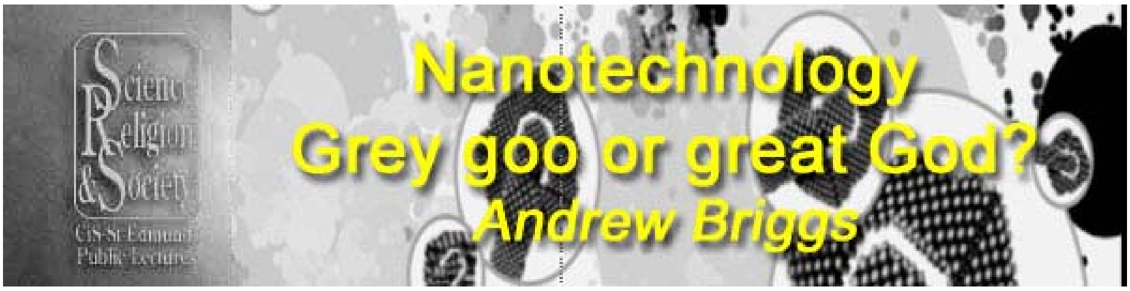


Lecture Contents

Professor Andrews Briggs delivered this lecture on Thursday 10th March 2005 in the Octagon Theatre, St Catharine's College, Cambridge. The lecture was followed by questions from the audience and later a dinner/discussion at St Edmunds College. A transcript of the lecture and the discussion can be viewed in html or downloaded as a pdf file, and an audio recording of the lecture and questions is also available at http://www.st-edmunds.cam.ac.uk/cis.

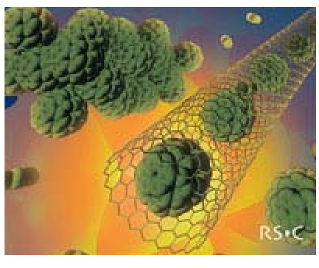
Brief Biography

Andrew Briggs studied for a degree in Physics at Oxford, followed by a PhD at Cambridge in the 1970s. He then did a degree in Theology and went back to Oxford where he is now Professor of Nanomaterials and Director of the Quantum Information Processing Interdisciplinary Research Centre.

Nanotechnology - Grey goo or great God?

Bob White: I would like to welcome Professor Andrew Briggs, who studied for a degree in Physics at Oxford, followed by a PhD at Cambridge in the 1970s. He then did a degree in Theology and went back to Oxford where he's now Professor of Nanomaterials. Today's lecture is on Nanotechnology. We look forward to him telling us both about that subject and about how his Christian faith is related to his work.

Andrew Briggs: Thank you very much indeed, Bob, for the invitation. There are three lectures taking place simultaneously in Cambridge at this moment. One of them is the Archbishop of Canterbury speaking, the second one is that Lord Broers, former Vice Chancellor of Cambridge is giving the Reith Lecture and the third one is just me! I am neither of the other two, so if you thought you were coming to hear the Reith Lecture, or the Archbishop of Canterbury, I shall quite understand if you want to leave now!



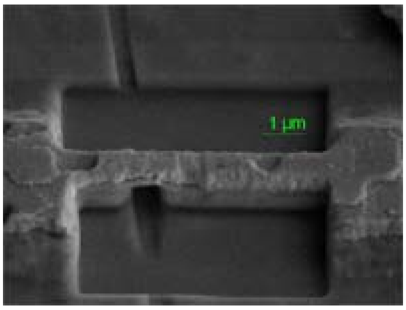
What is Nanotechnology? A report that was put together by a combination of the Royal Society and the Royal Academy of Engineering that came out last summer identified two topics. Nanoscience is the study of phenomena and the manipulation of materials at atomic, molecular and macromolecular scales, where properties differ significantly from those that are larger scale. Nanotechnologies are the design, characterisation, production and application of structures, devices and systems by controlling shape and size at the nanometre scale. I'll talk a little in a moment about what a nanometre is, but loosely speaking people think of nanotechnologies as being around a hundred nanometres or less. They think of nanoscience as the study of materials and systems and devices at that scale, and they think of nanotechnologies as actually manipulating them and doing engineering with them. The key point is that nanotechnology becomes interesting when small is not the same as big, when the very smallness of the materials and structures that you're looking at makes a significant difference to their properties and behaviour.

