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Nanotechnology: Peering into the future

In a few decades we will see the merging of human and machine, a world where there is no distinction between the biological and the mechanical; illness will be eradicated, and human beings will live to 150 and have radically enhanced physical and mental capabilities. The starring roles in this highly speculative, but potentially real scenario will be nanotechnologies.

Nanotechnologies will also change the face of energy, the environment, agriculture, communications and manufacturing. But, although we probably all aspire to better health a cleaner environment, or cheaper goods, we often disagree about the means by which we are prepared to achieve this. That is, how should we apply these powerful technologies?

What is nanotechnology

When you play with nanotechnologies you enter the quantum world where the laws of physics are distorted. A nanometer is one billionth of a metre, down almost to the level of atoms. Nanotechnologies involve manipulating matter (atoms and molecules) at the nanometer scale to create stuff that is useful for us.

Why nanotechnology

The behaviours and properties of materials can change at the nano scale. Magnetism, electrical and heat conductivity, strength, toxicity, chemical reactivity, sensitivity to pressure and temperature are the sorts of properties or behaviours that can change. These can be exploited to create a staggering array of technologies that will be useful in the fields of medicine, agriculture, manufacturing, communications and the environment.

Risk

All new and existing technologies have risks and nanotechnologies are no exception. How acceptable these risks are will differ between people. The question for us, as a society, is what is the most acceptable way to manage any risks and use these technologies to create the society we want to live in?

The following will take you on a swashbuckling journey into the imaginations of scientists and futurists researching and pondering ways to use nanotechnologies. Some will border on the science fiction; many are already in the lab and likely to become reality in the next decade or two – or sooner.

Medicine and health

Will humans go cyborg, where flesh, metal and microchip merge? Futurist Ray Kurzweil predicts human existence will, in the next few decades, undergo a large evolutionary leap because of nano and biotechnologies. Technology will become more integrated with our bodies. Kurzweil expects neural implants — effectively computer chips in our brains — that will allow devices to be plugged directly into our heads, giving us access to information as well as unprecedented information-processing powers[1].

Kurzweil also predicts that by 2030, we will have reverse engineered the brain, providing novel insight into how human intelligence works, and no doubt a new understanding of ourselves.

Ever thought SCUBA diving or marathon running was too much like hard work? One scientist has proposed theoretical designs for a nanorobotic red blood cell (respirocyte) that can deliver 236 times more oxygen to the tissues than natural red blood cells. He estimates that replacing ten percent of your red blood cells with respirocytes will enable you to do an Olympic sprint for 15 minutes without taking a breath, or stay underwater for four hours[2].

These technologies are one day likely to become reality, however, cyborgs and respirocytes are speculative, blue-sky stuff requiring knowledge we don't have yet. The following is based on early, but real research happening in laboratories today.

Brain boost

Artificial neurons made from carbon or polymer-based nanotubes (cylinders just a few nanometers across and only micrometres long) are being investigated as replacements for damaged neurons in people with diseases such as Parkinson's and other neuronal disorders[3]. Of course, there are alternative applications. What the futurists see is this technology used to enhance our cognitive abilities by tweaking existing neurons or establishing new connections. For instance, to increase intelligence, think faster or with greater clarity, and improve memory[1].

Killing cancer

Research groups worldwide are finding different ways to create and use nanoparticles to treat cancer. The nanoparticles can be based on a number of elements such as gold, diamond, carbon, iron, or biological polymers such as small peptides.

Similar to a 'smart bomb', the particles can be designed to attach specifically to tumour cells. The particles might be carrying a payload of cancer-killing drugs that are released when attached to the tumour cell, or they may heat up when exposed to specific wavelengths of light, which then kill the cancer cells. Other particles might carry DNA into cells which can switch off genes that make cells cancerous[4].

Smart bombs

Professor Frank Caruso at the University of Melbourne is developing a new class of disease-seeking, drug-carrying microcapsules that range in size from three micrometres down to 300 nanometres. The capsules are composed of multi-layers of polymer building blocks that are linked together by a molecule that stabilises the polymer layers, but can also be customised to allow the microcapsule to degrade in the environment specific to where you want the drug released. For example, this might be in the presence of blood clots, or even in particular compartments inside a cell. These capsules can also be designed to carry tumour-specific antibodies allowing targeted treatment of various cancers[5].

