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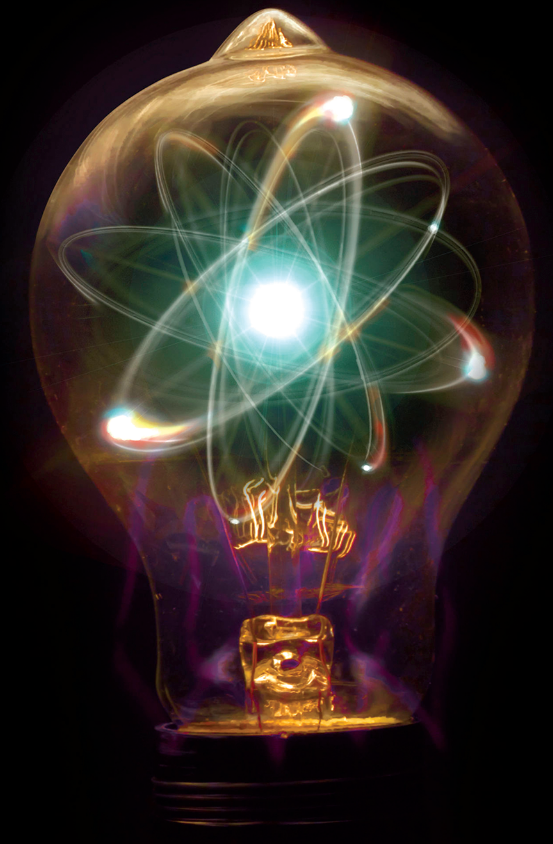
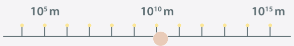
Discover the world with nuclear physics

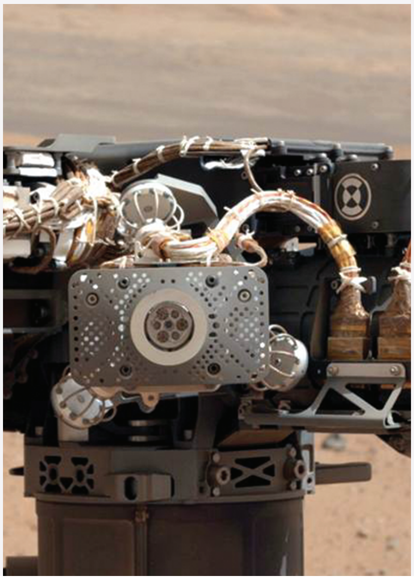


10 Ion Beam & Neutron Case Studies



Water on Mars

Technique: Ion Beam Analysis
Dimension: Solar System
Size: 150 million kilometres



Extraterrestrial rock chemistry using nuclear methods has been a continual topic of discussion ever since Anthony Turkevich reported the Surveyor V landing on the Moon in 1967. Comparable methods were used by the two Mars Exploration Rovers, Spirit and Opportunity, that landed on Mars in 2004, and are now also being used by the Curiosity rover that landed there in 2012.

The alpha-particle X-ray spectrometer (APXS) uses a radioactive curium source of both very energetic alpha particles and very energetic X-rays. The Mars rocks are bombarded with these particles and photons, and respond with X-rays characteristic of the constituent minerals.

Nowadays, X-ray analysis is a routine method used all over the world in many industrial applications and research labs. Usually the analysts are comparing the results from the sample of interest with a similar “standard” sample whose composition is known. Absolute measurements are not usually made, but on Mars the minerals could be anything – nothing can be assumed. After all, it is out of this world!

The Mars team have done an absolute analysis of the mineral composition of the Mars rocks, and it turns out that the Mars rocks are hydrated; some samples contain up to 18% water!

Credit: NASA/JPL-Caltech/MSSS – photojournal.jpl.nasa.gov/catalog/PIA16160

10^{-5} m 10^{0} m 10^{5} m

Historical forensics using hair analysis

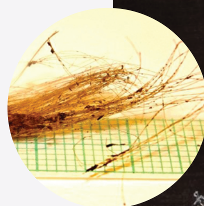
Technique: Neutron Activation Analysis
Dimension: World
Size: 1 - 10 metres

Was Tycho Brahe murdered?

