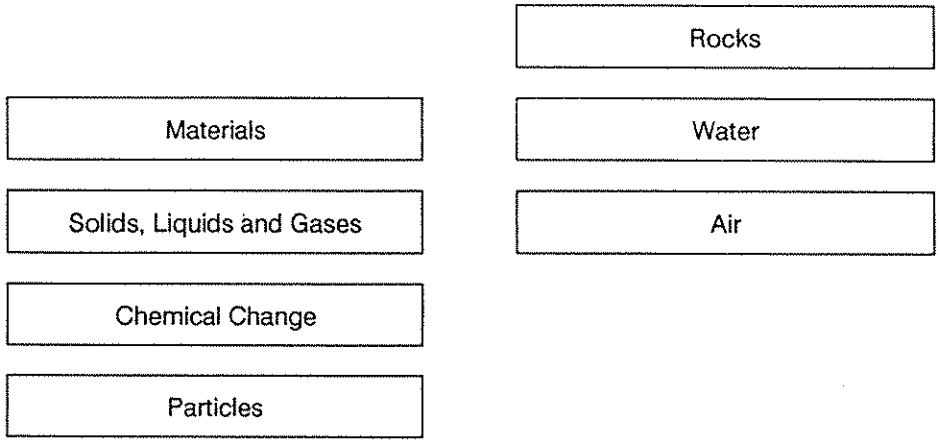

SOLIDS,
LIQUIDS
AND GASES

IMPORTANT NOTE

The realm of matter and materials is far too extensive to deal with as one domain, and yet it is difficult to identify clear demarcations. Any domain boundaries are necessarily artificial but seven domains have been chosen so as to focus upon the underlying structure of materials and the changes brought about by energy transfer.

This domain relates to other domains, as shown below, with 'Materials', 'Solids, Liquids and Gases', 'Chemical Change' and 'Particles' dealing with general issues and the other three domains dealing with specific important examples:



Pupils' understanding of materials will, of course, be rooted in their many first-hand experiences of what materials look and feel like and the way materials behave. Their ideas progress from understandings based on objects, through ideas of material substance of which objects are made, towards understandings in terms of chemical substances. It is therefore very important to use words carefully so as to distinguish between a material and its component chemical substances (see Introduction page 21: Material Substances). In this domain the word 'substance' is used to refer to a component (element or compound) of a 'material'.

When they have been introduced to the notion of particles, pupils can begin the long-term process of reconstructing their explantations of phenomena in terms of particles. The particulate model of matter is not only an idea to be developed in its own right: it is also a model to be used to explain the behaviour of materials in all contexts not only throughout work on inanimate materials but also in the context of thinking about living things and the processes of life. Thus the Science Maps and Learning Guides in many domains show both 'macro' and 'particulate' versions of certain ideas.

The term 'particle' is reserved for atom, molecule, ion or electron: small pieces of material are referred to as 'fragments', 'grains', 'bits' or 'droplets'.

SOLIDS, LIQUIDS AND GASES

The following sections have been designed for use in association with one another. The Learning Guides are supported by the Research Summary, the Science Map and The Teacher's View. It will also be helpful to refer to the Science Map and The Teacher's View when using the Research Summary.

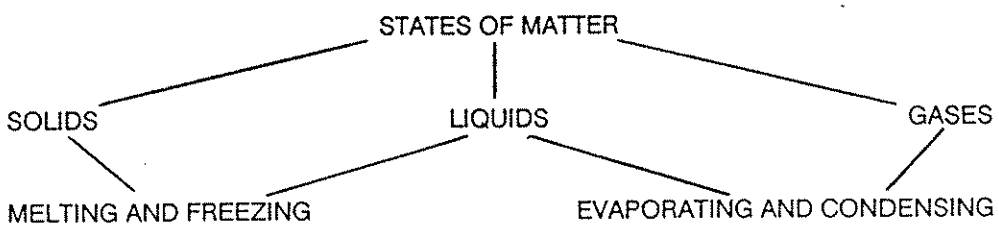
CONTENTS

Science Map

This map shows those ideas which make up a sound basis for understanding Solids, Liquids and Gases to work towards in the early secondary years. This is proposed as a coherent framework in itself which at the same time provides an appropriate basis for development. Critical ideas around which understanding is structured are identified in the map as shaded boxes and these goals make up the right hand column of the Learning Guides.

Learning Guides

These guides are the nucleus of the materials. They are folded so that children's prior ideas from the Research Summary are set alongside goals from the Science Map and they describe the challenges pupils face when it comes to restructuring their ideas. They also suggest interventions which could be used in teaching schemes to help pupils reach the goals. Related extracts from the National Curriculum are included. The Learning Guides in this domain are:



Research Summary: Children's Ideas

This is a brief outline of research into children's ideas, setting out the main prior ideas and understandings which teachers might expect to meet among pupils. These ideas make up the left hand column of the Learning Guides.

The Teacher's View

This section outlines those aspects of a deeper understanding which the teacher needs to have in mind whilst working with pupils.

