Future science

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I want to look with you into the future, to see how our understanding of the world, and our technology, might develop. There is great interest in the future, as is shown by the popularity of the 'Star Wars' films and the 'Star Trek' series. Nearly all the visions of the future that we have been shown, from H. G. Wells onwards, have been essentially static. They show a society that is in most cases, in advance of ours, in science, in technology, and in political organization. (The last might not be difficult.) By the time we are shown the future, science, technology, and the organization of society, are supposed to have achieved a level of near perfection. For example, the film *2001: A Space Odyssey*, showed us with a base on the moon, the launching of a manned, or should I say, personned flight to Jupiter (Figure 1).

I cannot see us managing that by the end of the year! We now have such heightened expectations, that some people feel cheated by politicians and scientists, because we have not already achieved the Utopian visions of the future.

So how will we develop in science and technology, over the next millennium? This is very difficult to answer. A scholar in the year 1000 might have expected the Day of Judgement to be at hand. If the world was to be spared for another millennium, the scholar might have hoped a return to the ways of the ancient world, which were seen as the ultimate standard of civilization up to about 1800. But he certainly would not have foreseen the explosion in science and technology, in the last two hundred years. Yet, at least at the end of the second millennium, the world is inhabited by people who are much the same as those in the year 1000. By the year 3000, this may well no longer be true. We can extrapolate existing trends, but the unexpected will probably happen, as it has in the past.

Observations of the heavenly bodies by Galileo and others, led to Newton's mathematical theory of gravity, published in 1679. Similarly, the observations of Faraday and others of magnetic induction and static electricity led to Maxwell's theory of electromagnetism, published in 1875. By the end of the 19th century, it seemed that we were about to achieve a complete understanding of the universe, in terms of what are now known as, classical laws. These correspond to what might seem the common-sense notion, that physical quantities such as position, speed and rate of rotation, should be both well-defined and continuously variable.

But common sense is just another name for the prejudices that we have been brought up with. Common sense convinced Aristotle that the planets should move in circles, because that is the most perfect figure. But observation showed they moved in elliptical orbits. Similarly, common sense might lead us to expect quantities like energy to be continuous. But from the beginning of the 20th century, observations began to show that energy came in discrete packets, called quanta. It seems that Nature is grainy, not smooth.

A new kind of theory, called quantum mechanics, was formulated in the early years of the 20th century. Quantum theory is a completely different picture of reality, so it should concern us all, but it is hardly known outside physics and chemistry, and not even properly understood by many people in those fields. In quantum theory, things do not have a single unique history, as our present-day common sense would suggest. Instead, they have every possible history, each with its own probability.

When one goes to the small lengths scales of individual particles, the uncertainty can become very large. For example, if one knows that a particle is at a point A at a certain time, then at a later time, it can be anywhere, because of the uncertainty in its velocity. To calculate the probability that it is at a point B, one has to add up

Figure 1. *2001: A Space Odyssey.*

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the probabilities for all the paths or histories that take it from A to B. This idea of a 'sum over all possible histories', is due to the American physicist, and one-time bongo drum player, Richard Feynmann.

Even what we think of as empty space is full of particles moving in closed loops in space and time. That is, they move forward in time on one side of the loop, and backwards in time on the other side (Figure 2).

The awkward thing is that because there is an infinite number of points in space and time, there is an infinite number of possible closed loops of particles. This caused trouble when people tried to combine quantum theory, with Einstein's general theory of relativity. This is the other great scientific revolution of the first half of the 20th century. It says that space and time are not flat, like common sense once told us that the earth was. Instead, they are warped and distorted by the matter and energy in them. An infinite number of closed loops of particles would have an infinite amount of energy, and would curl space and time, up to a single point.

Much of the work in theoretical physics in the last twenty years has been looking for a theory in which the infinities cancel each other out. Only then will we be able to unify quantum theory with Einstein's general relativity, and achieve a complete theory of the basic laws of the universe.

What are the prospects that we will discover this complete theory in the next millennium? I would say they were very good; but in 1980, I said I thought there was a 50–50 chance, that we would discover a complete unified theory, in the next twenty years. We have made some remarkable progress in the period since then, but the final theory, seems about the same distance away.

Research on nuclear and high-energy physics has taken us to length scales that are already very small. Can we go on forever, discovering structures on smaller and smaller length scales? Apparently not, as there is a limit to this series, just as there is to the series of Russian dolls within Russian dolls.

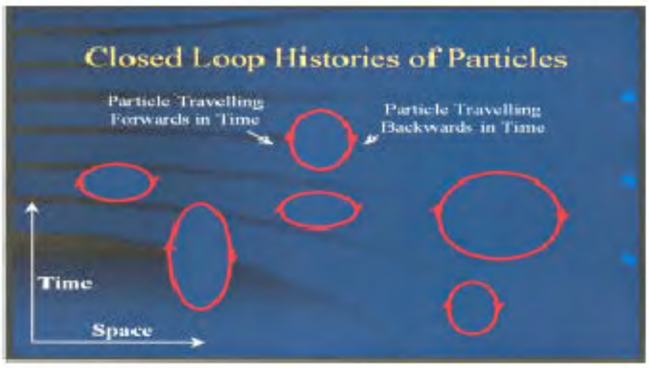

Figure 2. Closed loops of particles in empty space.

