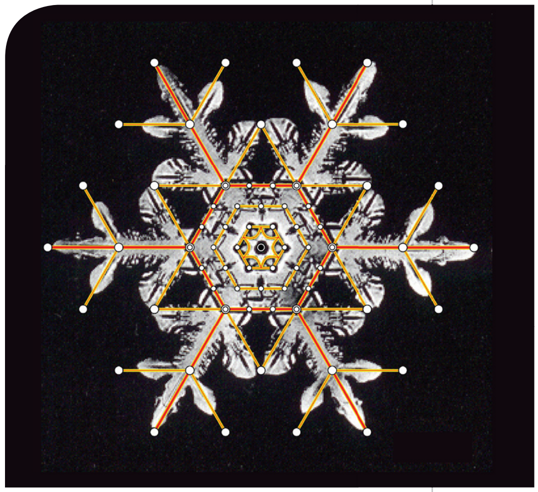
What is crystallography?

Crystals can be found everywhere in nature. They are particularly abundant in rock formations as minerals (gemstones, graphite, etc.) but can also be found elsewhere, examples being snowflakes, ice and grains of salt. Since ancient times, scholars have been intrigued by the beauty of crystals, their symmetrical shape and variety of colours. These early crystallographers used geometry to study the shape of crystals in the natural world.

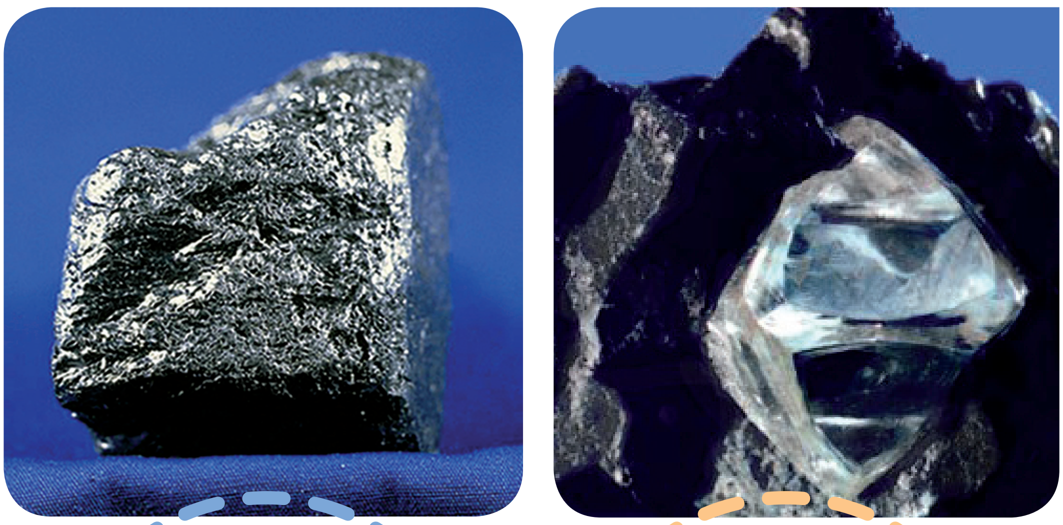
In the early 20th century, it was realized that X-rays could be used to 'see' the structure of matter in a non-intrusive manner. This marks the dawn of modern crystallography. X-rays had been discovered in 1895. They are beams of light that are not visible to the human eye. When X-rays hit an object, the object's atoms scatter the beams. Crystallographers discovered that crystals, because of their regular arrangement of atoms, scattered the rays in just a few specific directions. By measuring these directions and the intensity of the scattered beams, scientists were able to produce a three-dimensional picture of the crystal's atomic structure. Crystals were found to be ideal subjects for studying the structure of matter at the atomic or molecular level, on account of three common characteristics: they are solids, three-dimensional and built from very regular and often highly symmetrical arrangements of atoms.



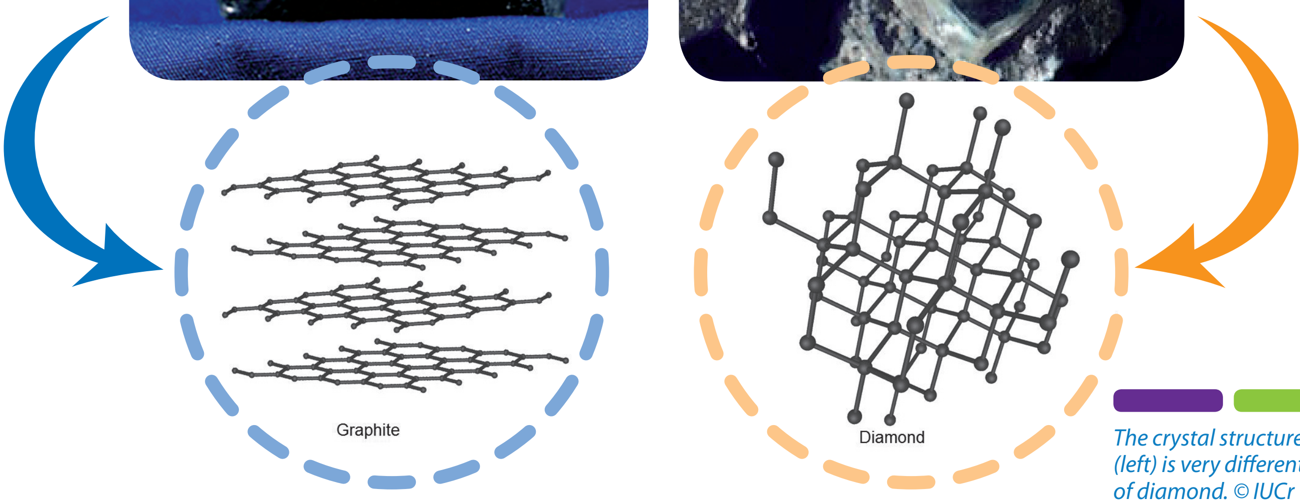
Snowflakes are crystals. Their hexagonal symmetry results from the way in which water molecules are bound to each other. Image: Wikipedia

Thanks to X-ray crystallography, scientists can study the chemical bonds which draw one atom to another. Take graphite and diamonds, for instance. These minerals hardly look alike: one is opaque and soft (graphite is used to make pencils), whereas the other is transparent and hard. Yet graphite and diamonds are close relatives, chemically speaking, both being composed of carbon. It is the ability to disperse light – owing to the structure of its chemical bonds – which gives a diamond its 'shine'. We know this thanks to X-ray crystallography.