Nuclear analytical techniques are used in criminal forensics, and have even played a pivotal role in helping to solve some high-profile historical forensics cold cases.

Johannes Kepler is famous for his laws of planetary motion, one of the keys for the acceptance of the heliocentric model of the Solar system and for the emergence of modern science in the late 16th and early 17th centuries. It was the Danish nobleman Tycho Brahe, who had made 40 years' worth of accurate astronomical observations that Kepler used to derive his laws from. In 1600, when Brahe was working in Prague as Imperial Court Astronomer, Kepler became his assistant. However, only after Brahe's death on 24 October 1601, did Kepler gain full access to his data as he was appointed Brahe's successor.

It was later suspected that Brahe was being poisoned with mercury – and Kepler was the prime suspect. In 2013, to investigate the suspicion radiochemical Neutron Activation Analysis – an extremely sensitive technique – was used on hairs from Brahe's moustache. The results were clear: two months before his death, the mercury concentration in his body was higher than the median level found in populations nowadays, but it was still at moderate levels. It was discovered that the mercury concentration had decreased steadily over the following two months preceding his death and that is why acute poisoning could be discarded.



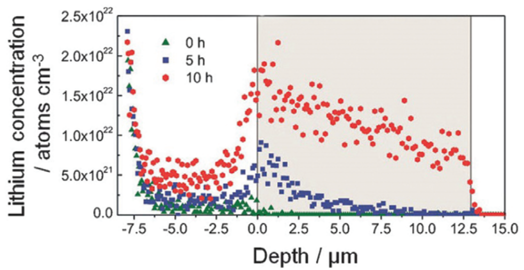
Credit: Janne Jönsson, Tycho Brahe Museum, Sweden | Credit: Jan Kučera, Nuclear Physics Institute, Řež, Czech Republic

Depth profiling Lithium-ion batteries with neutrons

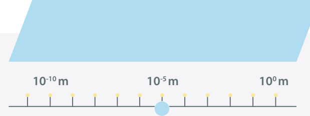
Technique: Neutron Depth Profiling
Dimension: World
Size: 1 - 10 centimetres

Rechargeable lithium-ion batteries are part of everyday life with widespread use in consumer electronics such as mobile phones and laptop computers. They are based on the migration of lithium ions between a positive electrode (cathode), a lithium-containing material and a negative electrode (anode), normally a porous material through an electrolyte. Lithium transport during charge and discharge of batteries is fundamental for their efficiency, capacity, and durability.

Real-time in-situ visualization and quantification of the changing lithium distribution in batteries during charging and discharging is extremely useful information to assist their development, and, in particular, to improve the understanding of the mechanisms which limit charge and discharge rates. Currently, there is one single technique that can deliver such a challenging feat: Neutron Depth Profiling.



Credit: Adapted from Danny X. Liu et al., 2014. – DOI: 10.1002/anie.201404197 | Credit: IAEA



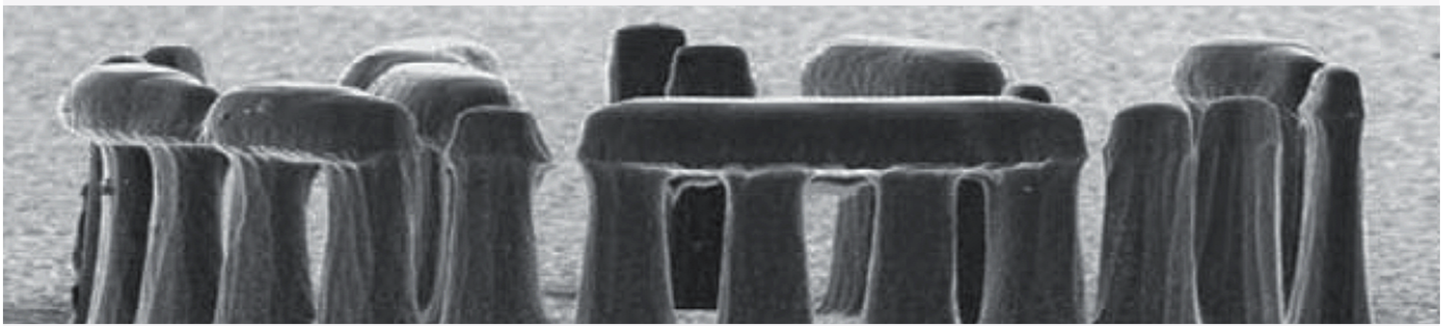
Technique: Ion Beam Micromachining
Dimension: Microworld
Size: 10 micrometres