Issues

Nanoparticles are tiny, often less than 30nm. This means many can easily enter cells, which is sometimes the intention in medical science. There is concern that some nanoparticles might be toxic to humans and other living things. Silver, for instance is used as an effective anti-microbial when embedded into everything from medical bandages to socks. But what is the fate of these silver nanoparticles once they enter the environment? Will they be detrimental to microbial life in soil and waterways?[6] Will nanoparticles used in drug delivery accumulate in cells and disrupt cellular function, or will the body break them down and remove them? The answer will differ for each nanoparticle and its application. Laboratory research has also indicated that certain nanoparticles can damage DNA even when there is a barrier between the particle and cell, but whether this will be able to be replicated in a human body and what level of exposure to these nanoparticles is required for irreparable damage to occur in still to be determined[7].

Stuff to think about

What are the goals for nanotechnologies in medicine: longer life, healthy life, elimination of all diseases, better brain power, fair and reasonable access to these technologies, however they are used?

With an increased knowledge of the brain and intelligence will likely come a more profound understanding of what it is to be human. Are there implications to tampering with intelligence or other cognitive abilities – either permanently through the integration of artificial neurons, or by genetic design that will mean any trait is passed onto the next generation, or temporarily with drugs? Will this mean we will need to redefine what it means to be human?[8]

What is an enhancement (as opposed to therapy) and who decides? Is there a difference between human enhancement as described above and our use today of computers, mobile phones and other technologies to enhance our lives, or drugs we take to change or enhance mood and cognitive abilities? Is there anything wrong with trying to improve human capabilities? That is, we as humans have always attempted to improve our physical and mental capabilities; is the use of nanotechnologies just an extension of this and is this part of being human? Is anyone harmed by doing this?

Will living longer change the fabric of society? For example, if nanomedicine helps extend the average human life span even twenty healthy years (Kurzweil and others are predicting even longer lifespans – some even suggest humans could become immortal), the family structure will change – an extra generation will need to be considered and there are likely to be significant effects on care responsibilities, life plans such as retirement age or starting a new career at 60, marriage and family planning, social and political institutions such as Medicare and superannuation are likely to be affected.

Who will have access to these technologies? Will we create a new class divide of the enhanced and un-enhanced? Are such technologies likely to exacerbate or reduce unjust inequalities? What about the rights of children? Do parents have a right or obligation to adopt such enhancement technologies for their children?

Computer power

Quantum mechanics drops you into a world of multiple realities, absolute uncertainty, and the potential for computers that will probe and help unravel the most complex and mysterious aspects of our universe. Such computing power will also allow instant collation, synthesis and analysis of information from databases worldwide. Computers linked to mobile insect-sized surveillance devices will track and download all your movements, your conversations and interactions with others. Your whole life will be stored on something the size of a memory stick, including your medical history and genetic profile that will reveal who you are: your features and foibles; your susceptibilities such as likelihood of getting cancer or heart disease; your tendencies for criminality, drug addiction, or psychoses. Your fridge and home heating will talk to your mobile and public utilities. And all this information will potentially be accessible to others.

On the social scene, as computer memory and processing power increase, new modes of information exchange andsocial engagement will immerse human interaction into virtual worlds that are as rich and socially complex as our physical world today…wait, this is already happening.

Swarm intelligence

Nanobots are often imagined as nano-sized, autonomous machines that roam the body curing all ills. Again, the rapid advances in science make this likely someday. Closer to reality are insect-sized robots that use nanotechnologies to fly, see, monitor or detect, report and make decisions based on what is happening in their environment. One European research team referred to as the I-SWARM project is developing ant-sized bots that will mimic the behaviour of social insects such as ants and termites. One of their robots alone is a physically simple beast. But put lots together that can communicate and interact with each other and you generate complex behaviours or what the researchers have coined 'swarm intelligence'. A swarm of bots could be programmed for a variety of applications, such as surveillance, micro-manufacturing, medicine, even cleaning[9].

Bee bots

Ever wondered how a fly can lazily avoid your swat or perform a pin-point landing on the tip of your kebab? Insects manage a lot of complex flight behaviours with a relatively simple brain. Researchers at Australia's ARC Centre of Excellence in Vision Science are beginning to unravel this ability using bees as their model and reverse engineering this capability to give vision, and greater autonomy to robots.