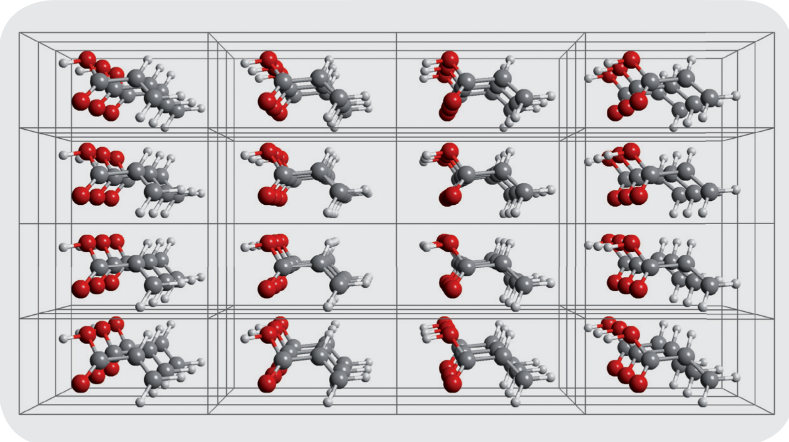
At first, X-ray crystallography could only be used to look at solid crystals with a regular arrangement of atoms. It could study minerals, for instance, and many other compounds, such as salt or sugar. It could also study ice but only until it melted.



A chunk of graphite (left) and a rough diamond (right). These two crystals may not look alike but they are actually closely related, as both are pure carbon. What gives the diamond its shine is its ability to disperse light, owing to the structure of its chemical bonds. Photos: Wikipedia



The crystal structure of graphite (left) is very different from that of diamond. © IUCr



3D image of a crystal structure. In a crystal, atoms, groups of atoms, ions or molecules have a regular arrangement in three dimensions.

This is because, in a liquid, the movement of molecules made it impossible to register a scattered signal that could be interpreted. Crystallographers discovered that they could study biological materials, such as proteins or DNA, by making crystals of them. This extended the scope of crystallography to biology and medicine. The discovery came at a time when the growing power of computers was making it possible to model the structure of these more complex crystals.

After 100 years of development, X-ray crystallography has become the leading technique for studying the atomic structure and related properties of materials. It is now at the centre of advances in many fields of science. New crystallographic methods are still being introduced and new sources (electrons, neutrons and synchrotron light) have become available. These developments enable crystallographers to study the atomic structure of objects that are not perfect crystals, including quasicrystals *(see box)* and liquid crystals *(see photo of television overleaf)*.

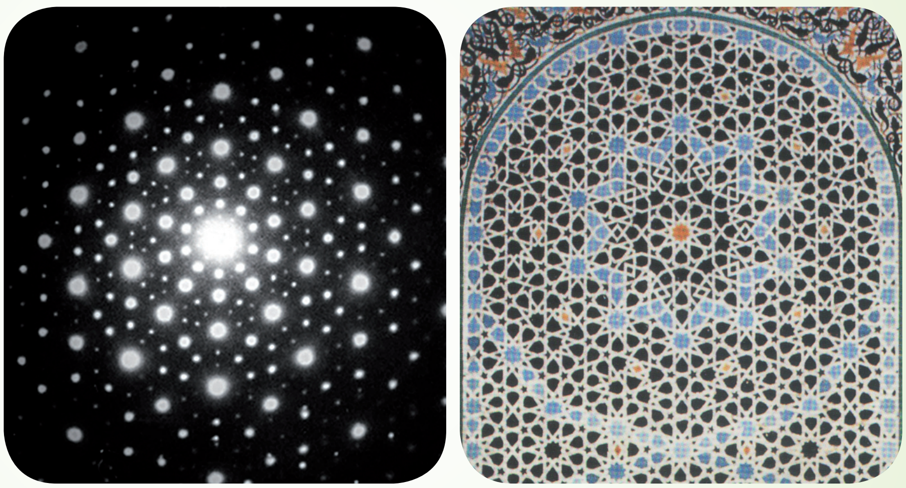
The development of machines capable of generating intense light and X-rays (synchrotrons) has revolutionized crystallography. Large research facilities housing synchrotrons are used by crystallographers working in areas such as biology, chemistry, materials science, physics, archaeology and geology. Synchrotrons enable archaeologists to pinpoint the composition and age of artefacts dating back tens of thousands of years, for instance, and geologists to analyse and date meteorites and lunar rocks.

QUASICRYSTALS: DEFYING THE LAWS OF NATURE

In 1984, Dan Shechtman discovered the existence of a crystal in which the atoms were assembled in a model that could not be strictly repeated. This defied the accepted wisdom about the symmetry of crystals. Up until then, it had been thought that only symmetrical geometric forms with 1, 2, 3, 4 or 6 sides could occur as crystals, since only these forms could be reproduced in three dimensions.

