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Changing Climates

Lecture 2: The Scientific Climate

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The scientific climate is always changing, with new discoveries and new forms of understanding. At the beginning of the 21st century the scientific climate is quite different from the way it was at the beginning of the 20th century. I want to describe some of those differences in the course of what I have to say. Every significant scientific discovery is a gift also to theology. It is telling us more about the structure and the history of the world we believe to be God's creation. So it's very natural for me to think that science and religion are friends and not foes.

The world is very surprising

If science teaches you anything, I think it is that the world is very surprising – beyond our powers to foresee, very often. I worked in quantum physics all my scientific life and the quantum world is quite different from the world of everyday. In the quantum world entities, like electrons or photons, can sometimes behave like waves and sometimes like particles. Now from an everyday point of view that's absurd: a wave is a spread-out flappy thing and a particle is like a bullet; so how can something be sometimes like one thing and sometimes like the other? At first it looks like a paradox, but we do in fact understand how the trick is done and I could if pressed explain it; but I don't think that is the main purpose of my talk this evening.

The world is certainly surprising and that means that the instinctive question for a scientist to ask is not, 'Is it reasonable?' as if we know beforehand the shape that reason has to take (no-one in 1899 would think it reasonable for something to behave sometimes like a wave and sometimes like a particle). Our instinctive question is something different. It is this: 'What makes you think that might be the case?' On the one hand that's a more open question – it doesn't pre-judge what the actual answer is going to be; what is a reasonable supposition; but a scientist will only embrace a new understanding if you can produce evidence in support of that. Science trades in motivated belief; but I also believe that religion trades in motivated belief. There are different kinds of belief and the kinds of motivations are different, but I think essentially that science and religion are cousins under the skin because they share in the search for truth.

The death of a merely mechanical world view

Now, what's happened in the 20th century to radically change the climate of science? Well, the first thing I'd say is that the 20th century saw the death of a merely mechanical view of the world. Following Newton's great discoveries [Sir Isaac Newton 1642-1727] physicists in the 18th century began to see the world as if it were a gigantic piece of clockwork. Newton himself didn't believe that, but Newton's successors, particularly in France, took that point of view, and essentially that continued in the 19th century. And of course if the world were clockwork, and if it had a god, the worst that god could be would be some kind of cosmic clock-maker who constructed it and wound it up and let it all tick away.

But in fact 20th century science saw the death of a merely mechanical view of the world. That death came about by the unexpected discovery of intrinsic unpredictabilities present in nature. The word 'intrinsic' is important there. I'm not talking about unpredictabilities that could be resolved if we measured things more accurately or calculated things a bit more exactly. These are *in principle* things that we can never actually predict. And the first area of physics in which this intrinsic unpredictability came to light was in quantum physics itself. In the sub-atomic world you can only give probabilities for things happening: this may happen or that may happen. This radio-active nucleus may decay in the next hour or it may not decay in the next hour. We can calculate the probabilities of these things happening very precisely, but we can't say whether that particular decay is going to take place in a particular period of time.

Chaos and Unpredictability: the discovery of systems

That's one discovery. Then, in the 1960s I suppose, we found that even the everyday world – the world apparently described by good old Newtonian mechanics – 'classical physics' as we call it – even that world was not as richly predictable as people had thought; and this was the discovery of 'chaos' theory. We found out that even in the everyday Newtonian world there are some systems, in fact there are many systems, which are so exquisitely sensitive to the slightest disturbance in their neighbourhood that future behaviour is intrinsically unpredictable. This is a very surprising discovery. One of the ways of referring to it was a scientific joke which referred to chaos theory as ‘the butterfly’ effect: that a butterfly stirring the air with its wings in the African jungle today can cause a disturbance which builds exponentially to cause a storm in East Anglia in a few weeks’ time. There are many clouds in the world; systems so intrinsically sensitive that we cannot know what their future behaviour is going to be. I can say to you with confidence that detailed long-term weather forecasting is never going to work. We shall never know about all those African butterflies.

