SCIENCE AND SENSIBILITY

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With trepidation and humility, I find myself the only scientist in this list of lecturers. Does it really fall to me alone to 'sound the century' for science; to reflect on the science that we bequeath to our heirs? The twentieth could be science's golden century: the age of Einstein, Hawking and relativity; of Planck, Heisenberg and Quantum Theory; of Watson, Crick, Sanger and molecular biology; of Turing, von Neumann and the computer; of Wiener, Shannon and cybernetics, of Plate Tectonics and radioactive dating of the rocks; of Hubble's Red Shift and the Hubble Telescope; of Fleming, Florey and penicillin; of moon landings, and – let's not duck the issue – of the hydrogen bomb. As George Steiner noted in the previous lecture, more scientists are working today than in all other centuries combined. Though also – to put that figure into alarming perspective – more people are alive today than have died since the dawn of Homo sapiens.

Of the dictionary meanings of sensibility, I intend "discernment, awareness" and "the capacity for responding to aesthetic stimuli". One might have hoped that, by century's end, science would have been incorporated into our culture, and our aesthetic sense have risen to meet the poetry of science. Without reviving the mid-century pessimism of C P Snow, I reluctantly find that, with only two years to run, these hopes are not realised. Science provokes more hostility than ever, sometimes with good reason, often from people who know nothing about it and use their hostility as an excuse not to learn. Depressingly many people still fall for the discredited clichŽ that scientific explanation corrodes poetic sensibility. Astrology books outsell astronomy. Television beats a path to the door of second rate conjurors masquerading as psychics and clairvoyants. Cult leaders mine the millennium and find rich seams of gullibility: Heaven's Gate, Waco, poison gas in the Tokyo underground. The biggest difference from the last millennium is that folk Christianity has been joined by folk science-fiction.

It should have been so different. The previous millennium, there was some excuse. In 1066, if only with hindsight, Halley's Comet could forebode Hastings, sealing Harold's fate and Duke William's victory. Hale-Bopp in 1997 should have been different. Why do we feel gratitude when a newspaper astrologer reassures his readers that Hale-Bopp was not directly responsible for Princess Diana's death? And what is going on when 39 people, driven by a theology compounded of Star Trek and the Book of Revelations, commit collective suicide, neatly dressed and with overnight bags packed by their sides, because they all believed that Hale-Bopp was accompanied by a spaceship come to "raise them to a new plane of existence"? Incidentally, the same Heaven's Gate Commune had ordered an astronomical telescope to look at Hale-Bopp. They sent it back when it came, because it was obviously defective: it failed to show the accompanying spaceship.

Hijacking by pseudoscience and bad science fiction is a threat to our legitimate sense of wonder. Hostility from academics sophisticated in fashionable disciplines is another, and I shall return to this. Populist 'dumbing down' is a third. The 'Public Understanding of Science' movement, provoked in America by Sputnik and driven in Britain by alarm over a decline in science applicants at universities, is going demotic. A spate of 'Science Fortnights' and the like betrays a desperate anxiety among scientists to be loved. Whacky 'personalities', with funny hats and larky voices, perform explosions and funky tricks to show that science is fun, fun, fun..

I recently attended a briefing session urging scientists to put on 'events' in shopping malls, designed to lure people into the joys of science. We were advised to do nothing that might conceivably be a 'turn-off'. Always make your science 'relevant' to ordinary people – to what goes on in their own kitchen or bathroom. If possible, choose experimental materials that your audience can eat at the end. At the last event organized by the speaker himself, the scientific feat that really

grabbed attention was the urinal, which automatically flushed as soon as you stepped away. The very word science is best avoided, because 'ordinary people' find it threatening.

When I protest, I am rebuked for my 'elitism'. A terrible word, but maybe not such a terrible thing? There's a great difference between an exclusive snobbery, which no-one should condone, and a striving to help people raise their game and swell the elite. A calculated dumbing down is the worst, condescending and patronising. When I said this in a recent lecture in the United States, a questioner at the end, no doubt with a warm glow in his white male heart, had the remarkable cheek to suggest that 'fun' might be especially necessary to bring 'minorities and women' to science.