Yet, when Dan Shechtman observed an alloy of aluminium and manganese under an electron microscope, he discovered a pentagon (five-sided shape). This 'outlaw' came to be known as a quasicrystal. Dan Shechtman's groundbreaking discovery would earn him the Nobel Prize in Chemistry in 2011.

As a consequence of the way in which their atoms are arranged, quasicrystals have unusual properties: they are hard and brittle and behave almost like glass, being resistant to corrosion and adhesion. They are now used in a number of industrial applications, one example being non-stick pans.



Source: diffraction pattern image, Physical Review Letters (1984), vol. 53, pages 1951–1953; image from the mosaic, Moroccan Crystallographic Association

Moroccan artisans (*Maalems*) have actually known about the patterns found in quasicrystals for centuries. Seven hundred years separate the two images above. The image on the left shows the diffraction pattern of a quasicrystal obtained by Dan Shechtman in 1984. The photo on the right shows a fine mosaic (*zellije*) in the Attaraine Madrasa in Fez (Morocco), dating from the 14th century. The images look remarkably similar, with both showing pentagonal patterns.

A brief history

Throughout history, people have been fascinated by the beauty and mystery of crystals. Two thousand years ago, Roman naturalist Pliny the Elder admired 'the regularity of the six-sided prisms of rock crystals.' At the time, the process of crystallizing sugar and salt was already known to the ancient Indian and Chinese civilizations: cane sugar crystals were manufactured from sugar cane juice in India and, in China, brine was boiled down into pure salt. Crystallization was also developed in Iraq in the 8th century CE. Two hundred years later, Egypt and the region of Andalucia in Spain would master the technique of cutting rock crystals for use in utensils and decorative items like the box pictured here. In 1611, German mathematician and astronomer Johannes Kepler was the first to observe the symmetrical shape of snowflakes and infer from this their underlying structure. Less than 200 years later, French mineralogist René Just Haüy would discover the geometrical law of crystallization.

Gem-studded box made in Egypt in about 1200 CE
© Musée de Cluny, France

In 1895, X-rays were discovered by William Conrad Röntgen, who was awarded the first Nobel Prize in Physics in 1901. It was Max von Laue and his co-workers, however, who would discover that X-rays travelling through a crystal interacted with it and, as a result, were diffracted in particular directions, depending on the nature of the crystal. This discovery earned von Laue the Nobel Prize in Physics in 1914.

Equally important was the discovery by father and son team William Henry Bragg and William Lawrence Bragg in 1913 that X-rays could be used to determine the positions of atoms within a crystal accurately and unravel its three-dimensional structure. Known as Bragg's Law, this discovery has largely contributed to the modern development of all the natural sciences because the atomic structure governs the chemical and biological properties of matter and the crystal structure most physical properties of matter. The Bragg duo was awarded the Nobel Prize in Physics in 1915.

Between the 1920s and the 1960s, X-ray crystallography helped to reveal some of the mysteries of the structure of life, with great ramifications for health care. Dorothy Hodgkin solved the structures of a number of biological molecules, including cholesterol (1937), penicillin (1946), vitamin B_{12} (1956) and insulin (1969). She was awarded the Nobel Prize in Chemistry in 1964. Sir John Kendrew and Max Perutz were the first to work out the crystal structure of a protein, earning them the Nobel Prize in Chemistry in 1962. Since that breakthrough, the crystal structure of over 90,000 proteins, nucleic acids and other biological molecules has been determined using X-ray crystallography.

One of the biggest milestones of the 20th century was the discovery of the crystal structure of DNA by James Watson and Francis Crick. Perhaps less well known is the fact that their discovery was made on the basis of diffraction experiments carried out by Rosalind Franklin, who died prematurely in 1958. The discovery of the 'double helix' paved the way to macromolecule and protein crystallography, essential tools of the biological and medical sciences today. Watson and Crick were rewarded with the Nobel Prize in Physiology or Medicine in 1962, together with Maurice Wilkins, who had worked with Rosalind Franklin.

Crystallography and crystallographic methods have continued to develop over the last 50 years; in 1985, for example, the Nobel Prize in Chemistry was awarded to Herb Hauptman and Jerome Karle for developing new methods of analysing crystal structures. As a result, the crystal structures of more and more compounds have been solved.

Recent Nobel Prizes have been awarded to Venkatraman Ramakrishnan, Thomas Steitz and Ada Yonath (2009, *see page 8*), to Andre Geim and Konstantin Novoselov (2010) for their groundbreaking work on graphene, the first of a new class of two-dimensional crystalline materials with unique electronic and mechanical properties, to Dan Shechtman (2011) for the discovery of quasicrystals *(see box on facing page)* and to Robert Lefkowitz and Brian Kobilka (2012) for revealing the inner workings of an important family of cell receptors which govern nearly every function of the human body.

In all, 45 scientists have been awarded the Nobel Prize over the past century for work that is either directly or indirectly related to crystallography. There is not enough room to list them all in this brochure but it is thanks to their individual contributions that crystallography has come to underpin all the sciences. Today, crystallography remains a fertile ground for new and promising fundamental research.

Why countries need to invest in crystallography

Crystallography underpins the development of practically all **new materials**, from everyday products like computer memory cards to flat television screens, cars and aeroplane components. Crystallographers not only study the structure of materials but can also use this knowledge to modify a structure to give it new properties or to make it behave differently. The crystallographer can also establish the new material's 'fingerprint'. A company can then use this 'fingerprint' to prove that the new substance is unique when applying for a patent.

In fact, crystallography has many applications. It permeates our daily lives and forms the backbone of industries which are increasingly reliant on knowledge generation to develop new products, including the agro-food, aeronautic, automobile, beauty care, computer, electro-mechanical, pharmaceutical and mining industries. The following are a few examples.