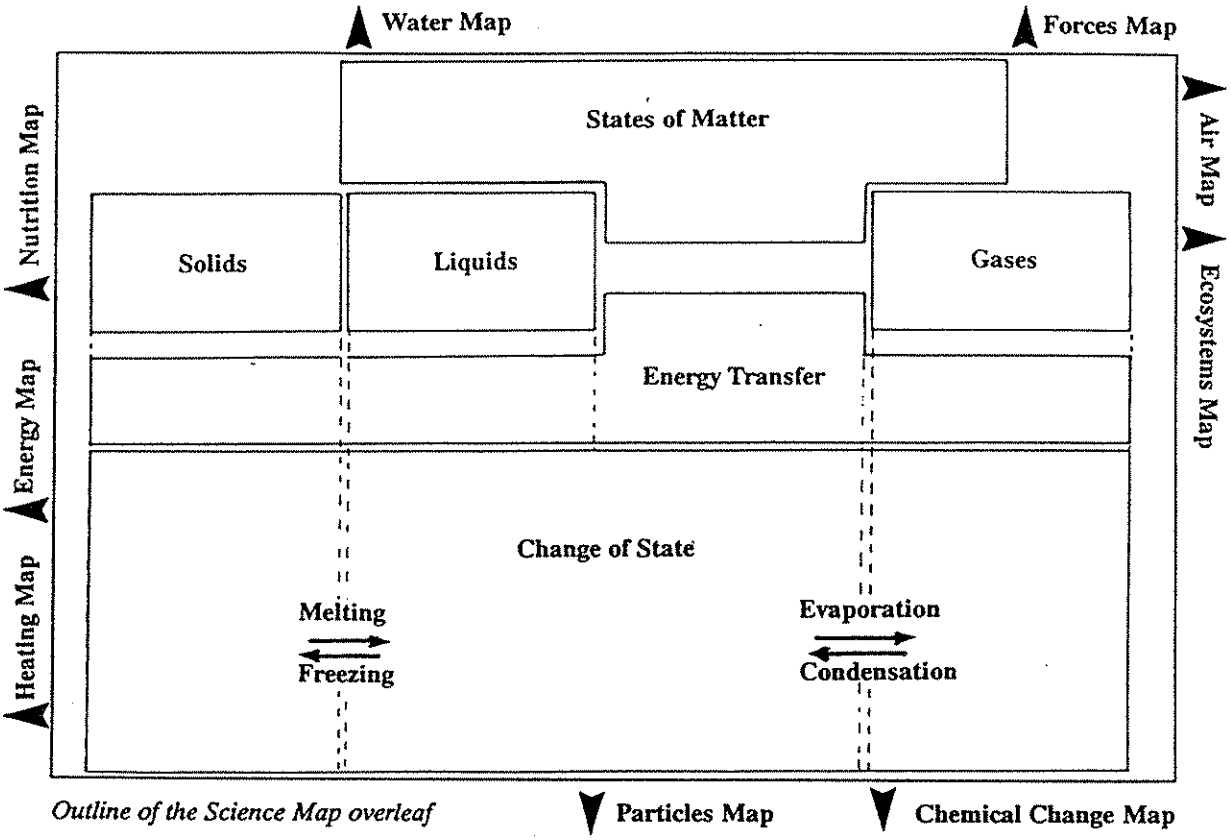
Additional Materials

Properties of Solids, Liquids and Gases: Criteria for Classifying.
Diagnostic Questions on Evaporation and Condensation.
Investigating Melting and Freezing Using a Datalogger.

Note: This domain, 'Solids, Liquids and Gases', overlaps with 'Materials', 'Chemical Change' and 'Particles'. The connections between the four sets of materials are indicated on the Science Maps.

SOLIDS, LIQUIDS AND GASES

SCIENCE MAP



The map overleaf shows those ideas which make up a sound, yet realistic basis to work towards in the early secondary years. This is proposed as a coherent framework in itself which at the same time provides an appropriate basis for development.

Critical ideas around which understanding is structured are identified in the map as shaded boxes and these goals make up the right hand column of the Learning Guides.

Some ideas about Solids, Liquids and Gases can be held in the form of a 'macro' view or in the form of a particulate model. For these ideas both views are presented within one box. A particulate view is a helpful one for pupils to have and it is one teachers are likely to want to work towards, accepting that pupils will develop their own personal versions of the particle model. However, the 'macro' view represents important understandings and may be the version appropriate to some pupils.

Aspects of a deeper understanding which the teacher needs to have in mind whilst working with pupils is outlined in The Teacher's View.

SOLIDS, LIQUIDS AN_ _ASES

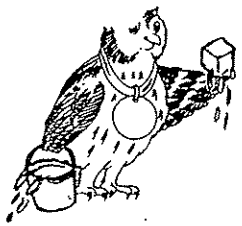
SCIENCE MAP

In everyday experience some materials are solids, some are liquids and some are gases.
(See Learning Guide: States of Matter)

Many substances can exist in solid, liquid, or gaseous form. They change from solid to liquid to gaseous form as they are heated, and back again as they are cooled. A substance is still the same substance when it has changed from one state to another.

The particles of a substance can be arranged as a solid, liquid or gas, depending upon their energy, but they are still the same particles.
(See Learning Guide: States of Matter)

For any substance, the solid form is denser than the liquid form, and the liquid form is denser than the gaseous form. Water is an exception in that ice is less dense than water at 0°C.



Solids are not all hard blocks: some are soft, and others are powdery. A solid takes up a definite amount of space and it has its own shape. Solids are not compressible.

The particles of a solid are closely packed together in a regular array, maintained by forces of attraction between them. Each particle vibrates about a fixed point.
(See Learning Guide: Solids)

All liquids are runny, but some are more runny than others. A liquid takes up a definite amount of space. It takes up the shape of its container. Liquids are not compressible.

The particles of a liquid are constantly moving, sliding over one another, in all directions. The particles are not fixed in relation to one another, but they are still closely packed together.
(See Learning Guide: Liquids)

Most gases are not visible: a few coloured gases can be seen. A gas spreads out in all directions to fill all available space: it has no shape. Gases are compressible: they can be compressed into smaller spaces.

The particles of a gas are constantly moving freely in all directions and far apart from one another. They travel in straight lines until they collide with one another or with the particles of the container.
(See Learning Guide: Gases)

If energy is transferred to or from a substance, it may change its temperature, change its volume, change its state or change to a different substance.

Transferring energy from a solid (cooling) makes it colder, decreasing its temperature.

Transferring energy to a solid (heating) usually makes it hotter, increasing its temperature.

When energy is transferred to a solid substance it eventually melts to become a liquid at the temperature which is its 'melting point'.

When energy is transferred to a solid substance at the temperature called its 'melting point' its particles move so vigorously that the particles are no longer 'fixed' in relation to one another and a liquid is formed.
(See Learning Guide: Melting and Freezing)

Transferring energy from a liquid (cooling) usually makes it colder, decreasing its temperature.

When energy is transferred from a liquid substance it eventually freezes to become a solid at the temperature which is called its 'freezing point'.