3D structure (Stonehenge) Ion beam micromachining

Nanofluidics technology is a great research enabler. Large scale production of nanofluidic devices is central to the burgeoning field of *lab-on-a-chip* devices with many important applications allowing chemistry with miniscule quantities of reagents. This case study explores the use of focused ion beams to prototype such new devices.

The Figure below shows an excellent example of what can be fabricated using a high-resolution ion nanobeam. The team wished to demonstrate the technique by creating a micro-reproduction of 80 micrometre total size: nearly one million times smaller than the original.

Devices created with ion beams are used in many applications, for example in investigating the way DNA folds and unfolds, a behaviour central to its function.

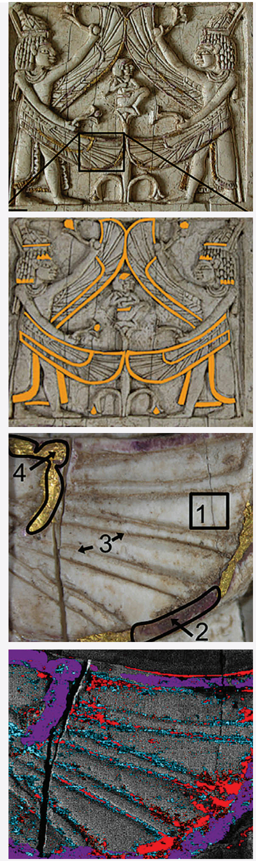


Credit: Watt et al, *Materials Today*, 2007 – DOI: 10.1016/S1369-7021(07)70129-3

10^{-5} m 10^{0} m 10^{5} m

Lost polychromy and gilding of Neo-Assyrian ivories

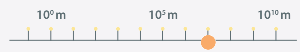
Technique: Ion Beam Analysis
Dimension: World
Size: 0.1 - 1 metres



Antique objects are known to have been brightly coloured, but the appearance of these objects has changed over time and paint traces are rarely preserved. Today only specific alteration phenomena like cracks and discolorations can be observed on the ivory surfaces. Where has the colour gone? Can it be reconstructed from the remaining traces on the objects, and what could we learn about them?

Elephant-ivory carvings by highly skilled Phoenician craftsmen from the Neo-Assyrian archaeological site of Arslan Tash in Syria and dated to the 8th century BC were excavated in 1928 and are now in the collections of the Louvre Museum in Paris, France and the Badisches Landesmuseum in Karlsruhe, Germany. The characterization of gilding based on Rutherford backscattering (RBS) data demonstrates the exceptional technological skills of the Phoenician craftsmen who carved the Arslan Tash ivories, and allows more precise reconstructions of the original polychromy when compared to previous work using the large synchrotron facility *ANKA* at the Karlsruhe Institute of Technology, Germany.

Credit: Albéric et al, *Talanta*, 2015 – DOI: 10.1016/j.talanta.2015.01.029



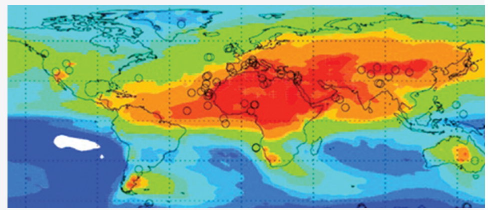
Monitoring air pollution worldwide

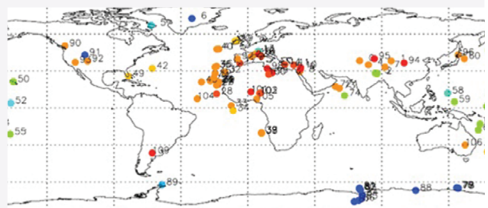
Technique: Ion Beam Analysis
Dimension: World
Size: 510 million km^2

Air pollution impacts human health and the environment in many ways. It influences the Earth's radiation balance and biogeochemical cycles, which affects the climate and leads to significant changes in the biosphere. Ion Beam Analysis (IBA) is a technology that can identify air pollution and its source, and helps us understand its impact on human health and the environment.

