Nanoethics and the purpose of new technologies

Talk delivered at 'Materials Choices' symposium
Royal Society for Arts, London, March 2003

I apologize for the banality of the question with which I want to begin, but I do hope to convince you that asking it is not simply a matter of solipsistic navel-gazing.

The question is this: What is science?

I'd venture to suggest that many working scientists will give an answer somewhat along the following lines, which I found in a book about scientific ethics:

> Science pursues the truth of general physical law, attempting to uncover underlying principles that govern the natural world.

That is to say, science is about understanding how the world works.

I decided to test this by taking a look at the most recent issues of the top journals in physics and chemistry: *Physical Review Letters* and *Journal of the American Chemical Society*. I wanted to know how many of the were concerned with telling us about how the world works, within the classical model of science exemplified by the likes of Galileo, Newton, Darwin and Lavoisier. This is not an easy thing to define, but I decided to divide the contributions into three categories:

1. Papers that explore the behaviour of systems that exist in nature, or of model systems designed to mimic those one might encounter in nature.
2. Papers that studied systems created artificially in the laboratory, for which there are no known natural analogues, and for which the objective is not to elucidate some general principle about, say, chemical bonding or statistical mechanics but to increase our understanding of specific human-made systems. Often this will have a particular applied motivation: for example, to understand the behaviour of quantum dots for information technology, to make improved superconductors or drug molecules.
3. Papers that report techniques and new methods of scientific analysis.

The results were as follows:

PRL:
Category 1: 21 papers
Category 2: 36 papers
Category 3: 4 papers

JACS:
Category 1: 2 papers
Category 2: 44 papers
Category 3: 3 papers

In other words, this little exercise suggests, ridiculously crudely, that about a third of physics and about 4 percent of chemistry is about understanding how the world works. Most of the remainder is about understanding how to make things, and how the things we've made function.

I always suspected that our canonical image of science – the one that is commonly peddled to the public – is very misleading when we talk about chemistry in particular. I had not, I confess, anticipated just how obscenely inaccurate it is. I suspected, knowing how the majority of physicists do not work at CERN but are instead involved in condensed-matter research, that the Galilean paradigm is not a good one for physics, but again I was surprised to see how little of modern physics has the character that we commonly tell people it has.

What is wrong, then, with our popular picture of science, and what has this got to do with ethics?

My point is simply this: if we misrepresent what science is, we prevent any serious debate about the responsibilities of scientists.

The classic argument divides science into the pure and the applied, or more stridently, splits science away from technology. Lewis Wolpert – who, it must be said, is hardly a democratically elected spokesperson for science but is nonetheless one of the most prominent 'voices of science' in the popular media – is quite explicit about this. He says:

> Technology is not science… Science produces ideas whereas technology results in the production of usable objects…

Once one accepts this distinction, Wolpert's conclusions about scientific responsibility are a natural corollary:

> [Scientists] have no more responsibility than other citizens… since scientists are providers of knowledge, they have an obligation to report the implications of that knowledge; but the implementation, the application, of that knowledge is a social and political decision which it is not for them to take. In these terms, science is not responsible for misapplication of knowledge.

Wolpert then worries that this might rob scientists of their due credit when they come up with something we like, such as antibiotics. He says,

> How, then, can we give credit to science for its positive applications? The answer, I think, is that knowledge, in the scientific sense, is intrinsically good.
> [All quotes are from L. Wolpert (1992), *The Unnatural Nature of Science*, Faber & Faber, London.]

Now, although this may all be laughable to those who think carefully about the social responsibilities of science, I think it is essential to remember that it is not at all laughable both to a great many practising scientists or to many commentators in the media. Sadly, I suspect our duty is not just to say what we think but to try to say it at least as loudly as people like Lewis Wolpert.