Unpredictability is concerned with what we can know (or what we can’t know) about future behaviour. If you like learned language, it’s concerned with ‘epistemology’ – what we can know. And it says that you cannot know the future behaviour of a quantum system; you can’t know the future behaviour of a chaotic system.

A world open to the future

One of the deepest problems of philosophy - and perhaps the deepest problem in the philosophy of science – is to figure out how what we know (‘epistemology’, if you like) relates to what is the case (‘ontology’, as the learned like to say). And there is no inevitable connection between the two. We have to make a decision about what connection there should be. We are ignorant of future behaviour. Future behaviour might be determined by some causes which are just inaccessible to us, that we can never get a hold on; that we can never measure. Unpredictability might simply be a fact of ignorance about the future. But it might be more than that. It might not be only that we can’t know what’s going to happen; it might be that the future is open to a variety of different things happening in the future. That would mean that unpredictability in that sense would not be a sign of ignorance, but a sign of a genuine openness present in the future of the world. And it is a matter for metaphysical decision whether we are going to interpret unpredictabilities as a science of ignorance or a science of openness in the process of the world. You can make up your mind about that.

I myself take the view that unpredictabilities are a sign of openness present in the world. Basically, as a scientist, my philosophical position is what people call ‘realism’. I believe that what we know actually is a reliable guide to what is the case. Now I think that’s obvious, but lots of clever people can tell you that things which are obvious are not necessarily so. It could be just a question of ignorance, but I believe that it's a sign of openness. I take a realist view of things.

My wife once gave me a sweatshirt which had on it the words she had often heard me speak on occasions such as this: *'Epistemology models tautology'*. You get some funny looks when you walk down the street wearing it (Laughter). What it means is that what we know is a reliable guide to what is the case. If you take that point of view, then you will say that in these unpredictabilities nature is open to its future in a way that the science of the.18th and 19th centuries would not be able to take into account.

Now saying that doesn't mean that the future has become a random lottery. It simply means that the causes that bring about the future are more than the causes that science itself is able to describe. Science describes causes essentially in terms of the exchange of energy between constituents: particles, atoms, whatever it may be. The exchanges between them are what bring about the future of the world. And, of course, this is an important component in bringing about the future of the world.

The person as agent

What I am suggesting to you is that the climate of 20th century science opens the option that there are other causal principles which bring about the future as well. One of them, I suppose, quite obviously and, I think, directly experienced by us, would be the potential act of an agent. When I choose to raise my arm, of course there's a 'bits and pieces' account of what's going on: currents activate the nerves; muscles contract. But there is more to it than that. It is *I* who decide to raise my arm. It's the action of me – the whole person acting as agent. And if, for example, you gave me an electric shock to make my arm start up, I would say *you* did that. I didn't do it. We all know (again, philosophers might deny it), but we all know, I think, pretty directly, that we have power to act as agents in the world. It's not the case that we didn't know this until quantum theory came along or until chaos theory came along. This is a basic fact which we have always known.

If science is able to begin to describe a physical world sufficiently open to the future that we can really concern ourselves as being inhabitants of it, it's a gain for science. And I would venture to go on to say that if we can act in the world as agents, playing our part in bringing about the future, it seems to me not inconceivable that God, the creator of this world, is able to act with the openness of the process of the world to bring about the future. In other words, God's providential action, within the open grain of nature, is also a possibility on the horizon.

So that's the first change in the scientific climate. We are not caught in a mechanical trap: the 18th century view of man as a machine. I think we've always known we're not automatons.

Complexity theory: the behaviour of systems

The next change in the scientific climate is one that's only just beginning to take place and it has promise for the future. The main technique of science has been, as I have already described, to talk in terms of 'bits and pieces': constituents exchanging energy have been the basic scientific picture. But we're just beginning, in quite a small way, to study systems treated in their totality: not pulled apart; not following science's motto of 'divide and rule'.