I worry that to promote science as all larky and easy is to store up trouble for the future. Recruiting advertisements for the army don't promise a picnic, for the same reason. Real science can be hard but, like classical literature or playing the violin, worth the struggle. If children are lured into science, or any other worthwhile occupation, by the promise of easy frolics, what happens when they finally confront the reality? 'Fun' sends the wrong signals and might attract recruits for the wrong reasons.

Literary studies are at risk of becoming similarly undermined. Idle students are seduced into a debased 'Cultural Studies', where they will spend their time 'deconstructing' soap operas, tabloid princesses, and tellytubbies. Science, like proper literary studies, can be hard and challenging but science is – again like proper literary studies – wonderful. Science is also useful; but useful is not all it is. Science can pay its way but, like great art, it shouldn't have to. And we shouldn't need whacky personalities and explosions to persuade us of the value of a life spent finding out why we have life in the first place.

Perhaps I'm being too negative, but there are times when a pendulum has swung too far and needs a push in the other direction. Certainly, practical demonstrations can make ideas vivid and preserve them in the mind. From Michael Faraday's Royal Institution Christmas Lectures, to Richard Gregory's Bristol Exploratory, children have been excited by hands-on experience of true science. I was myself honoured to give the Christmas Lectures, in their modern televised form, with plenty of hands-on demonstrations. Faraday never dumbed down. I am attacking only the kind of populist whoring that defiles the wonder of science.

Annually in London there is a large dinner, at which prizes for the year's best science books are presented. One prize is for children's science books, and it recently went to a book about insects and other so-called 'ugly bugs.' Such language is not best calculated to arouse the poetic sense of wonder, but let that pass. Harder to forgive were the antics of the Chairman of the Judges, a well known television personality (who had credentials to present real science, before she sold out to 'paranormal' television). Squeaking with game-show levity, she incited the audience to join her in repeated choruses of audible grimaces at the contemplation of the horrible 'ugly bugs'. "Eeeuurrrgh! Yuck! Yeeyuck! Eeeeeuurrrgh!" That kind of vulgarity demeans the wonder of science, and risks 'turning off' the very people best qualified to appreciate it and inspire others: real poets and true scholars of literature.

The true poetry of science, especially 20th century science, led the late Carl Sagan to ask the following acute question.

"How is it that hardly any major religion has looked at science and concluded, 'This is better than we thought! The Universe is much bigger than our prophets said, grander, more subtle, more elegant'? Instead they say, 'No, no, no! My god is a little god, and I want him to stay that way.' A religion, old or new, that stressed the magnificence of the Universe as revealed by modern science might be able to draw forth reserves of reverence and awe hardly tapped by the conventional faiths."

Given a hundred clones of Carl Sagan, we might have some hope for the next century. Meanwhile, in its closing years, the twentieth must be rated a disappointment as far as public understanding of science is concerned, while being a spectacular and unprecedented success with respect to

scientific achievements themselves.

What if we let our sensibility play over the whole of 20th century science. Is it possible to pick out a theme, a scientific leitmotif? My best candidate comes nowhere near doing justice to the richness on offer. The twentieth is The Digital Century. Digital discontinuity pervades the engineering of our time, but there is a sense in which it spills over into the biology and perhaps even the physics of our century.

The opposite of digital is analogue. When the Spanish Armada was expected, a signalling system was devised to spread the news across southern England. Bonfires were set on a chain of hilltops. When any coastal observer spotted the Armada he was to light his fire. It would be seen by neighbouring observers, their fires would be lit, and a wave of beacons would spread the news at great speed far along the coastal counties.

How could we adapt the bonfire telegraph to convey more information? Not just "The Spanish are here" but, say, the size of their fleet? Here's one way. Make your bonfire's size proportional to the size of the fleet. This is an analogue code. Clearly, inaccuracies would be cumulative. So, by the time the message reached the other side of the kingdom, the information about fleet size would have degraded to nothing. This is a general problem with analogue codes.

But now here's a simple digital code. Never mind the size of the fire, just build any serviceable blaze and place a large screen around it. Lift the screen and lower it again, to send the next hill a discrete flash. Repeat the flash a particular number of times, then lower the screen for a period of darkness. Repeat. The number of flashes per burst should be made proportional to the size of the fleet.

