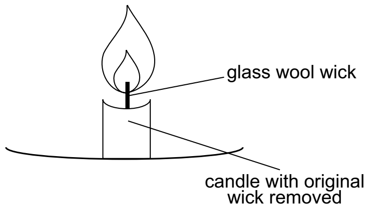
Task A Will boiling wax set alight?

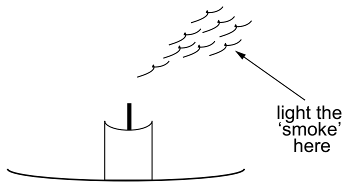
1. Your teacher will use a Bunsen burner to heat a piece of wax in a glass evaporating basin. What do you observe?
2. Your teacher will now put a lighted splint over the boiling wax. What do you observe?



Task B A glass wick candle

3. You will need a candle which has had the string wick replaced with glass wool. Put the candle on a watch glass and set it alight.
4. Look carefully at what is happening. What do you observe? What is happening to the wax and what part does the wick play in this?
5. Blow out the candle. Notice the 'white smoke' that comes off the wick for a short time while the glass is still hot. Re-light the candle. Blow out the candle and try to light the 'smoke' about 1 cm away from the wick.
6. Can you explain what this 'white smoke' might be?
7. Repeatedly blow out and re-light the candle. How far can you make the flame jump?





STUFF & SUBSTANCE:

A LIGHTED CANDLE

Task C Testing the products

8. Re-light the candle. Cover the lighted candle with a beaker until the candle goes out.

9. Why do you think the candle goes out?

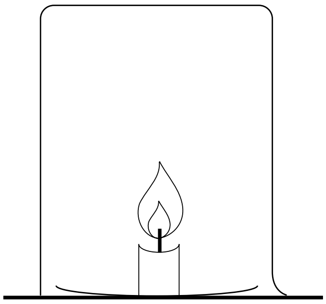
10. Notice the condensation around the sides of the beaker. Which substance is this? Test it with a piece of cobalt chloride paper. Were you right?

11. Re-light the candle and again cover it with a beaker until the candle goes out.

12. Remove the beaker and add a small amount of limewater to the beaker. Swill the limewater around, using a plastic lid to stop any limewater spilling out.

13. What do you observe? What conclusion can you make?

⚠ *Cobalt chloride is toxic – avoid prolonged skin contact with the cobalt chloride paper. Wear eye protection and wash hands after the practical.*



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PDF file of booklet

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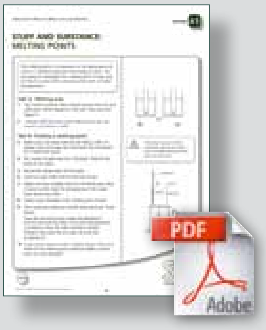
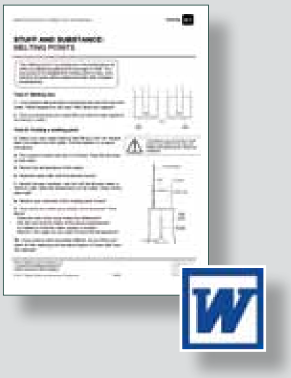


PDF files of student sheets

In addition to the whole booklet, the student activities are available as separate PDF files.



Word files of student sheets

Each student sheet also exists as a Word file. These files can be edited in order to adapt the activities to suit individual circumstances.

PowerPoint presentations

These contain the photographs and drawings shown in this booklet. They can be used to create custom-made presentations.

Links to e-resources

This pdf file contains links to the e-resources on the National STEM Centre eLibrary for each of the activities to enable quick access to the materials.

National STEM Centre

The e-resources are freely available online in the National STEM Centre eLibrary for use by teachers and students.

You can download the written materials in this booklet, and find further information from: Science Enhancement Programme www.sep.org.uk

The Science Enhancement Programme (SEP) is part of Gatsby Technical Education Projects. It undertakes a range of activities concerned with the development of curriculum resources and with teacher education.

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