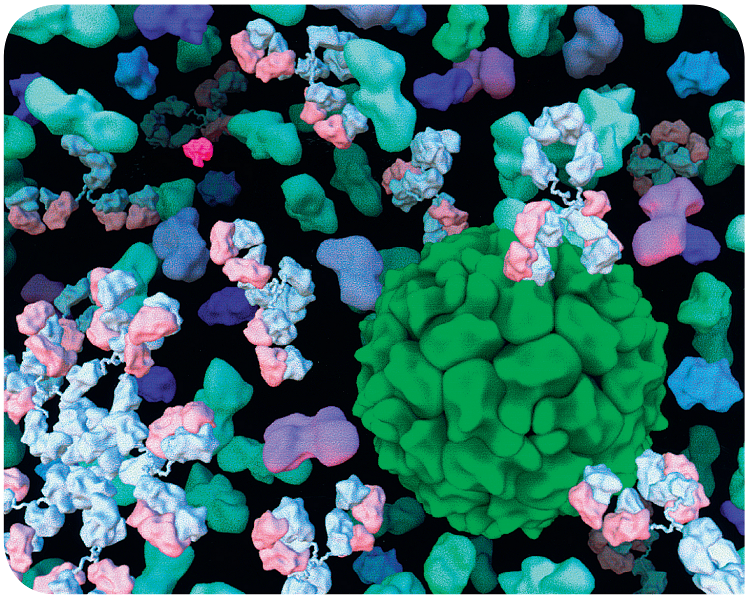
Mineralogy is arguably the oldest branch of crystallography. X-ray crystallography has been the main method of determining the atomic structure of minerals and metals since the 1920s. Virtually everything we know about rocks, geological formations and the history of the Earth is based on crystallography. Even our knowledge of 'cosmic visitors' like meteorites comes from crystallography. This knowledge is obviously essential for mining and any industry which drills into the Earth, such as the water, oil, gas and geothermal industries.

Drug design is strongly reliant on the use of crystallography. A pharmaceutical company looking for a new drug to combat a specific bacterium or virus first needs to find a small molecule capable of blocking the active proteins (enzymes) that are involved in attacking the human cell. Knowing the precise shape of the protein allows scientists to design drug compounds that can clamp onto the 'active' sites on the protein and thereby disable their harmful activity.

Crystallography is also essential to distinguish solid forms of a drug from one another, as these can be soluble under different conditions, affecting the efficacy of the drug. This is important for the generic pharmaceutical industry in Asia and Africa especially, where anti-HIV drugs are being manufactured with compulsory licensing to make them accessible to the poorest.

New materials are being used to develop smart clothing. Smart fabrics let in air or trap heat, according to whether the wearer is sweating or shivering. Inner garments can be equipped with sensors to monitor body temperature, breathing rate and heartbeat, for instance, and transmit messages to a wearer's cell phone. Outer garments could be designed to detect threats like toxic gases, harmful bacteria or extreme heat. Crystallographers can identify the properties needed to develop such new materials. ©Sharee Basinger/ publicdomainpictures.net

Today, crystallographers are able to study a wide variety of materials, including liquid crystals. Liquid crystal displays are used for the flat screens of televisions (pictured), *computers, cell phones, digital clocks and so on. The liquid crystal does not produce light itself but rather draws on an external source – such as the back light on a television – to form images, making for low-energy consumption. @ Shutterstock/Andrey_Popov*



Cocoa butter, the most important ingredient of chocolate, crystallizes in six different forms but only one melts pleasantly in the mouth and has the surface sheen and crisp hardness that make it so tasty. This 'tasty' crystal form is not very stable, however, so it tends to convert into the more stable form, which is dull, has a soft texture and melts only slowly in the mouth, producing a coarse and sandy sensation on the tongue. Luckily, the conversion is slow but if chocolate is stored for a long time or at a warm temperature, it can develop a 'bloom,' a white, filmy residue that results from recrystallization. Chocolate-makers thus have to use a sophisticated crystallization process to obtain the most desirable crystal form, the only one accepted by gourmets and consumers. Photo: Wikipedia

Antibodies binding to a virus. Crystallography is used to control the quality of processed drugs, including antiviral drugs, at the stage of mass production, in order to ensure that strict health and safety guidelines are met. © IUCr

The Curiosity rover used X-ray crystallography in October 2012 to analyse soil samples on the planet Mars! NASA had equipped the rover with a diffractometer. The results suggested that the Martian soil sample was similar to the weathered basaltic soils of Hawaiian volcanoes. Photo: NASA

Who is organizing the International Year of Crystallography?

The Year is being organized jointly by the International Union of Crystallography (IUCr) and UNESCO. It will complement two other international years led by UNESCO within the United Nations system, by contributing to the follow-up of the International Year of Chemistry (2011) and providing an introduction to the planned International Year of Light (2015). UNESCO is implementing all three years through its International Basic Sciences Programme.

Why now?

The International Year of Crystallography commemorates the centennial of the birth of X-ray crystallography, thanks to the work of Max von Laue and William Henry and William Lawrence Bragg. The year 2014 also commemorates the 50th anniversary of another Nobel Prize, that awarded to Dorothy Hodgkin for her work on vitamin B_{12} and penicillin (*see page 3 A brief history*).

Even though crystallography underpins all the sciences today, it remains relatively unknown to the general public. One aim of the Year will be to promote education and public awareness through a variety of activities (*see overleaf Who will benefit from the International Year of Crystallography?*).

Crystallographers are active in more than 80 countries, 53 of which are members of the International Union of Crystallography (*see map*). The Union ensures equal access to information and data for all its members and promotes international cooperation.

There is a need to broaden the base of crystallography, in order to give more developing countries expertise in this critical field for their scientific and industrial development. This is all the more urgent in that crystallography will play a key role in the transition to sustainable development in coming decades.