This digital code has huge virtues over the previous analogue code. If a hilltop observer sees eight flashes, eight flashes is what he passes along to the next hill in the chain. The message has a good chance of spreading from Plymouth to Dover without serious degradation. The superior power of digital codes has been clearly understood only in the twentieth century.

Nerve cells are like armada beacons. They 'fire'. What travels along a nerve fibre is not electric current. It's more like a trail of gunpowder laid along the ground. Ignite one end with a spark, and the fire fizzes along to the other end.

We've long known that nerve fibres don't use purely analogue codes. Theoretical calculations show that they couldn't. Instead, they do something more like my flashing Armada beacons. Nerve impulses are trains of voltage spikes, repeated as in a machine gun. The difference between a strong message and a weak is not conveyed by the height of the spikes – that would be an analogue code and the message would be distorted out of existence. It is conveyed by the pattern of spikes, especially the firing rate of the machine gun. When you see yellow or hear Middle C, when you smell turpentine or touch satin, when you feel hot or cold, the differences are being rendered, somewhere in your nervous system, by different rates of machine gun pulses. The brain, if we could listen in, would sound like Passchendaele. In our meaning, it is digital. In a fuller sense it is still partly analogue: rate of firing is a continuously varying quantity. Fully digital codes, like Morse, or computer codes, where pulse patterns form a discrete alphabet, are even more reliable.

If nerves carry information about the world as it is now, genes are a coded description of the distant past. This insight follows from the selfish gene view of evolution.

Living organisms are beautifully built to survive and reproduce in their environments. Or that is what Darwinians say. But actually it isn't quite right. They are beautifully built for survival in their ancestors' environments. It is because their ancestors survived – long enough to pass on their DNA – that our modern animals are well-built. For they inherit the very same successful DNA. The genes that survive down the generations add up, in effect, to a description of what it took to survive back then. And that is tantamount to saying that modern DNA is a coded description of the environments in which ancestors survived. A survival manual is handed down the generations. A genetic Book of

the Dead.

Like the longest chain of beacon fires, the generations are uncountably many. No surprise, then, that genes are digital. Theoretically the ancient book of DNA could have been analogue. But, for the same reason as for our analogue armada beacons, any ancient book copied and recopied in analogue language would degrade to meaninglessness in very few scribe generations. Fortunately, human writing is digital, at least in the sense we care about here. And the same is true of the DNA books of ancestral wisdom that we carry around inside us. Genes are digital, and in the full sense not shared by nerves.

Digital genetics was discovered in the nineteenth century, but Gregor Mendel was ahead of his time and ignored. The only serious error in Darwin's world-view derived from the conventional wisdom of his age, that inheritance was 'blending' – analogue genetics. It was dimly realised in Darwin's time that analogue genetics was incompatible with his whole theory of natural selection. Less clearly realised, it was also incompatible with obvious facts of inheritance. The solution had to wait for the 20th century, especially the neo-Darwinian synthesis of Ronald Fisher and others in the 1930s. The essential difference between classical Darwinism (which we now understand could not have worked) and neo-Darwinism (which does) is that digital genetics has replaced analogue.

But when it comes to digital genetics, Fisher and his colleagues of the Synthesis didn't know the half of it. Watson and Crick opened floodgates to what has been, by any standards, a spectacular intellectual revolution – even if Peter Medawar was going too far when he wrote, in his review of Watson's The Double Helix,

"It is simply not worth arguing with anyone so obtuse as not to realise that this complex of discoveries is the greatest achievement of science in the twentieth century."

My misgiving, about this engagingly calculated piece of arrogance, is that I'd have a hard time defending it against a rival claim for, say, quantum theory or relativity.

Watson and Crick's was a digital revolution and it has gone exponential since 1953. You can read a gene today, write it out precisely on a piece of paper, put it in a library, then at any time in the future reconstitute that exact gene and put it back into an animal or plant. When the human genome project is completed, probably around 2003, it will be possible to write the entire human genome on a couple of standard compact discs, with enough space over for a large textbook of explanation. Send the boxed set of two CDs out into deep space and the human race can go extinct, happy in the knowledge that there is now at least a sporting chance for an alien civilisation to reconstitute a living human being. In one respect (though not in another), my speculation is at least more plausible than the plot of Jurassic Park. And both speculations rest upon the digital accuracy of DNA.