We followed that procedure in science because it is easier to understand how 'bits and pieces' behave than to understand how complex collections of interacting 'bits and pieces' behave. We're just beginning, in a small way, to study the behaviour of systems treated in their totality, in their wholeness. These are not very complicated systems - nothing as complicated as a single living cell - but nevertheless sufficiently complicated to have interesting properties; in fact, quite startling and unexpected qualities. Some of these systems have been studied simply in terms of computer modelling; some of them are also physical systems studied directly.

I am going to describe a particular computer model that's been discussed by a man who is a pioneer of this 'complexity theory'. His name is Stuart Kauffman (b.1939) and his book, available in paperback, is called *At Home in the Universe* [OUP].

To describe Kauffman's model accessibly, suppose you have a large array of electric light bulbs. Now these bulbs can be in one of two states – either 'on' or 'off'. And the system was going to develop in steps, with every bulb of the array correlated with two other bulbs somewhere else in the array. What these two bulbs are doing now (those 'on', those 'off', one 'on', one 'off') will determine, in terms of simple rules, what the other is going to do at the next step of the proceedings. We'll start it off in a sort of random pattern of illumination – some of the lamps will be 'on', some of the lamps will be 'off', and we'll then let the system develop according to these rules.

Now I don't know what you would expect, but I would expect that nothing very interesting would happen at all. They would flicker on and off haphazardly for as long as you let them do so. In fact that is not at all the case. Very soon the system self-organises itself, to settling down to cycling through a very limited number of patterns of illumination. It generates spontaneously an enormous degree of order in its behaviour. If there are 10,000 light bulbs in the array, the number of possible patterns of illumination will be 2 to the 10,000, which is roughly speaking 10 to the 3,000 – which is a 1 followed by 3000 zeros. You don't have to be a great mathematician to see that that's a very, very big number indeed. So this system has a vast number of different states it *might* be in, but it turns out that the system will soon settle down simply to cycling through 100 different patterns. That's the spontaneous generation of an absolutely astonishing degree of order. Every time I tell this story I'm bowled over at the thought of it. And of course this is a property that is quite unforeseeable in terms of just thinking about that connection between the two light bulbs here and the one over there.

'Deep' theory

So what's going on? Actually we don't know what's going on. Complexity theory at the moment is at what you might call the 'natural history' stage. People study models, analyse their computer models of various sorts, and they find, time and again, this extraordinary power of spontaneous self-organisation is present in these systems. There clearly must be a 'deep theory' underlying all this, but we don't currently know what that theory is. However, we can make at least a sort of generalised guess. I hope and expect that well before the end of the 21st century we shall have such a theory. I may not live to see it, but I am sure it is waiting there to be discovered.

We can see the sort of shape such a theory will have. First of all it will be a holistic theory rather than a constituent theory. That is to say it will be concerned with systems in their totality rather than bits and pieces. And it will be concerned not so much with the exchange of energy between constituents in the conventional story that physics has had to tell, but it will be concerned with something that we might call information. It will be concerned with pattern formation – the patterns in which the energy flows and the hundred states in which that system continues to cycle.

The new theory will have, as its fundamental category, not energy but information. And therefore I believe that towards the end of the 21st century, if not before, we shall find that the fundamental categories of physical science, of thinking about the world, will be, of course, still energy, but alongside energy a second fundamental category which will be something like information pattern; dynamic pattern description. Again, that's a concept that clearly needs working on, but that seems to me to be the direction in which to work.

That's a very interesting thought. It's a development that contains within it a *glimmer* of being a step in a more profound direction. This sort of duality I am suggesting, this sort of complementarity between energy and information that we need to describe these complex systems, bears some faint and I think unmistakable analogical relationship with the much deeper, more puzzling, duality of matter and mind. I think we see a small step here in the direction of being able to understand how our mental experience and our physical experience are present in us, as important beings in some sort of complementary relationship to each other. Well that's a hope, and some of you may live to see it. I certainly hope so.