Their research has already led to the development of stereo vision to enable unmanned aircraft to see their way around obstacles in very low-level flight. The team has also collaborated with the US space agency NASA on the use of visual navigation for the tiny unmanned aircraft that are envisioned as the main explorers and mappers of the planet Mars.

Issues

Surveillance technologies and advances in medical diagnostics are likely to increase the amount of sensitive personal data that will be available on electronic databases, data that, with the aid of massive computing power, can be instantly mined and synthesized. This exposes real threats to civil liberties. Who should have access to this information and who will control access to it?[10]

Stuff to think about

Would you be prepared to potentially forgo some of your privacy if it meant such surveillance and computing power could lead to a safer world with less crime, terrorism, and more sophisticated medical care? Which applications and under what circumstances would these technologies be acceptable or unacceptable?

Information technologies have already altered social interaction. Twitter, blogs and chat rooms on the web have made, by accident or design, large amounts of personal information accessible to anyone with a computer. It has also meant physical proximity has become less crucial to communication. With the envisaged computing power, how will we socialise in the future and what changes will this bring to society?[8]

Energy and Environment

Quantum dots, carbon nanotubes and a range of other nanomaterials and ideas are being researched and tested to make thin, flexible solar panels made of plastic and unrolled like cling film, make batteries the width of human hairs, extract energy from carbon dioxide, construct ultra-sensitive detectors that can sniff out even single molecules of apollutant; and design more effective and inexpensive technologies to recycle water and clean up contaminated sites.

Diagnostics: The relatively large surface area of nanoparticles means they are more reactive and potentially therefore extremely effective at detecting specific molecules. Thousands of tiny detection and diagnostic devices could be permanently installed in unobtrusive places throughout populated areas or embedded within insect-sized nanobots on continuous patrol monitoring everything from air quality and industrial discharges to viral and bacterial pathogens such as flu virus or biological warfare agents.

Energy storage: All batteries use chemicals that are harmful to the environment. Imagine a battery made using a virus that is about half the size of a human cell and uses relatively non-toxic materials. A team at the Massachusetts Institute of Technology says it can build one. The initial idea is to use them to power medical implants, but if they can be scaled up then they could be incorporated into cars and computers where the battery will become part of the actual panel work. They might even be used in clothing[11].

Here comes the sun: We have more than enough sunlight hitting the earth to supply all the world's energy needs. Nanotechnologies are a vital link to tapping that energy and making it accessible to anyone. A consortium of Australian researchers including CSIRO and the University of Melbourne is only a few years away from making ultra-thin, flexible plastic solar cells on a machine similar to a printing press. Nanolayers of plastic form the solar cells to convert sunlight to energy. Initially, these plastic solar cells will only be about five percent efficient at converting sunlight to energy, compared to today's silicone-based solar cells which have efficiencies of about 15 percent. But because the plastic solar cells will be extremely cheap to manufacture even five percent efficiency is significant because they can be used to coat walls, roofs and even the casing of electronic devices – any surface you can think of really.

Cleaning up: Australia has an estimated 100,000 sites contaminated with a range of pollutants. Engineered nanomaterials have the potential to help clean them up and filter water to produce potable water for drinking. University of South Australia scientists have developed tiny particles of silica (sand) with a nano-thin coating of an active material that strips out bacteria and other contaminants from water to make it safe for drinking.

The larger surface area of nanoparticles also makes them a splendid sensor device. In water, for instance, it is possible to detect levels of pesticide, antibiotics, carcinogens or other pollutants to the level of one nanogram per litre – or one gram in a billion litres (2500 Olympic-sized pools), which is equivalent to detecting about a half of one kilogram in Sydney Harbour.

Zero Valent Iron (ZVI)

A nano form of iron known as zero valent iron (nZVI) has proven to be effective at detoxifying some of the nastiest environmental pollutants in soil and ground water, and in most cases it does this quicker and more effectively than anything tried so far.

For example, nZVI can bind arsenic irreversibly up to ten times more effectively than micron-sized particles. Tests have shown 99 percent removal of arsenic from samples. The iron and bound arsenic can be separated from the water with a magnetic field[12]

Issues

Nanoparticles are thought to have few risks while encapsulated in a matrix such as the thin-film solar panel. But there is a lack of research on the fate of nanoparticles and their effects on human and environmental health when they are free in the environment, for instance when the solar panel is disposed of or when free nanoparticles, such as nZVI, are used in remediation. To understand and quantify the potential risks, the mobility, bioavailability, toxicity and persistence of manufactured nanoparticles need to be studied in the environment. One of the main obstacles to achieving this is that we have yet to develop standard methods to readily detect and monitor nanoparticles in the environment[13].