It is helpful to think of these things on a series of different scales. The diagram shows a metre and then every time we move one tick to the right we divide by ten: that's ten centimetres – a football is somewhere around here – and then as we come down that's ten millimetres, that's one millimetre, there's a little tiny flea that you might be able to see with your eye – I don't know who it came from! Human hair is about 80 thousandths of a millimetre, this is a thousandth of a millimetre, or micrometre. Now we're getting down to blood cells and then even smaller little viruses and so on at a scale of about a tenth of a micrometer - that's a ten-thousandth of a millimetre. A hundred nanometers marks the onset of nanotechnology. Even smaller is the scale of one nanometre, which is one-thousandth of one-thousandth of one-thousandth of a metre, a billionth of a metre. There we've got something the size of sixty carbon atoms which, by a fascinating coincidence, are arranged geometrically in a pattern that maps on to the football over here. Here you've got that scale drawn out, in this case, on a linear scale and we'll look at one or two of these things as we go through. DNA would be down here, close to a nanometre in diameter.

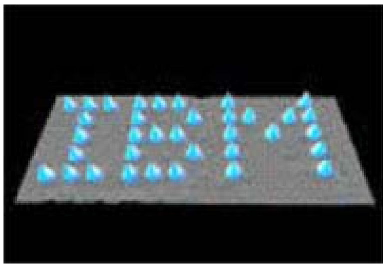
Another way of visualising all that is to zoom out and imagine that we're looking at the earth which is about ten thousand kilometres in diameter. As we zoom in, we can imagine ourselves looking at things in higher and higher magnification. At about two kilometres across we can pick out a football field. As we zoom in on that, we get down to a man about two metres high. This particular footballer has got a flea in his hair – there's this human hair and remember this is 80 micrometres in diameter, 80 thousandths of a millimetre and there's the flea clinging on to it. When the picture is about 1 millimetre across and as we zoom in some more, we begin to see some red blood cells which are about 10 micrometres in diameter. We continue to zoom in and begin to see things like DNA and nanoparticles and now we're beginning to move into the realm of nanotechnology, so now we've had to move away from what you might actually see down a microscope, to ball and stick models. We begin to look more closely still and here is that buckyball, about one nanometre across and with the same pattern on it as the football. We can actually see those buckyballs. Later on I'll show you some pictures but now we're beginning to move into the realm where all you can do is start to draw cartoons. At about a tenth of a nanometre in diameter we're moving to the stage where you could never see a picture like this with any microscope at all, you can only draw cartoons of them, and so on into the structure of an atom. I hope that gives you a picture of how one might zoom in across those different size-scales to get some feeling for where the realm of nanotechnology lies, in this regime from one hundred nanometres down to about one nanometre.

When one thinks about working in this realm of things that are below about a hundred nanometres or so, there are many people who realise that they have been working in this area for years and years without ever calling it nanotechnology at all; for example, the great majority of chemistry is done on that scale. I am reminded of Molière's *Le Bourgeois Gentilhomme* where the tutor is teaching Monsieur Jourdain about how speech works and explains to him what prose is, and Jourdain responds "Well, what do you know about that, these forty years now I have been speaking in prose without knowing it! How grateful I am to you for teaching me that". There may be lots of people around who, for at least forty years, have been working in nanotechnology without ever knowing it and they're grateful now to know it.

Our bodies have used nanotechnology all our lives and there are some remarkable kinds of nanotechnology going on in the body. Your stomach works by marvellous little nanotechnology motors pumping stuff in and out from place to place inside your body. Our muscles, anything that we move when we want locomotion, are a kind of nanotechnology – this little movie illustrates the way that myosin works when your muscles contract and expand. Many of the mechanisms were discovered by Andrew Huxley, who was working in London but living in Grantchester. Those things are found in the natural world, found in our bodies, and some people see amazing design in them; I'll come back to that later. But of course nanotechnology primarily means what we can do and ways that we can engineer things and that has gone from strength to strength in recent years.