Of course, digital theory has been most fully worked out not by neurobiologists or geneticists, but by electronic engineers. The digital telephones, televisions, music reproducers and microwave beams of the late twentieth century are incomparably faster and more accurate than their analogue forerunners, and this is critically because they are digital. Digital computers are the crowning achievement of this electronic age, and they are heavily implicated in telephone switching, satellite communications and data transmission of all kinds, including that phenomenon of the present decade, the World Wide Web. The late Christopher Evans summed up the speed of the twentieth century digital revolution with a striking analogy to the car industry.

"Today's car differs from those of the immediate post-war years on a number of counts. . . But suppose for a moment that the automobile industry had developed at the same rate as computers and over the same period: how much cheaper and more efficient would the current models be? If you have not already heard the analogy the answer is shattering. Today you would be able to buy a Rolls-Royce for £1.35, it would do three million miles to the gallon, and it would deliver enough power to drive the Queen Elizabeth II. And if you were interested in miniaturization, you could place

half a dozen of them on a pinhead."

It is computers that make us notice that the twentieth century is the digital century – lead us to spot the digital in genetics, neurobiology and – though here I lack the confidence of knowledge – physics.

For it could be argued that quantum theory – the part of physics most distinctive of the twentieth century – is fundamentally digital. The Scottish chemist Graham Cairns-Smith tells how he was first exposed to this apparent graininess:

I suppose I was about eight when my father told me that nobody knew what electricity was. I went to school the next day, I remember, and made this information generally available to my friends. It did not create the kind of sensation I had been banking on, although it caught the attention of one whose father worked at the local power station. His father actually made electricity so obviously he would know what it was. My friend promised to ask and report back. Well, eventually he did and I cannot say I was much impressed with the result. 'Wee sandy stuff' he said, rubbing his thumb and forefinger together to emphasise just how tiny the grains were. He seemed unable to elaborate further.

The experimental predictions of quantum theory are upheld to the tenth place of decimals. Any theory with such a spectacular grasp on reality commands our respect. But whether we conclude that the universe itself is grainy – or that discontinuity is forced upon an underlying deep continuity only when we try to measure it – I do not know; and physicists present will sense that the matter is too deep for me.

It should not be necessary to add that this gives me no satisfaction. But sadly there are literary and journalistic circles in which ignorance or incomprehension of science is boasted with pride and even glee. I have made the point often enough to sound plaintive. So let me quote, instead, one of the most justly respected commentators on today's culture, Melvyn Bragg:-

There are still those who are affected enough to say they know nothing about the sciences as if this somehow makes them superior. What it makes them is rather silly, and it puts them at the fag end of that tired old British tradition of intellectual snobbery which considers all knowledge, especially science, as "trade."

Sir Peter Medawar, that swashbuckling, Nobel Prize-winner whom I've already quoted, said something similar about 'trade'.

It is said that in ancient China the mandarins allowed their fingernails – or anyhow one of them – to grow so extremely long as manifestly to unfit them for any manual activity, thus making it perfectly clear to all that they were creatures too refined and elevated ever to engage in such employments. It is a gesture that cannot but appeal to the English, who surpass all other nations in snobbishness; our fastidious distaste for the applied sciences and for trade has played a large part in bringing England to the position in the world which she occupies today.

So, if I have difficulties with quantum theory, it is not for want of trying and certainly not a source of pride. As an evolutionist, I endorse Steven Pinker's view, that Darwinian natural selection has designed our brains to understand the slow dynamics of large objects on the African savannahs. Perhaps somebody should devise a computer game, in which bats and balls behave according to a screened illusion of quantum dynamics. Children brought up on such a game might find modern physics no more impenetrable than we find the concept of stalking a wildebeest.

