The Nobel Prize in Chemistry and the Golden Ratio: Science meets Art

This year's Nobel Prize in Chemistry goes to Dan Shechtman for discovering quasi crystals. When Shechtman, back in 1982, saw an unusual pattern on the screen of his electron microscope, he couldn't believe his eyes and put three question marks in his laboratory notebook beside the record of his observation. What he discovered would change the way chemists describe crystal structures, but it was hard to convince the scientific community of his findings. His first paper on the discovery, submitted to a learned journal, was promptly returned by the editor, who dismissed it out of hand.

Crystals have a fascination for mineralogists and non-scientists alike. Particles of crystalline substances, such as salt and sugar, or minerals like quartz and calcite, have characteristic shapes. A crystal was originally defined as a fragment of solid material bounded by plane surfaces, which intersect at definite angles. These angles determine the shapes of crystals.

Abbe Hauy (1743–1822), the 'Father of Crystallography', proposed that the regular shapes of crystals were due to a periodic, repeating, internal structure. He accidentally dropped a piece of calcite and was amazed by the way it shattered into smaller crystals of similar shape. This was what inspired his theory. At that time, there were no techniques available to verify his hypothesis. It was not until the development of X-ray diffraction, at the start of the 20th century, that the internal structure of crystals could be studied experimentally. This method was used by Max von Laue in Germany to determine the structure of common salt, which has a repeating cubic arrangement of sodium and chloride ions, accounting for the cubic shape of its crystals. X-ray diffraction was further developed by father and son team, William and Laurence Bragg, who won the Nobel Prize in Physics in 1915.

For most of the 20th century, crystals were described in terms of a three-dimensional lattice, consisting of a repeating unit, known as the 'unit cell'. The angles and dimensions of the unit cell can be measured by X-ray diffraction and from this the entire lattice can be described. Many two-dimensional patterns, for example on wallpaper or floor tiles, are also based on designs that repeat periodically. But what Shechtman discovered in the 1980s was a pattern that didn't repeat. It seemed to defy the laws of crystallography and geometry.

However, almost ten years before Shechtman's discovery, the British mathematician Roger Penrose had shown, using rhombic shaped tiles, that it is possible to create a mosaic pattern based on pentagonal symmetry, which never repeats itself. Such a pattern is referred to as being aperiodic. Solid materials with an aperiodic structure are now called quasi-crystals. (Roger Penrose is perhaps better known to the general public for his work with Stephen Hawking on black holes.)

Daniel Shechtman was born in Tel Aviv in 1941. Having obtained his Ph.D. from the Technion - Israel Institute of Technology in Haifa, he went to the USA to study the metallurgy of aluminium/titanium alloys. In 1975 he returned to Technion to work in the Faculty of Materials Engineering. In the early 1980s he was conducting research in Johns Hopkins University and it was there that he made his amazing discovery. Shechtman had prepared alloys of aluminium and manganese by rapidly cooling molten mixtures of the two metals. He used electron diffraction to examine the resulting solid. This is similar in principle to X-ray diffraction, but uses an electrons beam rather than X-rays.

Diffraction, the bending of waves around obstacles, was first demonstrated for light waves by Thomas Young (1773–1829), who passed light beam through very narrow slits and obtained a pattern of light and dark bands on a screen. This caused scientists to abandon the theory, proposed a century earlier by Isaac Newton, that light was a stream of particles. But Einstein's discovery of the photoelectric effect in 1905 showed that light does behave as a particle. It is now accepted that light has a dual character, having both wave and particle properties. X-rays are electromagnetic waves similar to light, having the same speed as light in a vacuum, but with a shorter wavelength and greater energy than light. The wavelengths of X-rays are comparable in magnitude to the spacing between atoms in crystals and can therefore be diffracted by crystals, producing a diffraction pattern which can be used to determine the positions of atoms in the crystal.

Electrons are tiny negatively-charged particles. But like light, they have a dual nature. They also exhibit wave characteristics and can be diffracted by crystals in a similar way to X-rays. This was first demonstrated by Davisson and Germer in 1927. Since then, electron diffraction has been developed as a means of investigating crystal structure and it was this method that Dan Shechtman was using when he made his discovery in 1982. The crystals he examined had pentagonal symmetry and were aperiodic, like Penrose tiling. Such patterns are found in Islamic art, for example in mosaics in the Alhambra palace in Granada, Spain and in shrines in the Middle East. The pattern involves the so-called 'Golden Ratio', which is the ratio of the diagonal to the side of a regular pentagon. It is also related to the Fibonacci sequence. This is a sequence of numbers in which each term is obtained by adding together the two previous terms. It starts off like this: 1, 1, 2, 3, 5, 8, 13, 21, 34, … Fans of Dan Brown may remember it from his novel 'The Da Vinci Code'. Leonardo Da Vinci himself made use of the Golden Ratio in many of his paintings. A picture divided according to this ratio (1.618 approximately) has a very pleasing composition. It is now used by crystallographers to calculate the positions of atoms in quasicrystals from their diffraction pattern. This is an area where Art meets Science.

Apart from being a scientific curiosity, quasicrystals have useful applications in new materials. They can impart strength to special types of steel and are being tested for uses as diverse as non-stick frying pans and diesel engines.

For more information on Shechtman's discovery, see the official website of the Nobel Prize: http://www.nobelprize.org/nobel_prizes/chemistry/laureates/2011/