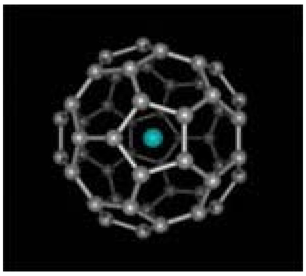
This diagram shows an example of using a beam of gallium ions to cut away a groove in a high-temperature superconductor. This is a scale of about five hundred nanometres and you can see that the ion beams are milling this material with terrific precision; these can be used to do machining of materials on a scale down to about fifty nanometres. A breakthrough in the field came in 1990 when Don Eigler, working at IBM laboratories in Almadon in California, moved individual xenon atoms around on a surface and, because he was working for IBM and perhaps wanted to get a pay rise, he thought a good way to demonstrate it would be to write the IBM logo. Each of these is an individual xenon atom that he's moved to the place where he wanted it to be. That means that fifteen years ago the stage was reached where it was possible to move atoms on a surface to a location of your choice.



One of the great drivers for nanotechnology is the progress that's being made with computers. Babbage's original calculating machine stood about a metre tall, and that has progressed to the transistors and now the integrated circuits that have been in use for thirty or forty years in computers. The question is how much smaller can you go on making them? This is a little device that was made in Tsukuba in Japan, a single electron transistor made with titanium dioxide on a titanium surface. Even this picture is about ten years old now.

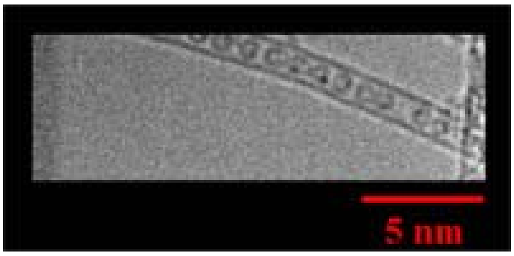
The head of Intel, Gordon Moore, observed that computers were getting smaller and smaller faster and faster and that the number of transistors on a chip was doubling roughly every 18 months. His observation has become known as "Moore's Law"; it's amazing the extent to which that trend has been maintained. Moore's Law is a wonderful thing to show to management because all you do is put a linear scale of years along here and a logarithmic scale of almost anything you like to do with computing up there, and you'll probably get a straight line. If it's something you want more and more of it'll be a straight line going up, and if it's something you want less and less of, like the number of electrons per device, you'll find it coming down. This is the number of electrons per device on a logarithmic scale. By about 2015 or so we'll be getting down to one electron per device. How do you get smaller than that? You're hitting the regime where the quantization of matter is going to make a difference and that's either going to stop you making further progress, or it may turn out to be something that you can exploit.

As an illustration of Moore's Law in practical terms, just over thirty years ago in 1974, Cambridge had one mainframe computer, an IBM 360. The random access memory of the computer was increased from two to three megabytes and it was such a big event that it was the talk of the town; it seemed that everyone in Cambridge was discussing it. The other day I bought a little bit of memory here on this USB stick; it's half a gigabyte, 516 megabytes, and it cost £20. That's a practical illustration of the extent to which Moore's Law is moving us along. Driven by these things and other considerations, people are studying the materials on the nanoscale.



Let me give you an illustration of the kind of thing that we do in our own lab in Oxford. We look at these little buckyballs – here's a cartoon of one – but here are some actual pictures of some. This is a transmission electron micrograph taken in Oxford by Dr Andrei Khlobystov; this is a single walled carbon nanotube with a diameter of about 1.4 nanometres, and each of these objects inside it is one of these little balls made up of sixty carbon atoms.

When you buy your 2006 edition of the "Guinness Book of World Records" you'll not only find an entry from Colin Humpheys' laboratory for the smallest hole, but you'll also find an entry for the smallest test tube. You'll see pictures like this and the reason this is the world's smallest test tube is that we did some experiments where we had a little length of this, about ten nanometres long, and inside it we put five molecules of C_{60} and two or three oxygen atoms. The volume of that test tube is 10 yoctolitres. A yoctolitre is a thousandth of a zeptolitre, so the volume is 0.01 zeptolitres. The number of yoctolitres in a teaspoonful is roughly equal to the number of teaspoonfuls in all the world's oceans. If you actually were to look over the shoulder of Andrei Khlobystov, who took the pictures, this is the sort of thing that you would see in the electron microscope. Here is our single-walled carbon nanotube and then these molecules actually have 82 carbon atoms in them; inside each one of these there is one atom of cerium, so you're seeing one atom of cerium inside a cage of 82 carbon atoms inside this single walled nanotube which is about 1.4 nanometres diameter.



I hope that these pictures give you a glimpse of what real nanotechnology actually looks like, but as you well know there's a great deal of confusion around about nanotechnology, sometimes propagated by people who ought to know better. I would like to tell you a little bit about where this confusion comes from and what its sources are.