When energy is transferred from a liquid substance at the temperature called its 'freezing point', movement of its particles is reduced, so that they become fixed in relation to one another and a solid is formed.
(See Learning Guide: Melting and Freezing)

Each substance has its own temperature for changing from a solid to a liquid and back again. Its melting point and its freezing point are the same.

Transferring energy to a liquid (heating) usually makes it hotter, increasing its temperature.

When energy is transferred to a liquid substance, it evaporates to become a gas.

When energy is transferred to a liquid substance, its particles move around more vigorously, move further apart, and eventually a gas may be formed.
(See Learning Guide: Evaporating and Condensing)

A liquid substance is evaporating slowly all the time to become a gas. When enough energy is transferred to a liquid substance it evaporates quickly (boils).

When a liquid evaporates slowly, particles from its surface escape, as a gas, into the surroundings. When a liquid boils, particles throughout the liquid escape as a gas.
(See Learning Guide: Evaporating and Condensing)

At a particular pressure each substance has its own temperature for boiling. This is called its 'boiling point'.

Transferring energy from a gas (cooling) usually makes it colder, decreasing its temperature.

When energy is transferred from a gaseous substance it can condense to become a liquid.

When energy is transferred from a gaseous substance, its particles move less vigorously, become closely packed and a liquid is formed.
(See Learning Guide: Evaporating and Condensing)

Condensation happens at a temperature which is at or below the boiling point of the substance.

Transferring energy to a gas (heating) makes it hotter, increasing its temperature.

OLIDS, LIQUIDS AND GASES

SOLIDS

Children's Prior Ideas

Children consider solids to be strong, hard and malleable, but they have difficulty in classifying powders and soft fabrics as solids.

Young children regard powders as liquids, but from about age eleven, they regard powders as intermediate between solids and liquids.

Many pupils regard fabrics as intermediate between solids and liquids.

Children associate the conversion of a bulk solid to a powdered solid with a loss of mass.

Secondary school pupils who can depict an ordered array of particles in solids, cannot necessarily explain the incompressibility or cohesion of solids in particle terms.

(See Solids, Liquids and Gases Research Summary)

The Challenge for Pupils

The challenge is to clarify a technical meaning of 'solid' which differs from the everyday meaning. Pupils need to extend their application of the word 'solid' from hard, rigid materials to include soft, non-rigid solids such as powders, fabrics and flexible materials. (See Learning Guide: States of Matter.) Pupils need to relate to the characteristic properties of solids: definite shape and non-compressibility (having a fixed volume at a given temperature) to materials and substances of which objects which are made rather than to the objects themselves.

In coming to a scientific understanding of 'solids', pupils need to re-examine the use of language such as 'solid as a rock' and 'pour flour into a bowl'. These expressions would encourage the distinction of different forms of solid, when a scientific view aims to bring powders and fabrics together with other solids.

Even with more 'scientific' language, the meanings of terms are not self-evident and they need clarifying. Non-compressibility needs to be distinguished from rigidity. When talking about compressibility we are referring to the solid itself, not to the mixture of solid and air as in rubber gloves or a scarf. Compressibility also needs to be distinguished from the change in shape which happens, for example when plasticine is 'squashed' into a different shape. (When plasticine is squashed it does not change in volume.)

Pupils might be encouraged to think about the way that powders and fabrics appear to change shape even though they are solids. They need to pick out a single grain or fibre, visible with a hand lens, and recognise it as a small solid object with its own definite shape. Then they may be able to think in terms of a number of these small objects moving in relation to one another to account for bulk changes of shape.

Pupils should bear in mind the all-embracing classification of states of matter - if an item is not a solid, then it must be a liquid or a gas.

In considering the particulate model of solids, pupils must beware of confusing visible grains with invisible particles.

Trying to explain the properties is a good opportunity for pupils to use the particle model. They need to try to account for observed properties of solids: that is that they have a definite volume (are non-compressible) and have a definite shape, in terms of the nature and the movement of particles in a solid. (See Particle Model Learning Guide and Particles Moving Learning Guide in 'Particles'.)

SOLIDS

Goal

Solids are not all hard blocks: some are soft, and others are powdery. A solid takes up a definite amount of space and it has its own shape. Solids are not compressible.

The particles of a solid are closely packed together in a regular array, maintained by forces of attraction between them. Each particle vibrates about a fixed point.

Related National Curriculum Programme of Study Key Stage 3

Pupils should have the opportunity to compare and study a range of physical properties....of materials. This study should involve working with solids.... (Sc3 i)

Pupils should investigate changes of state....They should be encouraged to explain these phenomena in terms of their developing ideas of the particulate model of matter. (Sc3 ii)

Related extracts from the National Curriculum Programmes of Study: Key Stages 1, 2 and 4

Pupils should collect and find similarities and differences between a variety of everyday materials....They should explore the properties of these materials referring, for example, to their *shape*,.... (KS1 Sc3 i)

Pupils should investigate a number of different everyday materials, grouping them according to their characteristics. Pupils should be given opportunities to compare a range of solids.... (KS2 Sc3 i)

Pupils should....use the kinetic theory to explain changes of state.... (KS4 Sc3 ii)

Related National Curriculum Statements of Attainment

Pupils should:

Sc3 i/1a be able to describe the simple properties of familiar materials.

Sc3 i/2a be able to group materials according to observable features.

Sc3 i/4a be able to classify materials as solids....on the basis of simple properties which relate to their everyday uses.

Sc3 ii/6b understand the physical differences between solids, liquids and gases in simple particle terms.

Sc3 ii/7c understand changes of state, including the associated energy changes,....in terms of the proximity and motion of particles.

LIQUIDS

Goal

All liquids are runny, but some are more runny than others. A liquid takes up a definite amount of space. It takes up the shape of its container. Liquids are not compressible.

The particles of a liquid are constantly moving, sliding over one another, in all directions. The particles are not fixed in relation to one another, but they are still closely packed together.

