Ri Christmas Lectures® 2012: The Modern Alchemist

Teaching Resource - Chemical Change

Overview:

This resource covers some interesting reactions which involve a state change during their progress; it also covers how the behaviour of matter changes in solids, liquids, and gases. The reactions are supported by video clips from the Ri Christmas Lectures® 2012, along with external links and material where appropriate.

States of Matter:

There are generally three states of matter which we come across in everyday life, these being Solid, Liquid, and Gas.

- Solids
  - Solids are generally thought of as ordered (or disordered), closely packed arrangements of atoms. The characteristics of a solid are that they have a reasonably stable shape and volume, and will resist changes to these (such as compression).
- Liquids
  - Liquids are capable of flowing motion; i.e. they will take the shape of a container as the molecules which make up a liquid are not held in fixed positions. However, liquids are difficult to compress, as the molecules are still closely packed, though not as tightly packed as in a solid.
- Gases
  - Gases have no fixed shape, they will take the shape of their container. However, unlike a liquid, they will also expand to fill the entire volume of any free space. The particles in a gas are spaced widely, meaning gases are easily compressed.

An important point to realise is that for a given material or substance, the solid state is the lowest in energy, followed by the liquid state, and the highest energy is the gaseous state. Therefore, to turn a material from a solid into a gas, energy must be provided (usually in the form of heat energy), and likewise, in order to turn a material from a gas to a solid, energy must be removed.

- **Video Clip - The States of Matter**

  In this clip from the 2012 Christmas Lectures®, Dr Peter Wothers and a group of volunteers demonstrate how the behaviour of individual molecules of Water changes when the state changes from a solid, to a liquid, to a gas.

Chemical Change - The States of Matter

Running Time 1 min 56 secs

State Changes:

When matter changes from one state to another, the process will have a specific name depending upon the starting and ending state; these are shown below.

- Solid to Liquid - Melting
- Solid to Gas - Sublimation
- Liquid to Solid - Freezing
- Liquid to Gas - Evaporation or Boiling
- Gas to Liquid - Condensation
- Gas to Solid - Deposition

The most difficult of these to understand are sublimation and deposition, and may require specific examples:

- A good example of deposition is water vapour in the air falling as snow.
- Sublimation can be shown visually by the use of either iodine crystals (which can be placed in a covered flask and gently heated to produce iodine vapour), or solid CO_2 (dry ice).

Solid to Liquid (Molten Metal):

Video Clip - Thermite Safe Cracking

In this clip from the 2012 Christmas Lectures®, Dr Peter Wothers demonstrates how we can extract iron from iron oxide - in the process, the reaction generates enough heat energy to melt the iron into a liquid.

Chemical Change - Thermite

Running Time - 3 min 24 secs

In this reaction, iron oxide and aluminium are mixed together as powdered solids. When this mixture is ignited by a piece of burning magnesium, the aluminium effectively 'steals' the oxygen from the iron (aluminium is a more reactive metal than iron), generating magnesium oxide and iron. The reaction is also hugely exothermic, and it is this heat energy which causes the iron produced to melt.

The equation for this reaction is shown below:

$$Fe_2O_3 + 2Al \rightarrow 2Fe + Al_2O_3$$

This reaction can be classified as a Redox reaction - therefore it can be split into two half equations:

$$2Al(0) \rightarrow 2Al(III) + 6e^-$$

Formal oxidation of the Aluminium; the Aluminium is acting as a reducing agent

$$2Fe(III) + 6e^{-} \rightarrow 2Fe(0)$$

Formal reduction of the Iron; the Iron is acting as an oxidising agent

A useful activity for a higher level group could be to construct the balanced equation for this reaction, including the half equations, and the roles of oxidising, and reducing agents.

More information on Redox reactions can be found on the RSC Learn Chemistry Website[1].