Personal uncertainty about the uncertainty principle reminds me of another hallmark that will be alleged for twentieth century science. This is the century, it will be claimed, in which the deterministic confidence of the previous one was shattered. Partly by quantum theory. Partly by chaos (in the trendy, not the ordinary language, meaning). And partly by relativism (cultural

relativism, not the sensible, Einsteinian meaning).

Quantum uncertainty, and chaos theory, have had deplorable effects upon popular culture, much to the annoyance of genuine aficionados. Both are regularly exploited by obscurantists, ranging from professional quacks to daffy New-Agers. In America, the self-help 'healing' industry coins millions, and it has not been slow to cash in on quantum theory's formidable talent to bewilder. This has been documented by the American physicist Victor Stenger. One well-heeled healer wrote a string of best-selling books on what he calls 'Quantum Healing." Another book in my possession has sections on Quantum psychology, quantum responsibility, quantum morality, quantum aesthetics, quantum immortality, and quantum theology.

Chaos theory, a more recent invention, is equally fertile ground for those with a bent for abusing sense. It is unfortunately named, for 'chaos' implies randomness. Chaos in the technical sense is not random at all. It is completely determined, but it depends hugely, in strangely hard-to-predict ways, on tiny differences in initial conditions. Undoubtedly it is mathematically interesting. If it impinges on the real world, it would rule out ultimate prediction. If the weather is technically chaotic, weather forecasting in detail becomes impossible. Major events like hurricanes might be determined by tiny causes in the past – such as the now proverbial flap of a butterfly's wing. This does not mean that you can flap the equivalent of a wing and hope to generate a hurricane. As the physicist Robert Park says, this is "a total misunderstanding of what chaos is about . . . while the flapping of a butterfly's wings might conceivably trigger a hurricane, killing butterflies is unlikely to reduce the incidence of hurricanes."

Quantum theory and chaos theory, each in their own peculiar ways, may call into question the predictability of the universe, in deep principle. This could be seen as a retreat from nineteenth century confidence. But nobody really thought that such fine details would ever be predicted in practice, anyway. The most confident determinist would always have admitted that, in practice, sheer complexity of interacting causes would defeat accurate prediction of weather or turbulence. So chaos doesn't make a lot of difference in practice. Conversely, quantum events are statistically smothered, and massively so, in most realms that impinge on us. So the possibility of prediction is, for practical purposes, restored.

In the late twentieth century, prediction of future events in practice has never been more confident or more accurate. This is dramatic in the feats of space engineers. Previous centuries could predict the return of Halley's Comet. Twentieth century science can hurl a projectile along the right trajectory to intercept it, precisely computing and exploiting the gravitational slings of the solar system. Quantum theory itself, whatever the indeterminacy at its heart, is spectacularly accurate in the experimental accuracy of its predictions. The late Richard Feynman assessed this accuracy as equivalent to knowing the distance between New York and Los Angeles to the width of one human hair. Here is no licence for anything-goes, intellectual flappers, with their quantum theology and quantum you-name-it.

Cultural relativism is the most pernicious of these myths of twentieth century retreat from Victorian certainty. A modish fad sees science as only one of many cultural myths, no more true nor valid than the myths of any other culture. In the United States it is fed by justified guilt over the appalling treatment of Native Americans. But the consequences can be laughable; as in the case of Kennewick Man.

Kennewick Man is a skeleton discovered in Washington State in 1996, carbon-dated to older than 9000 years. Anthropologists were intrigued by anatomical suggestions that he might be unrelated to typical Native Americans, and might represent a separate early migration across what is now the Bering Strait, or even from Iceland. They were about to do all-important DNA tests when the legal authorities seized the skeleton, intending to hand it over to representatives of local Indian tribes, who proposed to bury it and forbid all further study. Naturally there was widespread opposition from the scientific and archaeological community. What if Kennewick Man is an American Indian of some kind, it is highly unlikely that his affinities lie with whichever particular tribe happens to live in

the same area 9000 years later.

