# Ri Christmas Lectures® 2012: The Modern Alchemist

## Teaching Resource - Allotropes of Carbon

### Overview:

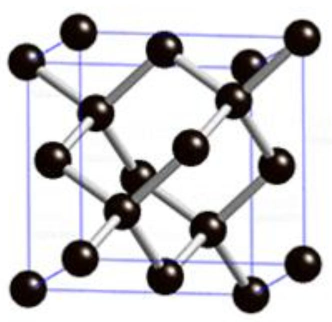
This resource contains information about the different allotropes of Carbon. These primarily being graphite, diamond, and fullerene (however recently discovered forms include graphene and nanotubes). This material is supported by potential discussion points, links to useful information, and video clips from the Ri Christmas Lectures® 2012

### What is an Allotrope?

- Allotropes are different physical forms of a pure element.
- Many elements have allotropes, including Carbon, Oxygen, Phosphorous, and Sulphur.
    - An interesting expansion exercise or homework project could be to produce a report regarding the different allotropes of Phosphorous or Oxygen.

### The Allotropes of Carbon:

- Carbon has 3 main natural allotropes, these are Diamond, Graphite, and Fullerene (not including amorphous carbon; i.e. soot). However, there are also recently discovered/engineered forms of carbon. These are Graphene, and Nanotubes.
- Diamond:
    - Diamond is one of the hardest materials known to man. It has a crystal structure built of carbon atoms arranged in tetrahedral orientations, allowing each atom to form 4 bonds.
    - The unit cell (repeating unit) which makes up a crystal of diamond is known as adamantane.
    - Diamond is a very poor electrical conductor, but an exceedingly good thermal conductor.



    - In recent times, methods for creating synthetic diamonds have been developed. These include the High Temperature High Pressure (HTHP) method, and Chemical Vapour Deposition (CVD).

- The HTHP method involves treating graphite under extremely high temperatures and pressures, as would be found in areas where natural diamonds form, deep within the Earth. More information can be found here[1].
- CVD is a relatively new method for producing diamond, and involves the build up of a sheet of diamond one layer of atoms at a time. More information about this technique can be found here[2].

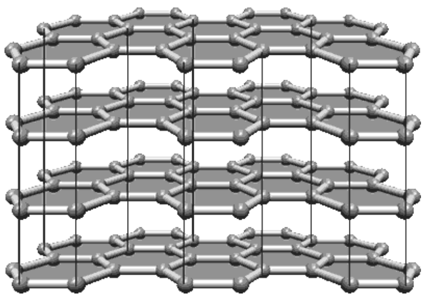
- **Video Clip: Synthetic Diamond, and using a Diamond to cut Ice**

  In this clip from the 2012 Ri Christmas Lectures®, Dr Peter Wothers demonstrates the thermal conductivity of diamond by using a volunteer's heat energy to cut through a block of ice.

  Using a Synthetic Diamond to Cut Ice

  Running Time: 2 min 29 secs

- Graphite:



  - Graphite is formed of flat sheets of carbon atoms which are formed of interlocking hexagons. The individual sheets are bound together by instantaneous dipole-dipole interactions.
  - The electrons in graphite are delocalised across the sheets, this makes them easily polarisable, allowing for greater Van der Walls interactions.
  - The delocalisation of electrons within graphite also allows it to act as an electrical conductor, unlike diamond.
  - Graphite has found many uses including crucibles for metal casting, batteries, lubrication, and in nuclear reactors.
  - An interesting research project could be into the industrial uses of graphite. - A general information resource regarding graphite and its uses can be found here[3].