Solid to Gas - Nitrogen Triiodide:

Video Clip - Detonation of Nitrogen Triiodide

In this clip from the 2012 Christmas Lectures®, Dr Peter Wothers demonstrates the explosive decomposition of nitrogen triiodide into nitrogen gas and iodine vapour.

Chemical Change - Nitrogen triiodide

Running Time 1 min 00 secs

In this reaction, the shock sensitive solid nitrogen triiodide decomposes to form nitrogen and iodine. As nitrogen gas is very stable, a large amount of energy is given out during the decomposition. This, combined with the rapid formation of gas, causes the material to effectively explode. The purple colour that can be seen is iodine vapour, expelled during the decomposition.

The equation for this reaction is shown below:

$$2NI_{3\,(s)} \rightarrow N_{2\,(g)} + 3I_{2\,(g)}$$

Nitrogen triiodide → Nitrogen + Iodine

Nitrogen triiodide is so unstable that even a single particle of alpha radiation can trigger it to explode. The reason for this instability comes from the low activation energy of the decomposition reaction, and the fact that the products of the decomposition are very stable. The stability of the products makes the decomposition of nitrogen triiodide very exothermic, therefore a lot of energy is released, and the material is seen to 'explode'.

Liquid to Solid - Supercooled Water:

Video Clip: Supercooled Water

In this clip from the 2012 Christmas Lectures®, Dr Peter Wothers demonstrates that water can sometimes be made to remain liquid far below its freezing point; and also that energy is released when water turns from a liquid, to a solid.

[1] Redox resources, Learn Chemistry, http://www.rsc.org/learn-chemistry/resource/listing?searchtext=Redox

Chemical Change - Supercooled Water

Running Time - 3 min 30 secs

In order to freeze, most liquids require impurities or the addition of a single crystal for the molecules which make up the liquid to start to form a solid around. These are known as condensation nuclei, and if they are missing (the liquid is really pure) then the liquid will not freeze.

In theory, ultra-pure water can be cooled to -48 °C before it will spontaneously turn into a solid; however this is very difficult to achieve.

A practical demonstration of this effect is easy to achieve; an open bottle of mineral water can be supercooled by placing it in a cooling bath made with ice and salt. After a few minutes, adding a crystal of ice to the bottle will start the freezing process.

The other interesting point in the video is that the temperature of the supercooled water actually increases during the freezing process; this is because as the water freezes, energy is being released by the formation of bonds within the water; the process is exothermic.

More information on supercooling, and a practical class activity is available here[2].

Liquid to Gas - Expansion of Steam

Video Clip - The Expansion of Steam

In this video clip from the 2012 Christmas Lectures®, Dr Peter Wothers demonstrates just how much space one millilitre of water can occupy when it is turned into steam.

Chemical Change - Expansion of Steam

Running Time - 3 min 58 secs

The expansion which is seen in the video would run to over 2000 times the original volume if the experiment was allowed to reach completion - 1 mL of water will turn into roughly 2000 mL of steam.

This is because the water molecules which make up the steam have much more energy than those in the liquid, meaning they can move much faster and further apart, taking up more space.

At a more in depth level, the behaviour of a gas can be predicted using an equation called the Ideal Gas Equation:

[2] Supercooling, Nuffield Foundation, http://www.nuffieldfoundation.org/practical-chemistry/supercooling-energetics-freezing

$$PV = nRT$$

where P is pressure

V is volume

n is the number of moles of gas

R is a constant called the Ideal Gas Constant (8.314 J K^{-1} mol^{-1})

and T is the temperature

The two most useful forms of this equation are those which calculate pressure, or volume - these are shown below:

To Calculate Pressure:

$$P = \frac{nRT}{V}$$

To Calculate Volume:

$$V = \frac{nRT}{P}$$

View the full 2012 Ri Christmas Lectures® - The Modern Alchemist, along with behind the scenes footage, and related content, at the [Ri Channel][3].

[3] The Ri Channel, www.richannel.org