Native Americans have impressive legal muscle, and 'The Ancient One' might have been handed over to the tribes, but for a bizarre twist. The Asatru Folk Assembly, a group of worshippers of the Norse Gods Thor and Odin, filed an independent legal claim that Kennewick Man was actually a Viking. This Nordic sect, whose case you may read in your copy of The Runestone, were actually allowed to hold a religious service over the bones. This upset the Yakama Indian community, whose spokesman feared that the Viking ceremony could be "keeping Kennewick Man's spirit from finding his body." The dispute between Indians and Norsemen might be settled by DNA comparison with Kennewick Man, and the Norsemen are quite keen to be put to this test. More probably, DNA would decide the case in favour of neither side. Further scientific study would certainly cast fascinating light on the question of when humans first arrived in America. But Indian leaders resent the very idea of studying this question, because they believe their ancestors have been in America since the creation. As Armanad Minthorn, religious leader of the Umatilla tribe, puts it: " From our oral histories, we know that our people have been part of this land since the beginning of time. We do not believe our people migrated here from another continent, as the scientists do."

Perhaps the best policy for the archaeologists would be to declare themselves a religion, with DNA fingerprints their sacramental totem. Facetious, but, such is the climate in the United States at the end of the 20th century, it is possibly the only recourse that would work. If you say, "Look, here is overwhelming evidence from carbon dating, from mitochondrial DNA, and from archaeological analyses of pottery, that X is the case" you will get nowhere. But if you say, "It is a fundamental and unquestioned belief of my culture that X is the case" you will immediately hold a judge's attention.

Also the attention of many in the academic community who, in the late twentieth century, have discovered a new form of anti-scientific rhetoric, sometimes called the 'postmodern critique' of science. The most thorough whistle-blowing on this kind of thing is Paul Gross and Norman Levitt's splendid book, Higher Superstition: The Academic Left and its Quarrels with Science. The American anthropologist Matt Cartmill sums up the basic credo:

"Anybody who claims to have objective knowledge about anything is trying to control and dominate the rest of us. . . There are no objective facts. All supposed "facts" are contaminated with theories, and all theories are infested with moral and political doctrines. . . Therefore, when some guy in a lab coat tells you that such and such is an objective fact . . . he must have a political agenda up his starched white sleeve."

There are even a few, but very vocal, fifth columnists within science itself who hold exactly these views, and use them to waste the time of the rest of us.

Cartmill's thesis is that there is an unexpected and pernicious alliance between the know-nothing fundamentalist religious right, and the sophisticated academic left. A bizarre manifestation of the alliance is joint opposition to the theory of evolution. The opposition of the fundamentalists is obvious. That of the left is a compound of hostility to science in general, of 'respect' for tribal creation myths, and various political agendas. Both these strange bedfellows share a concern for 'human dignity' and take offence at treating humans as 'animals'. Moreover, in Cartmill's words,

Both camps believe that the big truths about the world are moral truths. They view the universe in terms of good and evil, not truth and falsehood. The first question they ask about any supposed fact is whether it serves the cause of righteousness."

And there is a feminist angle, which saddens me, for I am sympathetic to true feminism.

"Instead of exhorting young women to prepare for a variety of technical subjects by studying science, logic, and mathematics, Women's Studies students are now being taught that logic is a tool of domination. . . the standard norms and methods of scientific inquiry are sexist because they are incompatible with "women's ways of knowing." The authors of the prize-winning book with this

title report that the majority of the women they interviewed fell into the category of 'subjective knowers', characterized by a 'passionate rejection of science and scientists.' These 'subjectivist' women see the methods of logic, analysis and abstraction as 'alien territory belonging to men' and 'value intuition as a safer and more fruitful approach to truth'."

That was a quotation from the historian and philosopher of science Noretta Koertge, who is understandably worried about a subversion of feminism which could have a malign influence upon women's education. Indeed, there is an ugly, hectoring streak in this kind of thinking. Barbara Ehrenreich and Janet McIntosh witnessed a woman psychologist speaking at an interdisciplinary conference. Various members of the audience attacked her use of the

. . . oppressive, sexist, imperialist, and capitalist scientific method. The psychologist tried to defend science by pointing to its great discoveries – for example, DNA. The retort came back: "You believe in DNA?"

Fortunately, there are still many intelligent young women prepared to enter a scientific career, and I should like to pay tribute to their courage in the face of such bullying intimidation.