Countries adhering to the International Union of Crystallography

Challenges for the future

In 2000, the world's governments adopted the United Nations' Millennium Development Goals, which set specific targets to 2015 for reducing extreme poverty and hunger, improving access to clean water and safe sanitation, curbing child mortality and improving maternal health, among other challenges.

Governments are currently preparing a fresh set of goals that will determine the development agenda for the post-2015 period. The following are some examples of how crystallography can help to advance this agenda.

Food challenges

The world population is expected to grow from 7 billion in 2011 to 9.1 billion by 2050. The combination of rapid population growth and a diet more heavily reliant on meat and dairy products than in the past may increase the demand for food by 70% by 2050. This presents a major challenge for agriculture.

State-of-the-art crystallographic techniques are driving research in the agricultural and food sectors. Crystallography can be used to analyse soils, for instance. One serious cause of deteriorating soils is salinization, which can occur naturally or be induced by human activities.

Structural studies on plant proteins can help to develop crops which are more resistant to salty environments.

Crystallography can also contribute to the development of cures for plant and animal diseases, one example being research into canker in crop species like tomatoes, or the development of vaccines to prevent diseases such as avian or swine flu.

In addition, crystallographic studies of bacteria are important for the production of food products derived from milk, meat, vegetables and other plants.

Water challenges

Although the world recently met the Millennium Development Goal target of halving the proportion of people without access to safe drinking water by 2015, sub-Saharan Africa and the Arab region are lagging behind, according to the *World Water Development Report* (2012) produced by the United Nations. The same target for basic sanitation currently appears out of reach, as half the population in developing regions still lacks access. Moreover, the number of people in cities who lack access to a clean water supply and sanitation is estimated to have grown by 20% since the Millennium Development Goals were established in 2000. The urban population is forecast to nearly double to 6.3 billion in 2050, up from 3.4 billion in 2009.

Crystallography can help to improve water quality in poor communities, for instance, by identifying new materials which can purify water for months at a time, such as nanosponges (tap filters) and nanotablets. It can also help to develop ecological solutions to improve sanitation.

Energy challenges

Whereas energy was absent from the Millennium Development Goals, it should be a key focus of the post-2015 development agenda. In September 2011, the UN Secretary-General launched the Sustainable Energy for All initiative. It comes at a time of growing concern over the impact of fossil-fuel intensive economies on the Earth's climate and recognition of the need to accelerate the transition to sustainable sources of energy. According to the International Energy Agency, carbon dioxide (CO_2) emissions increased by 5% to 30.6 gigatons (Gt) between 2008 and 2010, despite the international financial crisis. If the world is to keep global warming to 2° C this century, CO_2 emissions by the energy sector must not exceed 32 Gt by 2020.

Crystallography can identify new materials which can purify water for months at a time, such as nanosponges (tap filters) and nanotablets.
© Shutterstock/S_E

Yet global energy consumption is expected to climb by 50% between 2007 and 2035, with non-OECD countries accounting for 84% of the increase. In 2009, 1.4 billion people still lacked access to electricity. Demand for energy from renewable resources is expected to rise by 60% by 2035.

Crystallography can develop new products which lower a home's energy consumption (and heating bill) while curtailing carbon emissions, such as insulating materials. It can also identify new materials which reduce the cost of solar panels, windmills and batteries while making them more efficient, to reduce wastage and improve access to green technologies.

Greening the chemical industry

Greening the chemical industry will be central to greening the global economy. The chemical industry manufactures over 70,000 different products, ranging from plastics and fertilizers to detergents and drugs. It is highly dependent on petroleum, consuming 10% of global oil production to make 80–90% of its products. It is thus resource- and energy-hungry.

In addition, many solvents and catalysts are toxic and disposal of chemical waste is complicated and expensive. Toxic and carcinogenic substances are currently being released into the air, soil and water. According to the United Nations Environment Programme, Western Europe produced a total of 42 million tonnes of toxic waste in 2000, five million of which were exported a year later.

Crystallography can contribute to the development of ecological construction materials in developed and developing countries. It can also help to reduce pollution by replacing chemical solvents with 'green' inorganic solvents based on ionic liquids and CO_2. It can help to reduce mining waste and related costs by contributing to methods which selectively extract only the materials required.

Health challenges

Health challenges will remain daunting in the decades to come. There is still no effective vaccine or cure for such pandemics as HIV/AIDs, dengue fever and malaria, for instance, which continue to ravage the developing world in particular.

Many health problems in developing countries are linked to the lack of access to clean water and safe sanitation, including diaorrheal diseases like cholera or the chronic disease schistosomiasis, with an estimated 90% of cases at least reported in Africa.

However, developing countries are also exposed to the same chronic health burdens as developed countries, including heart disease, cancer and, increasingly, diabetes (*see photo*).

Other serious health concerns that affect rich and poor countries alike include the emergence of new pathogens and the growing resistance of bacteria to existing medical treatments.

Crystallography can tackle the growing resistance of bacteria to antibiotics, for instance. Together with Venkatraman Ramakrishnan and Thomas Steitz, crystallographer Ada Yonath has managed to determine the structure of the ribosome and the way it is disrupted by antibiotics. Ribosomes are responsible for the production of all proteins in living cells, including those of humans, plants and bacteria. If the work of the ribosome is impeded, the cell dies. Ribosomes are a key target for antibiotics, as antibiotics are able to attack the ribosomal activity of harmful bacteria while leaving human ribosomes untouched. In 2008, Prof. Yonath was awarded the L'Oréal-UNESCO Prize for Women in Science for her work and, a year later, all three scientists received the Nobel Prize.