Quantum theory: the death of a merely atomistic view of the world

Now another very important development that took place in the 20th century – it took a long time to sort it out – from about 1935 to about 1982/3 – has been the death of a merely atomistic view of the world. I've said that science's ruling motto has been 'Divide and Rule'. Our main weapon to try and understand things has been to split things up into component parts. Atomism has been the sort of approach that we have sought to follow. But actually it turns out that the sub-atomic world is not a world that can be described atomistically. There is intrinsic unavoidable relationality present in the physical world.

The person who began that discovery was Albert Einstein (1879-1955). Einstein had been one of the grandfathers of quantum theory with his description in 1905 of the photoelectric effect – a very important development step leading on the way to modern quantum theory. He came to hate his 'grandson'. He detested modern quantum theory and he was always trying to show that there was something wrong with it. He didn't like it being taught to fifth formers.

In 1935, Einstein thought he had found a flaw in the quantum-mechanical picture. He saw that quantum theory predicted the following extraordinary thing: that once two quantum entities – say two photons - interacted with each other, they would remain mutually entangled even if they separated very far spatially. So they were produced together, perhaps by the decay of an atom, and one of them stayed locally and the other goes far away - 'beyond the moon' is what we conventionally say. But if I do something to the one that is here, it will have an *immediate* influence, an immediate *effect*, on the one 'beyond the moon'. In some sense, though they are spatially separated, they remain a single system. Einstein thought it was such a spooky idea that it must show there was something wrong with quantum theory. For a long time people didn't quite know what to do about it, but eventually, in the early 1980s, a very useful experiment done in Paris by a French team showed that this is indeed a property of nature.

It's very important to realise that what's being spoken about here is an actual causal influence. Whatever I choose to do here will produce a particular effect 'beyond the moon'. There's nothing particularly surprising in what we may call an 'epistemological' connection. I mean, suppose there is a white ball and a black ball. I take the black ball in my clenched fist; you take the white ball in your clenched fist. I stay here and you go a mile down the road. You open your hand and see you have the white ball. You immediately know, of course, that I must have the black ball. That's just really something you didn't know before. There's nothing surprising in that. You always had the white ball; I always had the black ball. All that's happened is you now know that's the case. But this 'effect' – which is called the EPR effect [after Einstein, Podolski and Rosen, who are the three people who made the discovery] - is an actual change being produced at both ends. It's like, if I have a green ball, you have a blue ball. If I have a red ball, you find you have an orange ball. So it's a real causal influence, instantaneously going between the two: a very surprising, counter-intuitive property; but an absolutely unavoidable property of the sub-atomic world. Even the sub-atomic world cannot be described atomistically. There is a deep-seated relational narrative present in that world.

A tri-une God and a Relational world

So physics has discovered that reality is relational. I suppose that if you happen to be a trinitarian Christian believer, believing that the creator of the world is a *triune* God: believing in 'Being as Communion' (as John Zizioulas entitled his popular book), you would hardly be surprised that the world created by that triune God is also a world that is deeply and intrinsically endowed with relationship.

The anthropic principle: a very special universe

Another discovery that took place in the 20th century and has been around for about forty years or so is the discovery of a very special kind of universe. Now scientists really don't really like something to be special. Our instinct is to suppose that we are always dealing with the general case. And I would have supposed, and all my colleagues would have supposed, that the universe in which we live is just a common or garden specimen of what a universe might be like. But the more we come to understand the history of the universe – it's a very remarkable history as you know, which started 13.7 billion years ago, extremely simply, with an expanding ball of energy. That ball of energy, through a whole sequence of evolving processes, has now become the home of saints and scientists.

These processes are immensely rich and complex – in fact we are the most complicated consequences of that 13.7 billion year cosmic history; at least that we are aware of. The human brain sitting here inside our skulls is far and away the most complicated physical system we have ever encountered anywhere in our exploration of the universe. That in itself is an interesting thought and might suggest that something is going on in cosmic history and not just one thing after another.