One person who was able to do that in the past was Peter Medawar, whose dissection of this fatuous division between science and technology is so incomparable that I have to put it in his words:

> Francis Bacon was not the first to distinguish basic for applied science, but no one before him put the matter so clearly and insistently, and the distinction as he draws it is unquestionably just… Bacon's distinction is between research that increases our power over nature and research that increases our understanding of nature… Unhappily, Bacon's distinction is not the one we now make when we differentiate between the basic and applied sciences. The notion of *purity* has somehow been superimposed upon it, and in a new usage that connotes a conscious and inexplicably self-righteous disengagement from the pressures of necessity and use. The distinction is not now between the empirically founded sciences and those whose axioms were supposedly known a priori; rather it is between polite and rude learning, between the laudably useless and the vulgarly applied, the free and the intellectually compromised, the poetic and the mundane.
> [P. Medawar (1984), 'Two conceptions of science', in *Pluto's Republic*, Oxford University Press.]

(And Medawar goes on to add, irresistibly, "Let me say that all this is terribly, terribly English.")

The absurd thing is that even the most casual glance at journals like *PRL* and *JACS* will show you at once that the distinction between pure and applied science is totally unworkable. We can see scientists shifting constantly between those two within a single paper, even a single paragraph, sometimes even within a single sentence. In fact, according to Lewis Wolpert's definitions, most of what is published every week in *JACS*, and by implication in most of chemical research, is not science. Chemistry is barely a science. Physics is perhaps half a science, at best. It probably goes without saying what this implies for materials research. We tend to accept a definition of science that excludes most of what we would all recognize as science.

And so I want to suggest an alternative. Can we not simply say that *science is what scientists do*? After all, that is how art defines itself today. Scientists are often the first to demand that religion be held accountable for the actions of its churches, and not seek to exonerate itself by saying that those actions conflict with what the holy books say. So if we must have a definition of science, let it be an empirical one, not some lofty dogma that bears no relation to the daily practice.

Only when we accept that science is so intimately bound up with the task of devising and making the artificial can we begin to talk clearly about responsibilities.

I want to emphasize the link between what we are making and what effects it will have. This seems blindingly obvious, but I realised that it may not be so after reading the book I mentioned earlier called *Fundamentals of ethics for scientists and engineers*. I won't mention who the authors are, but I will say that the book contains a lot of perfectly valid discussion about issues such as personal conduct in a research establishment, risk and safety, whistleblowing, privacy, intellectual property, conflicts of interest, publication and plagiarism and so on. Nowhere did it appear to suggest that scientists or engineers (the two being very clearly distinguished) should ask themselves: 'Why am I doing this research? Who will benefit?'

Let me stress that I certainly do not think it should be a criterion of scientific research that it be to someone else's material benefit, any more than that should be a criterion for creating literature or music or philosophy. I don't demand to see practical benefits from research into Bose-Einstein condensation or lanthanide compounds. But given that so much of scientific work has in mind, at some distant stage, at the end of the road, an artifact, is it not reasonable for the scientist to wonder how the world might be changed by that artifact?

This has become a contentious question in the emerging science of nanotechnology. (Now there's a curious thing: a science that calls itself a 'technology'…) Nanotechnology is a difficult field to define, and indeed that is part of its problem. It is commonly suggested that nanotechnology is all about making machines and devices at the scale of nanometres, the size of molecules: a nanometre is a millionth of a millimetre. Actually the field is considerably more diverse than this, and I think one can be no more precise than to say simply that nanotechnology is about investigating, manipulating and engineering matter on scales of less than a micrometre. This includes – and I say this purely for illustrative purposes – such things as making chunks of materials of nanometre dimensions, called nanoparticles, which can be used for example as fluorescent tags to track molecules in cells or can be assembled into polycrystalline metals with new and interesting properties; making molecules that function as mechanical devices; shrinking the scale of microelectronic circuits further below the roughly 100-nm size limits on device dimensions. Nanotechnology has the same creative diversity as our everyday macroscopic technology, but exercised at a much smaller scale, beyond the resolution of the human eye.

To this extent, nanotechnology as an applied science is not obviously anything other than a continuation of existing trends in current technology and manufacturing: trends that seek increasingly fine control of the physical and chemical processes involved, and increasing reductions in scale. In microelectronics, for instance, the well-known observation called Moore's Law identifies the way that the scale of integrated circuits has shrunk at a steady rate over the past three or four decades such that the number of components on a chip has roughly doubled every 18 months. A similar trend exists in the data storage density in computer magnetic memories. Mechanical engineering too has become possible at ever smaller scales with the introduction of microelectromechanical systems (MEMS), and microfluidics technologies are making it possible to conduct chemical engineering, synthesis and analysis at ever smaller scales. Nanotechnology seeks to carry trends like this down onto the next rung of the ladder.