I have come so far with scarcely a mention of Charles Darwin. His life spanned most of the nineteenth century, and he died with every right to be satisfied that he had cured humanity of its greatest and grandest illusion. Darwin brought life itself within the pale of the explicable. No longer a baffling mystery demanding supernatural explanation, life, with the complexity and elegance that defines it, grows and gradually emerges, by easily understood rules, from simple beginnings. Darwin's legacy to the twentieth century was to demystify the greatest mystery of all.

Would Darwin be pleased with our stewardship of that legacy, and with what we are now in a position to pass to the twenty first century? I think he would feel an odd mixture of exhilaration and exasperation. Exhilaration at the detailed knowledge, the comprehensiveness of understanding, that science can now offer, and the polish with which his own theory is being brought to fulfilment. Exasperation at the ignorant suspicion of science, and the air-headed superstition, that still persist.

Exasperation is too weak a word. Darwin might justifiably be saddened, given our huge advantages over himself and his contemporaries, at how little we seem to have done to deploy our superior knowledge in our culture. Late twentieth century civilisation, Darwin would be dismayed to note, though imbued and surrounded by the products and advantages of science, has yet to draw science into its sensibility. Is there even a sense in which we have slipped backwards since Darwin's co-discoverer, Alfred Russel Wallace wrote The Wonderful Century, a glowing scientific retrospective on his era?

Perhaps there was undue complacency in turn-of-century science, about how much had been achieved and how little more advancement could be expected. William Thomson, First Lord Kelvin, President of the Royal Society, pioneered the transatlantic cable – symbol of Victorian progress – and also the second law of thermodynamics – C P Snow's litmus of scientific literacy. Kelvin is credited with the following three confident predictions: 'Radio has no future.' 'Heavier than air flying machines are impossible.' 'X-rays will prove to be a hoax.'

Kelvin also gave Darwin a lot of grief by 'proving,' using all the prestige of the senior science of physics, that the sun was too young to have allowed time for evolution. Kelvin, in effect, said, "Physics argues against evolution, so your biology must be wrong." Darwin could have retorted: "Biology shows that evolution is a fact, so your physics must be wrong." Instead, he bowed to the prevailing assumption that physics automatically trumps biology, and fretted. Twentieth century physics, of course, showed Kelvin wrong by powers of ten. But Darwin did not live to see his vindication, and he never had the confidence to tell the senior physicist of his day where to get off.

In my attacks on millenarial superstition, I must beware of Kelvinian over-confidence. Undoubtedly there is much that we still don't know. Part of our legacy to the 21st century must be unanswered

questions, and some of them are big ones. The science of any age must prepare to be superseded. It would be arrogant and rash to claim our present knowledge as all there is to know. Today's commonplaces, such as mobile telephones, would have seemed to previous ages pure magic. And that should be our warning. Arthur C. Clarke, distinguished novelist and evangelist for the limitless power of science, has said, 'Any sufficiently advanced technology is indistinguishable from magic.' This is Clarke's Third Law.

Maybe, some day in the future, physicists will fully understand gravity, and build an anti-gravity machine. Levitating people may one day become as commonplace to our descendants as jet planes are to us. So, if someone claims to have witnessed a magic carpet zooming over the minarets, should we believe him, on the grounds that those of our ancestors who doubted the possibility of radio turned out to be wrong? No, of course not. But why not?

Clarke's Third Law doesn't work in reverse. Given that 'Any sufficiently advanced technology is indistinguishable from magic' it does not follow that 'Any magical claim that anybody may make at any time is indistinguishable from a technological advance that will come some time in the future.'

Yes, there been occasions when authoritative sceptics have come away with egg on their pontificating faces. But a far greater number of magical claims have been made and never vindicated. A few things that would surprise us today will come true in the future. But lots and lots of things will not come true in the future. History suggests that the very surprising things that do come true are in a minority. The trick is to sort them out from the rubbish – from claims that will forever remain in the realm of fiction and magic.