But as we have come to understand the processes which changed that ball of energy into the world we now occupy, we come to see that while of course these processes took a long time – as far as we know it was 10 million years before there was any life in the universe – and of course self-conscious life like ourselves 'happened only yesterday' in cosmic terms, a few hundred thousand years ago. While it's true that these things have taken a long time to come actually to fruition, there is a very real sense in which the universe was pregnant with the possibility of carbon-based life essentially from the Big Bang onwards. By that I mean that the given physical fabric of the world – the actual laws of nature, the actual forces of nature - had to take a very specific form if the development of carbon-based life like us was ever, anywhere, to be a possibility in cosmic history.

It's not any old world that can produce things like you and me. Sometimes people call this the anthropic principle: a universe capable of producing *anthropoi* (the Greek word for human beings). No-one is suggesting they had to be five-fingered *homo sapiens*, but the life-blood capacity was built into the fabric of the world from the start. If it had not been so, the universe would not have had the fruitful history that it has had. That is a very surprising and unexpected discovery and I would like to take a little time to give you a couple of examples.

Hoyle's 'monkey': the fine tuning of carbon production

So here's an example. For your carbon-based life you need twenty-odd elements for light and the central element, in some sense, is carbon. The chemistry of life is the chemistry of carbon. Carbon has the ability to make those long-chain molecules which seem to be the biochemical basis of life.

Now very early in the universe, from about three minutes after the Big Bang, the whole universe is so energetic and high-temperature that it's like a cosmic hydrogen bomb with nuclear reactions going on all over the place. As the universe expands, it cools down and after only about three and a bit minutes it's become sufficiently cool for the nuclear reactions to stop. And the close nuclear structure of the world is at that moment frozen out; whatever the end point of that frantic three minutes turns out to be. And it turns out that the very early universe only makes two simple elements: it makes hydrogen and it make helium. In fact it makes three quarters of hydrogen and one quarter of helium and one of the triumphs of Big Bang cosmology is being able to predict that that's what we shall find in the universe; and that's what we actually do find.

So the very early universe doesn't make any carbon at all. So where does carbon come from? There is only one place in the universe where carbon is made and that's in the interior nuclear furnaces of the stars. As the universe expands and cools down, as stars and galaxies form, as the stars condense they heat up and eventually they get to a temperature where nuclear reactions start again – not universe-wide, but in the interiors of the stars. And every atom of carbon in our bodies was once inside a star. We are people of star-dust made of the ashes of dead stars. That's a beautiful thought in itself, I think.

Now one of the great problems for physics in the second half of the 20^{th} century was to figure out how carbon and in fact many other elements are made inside the stars. It's a very beautiful story. A lot of that work was done in Cambridge and a lot of it was done by a senior colleague of mine, Fred Hoyle (1915-2001). Now these chaps began to think about these problems and one of the complications was how to get helium nuclei to stick together. If you stick two helium nuclei together, you'll get beryllium-8. And if you stick another helium nucleus on, it will turn beryllium-8 into carbon-12. But you have to do it bit by bit, because when you're dealing with something as small as nuclei it's impossible to get three of them to coincide and stick together all at once. It's a natural process – helium, beryllium, carbon – but you have to do it bit by bit. But it doesn't work in a straightforward easy way, as it turns out that beryllium-8 is extremely unstable, breaking back down to two helium nuclei almost immediately (with a half life of 1×10^{-16} to 2.6×10^{-16} seconds). It doesn't naturally stay around long enough to capture the extra helium nuclei to turn itself into carbon.

So Fred Hoyle and his team were stuck; but they knew, of course, that there must be some way of doing it. And then Fred had a very good idea. He saw that if there was a very large enhancement effect in the trade resonance occurring in carbon at exactly the right energy, then the process of sticking on that third helium nuclei would go much quicker than was thought – in fact sufficiently quickly to have a reasonable chance, at least from time to time, of capturing an extra helium producing carbon. But you have to have this resonance and you have to have it at exactly the right level of energy for this process to be possible. So Fred went to the tables to check if that resonance was there - and it wasn't. But he knew it must be as it's the only way that carbon can be made. So he rang up some American friends of his – a father and son team known as the Lawrences who are very clever experimentalists (NB: Ernest Orlando Lawrence was winner of the 1939 Nobel Prize for Physics for his invention of the cyclotron) and said 'You chaps have missed something. There's a resonance for carbon that you haven't spotted.' They said they hadn't got time to find it – they had better things to do. But Fred was a very determined person when he got the bit between his teeth and he insisted and they found it.