But it is natural and indeed wise to ask whether nanotechnology makes entirely new things possible, and if so, what the consequences of this might be. There is some concern that nanotech raises novel and unique dangers, and the most familiar of these, in the public arena at least, is the notion of grey goo.

When nanotechnology first began to become a buzzword in the early 1980s, scientists began to think what might be achievable if one could carry out manufacturing at the molecular level, putting together structures by the precise placement of individual atoms or molecular fragments. This is of course essentially how molecular biology operates, by using those molecular machines called enzymes to cut molecules apart and paste them together in ways that are highly specific and selective. Eric Drexler in the US retained this general notion but proposed a very different physical realization of it with his idea of the molecular assembler, a nanoscale robotic device that operated rather like the robots on a car assembly line. They would pick up these atoms and molecular groups and slot them into position in some nanoscale structure. Atomic manipulation with the scanning probe microscopes in the late 1980s appeared to make this look like more than science fiction. But the problem was how one could make anything so incredibly intricate as a robotic nano-assembler, or nanobot, in the first place.

Drexler's idea was that they would make themselves. That's to say, one could ratchet up the ladder of complexity from crude prototypes to reliable nanobots that could put together copies of themselves, given the necessary raw ingredients. They'd be capable of replication. But he pointed out that if these replicating nanobots were to get out of hand, they might start pulling apart everything in their path and restructuring it into new nanobots, proliferating exponentially. Drexler imagined this mass of mindlessly replicating nanoscopic machines as a grey goo.

The 'grey goo' problem has become one of the most talked-about worries in nanotechnology. It has clearly caught hold of the public imagination as a possible scenario for technological Armageddon. Bill Joy, the chief scientist of the microelectronics company Sun Microsystems, gave this image some very prominent free advertising in 2000 when he wrote about it in *Wired* magazine after having read Drexler's book *Engines of Creation*. Joy asked whether there are some strands of scientific research, nanotech being one of them, that pose dangers so grave that we should voluntarily forgo pursuing them. Even the astronomer royal Sir Martin Rees has speculated about whether humankind might in this way sow the seeds of its own destruction through nanotechnology. The Hollywood appeal of grey goo is revealed by its appearance as the villain in Michael Crichton's current best-selling thriller called *Prey*, where it is created in a research lab and threatens all of humanity until wiped out by the hero in a conventional blitz of pyrotechnics.

So far, so silly, but that hasn't stopped grey goo from presenting something of an image problem for nanotechnology. Concerns of this nature were one of the reasons why the environmental group called ETC, based in Canada, called for a moratorium on nanotechnology at the World Summit on Sustainable Development in Johannesburg last year. The government's science minister Lord Sainsbury has also expressed private concerns over this aspect of nanotechnology, and I suspect that it is one reason why the government recently commissioned a report on the potential dangers and ethical questions of nanotechnology by the Better Regulation Task Force.

All of this ignores the fact that scientists working on nanotechnology don't take grey goo seriously at all. I don't think they are being complacent about this. Drexler's replicating nanobots are so unlike anything any serious scientist is currently trying to make, or has any real idea *how* to make, that the idea seems to be pure fantasy. Some leaders in nanotechnology, such as Richard Smalley at Rice University and George Whitesides at Harvard, think that Drexler's approach to nanotechnological fabrication – basically a very literal-minded downscaling of macroscale engineering that pays little heed to the possibilities and limitations of chemistry – is fundamentally flawed. Whether that's so or not, it is fair to say that most nanotechnologists think there are better ways of building structures and devices at the nanoscale. Even those chemists who are considering how to make molecular nanostructures that can truly replicate are doing so in a totally different way that seems to preclude the possibility of the process proliferating out of control.

Scientists are certainly capable of under-estimating risk, but everything I have seen about nanotechnology persuades me that grey goo is not a concern. Or rather, that it is a concern precisely because it is a chimera and so risks focusing attention on the wrong issues. If discussions about the ethics and dangers of nanotechnology become fixated on a worry that exists only in science fiction, we have a serious problem.

