The Power of 3

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Driving the future further

Size matters – the intriguing world of nanotechnology PART ONE

'The mysteries of the universe involve size, not time'

(to paraphrase Stephen King)

Overview

US engineer Eric Drexler first coined the term 'nanotechnology' in the 1980s. His vision of 'molecular manufacturing' – a sea of self-replicating nanobots moving molecules so quickly and positioning them so precisely that they could produce almost any substance from ordinary ingredients in a matter of hours – inspired a generation of chemists, computer scientists and engineers to start thinking small. (Drexler also hypothesised the doomsday scenario of 'grey goo', whereby those self-replicating bots consume Earth's entire biomass while building more of themselves.)

Fantasies aside though, what *is* nanotechnology?

The *American Heritage® Science Dictionary* describes it as "the science and technology of precisely manipulating the structure of matter at the molecular level. The term … embraces many different fields and specialities … but all are concerned with bringing existing technologies down to a very small scale, measured in nanometres. A nanometre [nm] – a billionth of a metre – is about the size of six carbon atoms in a row … "

From *The Foresight Institute*: "Nanotechnology is the study of phenomena and fine-tuning of materials at atomic, molecular and macromolecular scales, where properties differ significantly from those at a larger scale."

Most importantly, Thomas Theis of the IBM Watson Research Centre describes it as "an upcoming economic, business and social phenomenon [that some say] will revolutionise the way we live, work and communicate."

"Despite unprecedented government funding and public interest," avers *IopScience* however, "few can accurately define [its] scope, range or potential applications."

Nanotechnology now

While getting a handle on nanotechnology may not be easy, for decades scientists have been working at the nanoscale courtesy of electron microscopy, scanning probe microscopies and similar technologies that can now 'see' with a resolution down to the scale of a single atom.

Cells crawling across ceramic crystals [credit: Karin Hing, courtesy of the Wellcome Collection].

To give an idea of scale, consider the following:

- a strand of human DNA is 2.5 nm in diameter;
- there are 25,400,000 nm in an inch (2.54 centimetres);
- a human hair is around 80,000-100,000 nm wide;
- one gold atom is about a third of one nm in diameter, and
- a human fingernail grows around one nm a second.

Even the best compound microscopes cannot resolve parts of a specimen that are closer together than about 200 nm, so nanoscience involves considerable ingenuity. Tools and instruments – the hardware, software and supplies – used to measure and manipulate structures on the nanoscale include microscopes, probes, lithography systems, manipulation and fabrication systems, software and other accessories. In essence, though, nanotechnology is nothing more than the most fundamental understanding of how nature works at the atomic scale.

Science fiction, of course, has led the world to expect a great deal more: miniature body-probing robots and miniscule submarines; tiny cogs and gears created from atoms; carbon-nanotube space elevators; weather machines – even interplanetary exploration and habitation. Only time will tell …

Meanwhile, in the real world nanoscience has generated a plethora of new industries and delivered innovations in a range of others, including:

- quantum dots
- medicine and healthcare;
- computing;
- telecommunicxations;
- sensor technology;
- petroleum refining;
- automobiles;
- lightweighting of vehicles;
- tires;
- coatings;
- personal-care products (including sunscreens);
- smart and antibacterial fabrics;
- household products;
- packaging;
- construction and mining;
- environmental remediation;
- desalination;
- solar cells,

and more.

Gold nanoparticles coated with a cancer antibody that binds to tumour cells to aid in diagnosis and treatment [credit: Annie Cavanagh, courtesy of the Wellcome Collection].