Now that's a wonderful scientific story: to be able to predict a resonance in carbon by thinking about how carbon is made inside stars is an astonishing creative scientific achievement. *[NB*: *If the core temperature of a star exceeds 100 million kelvins (100 megakelvins), as may happen in the later phase of red giants and red supergiants, then a third helium nucleus has a significant chance of fusing with the beryllium-8 nucleus before it breaks down, thus forming carbon-12.]*

Fred ought to have won the Nobel Prize for that year. But there's more than that, because Fred, who had a life-long commitment to atheism, realised of course that if the laws of nuclear physics were a little bit different from the way they actually are, then either there would be no resonance in carbon or the resonance would be at some other energy and that would be no use at all. The principles of nuclear physics were finely tuned in such a way as to produce the resonance necessary to produce carbon. And he is reputed to have said (in a Yorkshire accent which is beyond my powers to imitate) that 'the universe is a put-up job'.

[NB: The energy levels needed in order to produce carbon in large quantities, were statistically very unlikely. Hoyle later wrote:

Would you not say to yourself, "Some super-calculating intellect must have designed the properties of the carbon atom, otherwise the chance of my finding such an atom through the blind forces of nature would be utterly minuscule." Of course you would . . . A common sense interpretation of the facts suggests that a superintellect has monkeyed with physics, as well as with chemistry and biology, and that there are no blind forces worth speaking about in nature. The numbers one calculates from the facts seem to me so overwhelming as to put this conclusion almost beyond question. (Fred Hoyle, 'The Universe: Past and Present Reflections'. *Engineering and Science*, November, 1981. pp 8-12). Hoyle, an atheist, said that this suggestion of a guiding hand left him "greatly shaken."]

In other words, Fred couldn't believe that this extraordinary fine-tuning was just a happy accident. It was too significant. As he didn't like the idea of God, he said some 'Intelligence' must have 'monkeyed' with the laws of nature. Well, what that means I don't know.

Leslie's firing squad: accident or intention?

Well, someone who writes about these questions is a philosopher called John Leslie. He's a very interesting philosopher and his book *Universes* (London and New York: Routledge, 1989) is one you might like to read. He is what I would call a parabolic philosopher, by which I mean that he does most of his work by telling stories. He's thought quit a lot about these fine tunings, and this is his story on the subject:

You are about to be executed. You're tied to the stake, your eyes are bandaged and the rifles of over fifty highly-trained marksmen are levelled at your chest. The order to fire is given – and you find you have survived.

So what do you do? Do you shrug your shoulders and go away saying 'Gee, that was a close one!'? I think probably not. Of course, if you hadn't survived you wouldn't have been able to ask the question anyway. But you *have* survived. And that is so unexpected that the rational thing for you to do is to seek some deeper explanation of your astonishing good fortune.

And, as Leslie says, there are just two types of possible explanation. Maybe there are many, many, many executions taking place today. If there are enough of them, even the best of marksmen occasionally miss. And you are in the execution where they all miss! That is one rational possibility.

There is another rational possibility which is that there is only one execution taking place today (namely yours) and the fact is that the marksmen are on your side and they miss by design.

Now you see the point of that charming story in relation to the fine tuning that has produced carbon in our universe. Of course, if it hadn't done so we wouldn't be here to be asking the question, any more than if the chap who hadn't survived the execution would be here to ask why he had survived it. Nevertheless, the combination of the totally improbable with the highly significant does call for an explanation.