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ey Stage 3

ıpils should have the opportunity to compare and udy a range of physical properties....of materials. his study should involve working with....liquids .They should develop understanding of the main ıys to classify and group the materials. (Sc3 i)

ıpils should investigate changes of state....They ould be encouraged to explain these phenomena terms of their developing ideas of the particulate odel of matter. (Sc3 ii)

Related extracts from the National Curriculum Programmes of Study: Key Stages 1, 2 and 4

Pupils should collect and find similarities and differences between a variety of everyday materials....These should include....water and other liquids. (KS1 Sc3 i)

Pupils should investigate a number of different everyday materials, grouping them according to their characteristics. Pupils should be given opportunities to compare a range of....liquids.... (KS2 Sc3 i)

Pupils should....use the kinetic theory to explain changes of state.... (KS4 Sc3 ii)

Related National Curriculum Statements of Attainment

Pupils should:

Sc3 i/1a be able to describe the simple properties of familiar materials.

Sc3 i/2a be able to group materials according to observable features.

Sc3 i/4a be able to classify materials as....liquids....on the basis of simple properties which relate to their everyday uses.

Sc3 ii/6b understand the physical differences between solids, liquids and gases in simple particle terms.

Sc3 ii/7c understand changes of state, including the associated energy changes,....in terms of the proximity and motion of particles.

GASES

Goal

Most gases are not visible: a few coloured gases can be seen. A gas spreads out in all directions to fill all available space: it has no shape. Gases are compressible: they can be compressed into smaller spaces.

The particles of a gas are constantly moving freely in all directions and far apart from one another. They travel in straight lines until they collide with one another or with the particles of the container.

Related National Curriculum Programme of Study Key Stage 3

Pupils should have the opportunity to compare and study a range of physical properties....of materials. This study should involve working with.... gases....They should develop understanding of the main ways to classify and group the materials. By experiment pupils should see that gases have mass. (Sc3 i)

Pupils should investigate changes of state, diffusion, dissolving, and the behaviour of gases under different conditions of temperature and pressure. They should be encouraged to explain these phenomena in terms of their developing ideas of the particulate model of matter. (Sc3 ii)

Related extracts from the National Curriculum Programmes of Study: Key Stages 1, 2 and 4

Pupils should collect and find similarities and differences between a variety of everyday materials....These should include....air.... (KS1 Sc3 i)

Pupils should investigate a number of different everyday materials, grouping them according to their characteristics. Pupils should be given opportunities to compare a range of....gases.... (KS2 Sc3 i)

Pupils should investigate the quantitative relationships between the volume, temperature and pressure of a gas, and use the kinetic theory to explain changes of state and other phenomena.... (KS4 Sc3 ii)

Related National Curriculum Statements of Attainment

Pupils should:

Sc3 i/1a be able to describe the simple properties of familiar materials.

Sc3 i/2a be able to group materials according to observable features.

Sc3 i/4a be able to classify materials as....gases....on the basis of simple properties which relate to their everyday uses.

Sc3 ii/6b understand the physical differences between solids, liquids and gases in simple particle terms.

Sc3 ii/7c understand changes of state, including the associated energy changes,....in terms of the proximity and motion of particles.

Sc3 ii/7d understand the relationships between the volume, pressure and temperature of a gas.

Children's Prior Ideas

Young children are not aware that air and other gases are materials. They may say that air exists, yet consider it as something abstract like 'thoughts'.

Many children think of 'air' as being 'good' as it is used for breathing and life, while they think of 'gas' as being 'bad' and dangerous.

Even when they are aware of gases as materials, many pupils do not regard 'gas' as having mass and weight.

Even when they have been introduced to a particle view, some pupils do not indicate that a gas is composed of particles. However, most secondary school children can think of a gas as being composed of particles but few accept that there is empty space between the particles. They think that there is a continuous substance, often thought to be air, between the particles of a gas.

(See Solids, Liquids and Gases Research Summary)

The Challenge for Pupils

It is difficult for children to accept that gases exist at all. (See Air as a Material Learning Guide in 'Air', All Materials Learning Guide in 'Materials', and Learning Guide: States of Matter.)

By observing demonstrations involving gases, pupils can be helped to identify the criteria used to categorise gases: no fixed shape, no fixed volume (compressible). Ideas of compressibility can be developed by experimenting with air-filled syringes and plastic bags. The 'feel' of compressed air 'pushing back' helps to develop the idea that air exerts pressure in all directions. (See Pressure Learning Guide in 'Forces'.)

In order for pupils to appreciate that gases have no shape, a coloured gas can be shown to fill any size or shape of container. This would have to be via secondary sources such as video, since all coloured gases happen to be poisonous. The movement of a gas out of a container when it is opened, such that it spreads through the room, can be demonstrated using onion or perfume smells. This depends, however, on children accepting that a gaseous substance is involved in the movement of smells, as smells are often considered as disembodied entities in themselves.

Once pupils have been introduced to the particulate model they can 'try it out' by applying it to explain the properties of gases. This is an opportunity for pupils to use their imagination in applying a model to account for the observed properties of gases: variable volume (compressibility), and having no definite shape. (See Particle Model Learning Guide and Particles Moving Learning Guide in 'Particles'.)

STATES OF MATTER

Goals

In everyday experience, some materials are solids, some are liquids and some are gases.

Many substances can exist in solid, liquid or gaseous form. They change from solid to liquid to gaseous form as they are heated, and back again as they are cooled. A substance is still the same substance when it has changed from one state to another.

The particles of a substance can be arranged as a solid, liquid or gas depending upon their energy but they are still the same particles.

Related National Curriculum Programme of Study Key Stage 3

Pupils should have the opportunity to compare and study a range of physical properties....of materials. This study should involve working with solids, liquids and gases....They should....develop understanding of the main ways to classify and group the materials. (Sc3 i)

Pupils should investigate changes of state....They should be encouraged to explain these phenomena in terms of their developing ideas of the particulate model of matter. (Sc3 ii)

Related extracts from the National Curriculum Programmes of Study: Key Stages 1, 2 and 4

Pupils should collect and find similarities and differences between a variety of everyday materials. They should explore the properties of these materials referring, for example, to their *shape, colour and texture.* (KS1 Sc3 i)

They should explore the effects of heating some everyday substances, for example *ice, water, wax and chocolate,* in order to understand how heating and cooling bring about melting and solidifying. (KS1 Sc3 iii)

Pupils should investigate a number of different everyday materials, grouping them according to their characteristics. Pupils should be given opportunities to compare a range of solids, liquids and gases and recognise the properties which enable classification of materials in this way. (KS2 Sc3 i)

Pupils should....use the kinetic theory to explain changes of state.... (KS4 Sc3 ii)

Related National Curriculum Statements of Attainment

Pupils should:

Sc3 i/1a be able to describe the simple properties of familiar materials.