Nanotechnology was first popularised by a film made in 1968 of Isaac Asimov's science fiction story *Fantastic Voyage*. I'm told that at the time people went to see it because it starred Raquel Welch! It's the story of some scientist whose work is crucial to the US defence effort who gets some sort of problem or clotting in his brain. The way they decide to solve this is put a scientist and crew – and Raquel Welch – inside a submarine and shrink it down into a size where it can travel along the blood vessels to the brain, where they can fix everything by laser surgery. I did actually watch the film to find out what it's about; I don't recommend it, as it's incredibly boring. There is the obligatory series of crises, for example, when they go through the heart and there's great turbulence. There's a great deal of science that wouldn't work; if you shrunk a laser down to that size, the wavelength would be all wrong.

There was a more recent film called *Agent Cody Banks* made in 2003 and I'll show you a clip from that in a moment. The person who I think has done more to inform – and to misinform – the public about nanotechnology is a man called Eric Drexler who works out of Palo Alto in California. One of his books is called *Engines of Creation*, in which he has all these fantastic machines that are supposed to be assembling things at a molecular level. Many people can't quite decide whether he's a nutter or a harmless enthusiast! These are pictures taken from his book: these are supposed to be individual atoms and here you see this marvellous desktop self-replicating machine. The whole thesis of his early work was that you could create, at an atomic level, self-replicating machines. Most professionals in this field find it so fantastic as to be not worthy of serious credence. The most famous person who has criticised it is Richard Smalley, one of the three people who was awarded the Nobel Prize for the discovery of fullerenes. In Drexler's visions the self-replicating machines are very much smaller than viruses, which are the smallest known self-replicating things in biology and are a great deal smaller than cells. When people talk about what nanotechnology is going to do for us, you get two extremes, one of which is that nanotechnology will save the world. Let me show you this clip from *Agent Cody Banks*. … Well!

The concept of nanotechnology became encapsulated in the public phrase of "grey goo". Eric Drexler wrote in 1986: "As engines of destruction, nanotechnology and other artificial intelligence systems will lend themselves to more subtle uses than do nuclear weapons. A bomb can only be used to blast things but nanomachines and artificial intelligence systems can be used to infiltrate seas or control a territory or a world." And the *American Spectator* wrote that "The nightmare is that combined with genetic materials, and thereby self-replicating, these nanobots will be able to multiply themselves into a 'gray goo' that could outperform photosynthesis and usurp the entire biosphere, including all edible plants and animals." That was 2001. The Guardian commented later that year "Grey goo is a wonderful and totally imaginary feature of some dystopian science fiction future in which nanotechnology runs riot and microscopic, earth-munching machines escape from a laboratory to eat the world out from under our feet". The *Agent Cody Banks* film goes on like this … Well, there you are!

In the novel *Prey* by Michael Crichton the hero Jack discovered his wife's company had created a self-replicating nanotechnology, a swarm of microscopic machines. Originally meant to serve as a military eye in the sky, a swarm escaped into the environment seemingly intent on killing the scientists trapped in the facility. The dust jacket says "Drawing on up-to-the-minute scientific fact, *Prey* takes us into the emerging realms of nanotechnology and artificial distributed intelligence in a story of breathtaking suspense which was read by His Royal Highness Prince Charles". In 2003 the headlines read "Prince Charles fears grey goo nightmare". That phrase doesn't actually appear anywhere in Michael Crichton's book and a year later Prince Charles had to say that he was misrepresented and that he did not believe in self-replicating nanotechnology.

Well, what are we to make of all this and what are to make of it particularly in the Christian perspective? I want to look one at a time at the two areas of nanoscience and of nanotechnology.

As we have seen, there are remarkable examples of nanoscience, both in biological systems and in those that we can create and study in the laboratory. Does any of it make a difference to our understanding of God as creator? To shed a bit of light on this I want to draw out four belief paradigms.

The first one is the position of the agnostic, a term coined by T.H. Huxley in the 19th Century to mean one who holds that the existence of anything beyond material phenomena cannot be known. But although he coined it in that very precise sense, he rather quickly lost control of the word and it came to mean a sort of excuse for sitting on the fence and not making up your mind. The story is told that someone went to Benjamin Jowett, the Master of Balliol in the 19th Century, and proudly told him that he was an agnostic. Jowett replied “Young man, in this university we speak Latin not Greek, and the Latin for agnostic is ignoramus.”