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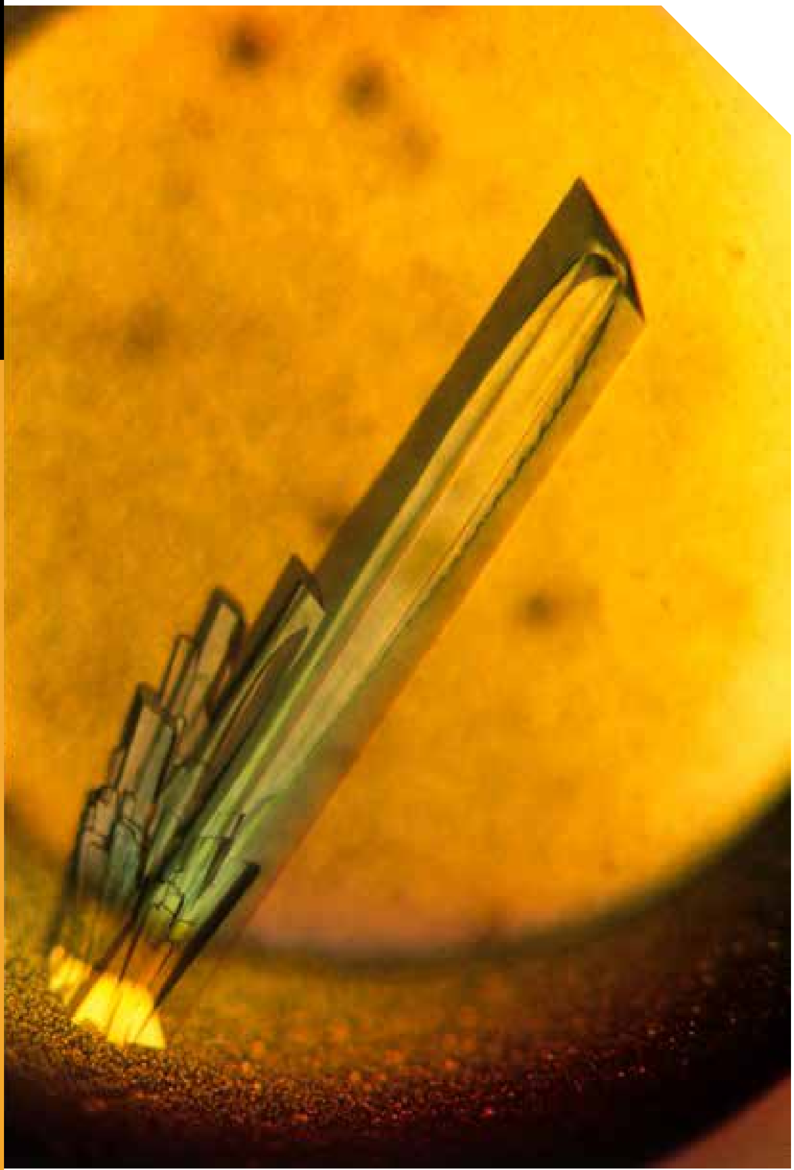
Can nanotechnology green the planet?

Today, many concede that one of the most pressing problems facing Earth is global warming. It's impelling many countries to relinquish their dependence on fossil fuels and embrace cleaner forms of transport, as well as renewable sources of power and storage mechanisms for the energy they produce – which, as outlined in previous issues of *The Power of 3*, has led to burgeoning demand for and manufacture of rechargeable lithium-ion batteries. The result? Even more pressure on the planet's already depleted resources, plus the potential to create massive environmental headaches in terms of end-of-use disposal.

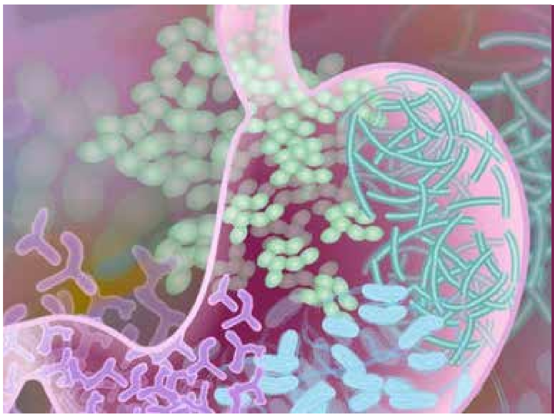
Part of the answer lies in more efficient reservoirs of energy – new generations of battery materials that fulfil the needs of end-users – and the most promising of those will involve nanotechnology, which has the potential to:

- improve safety through the creation of less flammable battery materials;
- enhance a battery's available power and lessen charging time by coating the surface of the electrode with nanoparticles;
- increase the surface area of a battery's electrode and in so doing facilitate the flow of current between the electrode and the chemicals within that battery;
- improve energy density (charge per unit volume) by packing more material into battery electrodes;
- enhance the electrochemical properties of electrodes by doping them with trace metals on a molecular scale, and
- improve battery shelf life by using nanomaterials to separate the liquids and solids within, thereby eliminating the low-level discharge common to conventional batteries.

In summary, and despite the doomsayers, nanoscience and nanotechnology involve exciting interchanges across a range of disciplines working at the tiniest of scales. Together, they represent a new and expanding frontier with great promise for improvements in quality of life, including new treatments for disease, greater efficacy in computer data storage and processing, and ever more efficient energy storage and use.



Crystals of a DNA repair protein bound to DNA [credit: Bernard O'Hara & Renos Savva, courtesy of the Wellcome Collection].



Beneficial gut bacteria [credit: Darryl Leja, National Human Genome Research Institute, National Institutes of Health].

And finally …

Microbiomes are communities of microorganisms that exist almost everywhere on Earth and influence how plants and animals (including humans) interact with their environments. One new and exciting area of health research involves investigating the holistic effect of the gut microbiome on the human body. As so often happens, scientific insights follow on technological development – in this case, advances in nanoscience focused on DNA research. Scientists now know that the human gut microbiome plays a role in a whole range of moods, behaviours and illnesses, among them anger, depression, PTSD, obesity, high blood pressure, colon cancer, multiple sclerosis, Alzheimer's disease … the list goes on. While studies are ongoing, it's becoming increasingly evident that a wholesome diet, lack of disruption to circadian rhythms and adequate exercise all play a role in keeping people well. The adage 'You are what you eat' (and how you sleep and play) has never rung so true.

Which Perth-based company will use nanotechnology to help close the 'energy-metal' loop?

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