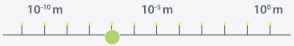
Air particulate matter (APM) consists of solid particles and liquid droplets dispersed in the air such as smoke, dust and fog. APM can be classified as coarse (PM10) and fine fractions (PM2.5): particles smaller than 10.0 microns and 2.5 microns, respectively. PM2.5 is more dangerous and long-lasting than PM10 and, if breathed in, can get deep into the lungs and cause serious health issues, whereas coarse dust falls out of the air in a short period of time.

IBA is an efficient technique which can be used together with other conventional methods to monitor air pollution. The main advantage of this method is that it allows experts to collect huge amounts of data with an extremely sensitive technique. This ability to detect very small amounts of elements helps experts to identify the sources of pollution.



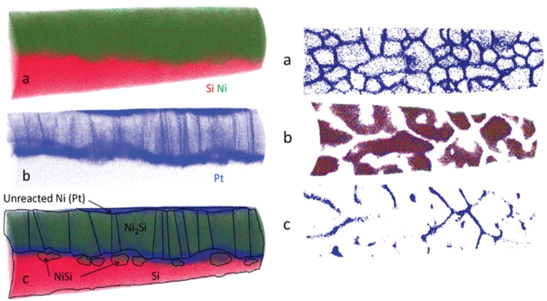


Credit: Zhang et al, *Biogeosciences*, 2015 – DOI:10.5194/bg-12-5771-2015



Nanostructure of nano-crystalline materials

Technique: Ion Beam Analysis
Dimension: Nanoworld
Size: 100 nanometres

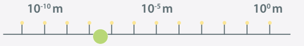


Nickel silicides are widely used for making electrical contact to complementary metal-oxide-semiconductor (CMOS) devices in advanced integrated circuits, a technology present in multiple electronics applications. They have been the preferred material since 2006. However, their high temperature behaviour is complex and, crucially, improved by the presence of platinum.

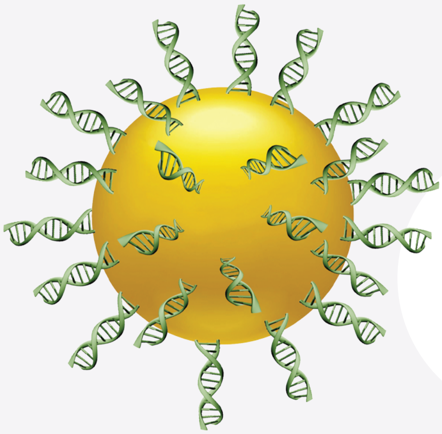
Valuable information about the influence of the platinum in improving the properties of these materials as they are annealed was obtained using real-time Rutherford Backscattering Spectrometry (RBS) (see Figure), where the very large quantity of data resulting is analysed in real-time by an artificial neural network.

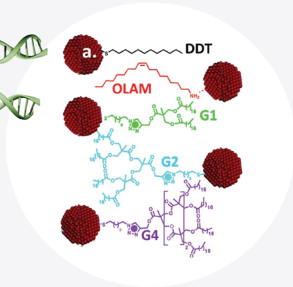
This is an important example, and one of many quantitative real-time RBS observations of diffusion and phase separation during annealing of multilayer samples. These real-time measurements can be much more efficient compared to a conventional approach, and give details of processes that are hard (or impossible) to obtain otherwise.