“Atheism” means a disbelief in, or a denial of, the existence of God. The first use of it in the Oxford English Dictionary is from Francis Bacon in the 17th Century, “A little superficial knowledge of philosophy may incline the mind of man to atheism”.

“Deism” is a technical term which apparently was first used by Richard Bentley to mean belief in the existence of God with a rejection of revelation closely allied to the concept of natural religion.

And finally there is “theism”, which the Oxford English Dictionary defines as belief in the deity or deities, as opposed to atheism; and specifically belief in one God as creator and supreme ruler of the universe, specifically in distinction to deism. Atheism does not deny revelation.

I have summarised that in tabular form, in the diagram. You have two columns, one of them is headed *creator* and the other one *sustainer*. *Agnosticism* claims that you cannot know. *Atheism* denies that there is a God at all, so he’s neither creator nor sustainer. *Deism* acknowledges that there is a God who creates everything, but denies that there is any subsequent revelation and denies God’s activity in the world now. And *theism* affirms God’s activity in creation and his activity in the world; indeed there’s really no distinction between the two.

This becomes significant when you try to examine the argument from design. The old argument from design says that the exquisite structure of the world and of animal systems, and we might now say of biomolecular systems, seems to be perfectly intended for their optimum function. What is the origin of this? Paley, early in the 19th Century, used the analogy that if you find a watch on a beach, you would infer that there must be a watchmaker. Charles Darwin said Paley’s work was one of the few things he really benefited from when he was studying here at Cambridge. The argument from design has re-emerged recently in the particular form of so-called intelligent design. There was a tour last year by Philip Johnson, a lawyer and professor at University of California at Berkley, who was touring the UK advocating something rather analogous to intelligent design. Many people have come across intelligent design through a book called *Darwin’s Black Box*, written by Michael Behe, who is a professional biologist by training. Loosely speaking you can say that intelligent design admits that evolution occurs but identifies lacunae in the evidence for evolution, where it says “Ah, you see there, that must have been God working; that shows that there’s an intelligent designer behind it all”. An important component of this kind of argument is that you have to show the inadequacy of the normal scientific study in the field.

In Chapter 1 of *Darwin’s Black Box*, Behe writes “This book is about an idea–Darwinian evolution–that is being pushed to its limits by discoveries in biochemistry…. When sciences such as physics finally uncovered their foundations, old ways of understanding the world had to be tossed out, extensively revised, or restricted to a limited part of nature. Will this happen to the theory of evolution by natural selection?” I’m not sure that many physicists will recognise that old ways of understanding were tossed out by new discoveries and I’m not sure how many biologists would subscribe to that either. But whatever the details, the fundamental misunderstanding is coming from a mistaken kind of view about how God works in the world. Here's a picture of a green circle which encapsulates all observed phenomena; if you have no science at all, then none of it can be explained and so all of it is caused by God. As science progresses you begin to get bits on the left hand side that we can explain and those are caused by science, and so there's a little bit less caused by God. As science progresses, I suppose we could extrapolate to the time when we'll be able to explain the whole lot. Carl Sagan, in his foreword to *A Brief History of Time* by Stephen Hawking, talks about a universe with no age in space, no beginning or end in time, and nothing for the creator to do. This picture is sometimes described as *God of the Gaps*, and just before Professor White wishes he had never invited me to speak, I should quickly say that that picture is utterly wrong. It's wrong for all sorts of reasons. It's wrong to think that "all observed phenomena" is a constant; I actually think the observed phenomena are expanding rather faster than our ability to explain them. But it's most wrong to suppose that what we can give an account of scientifically is therefore no longer caused by God.