Sc3 i/2a be able to group materials according to observable features.

Sc3 iii/2b know that heating and cooling everyday materials can cause them to melt or solidify or change permanently.

Sc3 i/4a be able to classify materials as solids, liquids and gases on the basis of simple properties which relate to their everyday uses.

Sc3 ii/6b understand the physical differences between solids, liquids and gases in simple particle terms.

Sc3 ii/7c understand changes of state, including the associated energy changes,....in terms of the proximity and motion of particles.

EVAPORATING AND CONDENSING

Children's Prior Ideas

Some children know that water 'boils away'. Some of them are aware that it forms steam.

Children, at the ages of five or six, believe that when a wet surface dries, the water just disappears. They accept that it just happens and offer no explanation.

It is not until the ages of 8-10 that they are likely to attempt to conserve the (evaporated) substance by suggesting that it must go to some place. The place is often thought of as some sort of receptacle such as the container or supporting surface. They therefore think that the water penetrates the solid object.

Even when children are aware of liquid evaporating, they suppose that weight or mass is lost, either completely by the substance disappearing, or partially by the gas weighing less than the liquid.

Few children, even in secondary school, understand that a pure substance has a specific boiling point.

Few pupils relate evaporation to the behaviour of particles.

Many secondary school pupils know that water vapour can be changed to water, but few apply this knowledge when explaining the appearance of water on a cold glass surface.

(See Solids, Liquids and Gases Research Summary)

The Challenge for Pupils

Children have experience of things 'drying up' (such as puddles and laundry) and they need to apply the word 'evaporation' to these. Furthermore they need to appreciate that water does not just 'disappear', it changes into a gas, that is, a change of state is occurring. (See Learning Guide: States of Matter.) Pupils need to study the more visible changes of melting and freezing before they tackle the challenges of evaporation and condensation. Heating water by an obvious source is an introduction to evaporation. However, pupils may need help in recognising heating as transferring energy to the liquid to enable it to evaporate. (See Energy Transfer in Heating Learning Guide in 'Heating'.) Moving from the idea of deliberate heating by human intervention, to energy transfer when evaporation occurs 'naturally' from puddles, rivers, or washing up presents a major challenge. (See Additional Material: Diagnostic Questions.) It is difficult to accept that energy is 'taken in' from the surroundings. This may best be approached by logical argument. If pupils can accept that 'feeling cold' indicates energy being transferred from their bodies, experiences such as feeling cold when water dries from the skin after swimming or when propanone, put onto the hand, evaporates rapidly, may help them to confirm the idea. Considerations of humidity, wind, surface area and so on, for the drying of laundry are distinct from the main 'energy' idea addressed here. They may be appropriate as a context for experimental design but should not be allowed to confuse the 'energy issue' in conceptual development.

Those pupils who have been introduced to the particle model will find that evaporation makes more sense once they can explain it in terms of the model. (See Particles Moving Learning Guide in 'Particles'.)

Pupils need to recognise boiling as a special case of evaporation. They need to relinquish their everyday meaning of 'boiling' as 'very hot' and to re-establish 'boiling' as particular phenomenon when bubbles of gas escape from the liquid (through the observation of water boiling in a glass beaker). To apply 'boiling' to other liquids, pupils can think about cooking oil bubbling at a very high temperature and ethanol boiling in a hot (but not boiling) water bath at a relatively low temperature.

Pupils may apply the particle model to relate slow evaporation and rapid boiling.

Pupils need to understand that condensation is the reverse of evaporation, not just of boiling: both happen over a range of temperatures. The idea of energy being transferred from a substance even more difficult than the idea of energy being given to it. The concept of cooling as transfer of energy away from an object, rather than as 'cold being given to it' needs to be revisited frequently. (See Temperature and Heat Learning Guide in 'Heating'.) Observing condensation on the outside of a beaker of iced water, may be useful to show the phenomenon and stimulate discussion. (See Additional Material: Diagnostic Questions.) ('Everyday' instances of condensation on cold walls and windows, and dew on grass are very difficult to explain because of the complicating factor of humidity.) Explanation of condensation, in terms of energy transfer from a gas, needs to arise from logical argument, by identifying condensation as the reverse of evaporation, and by comparison with the melting/freezing reversible change of state. Pupils could apply this idea by explaining why a steam scald is worse than a hot water scald.

Condensation is easier to understand when pupils are able to explain it by the particle model. Ideas about changes of state offer an important bridge to join ideas about materials with ideas about energy (see Introduction: Energy). This allows for pupils to relate the particle model to ideas about energy transfer.

SOLIDS, LIQUIDS AND GASES

MELTING AND FREEZING

Children's Prior Ideas

Many children do not distinguish between melting and dissolving and use the two words indiscriminately.

Many children think of melting as a gradual process, similar to dissolving, and do not recognise that it happens at a particular temperature. Similarly, they do not recognise that freezing happens at a particular temperature.

Children often think that there is a loss of weight or mass when a solid changes to a liquid.

Children with a particle view explain freezing as 'particles becoming packed closer together'.

(See Solids, Liquids and Gases Research Summary)

The Challenge for Pupils

An initial challenge for pupils is to distinguish between melting and dissolving. Children's experience of melting and dissolving looking the same, and everyday expressions such as 'melt in the mouth' make it difficult for them to make the scientific distinction between these processes. Moreover, children usually meet both melting and dissolving in the context of water which further confuses the two processes. An approach to distinguishing the processes may be via a card sort exercise. (See Introduction: Teaching Science with Children's Thinking in Mind.) Children need to recognise that 'melting' involves only one substance and also that it involves heating, whereas 'dissolving' involves two substances and can happen without heating. They may already have the idea that heat is needed to melt things. They need to refine this idea to recognise heating as a transfer of energy. (See Energy Transfer in Heating Learning Guide in 'Heating.) They need to associate transfer of energy with a temperature difference, for example to explain why ice melts on a table without heat being 'deliberately' applied to it.