The tropics in particular are blessed with a rich biodiversity that often remains underexploited. Crystallography can help countries to identify the properties and behaviour of endogenous plants, with a view to developing skin and health care products, herbal remedies and so on.

Who will benefit from the International Year of Crystallography?

The Year will target governments

By interacting with them and advising on the design of policies which:

- finance the establishment and operation of at least one national crystallography centre per country;
- develop cooperation with crystallography centres abroad, as well as with synchrotron and other large-scale facilities;
- foster the use of crystallography in research and development;
- foster research in crystallography;
- introduce crystallography into school and university curricula, or modernize existing curricula.

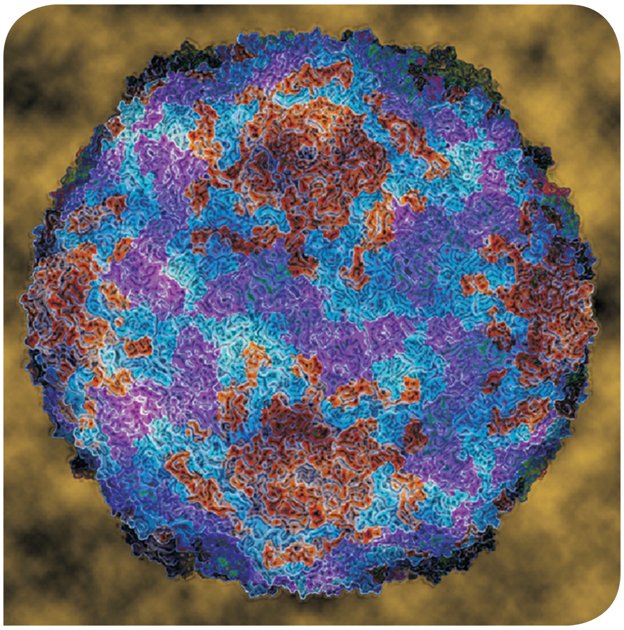
In addition, a series of regional summit meetings are planned to highlight the difficulties in conducting first-rate scientific research in parts of the world and identify ways of overcoming these. The meetings will bring together countries that are divided by language, ethnicity, religion, or political factors, to delineate future perspectives for science, technology and related industrial development, and identify job opportunities.

The Year will target schools and universities

To introduce the teaching of crystallography where it is still absent, via, *inter alia*:

- travelling laboratories prepared by the International Union of Crystallography which will demonstrate how diffractometers work in countries in Asia, Africa and Latin America, in collaboration with diffractometer manufacturers;
- the ongoing Initiative in Africa for universities (*see box overleaf*), which will be intensified and extended to countries in Asia and Latin America which lack crystallography teaching;
- hands-on demonstrations and competitions in primary and secondary schools;
- problem-solving projects for school pupils which use their knowledge of crystallography, physics and chemistry;
- a travelling exhibition for schools and universities on Crystallography and Geometric Art in the Arabo-Islamic World, organized by the Moroccan Association of Crystallography (*see box page 12*). The exhibition will also demonstrate crystallization and X-ray diffraction using a portable diffractometer.

In the past 20 years, the number of people with diabetes worldwide has risen from 30 million to 230 million, according to the International Diabetes Federation. Seven of the top ten countries for diabetes are either developing countries or emerging economies, including China and India. In the Caribbean and Middle East, about 20% of adults suffer from diabetes. Had the structure of natural insulin, produced by the pancreas, not been determined by X-ray crystallography, it would be impossible to manufacture the life-saving biosynthetic 'human' insulin today. Photo: Wikipedia



Virus. You cannot design drugs without knowing the structure of relevant proteins. © IUCr

The Year will target the general public

To increase awareness of the way in which crystallography underpins most of the technological developments in modern society but also its role in cultural heritage and art history, via:

- public conferences organized by members of the International Union of Crystallography on themes like the paramount importance of protein crystal structures in drug design, crystallography and symmetry in art, or crystallographic analysis of artworks and ancient materials;
- sponsorship of poster exhibitions highlighting the usefulness and marvels of crystallography;
- the submission of articles to the press, television and other media on the contribution crystallography makes to the global economy.

DEVELOPING CRYSTALLOGRAPHY AT AFRICAN UNIVERSITIES

©Serah Kimani

One of the International Union of Crystallography's main missions is to provide faculty and PhD students in developing countries with training in crystallography teaching and research methods.

In collaboration with South African universities and the South African Crystallographic Association, the Union has organized a number of courses over the past decade in English-speaking African countries. The partnership has also awarded a fellowship to two exceptional PhD students from Kenya, Serah Kimani (*pictured*) and Ndoria Thuku, to enable them to complete their theses in South Africa. Serah Kimani's thesis involved determining as many as 40 crystal structures. She took up an appointment at the University of Cape Town in 2012. Ndoria Thuku's thesis involved determining the crystallographic structure of *Rhodococcus rhodochrous*, a bacterium used as a soil inoculant to promote plant health in agriculture and horticulture. Since graduating in 2012, Dr Thuku has been a postdoctoral research fellow in the Division of Medical Biochemistry at the University of Cape Town.

In 2011, the International Union of Crystallography designed an ambitious programme for sub-Saharan African countries. Known as the Crystallography in Africa Initiative, the programme not only trains teaching staff and PhD students in crystallography but also provides participating universities with diffractometers worth between 80,000 and 150,000 euros each, in order to enable them to conduct international research. A key partner in this endeavour is Bruker France, a private enterprise which has agreed to supply diffractometers in perfect working order to all the universities identified by the Union. The Union covers the cost of delivering the diffractometer to each university. In return, the recipient universities maintain the diffractometer and cover the cost of related equipment, such as the computer and X-ray tube.