Rather preferable is the inscription that you find on the doors of the old Cavendish Laboratory in Free School Lane, Cambridge, where now the Department Materials of Materials Science and Metallurgy is – we've got at least two Professors of Materials here and various other distinguished research fellows as well. If you go in from the Free School Lane entry you'll pass that inscription in Gothic script, so it's not very easy to read, in Latin, which a decreasing proportion of Cambridge scientists are able to understand. It was put there at the request of Clerk Maxwell, the first Cavendish Professor. There's a sequel to that which is described in the *European Journal of Physics* in an article on the Cavendish Laboratory by Professor Sir Brian Pippard. "The great oak doors opening on the site of the original building had carved on them, by Maxwell's wish, the text from Psalm 111 *Magna opera Domini esquisita in omnes voluntates ejus.* Shortly after the move to the new buildings in 1973 a devout research student suggested to me that the same text should be displayed, in English, at the entrance. I undertook to put the proposal to the Policy Committee, confident that they would veto it; to my surprise, however, they heartily agreed both to the idea and to the choice of Coverdale's translation, inscribed here on mahogany by Will Carter." He also relates the legend that when Lord Rayleigh wished to use the same text to stand at the beginning of the six volumes of his Collected Papers, Cambridge University Press demurred on the grounds that some might misunderstand who was the Lord referred to, but the text does actually stand in his collected papers.

I was that devout research student. Here is a picture of the entrance to the new Cavendish Laboratory with the text carved with the William Coverdale translation. I love it, because what it says is that what scientists in the Cavendish Laboratory – and in any other research laboratory for that matter – are doing is studying how God makes the world work, and you could not get further away from the *God of the Gaps* than that.

Let me go on rather more briefly to the question of what we should be doing with our new capabilities in nanotechnology, how we should be using it and, particularly, how we should answer the challenge that we're not supposed to play at God. A key text in this is in Genesis where the writer describes God making man in his own image. The word for image is this root here, SLM; it's a very rich word with a wealth of meaning in it. The meaning can relate both upwards to man's relationship to God and outwards, or downwards if you like, to that over which he has dominion. I suppose that everyone would agree that the word “image” there refers to the whole of man, not just his intellectual bit. In its original Hebrew it means predominantly just another one, a duplicate. It refers upwards to a relationship with God, in other words it means having similar properties to and hence the capacity to relate to. Claus Westermann in *Creation* wrote “Mankind is created to stand before God.” Eichrodt in his *Theology of the Old Testament* wrote “Personhood is bestowed on him as the distinctive characteristic of his nature.” The word also refers downwards to man’s relationship to creation; von Rad described man as God’s executive to take responsibility for the world. David Clines wrote “Man himself is the image of God, who has no image of his own”, referring to the fact that if someone conquered a territory in the ancient near East they would set up a statue of themselves to remind people who was boss. The word therefore includes the concept of accountability. Charlie Moule put it like this, “Perhaps the most satisfying of the interpretations of the meaning of the image of God in man is that which sees it as basically *responsibility*”.

I want to end by talking about something that is being opened up by nanotechnology, particularly in the implementations of information processing, and this relates to new insights that have come about in the last twenty years or so concerning the physical nature of information. This is the timescale over which people have begun to realise the significance in the scientific world, but of course you can go much further back to John’s gospel where John wrote “the word flesh became.” I have given you a word-for-word translation of the Greek there because it emphasises how there’s a juxtaposition in that sentence of “word” and “flesh”. *Λογος* was a very rich term at the time that John was using it: it had a Hebrew background meaning the word of God, which was active and did things, and it also had a Greek connotation, particularly from the writings of Philo, as an encapsulation of a controlling principle of the universe. John is describing how, in Christ, this Logos with all this rich association of meaning, actually became physical.

People have been beginning to realise that many of the concepts that we would hitherto have thought of as abstract have a physical embodiment that is inseparable from their very nature. It may be that biologists and psychologists have been realising this for some time; here are one or two quotes from the “World of Psychology” which I was given by Malcolm Jeeves, illustrating how concepts like behaviour and personality, and one might almost say responsibility and belief, are inseparably embodied in the physical stuff of the brain. There has been a growing evidence for that, perhaps most recently and most notably from functional magnetic resonance imaging. In my own field people have been realising progressively through the twentieth century that information, which one might previously have thought of as a sort of abstract quantity, is physical. In the 1940s Shannon developed the mathematical nature of information. It turned out that the mathematics that was used to describe information in a noisy environment was exactly and precisely the same as the mathematics that had been developed for statistical physics in the nineteenth century to describe gases; that is why in information theory, terms like entropy have come to be used. Every time we make a phone call or use the internet, we’re using technology that has been installed by engineers who have grown up being trained in Shannon’s mathematical theories of information.