That's precisely the concern raised in a recent paper in the journal *Nanotechnology* by a team of scientists at the Canadian Joint Center for Bioethics [A. Mnyusiwalla, A. S. Daar & P. A. Singer, 'Mind the gap': science and ethics in nanotechnology, *Nanotechnology* **14**, R9-R13 (2003)]. It warns that there is a paucity of serious, published research into the ethical, legal and social implications of nanotechnology. The paper implies that unless the scientists involved in nanotech research take the lead in airing these implications, there is a real possibility that the public and governments will latch onto fictitious dangers flagged by the likes of apparently authoritative but in fact ill-informed general commentators like Bill Joy, and try to rein in the discipline in any case. The authors of the report warn that "there is a danger of derailing nanotechnology if the study of ethical, legal and social implications does not catch up with the speed of scientific development."

It's pertinent to ask why this should be so. After all, there have been plenty of scientific developments that, while in retrospect did carry potential hazards, nevertheless emerged in an atmosphere of either benign public trust or utter indifference. But we now live in a different world, with a heightened public distrust of new science and technology highlighted by the debates that have raged about genetic modification, cloning and stem-cell research. It is significant that the authors of this Canadian paper are essentially *bio*ethicists, who have an awareness of the urgent need for ethical discussions of new technologies. Physical scientists have not previously felt the impact of this new cultural climate.

As a result, the ethics of nanotechnology have not really been addressed even when funds have been specifically allocated for doing so. In 2001 the US National Nanotechnology Initiative allocated between $16 and $28 million for the study of its societal implications, but only about half that budget was used.

‘Mind the gap’ does a valuable job of identifying some areas of nanotechnology that genuinely do need to be debated from an ethical perspective. For example, it raises the issue of equity, asking: ‘who will benefit from advances in nanotechnology?’ Nanotech offers potential benefits in area such as biomedicine, clean energy production, safer and cleaner transport, and environmental remediaton: all areas where it could be of help in developing countries. But it is at present mostly a very high-tech and cost-intensive science, and a lot of the current research is focused on areas of information technology where one can imagine the result being a widening of the gulf between the haves and the have-nots.

Other groups, such as Greenpeace, are raising similarly broad-based societal questions about NT. Is it primarily about wealth creation, or improving our quality of life, or something else? Who is developing it, and why? With what responsibility, justification and accountability? Who deals with potential problems, and how? Is there, and should there be, a public mandate for it?

One specific area of concern is the environmental safety of nanoscale materials. Some people have asked whether the ultra-small particles and fibres that nanotechnology produces, such as carbon nanotubes, might become the new asbestos. Or perhaps they might, by being taken up by bacteria, enter the food chain and accumulate in cells. These are valid questions, and haven’t yet been extensively explored – perhaps in part because they look rather far from the cutting edge of the discipline. And there is arguably some urgency about these issues, because nanoscale materials are already being used commercially – for example, nanoparticles of titanium dioxide are used as UV absorbers in suncreams. These particles also absorb and concentrate toxic heavy metals such as cadmium. Because the materials from which nanoparticles are made (carbon, for instance) are generally regarded as safe at the macroscopic level, there is currently no need for them to be registered as new chemicals. But because their properties and dispersal mechanisms, such as their ability to enter into cells, might be quite different from macro materials, there is no guarantee that problems of bioaccumulation and toxicity might not arise purely on account of their size. This may of course turn out not to be a problem at all, but we cannot take that for granted. The US Environmental Protection Agency has now allocated funding to the study of the environmental impacts of nanotechnological products. They are being studied, for example, at the Center for Biological and Environmental Nanotechnology at Rice University, one of the hubs of nanotech research, where the effects of nanoparticles on the toxicity and transport of environmental pollutants such as heavy metals are being investigated.