The Year will target the scientific community

To foster international collaboration between scientists worldwide, with an emphasis on North–South collaboration, via:

- the launch of an open access journal on crystallography, which will be called *IUCrJ*;
- joint research projects involving large synchrotron facilities in both developed and developing countries, such as the facility in Brazil or the SESAME facility in the Middle East, born of a UNESCO project (*see photo page 14);*
- consultations to identify the best way to save all diffraction data collected in large-scale facilities and crystallography laboratories.

Cover of the first issue of the new open access journal, available at: www.iucrj.org

The first faculty staff to be trained in how to use these instruments comes from the University of Dschang in Cameroon. Teaching staff and PhD students were given an intensive 20-hour course in February 2012, in order to prepare them for the arrival of the diffractometer the following year.

The Cameroon Crystallographic Association was founded at this time. The fledgling association ran its first course from 7 to 13 April 2013 in Dschang. The course focused on how to use diffraction to determine crystalline structures and attracted 24 professors and PhD students from universities across Cameroon and the wider sub-region. It was cofinanced by the International Union of Crystallography, Cameroon Crystallographic Association, University of Dschang and Bruker.

The next countries to benefit from the initiative will be Côte d'Ivoire, Gabon and Senegal. One university is being targeted in each country. This university will in turn be expected to train staff at other national universities and to act as a national crystallographic centre. Each national centre will be entitled to free access to the International Union of Crystallography's specialist publications.

The International Union of Crystallography is currently contacting other sponsors, in order to generalize the Crystallography Initiative in Africa across the entire continent.

The International Year of Crystallography should also make it possible to extend the initiative to developing countries in Asia and Latin America.

For details:
claude.lecomte@crm2.uhp-nancy.fr

Prof. Claude Lecomte, Vice-President of the IUCr, teaching a crystallography course at the University of Dschang in Cameroon in February 2012
© Patrice Kenfack/Cameroon Crystallographic Association

SYMMETRY IN ART AND ARCHITECTURE

Be it a human face, a flower, a fish, a butterfly – or a non-living object like a seashell –, symmetry pervades the natural world. It has always fascinated human civilizations, which have reflected symmetry in their art and architecture for thousands of years.

Symmetry can be found in all human expressions of creativity: carpets and rugs, pottery, ceramics, drawing, painting, poetry, sculpture, architecture, calligraphy, etc. There is symmetry in the Chinese alphabet, for instance. Symmetry in Chinese art and architecture is a manifestation of the Chinese philosophy of seeking harmony through balance.

Yoruba bronze head from the Nigerian city of Ife, 12th century CE
Photo: Wikipedia

Art and architecture may demonstrate different forms of symmetry. A pattern that repeats itself indefinitely is said to show translational symmetry. It can be one-dimensional like the frieze below, or two-dimensional like the winged animals in the image here.

Chinese symbol for happiness, pronounced shuangxi

In bilateral symmetry, the left and right sides are mirror images of one another. One example in nature is a butterfly. Bilateral symmetry has always been a common feature of architecture, historic examples being the **Taj Mahal** in India (*pictured*), the Forbidden City in China or the Mayan temple of **Chichen Itza** in Mexico (*pictured*). Bilateral symmetry is also common in art, although perfect symmetry in painting is rare.

If a figure can be rotated about its axis or a particular point without changing the way it looked originally, it is said to show rotational symmetry. The pyramids of Giza in Egypt, for instance, show rotational symmetry of order four (including the base). The interior of the dome of the **Lotfollah Mosque** in Iran (*pictured*) shows rotational symmetry of order 32, starting around the point located at the centre of the figure.

Two-dimensional image by Maurits Cornelis Escher (Netherlands)
© M C Escher Foundation

Geometric patterns have pervaded the art of many civilizations. Examples are the sand paintings of the Navajo Indians in North America, the **kolam of south India** (*pictured*), Indonesian batik (tie-dyeing), the art of Australian Aborigines and Tibetan mandalas.

Taj Mahal, India, completed in 1648, today a UNESCO World Heritage property
Photo: Muhammad Mahdi Karim/Wikipedia

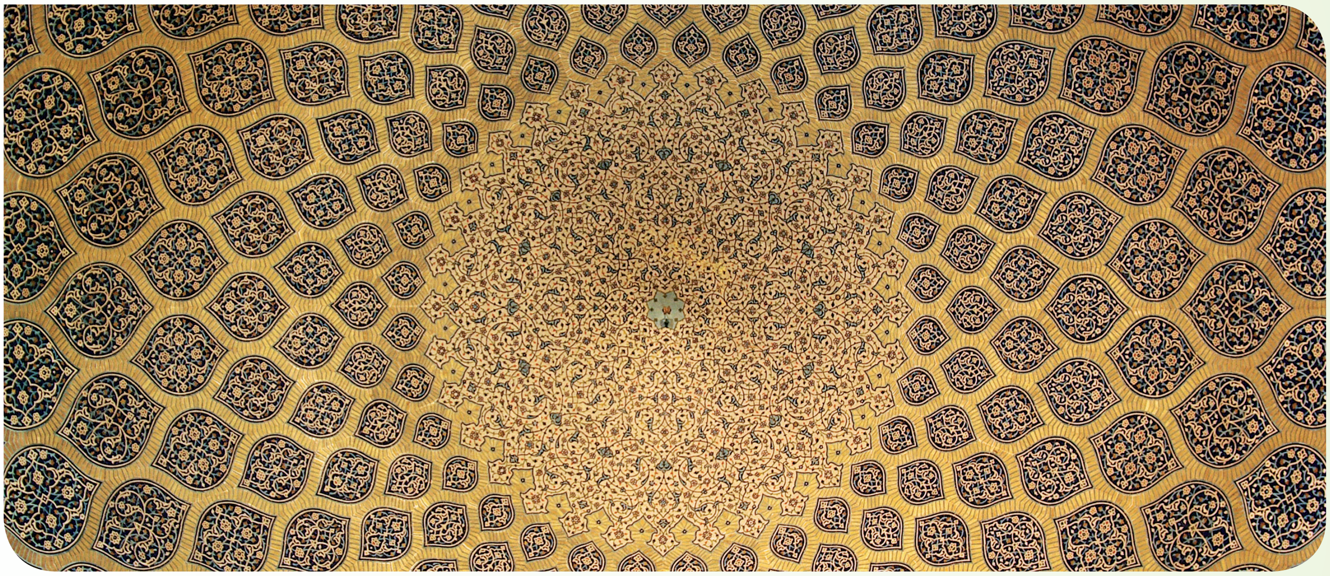
Mayan temple in Chichen Itza in Mexico, which flourished from about 600 to 900 CE, today a UNESCO World Heritage property
© S. Schneegans/UNESCO