In 1985 David Deutsch, who lives up on Headington Hill in Oxford, started to talk about the physical nature of information. Having perceived that information is physical, and then at the tiniest level, what we now call nanotechnology level, when things are obeying the laws of quantum physics, he saw that information must be capable of being described in quantum form and that that would open up whole new possibilities for what you could do with information processing. Many people regard his Royal Society paper of 1985 as the manifesto of quantum computing; it has been followed by an explosion of research in the field.

A critic of quantum computing in the early days was Rolf Landauer. Shortly before he died he became a little less sceptical and he wrote a paper "The Physical Nature of Information", whose title has become something of a catchphrase. Much of the paper is about quantum computing, but he also went on to talk about what this taught us about the nature of the world, and in particular the relationship between theory and the experiment. He ended up with a sort of anti-platonic kind of approach, refuting that in the beginning was theory and the physical world is the manifestation of that; he would rather put it the other way round, or at least allow it to be something of an epistimological circle. In describing this he quotes from the beginning of John's gospel, where John is describing how in Christ, what was not physical became physical and was embodied (literally) in human form.

I hope that I have given you some idea of what nanotechnology is, some idea of the real things we can do with nanotechnology in the biological, medical and computing worlds; there are further exciting things that can be done in a number of other worlds. In the popular mind there is probably more disinformation about nanotechnology than accurate information and I hope that those of us who are scientists can help to put that right. The developments in nanoscience and in nanotechnology will raise in new forms the questions about what we learn about the creator from our study of science, and what sort of responsibility we are called upon to exercise as these new capabilities become available to us. Let me end with something for you to think about as you go to sleep. Here is a picture, which I suppose is meant to be a set of red blood cells, with this little nanobot injecting them. The finishing question is: where does that picture lie on the spectrum from pure fantasy to technological feasibility?

Questions Following the Lecture

Rachel Oliver: I have a question to do with the *God of the Gaps* idea and wonder if you could comment. I find it very strange that Christians sometimes get scared of evolution and come up with intelligent design, which strikes me as having a stupid God, saying "Oh I've done that bit wrong and I'm going to correct it; oh, and that bit too, I'll have to correct it" to fit all these specific things in intelligent design. To me the main thing is if you're going to accept religion, accept it.

Andrew Briggs: I have very little to add to what you said, Rachel; I think you've said it all. I suppose the only thing I could comment on would be the consequence that I perceive of this, which is that, amongst believers, it leads to intellectual laziness. There are some real issues to grapple with in the question of how God acts in the world. There are some very difficult questions there and instead of addressing the challenging questions and wrestling with them, some people accept this sort of cop-out which says when the science gets difficult you just say that the scientists have got it wrong, and so on. So I don't think that leads to intellectual rigour and I think it's very unhelpful. I also think that it's unconvincing to unbelievers who therefore don't take it seriously and stay unconvinced. I don't know if anyone else would like to add to that. Is there anyone here who wants to stand up and vigorously defend the concepts of intelligent design?

Q: What I would say is it poses questions but it must not be used as a cop-out. This idea of irreducible complexity is something which is still being argued, which people still find there's a possibility you can argue about it. There's the idea that if you can't test a theory and you can't attack it, then it's very hard to make progress on understanding the theory better so it's legitimate to attack evolution. You can't dismiss the possibility that evolution is true and use that as an intellectual cop-out, as you say, but that doesn't mean there are good arguments behind what some of the intelligent design people are trying to do – some of them are doing good science producing good questions but some theories need to be dismissed as a kind of a fantasy of creationism that is too intellectually ridiculous.

Andrew Briggs: There are other people in this room who are much more professional in the life sciences research than I am – I don't know whether they want to comment, or whether you want to move on to other topics of discussion.

Q: Can I ask a question about the perception of nanotechnology. Why do you think that the idea of nanobots and grey goo caught on so well? Why do people like to be frightened by new science?

Andrew Briggs: I don't know the answer to that question! I did actually read Michael Crichton's book *Prey*; I found it quite a good read and I thought it was rather fun, though I think he's got into terrible trouble for his new book on global warming. I suppose it's easier to make a scare story, and it makes the headlines better than just a story of steady systematic progress. It's also quite difficult to communicate concepts like logarithmic scale to people who don't have a strong foundation in mathematics, so you keep having to use analogies like my comparison between a yoctolitre and a teaspoon, and so on. Perhaps other people here have better answers to that question.