Basically there are just two forms of explanation. Maybe there are many, many different universes, all with different laws of nature, all in fact detached from each other, unconnected with each other. If there are a colossal number, in one of them things will be okay for carbon-based life – and that of course is the one where you and I live, because we are carbon-based life. That would be the 'many universes' or 'multi-verse' explanation. Of course there is another explanation. Maybe there is one universe, which is made in such a way that it is *not* 'any old world' but is endowed by its creator with just those finely tuned laws of circumstances which have allowed it to have a fruitful history.

So multi-verse or creation – which shall we choose? Well, Leslie says it's six of one and half a dozen of the other. He may well be right about that. First of all, both explanations are meta-scientific – they go beyond science. Science can only speak of one universe that we are actually able to observe. It is speculative in the extreme to think there are lots of other universes. And of course it is speculative to think that there is a God who is the creator of the world.

These are explanations that go beyond science – and *need* to go beyond science. And Leslie says, if you're just thinking about fine tuning, either you choose the multiverse or you choose the universe. But I think the multiverse choice only does one piece of exponential work. It explains - it explains away - the fine tuning of our universe. And I believe there is a cumulative case for believing in a creator God: not only because of the fine tuning of the world, but because the deep order of the world would seem to suggest a divine mind behind it; because of the widespread human testimony of encounter with a sacred reality, and so on. There is a cumulative case for theism, which seems to me to tip the balance in favour of that explanation.

DNA and the human genome: a small shot at biology

Well now – I'm a physicist and I've been talking entirely about physics, and it's about time I had a little shot at saying something about biology. It will be a fairly small shot I'm afraid. But it's necessary, I think, not least because most people believe that the greatest scientific discovery of the second half of the 20^{th} century was the explanation of genetics in terms of DNA (Deoxyribonucleic acid). It seems to me to be an achievement in biology equivalent to that in physics of Newton's discovery of the law of universal gravity.

But the discovery of DNA has also produced further problems to think about. Of course, when the Human Genome Project unveiled the actual DNA structure for human beings, one of the big surprises was that it didn't have as many genes in it as one would have thought. Only 30,000 genes are present in the human genome, which is pretty small when you think of the complexity that we have. And it's also clear, of course, that genes work in very subtle and collaborative ways. It isn't that there is a gene for this, a gene for that and a gene for the other. There are genes for some things – perhaps eye colour – but most genes work together collaboratively: collections of genes determining various things. Working out how that happens and how that leads to all the many, many different proteins to make up a living body – that is still an ongoing research programme of very considerable complexity.

The curious case of the London taxi driver

However, we have come to realise that a great deal of the structure of a human being is not genetically predetermined, but is formed by experience. As I've already said, the human brain is by far the most complex physical system that we have encountered in our exploration of the physical world. The number of neurons – the number of nerve cells – in our brains, is about is 100,000,000,000 – which is about the same number of stars in our galaxy – and there are 10 to the 14 connections between those neurons. It is an immensely complex system. 30,000 genes couldn't *begin* to specify that complexity. We know the brain is plastic – its connections can be strengthened or weakened – through experience and so on. Much of the structure of our brains is formed by experience, by encounters with reality, and not predetermined by genetic determinism.

I'm sure you all know the story about the London taxi drivers – how the London taxi drivers have to spend two years getting 'the Knowledge' as they call it, to find their way around the complicated streets of the capital. And somebody a while ago who made a study of whatever it is – these special connections – found that part is more developed in these taxi drivers than in the average population. Their experience of having to learn ‘the Knowledge’ has changed their brains.

So, while the discovery of DNA is extremely important, and a basis for all sorts of explorations in the future, it certainly is no grounds for thinking about a sort of crude form of genetic determinism. To speak, as Richard Dawkins does, of human beings as a genetic survival machine, is I think crassly reductionist.