Stuff to think about

How will these technologies be deployed, should they become scientifically and commercially viable? Will the people who need them most, such as those without clean water, be able to afford them?

When do the risks of technologies that might help remediate contaminated sites, especially contaminated ground water that has mobile pollutants, become acceptable?

Risk assessment research

Scientists have a tougher than normal task when it comes to studying the toxicity of nanomaterials. A nanoparticle's size, shape and other physical properties such as crystalline structure or the presence of other molecules attached to it can influence their toxicity. This can make it hard to know what you are studying, especially when even small changes in experimental conditions can sometimes produce dramatically different results. This is difficult enough in a controlled lab environment, but exacerbated when you step outside the lab. It makes any toxicity test hard to validate.

To overcome this, a lot of research is focusing on a few key areas that include developing a way to determine what physical and chemical properties of nanomaterials make them hazardous, and life-cycle assessments of nano-products to understand the long-term safety of products containing nanomaterials.

There are a number of Australian research groups investigating toxicology and risk assessment associated with nanotechnologies. CSIRO is one of these.

Nano at CSIRO

CSIRO is trying to identify, understand and minimise the risks associated with the development of nanotechnology-based products by investigating the following:

• The life-cycles of nanoparticles used in CSIRO research to identify where humans and the environment may be at risk from exposure

• Monitoring workplace exposure to nanoparticles

• Determining the impact on human health upon workplace exposure, and from use of products containing nanomaterials

• Determining the fate and transport of nanoparticles in the environment

• Determining nanoparticle toxicity to ecosystems in soil and water

• Fully characterising the properties of nanoparticles and determining the nanoparticle metrics associated with any toxic effect

• Developing a set of human and environmental predictive models for the toxicological effects of nanomaterials.

CSIRO sunscreen safety research

One specific CSIRO project is investigating the health and safety of sunscreens and cosmetics containing metal-oxide nanoparticles. Their experiments will determine if these nanoparticles penetratethe skin when used under normal conditions; if there are any health effects from the long-term use of these products, and what the long-term fate of these nanoparticles is in the Australian environment, for example, are there risks to living things from waste disposal, spills or general dispersion in the environment.

There is concern that the small size of the metal-oxide nanoparticles might allow them to penetrate human skin and enter the body. If they are capable of doing this it is possible the particles might enter living cells and disrupt cellular function.

Results from the various studies should be available between early 2010 and mid 2011

Stuff to think about

Values and beliefs play an important part in informing views and appropriate responses to issues. Often this involves contrary views that will not be resolved by facts and education8. In other words, we all assess risk differently, therefore what constitutes an acceptable risk will differ between people.

Based on your personal perceptions of risk and benefit, which nanotechnology applications can help society to flourish in a socially just and environmentally sustainable way? How do we decide what is socially just and sustainable?

Regulatory agencies

In Australia, the regulation of nanomaterials falls under the jurisdiction of a number of departments and agencies. In the environmental field, the most relevant are the Department of Environment, Water, Heritage and the Arts, and the National Industrial Chemicals Notification and Assessment Scheme (NICNAS). The NICNAS Nanotechnology Advisory Group (NAG) advises the NICNAS Director on regulatory and safety impacts of industrial nanomaterials. The group's members are drawn from industry, community, academia and NICNAS.

Other regulatory agencies include the following:

Therapeutic Goods Administration

SafeWork Australia

Food Standards Australian New Zealand

Stuff to think about

Nanotechnology provides many opportunities that must be explored from an ethical perspective, and these go beyond just the negative issues. For example, which nanotechnologies deserve to be given precedence in research policies: those that might solve energy supply problems, clean drinking water or other environmental issues?

Because ethical decisions are often driven by different values, it is important that a broad range of perspectives is heard on the uses of nanotechnologies. This may mean that sometimes a consensus can't be reached.

Web sites

NICNAS: www.nicnas.gov.au

CSIRO: www.csiro.au

DIISR: www.innovation.gov.au

NanoSafe Australia: www.rmit.edu.au/nanosafe

SafeWork Australia: http://safeworkaustralia.gov.au/

Food Standards Australia New Zealand: www.foodstandards.gov.au

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More information

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