Credit: Mangelinck et al, *Scripta Materialia,* 2010 – DOI: 10.1016/j.scriptamat.2009.12.044



Neutron research in nanoparticles for medicine



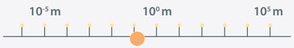


Technique: Neutron Scattering
Dimension: Nanoworld
Size: 10 - 100 nanometres

Nanoparticles often have interesting and sometimes unexpected properties. A large proportion of the atoms are at the surface, which behaves differently than the bulk: in this case, size matters. Suspensions of gold nanoparticles can be red, black, or violet, but not yellow or golden, depending on the nanoparticle size. Gold nanoparticles are of great interest for medical applications as organic big molecules such as a medical drug or DNA can be fixed to their structure and used as drug delivery systems. Other applications include bio-imaging and the use of biomarkers for screening of diseases such as cancer.

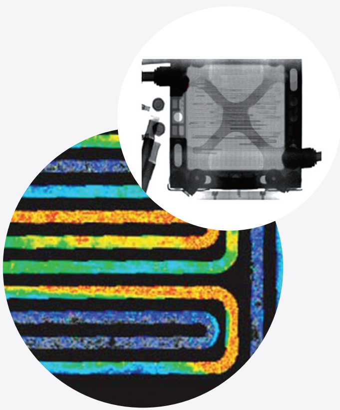
To develop these organic-inorganic systems, techniques such as Small Angle X-ray Scattering and Small Angle Neutron Scattering are used. The combination of the two techniques provides nanometre-scale size resolution for these hybrid nanomaterials.

Credit: IAEA | Credit: Benjamin T. Diroll et al., 2015 – DOI: 10.1021/acs.nanolett.5b04011



Neutron imaging in fuel cells research

Technique: Neutron Imaging
Dimension: World
Size: 1 - 50 centimetres

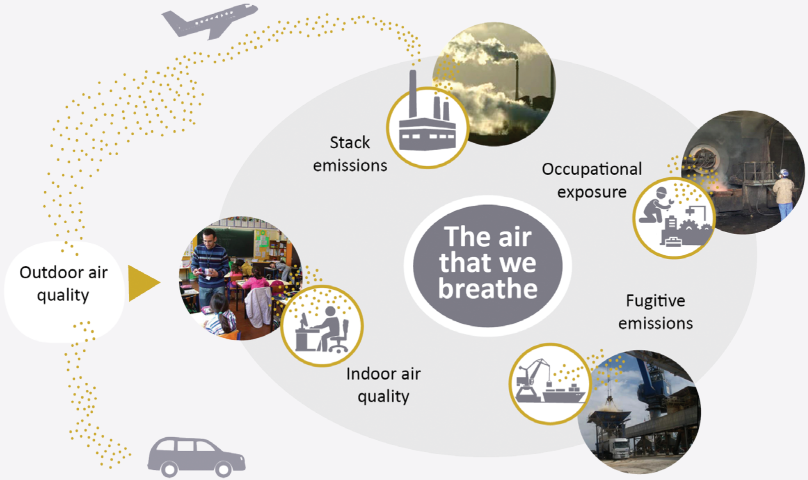


Polymer electrolyte membrane (PEM) fuel cells produce electrical energy directly from hydrogen with efficiency reaching 60% in electrical energy conversion and 80% when thermal energy is included. The only by-product of this process is water, which significantly reduces pollutant emissions when compared to traditional fuels. No wonder that they are actively researched as an alternative to fossil fuels in transportation.

The principle of neutron imaging is the same as for X-ray tomography, used commonly in CT imaging devices. A beam of neutrons (or X-rays) crosses an object, where some attenuation of the beam takes place, depending on the materials crossed at each location. An image is formed by a camera placed behind the sample: this is a simple radiography. The sample is located on a rotating stage to expose it from various angles. Based on all the images, a 3D reconstruction of the object is obtained.

Neutrons can see what X-rays cannot: hydrogen! Therefore, water production, transport, and removal through the PEM cell can be observed in real time, giving precious information that is used to optimize and produce better PEM fuel cells.