The Dawkins dilemma

In fact Dawkins himself recognises that. In *The Selfish Gene* (published 1976), having spent 130-140 pages explaining that animal life is the gene’s way of making more genes – that we are genetic survival machines – on the very last page of the book he says ‘we alone can rebel against the selfish replication’ – we alone don’t have to follow the ruthless strategies of genetic survival as he has portrayed them in the book. Now where does that come from? I don’t know. Well, I do. I think it comes from our intimations of God’s perfect will for us. I think we have moral knowledge, which is certainly influenced by evolutionary processes, and is no doubt constrained in various ways by our genetic makeup. My conviction that torturing children is wrong is not simply the result of some curiously concealed genetic survival strategy, nor is it simply the convention of our society. It’s a fact. It’s a moral fact. There is a realm of moral reality which science is not set up to speak about, to reconcile questions of value in that sort of way. But we have real moral problems which need some explanation, which to me derive from intimations of God’s good and perfect will.

Consciousness: the private pathways of the brain

Finally, a science which is making very great progress at the moment in ways which are extremely interesting and, to me, welcome is neuro-science. People are finding a great deal about the various pathways by which our brains process information: which parts of the brain light up when forms of activity are taking place. All this has to be welcomed. But we also have to be aware of what it is we are welcoming.

For example, people have found that when Buddhist monks meditate or when Roman Catholic Carmelite nuns meditate, the same part of the brain lights up. Well that’s very interesting; but it’s what we would expect. If we’re embodied beings, whatever we do, some part of our brain is going to be active. When I think about physics, another part of my brain lights up. Now when I think about physics, any more than the results from the monks and nuns, this tells us nothing about the character and nature of meditation; so we have to be careful not to overplay our hand. And again, in relation to the neural pathways that process information, although we welcome that information, there is an enormous yawning gap between that kind of talk, interesting and important and significant as it is – neurological talk of that kind - and the simplest mental experience of feeling hungry or seeing red. We simply don't know how to bridge that gap from neural patterns of firing to cornea, to field, to mental experiences of that kind. I don't rejoice in that ignorance, but it's so important to recognise that at the moment it's there.

So when people talk about consciousness being the Last Frontier, which the heroic armies of science are just about to cross, I think we should take that with a very big pinch of salt. It's just possible that science will never be able to tell us anything about consciousness. You see, the thing that's strange about consciousness is that it's a private experience. The only consciousness I have direct access to is my own consciousness. When I think about my own consciousness I can't divorce that from whatever it is that I am particularly aware of at the time I think about it. Anything else in science, whether it's the material world or whether it's the biological world, we can study from a distance; we can externalise it, look at it from the outside and see what's going on. But consciousness we can't look at from the outside. It's an intrinsically internal experience. I don't know whether you see red in the same way I see red, or not. So I think we have to be careful about scientists' claims which I think are over the mark.

The successes (and limits) of science

Well, that's been a ramble around the scientific climate of the 20th century. I hope I've been able to convince you that all sorts of interesting things have happened in the 20th century; that we have a richer, more supple and interesting understanding of the world in which we live with science at the beginning of the 21st century than we had with science at the beginning of the 20th century. Science has been extraordinarily successful in that century. In fact, you can make an argument that most of science is in fact 20th century science, so rapid and extensive have been the extensions of our understanding in that sort of way. It's very successful, but we must temper its success by the poorness of its ambition. It doesn't seek to ask or answer every question about the world. It essentially asks the question of process: *how* does it come about, *how* do things happen? And it deliberately, as part of its self-definition, brackets out questions of meaning and value. The whole of science does not pretend to speak about those, but we all know that those are an important part of the world.

Suppose you were to ask a scientist, as a scientist, to tell you all he or she can about music, in scientific terms. I believe that they would say it is your response to the impact of sound-waves on the ear-drum; and of course this is obviously true and in its way worth knowing. But the mystery of music is surely much deeper than that. That temporal succession of packets of sound can create in us an encounter with a reality of beauty – that's something that science is not able to help us understand. Science trawls experience in a coarse-grained net and though you have some very fascinating things in that net, many other things of the greatest significance, important to us particularly as persons, slip through the wide meshes of that net.

So we should welcome scientific advances and theology should be faithful to what science is able to tell us about the creation of the world in which we live. But science by itself, in my view, can never be enough. [*Applause*].

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