The traditional experiments to determine the melting point of ice or wax may not convince children that while a substance is melting its temperature stays the same. In order to be convinced, children need to be able to read a thermometer, to believe what they read when it appears to contradict their prior ideas, and to watch and record the physical changes in parallel with the temperature. Measuring the temperature with a sensor and recording it graphically on a screen may help to overcome some of the technical difficulties. (See 'Investigating Melting and Freezing using a Datalogger' in the Additional Materials.) Realising that a particular substance always melts at the same temperature is a further challenge: this is not a foregone conclusion for pupils.

Those pupils who have been introduced to the particle model can try to use it to explain melting in terms of the model. It is an opportunity to try out the model in explaining how a substance with the characteristics of a solid can change the characteristics to those of a liquid.

Pupils need to distinguish the everyday use of 'freezing', meaning 'very cold', from the scientific meaning. They also need to extend their understanding of freezing from the everyday example of water freezing, to include other substances such as molten wax solidifying or molten iron solidifying. Moreover, pupils need as much experience as possible of substances, other than water, existing in more than one state. (See Learning Guide: States of Matter.) Pupils find the idea of energy being transferred from a substance even more difficult than the idea of energy being given to it. The concept of cooling as transfer of energy away from an object, rather than as 'cold being given to it', needs to be revisited frequently. (See Temperature and Heat Learning Guide in 'Heating'.) Practical determination of the freezing point and acknowledging that it is the same as the melting point, therefore presents extra difficulties as well as the technical problems mentioned for determining the melting point. Moreover, pupils need to recognise the melting/freezing change as reversible. Topics in the Solids, Liquids and Gases domain need to be drawn together for pupils to appreciate the overall framework of ideas about states of matter, critical temperatures for change and energy involvement. Pupils may be able to draw together their own ideas and draw diagrams to represent the relationships. (See The Teacher's View.)

Those pupils who have been introduced to the particle model can try to use it to explain freezing in terms of the model. Change of state offers an important bridge joining ideas about materials with ideas about energy (see Introduction: Energy), and it provides an opportunity for pupils to relate the particle model to ideas about energy transfer.

MELTING AND FREEZING

Goals

When energy is transferred to a solid substance it eventually melts to become a liquid at the temperature which is its 'melting point'.
When energy is transferred to a solid substance at the temperature called its 'melting point' its particles move so vigorously that the particles are no longer 'fixed' in relation to one another and a liquid is formed.

When energy is transferred from a liquid substance it eventually freezes to become a solid at the temperature which is called its 'freezing point'.
When energy is transferred from a liquid substance at the temperature called its 'freezing point', movement of its particles is reduced so that they become fixed in relation to one another and a solid is formed.

Related National Curriculum Programme of Study Key Stage 3

Pupils should investigate changes of state,.... They should be encouraged to explain these phenomena in terms of their developing ideas of the particulate model of matter. Their study should extend to an investigation of the temperature changes that occur during changes of state.... (Sc3 ii)

Related extracts from the National Curriculum Programmes of Study: Key Stages 1, 2 and 4

They should explore the effects of heating some everyday substances, for example, *ice, water, wax and chocolate,* in order to understand how heating and cooling bring about melting and solidifying. (KS1 Sc3 iii)

Pupils should....use the kinetic theory to explain changes of state.... (KS4 Sc3 ii)

Related National Curriculum Statements of Attainment

Pupils should:

Sc3 ii/6b understand the physical differences between solids, liquids and gases in simple particle terms.

Sc3 ii/7c understand changes of state, including the associated energy changes,....in terms of the proximity and motion of particles.

EVAPORATING AND CONDENSING

Goals

When energy is transferred to a liquid substance, it evaporates to become a gas.

When energy is transferred to a liquid substance, its particles move around more vigorously, move further apart, and eventually a gas may be formed.

A liquid substance is evaporating slowly all the time to become a gas. When enough energy is transferred to a liquid substance it evaporates quickly (boils).

When a liquid evaporates slowly, particles from its surface escape, as a gas, into the surroundings. When a liquid boils, particles throughout the liquid escape as a gas.

When energy is transferred from a gaseous substance it can condense to become a liquid.

When energy is transferred from a gaseous substance, its particles move less vigorously, become closely packed and a liquid is formed.

Related National Curriculum Programme of Study
Key Stage 3

Pupils should investigate changes of state,....
They should be encouraged to explain these phenomena in terms of their developing ideas of the particulate model of matter. Their study should extend to an investigation of the temperature changes that occur during changes of state.... (Sc3 ii)

Related National Curriculum Programmes of Study: Key Stages 1, 2 and 4

Pupils should....use the kinetic theory to explain changes of state.... (KS4 Sc3 ii)

Related National Curriculum Statements of Attainment

Pupils should:

Sc3 ii/6b understand the physical differences between solids, liquids and gases in simple particle terms.

Sc3 ii/7c understand changes of state, including the associated energy changes,....in terms of the proximity and motion of particles.

SOLIDS, LIQUIDS AND GASES

STATES OF MATTER

Children's Prior Ideas

Children recognise that solids and liquids exist, but they have more difficulty in recognising the existence of gases as material substances.

Pupils often believe that when substances undergo a change of state, there is a change of mass.

Children associate a the conversion of a bulk solid to a powdered solid with a 'loss of mass'.

When they think in terms of particles, many pupils attribute macroscopic properties to individual particles - they think that a particle can be in the solid, liquid or gaseous state.