Figure 3. Planck length is a millimetre divided by a hundred thousand billion billion billion.

Eventually, one gets down to a smallest doll, which cannot be taken apart anymore. In physics, the smallest doll, is called the Planck length, and is a millimetre divided by a hundred thousand billion billion billion (Figure 3).

We are not about to build particle accelerators, which can probe to distances that small. They would have to be larger than the solar system, and they are not likely to be approved in the present financial climate. However, there are consequences of our present theories which can be tested by much more modest machines. By far the most important of these is supersymmetry, which is fundamental to most of the attempts to unify Einstein's general relativity, with quantum theory.

I expect supersymmetry will be confirmed eventually by experiments at CERN, Geneva. But it would not be possible to probe down to the Planck length in the laboratory. We can study the Big Bang to get observational evidence at higher energies and shorter length scales than we can achieve on earth. However, to a large extent, we shall have to rely on mathematical beauty and consistency to find the ultimate theory of everything. Nevertheless, I am confident that we will discover it by the end of the 21st century, and probably much sooner. I would take a bet at 50–50 odds, that it will be within twenty years, starting now.

By far the most complex systems that we have, are our own bodies. Life seems to have originated in the primordial oceans that covered the earth four billion years ago. And the origin of that life (and all life today) is the highly complicated molecule DNA, which is the basis for all life on earth. It has a double helix structure, like a spiral staircase, as shown in Figure 4, which was discovered by Francis Crick and James Watson in the Cavendish lab at Cambridge in 1953.

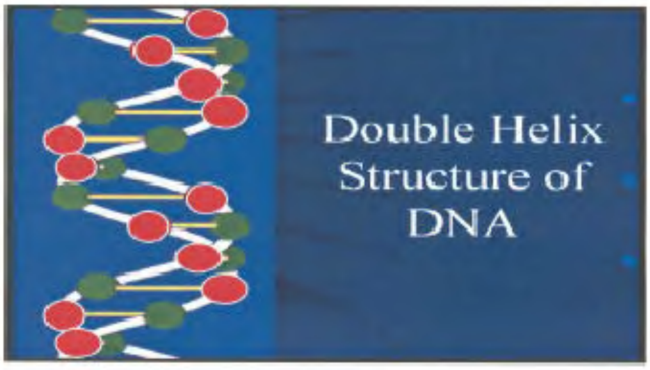

Figure 4. Double helix of a DNA molecule.

As the DNA made copies of itself, there would have been occasional errors in the order of the nucleic acids along the spiral. In most cases, the mistakes in copying would have made the DNA unable to reproduce itself, and so would die out. But in a few cases, the mutation would increase the chances of the DNA surviving, and reproducing. Thus the information content in the sequence of nucleic acids would gradually evolve and increase in complexity.

Biological evolution is very slow. The complexity or number of bits of information that are coded in the DNA is roughly the number of nucleic acids in the molecule. For the first two billion years or so, the rate of increase in complexity must have been of the order of one bit of information every hundred years. The rate of increase of DNA complexity gradually rose to about one bit a year, over the last few million years. But then a major new development occurred about six or eight thousand years ago. We developed written language. This meant that information could be passed from one generation to the next, without having to wait for the very slow processes of random mutations and natural selection to code them into the DNA sequence. The amount of complexity increased enormously.

This transmission of data through external, non-biological means has led the human race to dominate the world, and have an exponentially increasing population. But now we are at the beginning of a new era in which we will be able to increase the complexity of our own DNA. Clearly, developing improved humans will create great social and political problems, with respect to unimproved humans. Assuming that we do not destroy ourselves, I expect we will spread out first to the planets in the solar system, and then to the nearby stars. Even if life has developed in other stellar systems, the chances of catching it at a recognizably human stage, are very small. Any alien life we encounter will either be much more primitive or much more advanced. And if it is more advanced, why has it not spread through the galaxy and visited the earth? It could be that there is an advanced race out there, which is leaving us to stew in our own primitive juices. I doubt they would be so considerate to a lower life form. A more reasonable explanation is that there is a very low probability, either of life developing on a planet, or of that life developing intelligence. We tend to see intelligence as an inevitable consequence of evolution. But is that true? It is not clear that intelligence has much survival value. Bacteria do very well without it, and will survive us, if our 'intelligence' causes us to wipe ourselves out in a nuclear war.

So what will the future be like? I think we will be on our own, but rapidly developing in biological and electronic complexity. Not much of this will happen in the next hundred years, which is all we can reliably predict. But by the end of the next millennium, if we get there, the difference from today's science fiction will be fundamental.