There is a huge military interest in nanotechnology, particularly in the USA. Some of this is stimulated simply by the prospect of better electronics – faster, more compact, more robust – with all the implications that has for improved communications, missile guidance and so forth. But there are also possibilities for developing new weapons or new systems for offensive combat. The US army has established a $50 million nanotech research centre called the Center for Soldier Nanotechnologies at MIT, which makes its ambitions very plain: 'Imagine the psychological impact upon a foe when encountering squads of seemingly invincible warriors protected by armour and endowed with superhuman capabilities, such as the ability to leap over 20-foot walls.' All this is sold with Robocop-style images of 'performance-enhanced' soldiers in nanotechnological battle gear – images that, it turns out, were lifted directly (and without permission) from a sci-fi comic book. Even setting aside questions of ethics, you have to wonder whether this kind of nanotechnology is seriously concerned about disentangling science fiction from reality.

There is fertile ground here for growing spectral fears of incredibly high-tech nanotechnological terrorism that ignores the stark effectiveness of the decidedly quick and dirty methods that seem to be on today's menu. So we need to be careful about how much paranoia is really warranted by military nanotechnology. The real implications of 'soldier nanotechnologies' for international relations and security may, like missile defence systems, lie more with the concept than with the physical realization. More immediately relevant, perhaps, are questions that arise from the potential of nanotechnology in developing surveillance systems that could be almost invisible or undetectable.

The authors of 'Mind the gap' say that suggestions of a moratorium on nanotechnology should be a 'wake-up call'. They say that it is essential to close the current gap between the science and the ethics of nanotechnology, and propose that the lessons of genomics and biotechnology might be usefully applied. For example, it is important that 'nanoethics' should not become a ghetto more or less unconnected to the major scientific players or the relevant industries, that this field should be global in extent and include the voices and the needs of developing countries, and that the importance of public engagement should be recognized. These all seem to me to be worthwhile suggestions. But I am struck by how more or less all of the concerns and recommendations raised by this paper and by the recent Better Regulation Task Force report are not at all specific to nanotechnology. Questions about safety, about equity, military involvement and openness are ones that pertain to many other areas of science and technology. It would be a grave and possibly dangerous distortion if nanotechnology were to come to be seen as a discipline that raises unprecedented ethical and moral issues – in this respect, I think it genuinely does differ from some aspects of biotechnological research. Nanotechnology is, after all, not a monolithic enterprise with a single, well defined goal. Yet it is perhaps the first major field of science, applied science or technology – call it what you will – to have emerged in a social climate that is sensitised in advance to the need for ethical debate in emerging technologies. We have seen – for example with stem-cell research – what the deleterious consequences can be for a science that has failed to provide a fully informed environment within which to evolve its aims and objectives. If nanotechnology is to avoid that fate, it needs not only to tell people why it exists but to think about that question very carefully for itself.

I am concerned that if we were to begin convening committees to oversee the ethical dimensions of nanotechnology, they will take the soft option. They will set in place guidelines for health and safety, good industrial practice, environmental responsibility and so forth – all important issues, and urgently needed – while sidestepping the wider and more difficult questions that have been raised: who is doing this, and why, to what end, and for whose benefit? Scientists do not feel comfortable addressing these things, while businesses are more actively unwilling to hear them. On the other hand, I am not really sure that they *are* issues that can be addressed adequately from within the, in this context, narrow scope of nanotechnology. Nanofabrication methods are likely, for example, to introduce still greater increases in the power and pervasiveness of information technology, but they are in this respect merely a tool, and they may merely sustain existing trends in this direction. That debate is surely one that needs to happen around the information technology industry itself, not among people working specifically on nanotech. Likewise with questions about technological enhancement of the capabilities of the human body. If these things were to come to be seen as concerns specific to nanotechnology, I wonder if that would ultimately inhibit rather than encourage the public debate about them.

Yet the pragmatic truth is that, if nanotechnology does not acknowledge some kind of ethical dimension, that will be forced upon it in any case. Those working in the field know that nanotech is not really a discipline at all, it has no coherent aims, it is not the sole concern of any one industrial sector. But even funding agencies speak of it as though this were not so. To the public mind, organizations such as the US National Nanotechnology Initiative surely suggest by their very existence that nanotech has some unity, and it is therefore quite proper that people will want to be reassured that its ethical aspects are being considered. If we do not find some way of doing so, we risk letting the matter be taken out of the hands of scientists altogether. If scientists do not do it, someone else surely will.