(See Solids, Liquids and Gases Research Summary)

The Challenge for Pupils

Children are familiar with the words 'solid', 'liquid' and 'gas', but they still need to acknowledge these as categories in a classification system into which all materials fit. Materials are made of substances. (See Material Substances Learning Guide in 'Materials'.) However, pupils are likely to meet the idea of solid, liquid and gaseous states in the context of materials (mixtures of substances) in the first instance. Recognising the three states of matter and being able to place any material as 'solid', 'liquid' or 'gas' is an important step towards a coherent view of materials and their behaviour. Pupils may still have difficulty with the existence of gases even when they are aware of solids and liquids. They could be given a range of experiences of gases: coloured, smelly and moving. Discussion of their ideas about gases, such as the poisonous nature of some gases, may reinforce the concept that gases are 'real'. However, it is difficult to convince pupils that colourless and odourless and non-poisonous gases exist. Weighing air may help. (See Air as a Material Learning Guide in 'Air' and All Materials Learning Guide in 'Materials'.)

When considering liquids, pupils could try mixing an immiscible liquid with water. This may be a useful bridge to challenge the idea that all liquids contain water.

They need experience of classifying a wide range of materials as solid, liquid or gas, including materials which cannot easily be assigned to one of the three categories. Pupils need to build up an agreed set of criteria for solid, for liquid and for gas, as they try to make decisions, especially about the more difficult examples such as fabrics or powders. Hardness, pourability, shape, or having a definite volume, emerge as characteristics which distinguish between solids, liquids and gases. Pourability would not distinguish powders from liquids and pupils may need to think about the making of powders by grinding blocks in order to recognise them as solid rather than liquid. (See Additional Materials.)

Water provides a ready example of a substance existing in solid, liquid and gaseous form. Pupils are familiar with the change from ice to water, although the existence of water as water vapour is harder for pupils to accept. They may need to be convinced that water does not disappear to nothing when it evaporates. (See Air Gases Learning Guide in 'Air' and Water Vapour Learning Guide in 'Water'.) Changing the substance back and forth from one state to another may help to persuade pupils that they are dealing with the same substance in different forms. However, many reversible chemical reactions have the same effect. The challenge is to accept change of state without clear perceptual evidence of an unchanging substance. Pupils face a difficulty in imagining all three states of other substances, some of which need very low and very high temperatures to change state. (The fact that some solid substances decompose before they liquify adds a further complication.) Some examples, such as the melting of wax can extend first hand experience to some extent. Mostly, pupils have to rely on secondary sources through which they can begin to think about liquid oxygen or mercury vapour, for example. They will need considerable experience of this kind if they are to develop a general idea of states of matter.

Some pupils will have begun to think of the particles of a substance as constantly moving. (See Particles Moving Learning Guide in 'Particles'.) The characteristics of solids, liquids and gases can be accounted for in terms of the relationship between particles (see Learning Guides: Solids, Liquids, Gases), and this focus on the relationship between particles helps to establish the 'permanence' of the particles themselves.

LIQUIDS

Children's Prior Ideas

Children think of liquids as 'runny' or 'things which can be poured' and include powders in their classification.

Children regard all liquids as 'watery', 'made of water' or 'containing water'.

The liquid form of a material is considered to have less 'weight' than its solid form, and more 'weight' than its gaseous form.

Pupils do not necessarily conserve volume of liquids, when a volume of liquid is poured into a container of a different shape.

A view of liquids being continuous seems to persist in children's thinking for longer than for solids or gases.

Even after introduction to the particle theory, some children believe that there is a continuous substance between the particles of a liquid.

Having accepted the particle theory, most pupils regard the liquid state as being halfway between solid and gas, in terms of molecular spacing and speed.

(See Solids, Liquids and Gases Research Summary)

The Challenge for Pupils

In order to define the term 'liquid', pupils need to extend their idea of liquid beyond the familiar example of water. This will lead them to consider the many examples of aqueous solutions and suspensions such as washing-up liquid and milk, and also the few available liquids that do not have water in them (such as vegetable oil, paraffin, organic solvents and mercury, some of which can be shown to be immiscible with water). (Pupils must to be introduced to mercury and to organic solvents in a safe context.) By considering a range of liquids they can identify the criteria used to categorise liquids: definite volume (non-compressibility) and variable shape. (See Learning Guide: States of Matter.) They might note that liquids are like solids in having a definite volume (at a given temperature) but that they differ from solids in not having a definite shape.

It is difficult for some children to reconcile a definite volume with a variable shape. The idea of a liquid taking up a specific volume may be explored by experimenting with a constant volume of water but varying the shape of the container.

Children may expect a liquid to be compressible. An experience with a sealed syringe will help to persuade them that it is not. They may compare the non-compressibility of water, with the compressibility of air in another syringe. Some pupils may be able to relate their understanding of non-compressibility of water to the application of hydraulics in technology studies.

Pupils who have been introduced to the particle model can apply it to explain the observed properties of liquids. The similarity of liquids with solids, in terms of having a definite volume (non-compressibility) can be explained by the idea that the particles in a liquid are as close together as they are in a solid. (See Particle Model Learning Guide and Particles Moving Learning Guide in 'Particles'.)

SOLIDS, LIQUIDS AND GASES

LEARNING GUIDES APPENDIX: RELATED EXTRACTS FROM THE NATIONAL CURRICULUM PROGRAMME OF STUDY FOR KEY STAGE 3

References relating to the Learning Guides are underlined below:

Sc3 strand i - the properties, classification and structure of materials

Pupils should have the opportunity to compare and study a range of physical properties, including density, thermal and electrical conductivity of materials. The materials could be man-made or naturally occurring, and should be studied in everyday uses. This study should involve working with solids, liquids and gases and include metals, ceramics, glass, plastics and fibres. They should make measurements where appropriate and develop understanding of the main ways to classify and group the materials. By experiment pupils should see that gases have mass. They should learn how to distinguish between elements, compounds and mixtures. Using indicators, they should classify aqueous solutions as acidic or alkaline on the basis of their pH and investigate the reaction between acids and bases. They should classify metals and non-metals, some by direct observation and others with the help of tables of data, and should recognise similarities and trends within groups in the periodic table. Their study should involve at least one group of metals and one of non-metals. Pupils should make predictions from the reactivity series of metals. Pupils should learn how to separate and purify the components of mixtures.