Islamic civilizations from about the 7th century onwards used geometric patterns in mosaics and other art forms to connect spirituality visually with science and art. Islamic art may have inspired the Western school of geometric abstraction of the 20th century, two proponents of which were **Maurits Cornelis Escher** and **Bridget Riley** (*pictured*). Escher was reputedly inspired by a visit to the Moorish palace of Alhambra in Spain.

Throughout 2014, the Moroccan Crystallographic Association is organizing a travelling exhibition on Crystallography and Geometric Art in the Arabo-Islamic World. For details, write to:
Abdelmalek Thalal: abdthalal@gmail.com

Kolams like this one in Tamil Nadu are drawn in rice powder or chalk in front of homes to bring prosperity. They can be renewed daily.
Photo: Wikipedia

Dome-shaped ceiling of the Lotfollah Mosque in Iran, completed in 1618, today a UNESCO World Heritage property
Photo: Phillip Maiwald/Wikipedia



Al-Attarine Madrasa (school) in Fez, Morocco, a World Heritage property. It was built by the Marinid Sultan Uthman II Abu Said in 1323–1325.
© A. Thalal

Shadow Play by Bridget Riley, UK, 1990
Photo: Wikipedia

One-dimensional frieze
Image: Moroccan Crystallographic Association

How can my country boost crystallography in 2014 and beyond?

Any country interested in developing knowledge-based industries or adding value to raw products must have an endogenous capacity in crystallography. During the Year, developing countries in Africa, the Arab region, Latin America, the Caribbean and Asia can do a lot to boost crystallography on their soil.

Ways to improve training and research

As we have seen, crystallography is an interdisciplinary science that spans physics, chemistry, materials science, geology, biology, pharmaceutics and medicine. Scientists with a background in any of these fields are thus potential crystallographers. Throughout 2014, the International Union of Crystallography will be encouraging more countries to become members, in order to facilitate international cooperation in training and research, as well as access to information and knowledge.

Once trained, crystallographers need appropriate infrastructure, in order to apply their skills. UNESCO and the International Union of Crystallography recommend that governments set up at least one national crystallography centre equipped with a diffractometer and that they endow it with sustained funding. Once the diffractometer has finished analysing the structure of a crystal, the crystallography centre can then model it using crystallographic software. As partners in the Year, diffractometer manufacturers will guarantee an affordable price for the purchase of a diffractometer and offer local training in maintaining these instruments.

It is important for the government to put policies in place which facilitate the centre's linkages with universities and industry within the country, as well as with other crystallography centres around the world, in order to drive knowledge-based sustainable development.

The completed shielding wall in the experimental hall of the SESAME synchrotron light source in the Middle East, an intergovernmental centre in Jordan that has been set up under the auspices of UNESCO and brings together Bahrain, Cyprus, Egypt, Iran, Israel, Jordan, Pakistan, the Palestinian Authority and Turkey, as well as 13 Observer States that include Japan and the USA. The SESAME building was completed in 2008 and the laboratory should be fully operational by early 2016. © SESAME

The government should also foster the development of ties between the national crystallography centre and national and international synchrotron light sources like SESAME in Jordan *(see photo)*.

In order to share knowledge of scientific and technological developments in crystallography and give greater visibility to the publications of crystallographers from developing countries in particular, the International Union of Crystallography is launching an open-access journal on crystallography, *IUCrJ* (*see photo page 11*).

UNESCO and the International Union of Crystallography are also encouraging governments to set up regional or sub-regional hubs offering training and experimentation in crystallography, in order to rationalize resources for institutional capacity-building.

Training the crystallographers of tomorrow

Now is the time for countries to train a critical mass of crystallographers. Governments can take steps to modernize school and university curricula by fostering a better correlation with crystallography in the curricula of physics, chemistry, biology and geology. UNESCO and the International Union of Crystallography are at governments' disposal to provide guidance on curricular development.

They also invite governments to express interest in hosting the travelling laboratory on crystallography that has been designed specifically for youth.

The International Union of Crystallography has also devised problem-solving projects and competitions for schools which use their knowledge of crystallography, physics and chemistry. The aim is to demonstrate the practical applications of these sciences for the development of agriculture, drug design, 'green' new materials and so on. Countries are invited to express interest in organizing such competitions at the national level.

To participate in the International Year of Crystallography

The 195 Member States of UNESCO are invited to contact UNESCO's team within the International Basic Sciences Programme (IBSP) or the International Union of Crystallography, in order to put together a programme for implementation in their country in 2014.

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Crystallography helps to determine the ideal combination of aluminium and magnesium in alloys used in aeroplane manufacture. Too much aluminium and the plane will be too heavy, too much magnesium and it will be more flammable. © Shutterstock/IM_photo

The programme of events for the Year and relevant teaching resources are available from the official website:

www.iycr2014.org