It is right that, at the end of our century, we should show the humility that Kelvin, at the end of his, did not. But it is also right to acknowledge all that we have learned during the past hundred years. The digital century was the best I could come up with, as a single theme. But it covers only a fraction of what 20th century science will bequeath. We now know, as Darwin and Kelvin did not, how old the world is. About 4.6 billion years. We understand – what Alfred Wegener was ridiculed for suggesting – that the shape of geography has not always been the same. South America not only looks as if it might jigsaw neatly under the bulge of Africa. It once did exactly that, until they split apart some 125 million years ago. Madagascar once touched Africa on one side and India on the other. That was before India set off across the widening ocean and crashed into China to raise the Himalayas. The map of the world's continents has a time dimension, and we who are privileged to live in the Plate Tectonic Age know exactly how it haschanged, when, and why.

We know roughly how old the universe is, and, indeed, that it has an age, which is the same as the age of time itself, and less than twenty billion years. Having begun as a singularity with huge mass and temperature and very small volume, the universe has been expanding ever since. The 21st century will probably settle the question whether the expansion is to go on for ever, or go into reverse. The matter in the cosmos is not homogeneous, but is gathered into some hundred billion galaxies, each averaging a hundred billion stars. We can read the composition of any star in some detail, by spreading its light in a glorified rainbow. Among the stars, our sun is generally unremarkable. It is unremarkable, too, in having planets in orbit, as we know from detecting tiny rhythmic shifts in the spectrums of stars. There is no direct evidence that any other planets house life. If they do, such inhabited islands may be so scattered as to make it unlikely that one will ever encounter another.

We know in some detail the principles governing the evolution of our own island of life. It is a fair bet that the most fundamental principle – Darwinian natural selection – underlies, in some form, other islands of life, if any there be. We know that our kind of life is built of cells, where a cell is either a bacterium or a colony of bacteria. The detailed mechanics of our kind of life depend upon the near-infinite variety of shapes assumed by a special class of molecules called proteins. We know that those all-important three-dimensional shapes are exactly specified by a one-dimensional code, the genetic code, carried by DNA molecules which are replicated through geological time. We understand why there are so many different species, although we don't know how many. We

cannot predict in detail how evolution will go in the future, but we can predict the general patterns that are to be expected.

Among the unsolved problems we shall bequeath to our successors, physicists such as Steven Weinberg will point to their Dreams of a Final Theory, otherwise known as the Grand Universal Theory, or Theory of Everything. Theorists differ about whether it will ever be attained. Those who think it will would probably date this scientific epiphany somewhere in the 21st century. Physicists famously resort to religious language when discussing such deep matters. Some of them really mean it. The others are at risk of being taken literally, when really they intend no more than I do when I say "God knows" to mean that I don't.

Biologists will reach their grail of writing down the human genome, early in the next century. They will then discover that it is not so final as some once hoped. The human embryo project – working out how the genes interact with their environments, including each other, to build a body – may take at least as long to complete. But it too will probably be finished during the 21st century, and artificial wombs built, if these should be thought desirable.

I am less confident about what is for me, as for most biologists, the outstanding scientific problem that remains: the question of how the human brain works, especially the nature of subjective consciousness. The last decade of this century has seen a flurry of big guns take aim at it, including Francis Crick no less, and Daniel Dennett, Steven Pinker and Sir Roger Penrose. It is a big, profound problem, worthy of minds like these. Obviously I have no solution. If I had, I'd deserve a Nobel Prize. It isn't even clear what kind of a problem it is, and therefore what kind of a brilliant idea would constitute a solution. Some people think the problem of consciousness an illusion: there's nobody home, and no problem to be solved. But before Darwin solved the riddle of life's provenance, in the last century, I don't think anybody had clearly posed what sort of a problem it was. It was only after Darwin had solved it that most people realised what it had been in the first place. I do not know whether consciousness will prove to be a big problem, solved by a genius; or will fritter unsatisfactorily away into a series of small problems and non problems.

I am by no means confident that the 21st century will solve the human mind. But if it does, there may be an additional byproduct. Our successors may then be in a position to understand the paradox of 20th century science:- On the one hand our century arguably added as much new knowledge to the human store as all previous centuries put together; while on the other hand the 20th century ended with approximately the same level of supernatural credulity as the 19th, and rather more outright hostility to science. With hope, if not with confidence, I look forward to the 21st century and what it may teach us.

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