Credit: Manke et al., 2008 – DOI: 10.1063/1.2946664 | Credit: Satija et al., 2004 – DOI: 10.1016/j.jpowsour.2003.11.068



10⁻⁵ m 10⁰ m 10⁵ m

The air we breathe

Technique: Neutron Activation Analysis + PIXE
Dimension: World
Size: 10 metres - 10 kilometres

No matter where we are, indoors at home, school, work, fitness centres, or outdoors in the city, in the countryside, or by the coast, the air that we breathe carries Air Particulate Matter (APM) from a variety of sources. Careful analysis of the APM granulometry and chemical composition can be used to "fingerprint" each source.

Neutron Activation Analysis (NAA) and Particle Induced X-ray Emission (PIXE) are very often used in air quality studies due to their high sensitivity to metals and many other elements of interest – from 0.1 ng/m^3 (nanogram per cubic metre of air) in favourable cases to 1000 ng/m^3 – and due to their ease of use – APM collected on a medium such as filter paper can be analysed together with its medium directly without further sample preparation. Their multi-elemental detection capability can be used in fingerprinting and apportionment of sources because each source is characterized by a given set of elements.

Credit: IAEA

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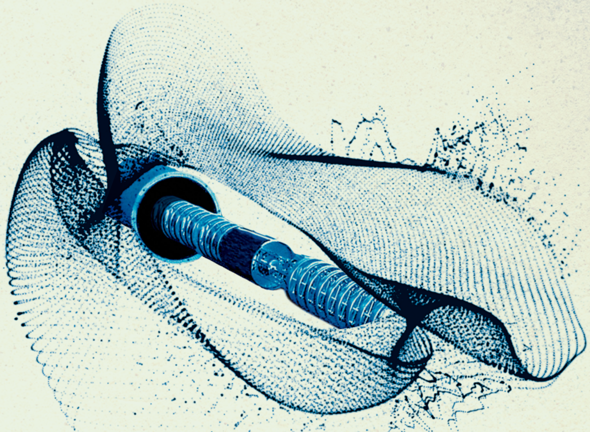
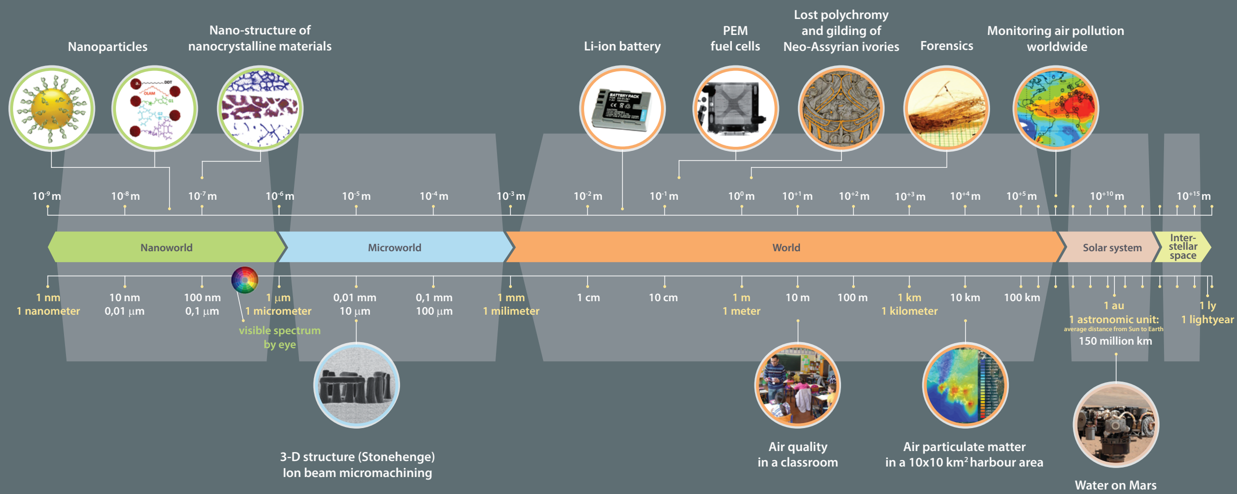
Accelerator Knowledge Portal

nucleus.iaea.org/sites/accelerators





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