Q: The point about scaremongering is that it masks genuine and probably really good ethical issues. I wondered from your lecture, apart from the scale of hiding all these other things, if there are other genuine ethical issues arising from nanotechnology that you wanted to highlight. While not scaremongering, do you think there are actually serious things that we should think about the consequent implications?

Andrew Briggs: In the Royal Society - Royal Academy of Engineering report they do have a section on ethical issues that are raised, but it has to be said that it's a very small, and in my view very weak section, compared with the amount they discuss about regulatory issues. That may of course be partly because of the brief of that report. There are some very important regulatory issues about safety and risk and so on, and my own observation is that those who are working professionally in the field take these things extremely seriously. I know Alan (Windle), who's here this evening and who probably has the world's best production of nanotubes, has looked very carefully into the risk issues associated with nanotubes, both in his own laboratory and for others using them and working in the field. So there are very important risk and safety issues there but although the details are new, I don't see that as a generically new family of questions that are different from other issues in the Control of Substances Hazardous to Health.

Alan Windle: We just focus on particles, or nanotubes as a particularly shaped particle. Particles are bad news as a body basically - I don't think it's necessarily anything to do with them being nanosize. One key aspect is that regulation of the cleanest breathing air has hitherto been done on the basis of how many grammes there are per cubic metre of air. Of course if you've got something which is nanosize, you've got millions and millions of things per gramme and so there are moves to say there should be regulation by the number of atoms per particle. We have to look at the issue of asbestos: asbestos is a very nasty shaped particle. There is one subset of the toxicologists who believe that shape in asbestos - or particularly nasty types of asbestos – is the most important issue; there's another school of toxicology saying it is a specific chemical activity that is the main problem. Those are nano-size particles.

Just to bring it home, we take precautions in our lab dealing with nanoparticles. We don't want them in the air because I don't want my group to be breathing them. As we know from smoking, breathing particles is very bad news but my fear is that because we take so many precautions in terms of fume cupboards and suck a lot of air through them, I'm actually sucking in a lot of nasty air from the Lion Yard car park which is probably producing a much greater risk than the particles. I think it's very important in terms of public perception that one is prepared, fairly and equally, to put before the public the benefits and risks, and leave it to the public to make up their minds. This is what we have learnt from Genetically Modified foods, that it was actually the sense of making a profit and therefore having the technology remain secret that I think fuelled that public controversy. We don't want to make the same mistake with nanotechnology. But funnily enough it's the grey goo thing which took the spotlight off the risks of particles and that of course was seen as the huge fear, until Prince Charles got on the bandwagon.

Q: I'd like to ask about the source of the rather scary predictions about nanotechnology. There is a fantasy of machines that will take us over and will become superior to human beings. It always seems to me that people who pose that are the computer scientists, who somehow assume that they will be in charge of these machines – there's a sort of grandiosity about this, and I wonder if there's a sort of similar grandiosity of these rather scary fantasies about grey goo. The other possibility – perhaps I can just gently float it, I would be interested to hear what you think about it – is whether there's something demonic about these fantasies.

Andrew Briggs: That's very interesting. There's a fear of the unknown, so if you ask what should we be doing at a practical level about this I think there are two things that we cay say, though they are much easier to state than to implement.

The first one is that there is a great need for those of us who have some sort of knowledge of the field to take the trouble to communicate the factual, realistic, accurate scientific basis, in a form that communicates as effectively as a novel by Michael Crichton does. I think there is a big need for communication there.

The second and even greater need is in the education particularly of kids at primary and secondary school. We are seeing a dearth of young people going into particularly the physical sciences, but maybe the life sciences too, and this is not restricted to the UK - it has been well documented in Australia where they have seen parallel problems to the sort of things that were described by Gareth Roberts in the UK. In all this discussion about 'A' levels and so on, we are doing a great disservice to the most able students by denying, for example, in 'A' levels the opportunity for them to use their mathematics in their science studies. It's popularly said that students are not doing the science 'A' levels because they're too hard; there may be a bit of truth in that, or a perception of it, but I think also that the syllabus is too boring, we're not making it interesting enough and letting the kids use their full intellectual faculties. I don't know how to relate that to your statement about demonic influences, but I do think those are practical things that we can do address the strangeness of the field by helping people to appreciate the underlying science.

For more information about the Cambridge CiS-St Edmunds lecture series please see the website:

www.st-edmunds.cam.ac.uk/cis

This lecture was sponsored by the Templeton Foundation.