[1] International Diamond Laboratories, http://www.diamondlab.org/80-hpht_synthesis.htm
[2] Synthetic CVD Diamond, http://www.e6cvd.com/cvd/
[3] USGS, Graphite, http://minerals.usgs.gov/minerals/pubs/commodity/graphite/graphmyb04.pdf

- Fullerenes:

  - Fullerenes were discovered by a research group lead by Harry Kroto, Richard Smalley, and Robert Curl in 1985.
  - The first observed fullerene was $C_{60}$, or as it is now named, Buckminsterfullerene.
  - The name 'Fullerenes' is derived from the architect Buckminster Fuller, who designed geodesic domes which were constructed of interlocking hexagons and pentagons; identical to those seen within the structure of Fullerenes.
  - The most famous of the Fullerenes, $C_{60}$, takes the form of a 'football' consisting of 20 hexagons, and 12 pentagons.
  - A history of the discovery of Fullerenes can be found here[4].
  - $C_{60}$ is not the only size of Fullerene to be discovered. Other well characterised Fullerenes include $C_{70}$, $C_{84}$, and $C_{540}$; although in theory, an unlimited number of Fullerenes could exist, based upon 12 pentagonal faces, and any number of hexagonal faces.
  - Fullerenes have two distinct bond lengths within their structure. A shorter (135 pm) length which corresponds to a double bond, and a longer (146 pm) which corresponds to a single bond.
  - These double and single bonds are similar to those in benzene, allowing for delocalisation of electrons across the entire structure.
  - A resource detailing some of the emerging uses for Fullerenes is available here.[5]

**Video Clip - Proving Diamond and Graphite are formed of Carbon, and the Discovery of Fullerenes:**

In this clip from the 2012 Ri Christmas Lectures®, Dr Peter Wothers and Nobel Prize winner Prof. Sir Harry Kroto demonstrate that graphite and diamond are both forms of carbon (by burning them...), and Prof. Kroto discusses the discovery of Fullerenes.

Diamond, Graphite, and the Discovery of Fullerenes

Running Time: 7 min 12 secs

**Other Forms of Carbon:**

- Graphene:

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[4] American Chemical Society, Discovery of Fullerenes, www.acs.org
[5] Nano-C, Fullerene Applications, http://www.nano-c.com/fullereneapp.html

- Graphene is a relatively recently discovered form of carbon, consisting of a single sheet of carbon atoms, with a structure similar to graphite; however, as it only consists of a single sheet, it is only one atom thick.
- Graphene was originally isolated in the UK at the University of Manchester, by (now Professors) Andre Geim, and Kostya Novoelov, and lead to them being awarded the Nobel Prize in 2010.
- The properties of graphene are said to include high electrical conductivity (due to the delocalisation of electrons throughout the entire material), and a thermal conductivity higher than that of diamond.
- Graphene is also believed to be one of the strongest materials known, with stress testing suggesting that the material is around 300 times stronger than steel.
- Graphene research is believed to be one of the most important emerging areas of chemistry. Recently, the EU awarded around €1bn to fund research into the applications of graphene.
- A resource is available from the University of Manchester[6] detailing some areas of graphene research. Further information on graphene can be found in this[7] resource from the RSC Learn Chemistry site.

- Nanotubes:
  - Carbon nanotubes consist of tubular structures composed of a graphene sheet rolled into a tube, which is capped at either end by a half-fullerene.
  - Nanotubes can exist as single walled, or multiwalled structures; the multiwalled nanotubes can be thought about as 'Russian-dolls' stacking inside one another, or alternatively, as a 'scroll'.
  - Nanotubes have several interesting properties, foremost among these being high tensile strength (measured as capable of supporting up to 6422 kg $mm^{-2}$), and electronic properties which allow them to act as normal conductors, or semiconductors (depending on their structural properties).
  - Potential applications for nanotubes include molecular machinery[8], electronics, high strength materials, and possibly even space elevators[9].

*View the full 2012 Ri Christmas Lectures® - The Modern Alchemist, along with behind the scenes footage, and related content, at the Ri Channel[10].*

6 University of Manchester, Graphene, http://www.graphene.manchester.ac.uk/
7 Learn Chemistry, Graphene Future Applications, http://www.rsc.org/learn-chemistry/resource/res00001019/graphene-future-applications
8 IOP Science, http://iopscience.iop.org/0953-8984/16/8/012
9 NASA, http://science.nasa.gov/science-news/science-at-nasa/2000/ast07sep_1/

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