Sc3 strand ii - explanations of the properties of materials

Pupils should investigate changes of state, diffusion, dissolving, and the behaviour of gases under different conditions of temperature and pressure. They should be encouraged to explain these phenomena in terms of their developing ideas of the particulate model of matter. Their study should extend to an investigation of the temperature changes that occur during changes of state and to other changes, such as expansion, that occur during heating and cooling. They should be introduced to atoms, ions and molecules as types of particle and should develop models to explain the properties of some substances. Pupils should be introduced to radioactivity and radioactive substances through demonstration experiments. They should also be made aware that radioactive substances emit ionising radiations of different types, some of which are present naturally as background radiation.

Children's ideas about

SOLIDS, LIQUIDS AND GASES

RESEARCH SUMMARY

This is a brief outline of research setting out the main prior ideas and understandings which teachers might expect to meet among pupils.

SOLIDS, LIQUIDS AND GASES

Before reading this summary of children's prior ideas, it may be helpful to look at the Science Map and The Teacher's View so as to have a useful overall perspective from which to view children's understanding.

Introduction

This summary draws upon the research literature relating pupils' ideas about solids, liquids and gases. It deals in turn with the following:

The solid state
The liquid state
The gaseous state
Melting
Freezing
Evaporation
Boiling
Condensation
Sublimation
Dissolving
Natural phenomena related to changes of state
Implications of the research findings for teaching

The solid state

Classifying materials as solids

Several researchers have investigated pupils' ideas about solids [1,2,3]. For example, Stavy and Stachel [1] studied developing ideas about solid materials held by Israeli children between the ages of 5 and 13. Their research indicates that younger children tend to regard rigid materials as solids whereas they regard powders as liquids and non-rigid materials (for example, plasticine, sponge and cloth) as intermediate between solids and liquids. Pupils justify such views by stating that powders are liquids because they 'can be poured' and that non-rigid materials are neither solid nor liquid because they are 'soft' or 'crumble' or 'can be torn'. Thus children appear to group materials according to appearance and behaviour with the result that they associate solidity with hardness, strength and non-malleability.

By the time that pupils reach age eleven, they tend to regard powders as an intermediate group of materials rather than as liquids and this is proposed as a suitable time to assist development of the idea of powder as small pieces of solid. Although this is a useful progression of ideas, these researchers warn that, when subsequently learning the particulate theory of solids, pupils may wrongly infer that the theoretical particles are 'powder grains'. They suggest therefore that, before they learn particulate theory, pupils should be capable of classifying materials according to a science view of the states of matter.

Conception of solid material and conservation of mass

From a child's viewpoint, the conversion of bulk solid to powdered solid, (or to a liquid) is likely to be accompanied by diminished mass [4] [1].

Particle conceptions of the solid state

Dow et al [5] explored secondary pupils' particle ideas and found that although they could depict the solid state as an ordered arrangement of molecules, they gave no reason why the structure should hold together, nor were they able to explain the incompressibility of solids. When prompted to adjust their model for incompressibility, they could not explain the vibration of molecules. These researchers concluded that children understood most attributes of the particle model 'one at a time', but were 'not able to put all these attributes together as a single conception of molecular behaviour within a solid'.

The liquid state

Classifying materials as liquids

Stavy and Stachel [1] found that children appear to identify liquids as materials that are 'runny' or 'can be poured'. Consequently, their view of liquids includes materials outside the accepted science classification, for example, powders. Further, because, in a child's view, the exemplary liquid is water, all liquids may be regarded as 'watery', or 'made of water', or 'containing water'. Jones and Lynch [2] noticed that some children found the task of classifying more viscous liquids such as paste, honey, and tomato sauce to be more problematic than one 'runny' ones.

Liquid state and conservation of mass/weight

Children may regard the liquid form of a material as having less weight (or, occasionally, more weight) than the same mass of its solid form (see 'Melting' below). Similarly, they may regard the liquid form of a material as having more weight than the same mass of its gaseous form (see 'Evaporation' below).

Particle ideas of the liquid state

The science idea that liquids are composed of tiny invisible particles in constant motion and can roll over one another is quite different from children's ideas. In general, before instruction, pupils regard liquids as continuous and static. Novick and Nussbaum [6] found that, even after instruction in the kinetic theory, over 10% of a sample of 13-14 year-olds did not apply the particulate model to liquids. They depicted liquids air as continuous and not particulate (see page 8 '*Particle views of the liquefaction of air*'). Dow et al [5] investigated the particle ideas of liquids held by secondary school pupils. They found that pupils' misconceptions of the science view mainly arise from regarding the liquid state as a halfway stage between solid and gas. As a result, children hold ideas about molecular spacing and speed that are much too large. Often their idea of random motion does not include speed but only direction. Further, they expect the molecules to slow down over time. In summary, these researchers suggest that, so far as the pupils' conception of a liquid goes, first, there is no reason for the liquid to have a fixed volume - the molecules would just move apart from each other; second, the liquid would be compressible; and, third, evaporation is not explained in terms of molecular events near the surface - if, indeed, a 'molecular' surface is conceived at all.

The gaseous state

Development of a conception of the gaseous state

Several researchers [7 8 9 10 11 12] have studied pupils' conception of 'gas' and found that, initially, they do not appear to be aware that air and other gases possess material character. For example, although young children may say that air and smoke exist, they regard such materials as having transient character similar to that of 'thoughts'. In many children's thinking, air and gas have contrasting affective connotations: air is 'good' and is used for breathing and life; gas is 'bad', as it is poisonous, dangerous and inflammable.

Later, pupils develop an awareness of the material character of gases and regard them as materials that spread. They know that some gases can be seen though most are colourless, odourless and transparent. However, they may not regard 'gas' as having weight or mass. Leboutet-Barrell [13] suggested that this is because children's most common related experience is that gases tend to rise or float. This view is supported by studies which show that children, aged 9-13, tend to predict that gases have the property of a negative weight. They think that the more gas that is added to a container, the lighter the container becomes [7 12]. Consequently, until they construct the idea that gases have mass, pupils are unlikely to conserve mass when describing chemical changes that involve gases as either reactants or products [10].