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1

Is science enough?

A little while ago I was idly watching Australian television when a long interview by satellite with the geneticist Richard Dawkins appeared on the screen. The first half hour or so of the programme was devoted to a fluent exposition of Professor Dawkins' well-known bleak views of the meaningless character of terrestrial and cosmic history, which he sees as a concatenation of inane events whose only connecting thread is the propagation and survival of limited structure-carrying systems such as genes. In the closing minutes of the interview, however, the character of the conversation underwent a startling change. Dawkins explained that, though he might have sounded like an austere and somewhat desiccated character, he was in fact a warm person in whose life the experiences of human affection and scientific wonder played vital roles. He also called on us to transcend the narrow motivations of the selfish genes and to repudiate those notions of eugenics or racism that might have seemed to follow from a policy of genetic survival at all costs.

I do not doubt for a moment the authenticity of these closing remarks. A fully alive and responsible human being could hardly say less. Yet I longed for the interviewer to inquire where these humane and moral encounters found their lodging in the empty world, devoid of meaning, which the speaker had been describing. Richard Dawkins is celebrated as being the apostle of an extreme and unrelenting material reductionism.[1] In theory, for him science must be enough, because there is no other reliable form of knowledge to be had. The richness of experience and insight that makes human life worth living is, in his official view, reduced to epiphenomenal triviality.

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We are entitled to require a consistency between what people write in their studies and the way in which they live their lives. I submit that no-one lives as if science were enough. Our account of the world must be rich enough – have a thick enough texture and a sufficiently generous rationality – to contain the total spectrum of human meeting with reality. The procrustean oversimplification of a fundamentalist reductionism will not begin to suffice. In fact, it cannot even embrace the practice of science itself, which calls for judgements of value (we seek elegant and economic theories) and whose chief reward is the experience of wonder at the rational beauty of the physical world. The discoveries of science place in our hands an enhanced power to do good or ill, and scientists have to participate in the human search for insight in order to act wisely and to avoid harm. The deliverances of science constrain our metaphysical understandings but they do not determine them. There is much else that must also be taken into account. The context of science is the human context; it is an activity of persons, involving unspecifiable powers of creative imagination. Science by itself is not enough even to describe the pursuit of science itself.

It is the purpose of this book to go beyond science in order to consider the wider setting in which its activity takes place. I greatly value scientific discovery, and the marvellous insights that it provides, but I could not possibly think science was sufficient on its own to quench that thirst for understanding which is so natural a desire of the scientist. The chapters that follow explore some relevant themes. The first must be devoted to a defence of science as a reliable source of knowledge within its own self-limited domain. Such a defence is certainly necessary in these post-modern times. Scientists, as scientists, may not know enough, but they have caught sight of one needful thing: there is a truth to be found. We should acknowledge that their discipline is a part of that truth.

NOTE

1. R. Dawkins, *The Selfish Gene* (Oxford University Press, 1976); *The Blind Watchmaker* (Longman, 1986); *River out of Eden* (Weidenfeld and Nicolson, 1995).

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Understanding the physical world

Looking for answers

One of the most impressive aspects of science is its power to provide universally satisfactory answers to the questions that it asks. When I was a young research student, many years ago, we supposed the fundamental constituents of nuclear matter to be protons and neutrons. In the course of the following twenty-five years a complex interplay of experimental discovery and theoretical insight led eventually to the identification of a new level in the structure of matter: the celebrated quarks, and the particles which make them stick together, which (I regret) are called gluons. There was much argument and perplexity along the way, but in the end the dust settled and we could all agree that a great new discovery had been made. This unanimity of conclusion is very convincing. It leads people to see science as real knowledge – indeed, perhaps, the only form of real knowledge, since such unanimity does not seem to be forthcoming in other domains of human inquiry, such as politics, ethics or religion. This leads to what one might call the hagiographical account of science: it is the canonical source of what we can know about the nature of reality. People who wish their belief to be based in the solid ground of fact should look to science alone and eschew the treacherous swamps of mere opinion that surround it. This strategy may very well lead to a diminished account of the world – for it deliberately sets aside almost all that makes human life worth living – but, if we are sternly honest, it is the meagre best that is to be had. That is how the hagiographical account sees

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the situation. Science is our only reliable guide in the perplexity of human experience.

While this way of evaluating science appears to be quite widely assumed, and while it certainly has some vigorous proponents among reductionist scientists (particularly biologists[1]), it is by no means the only evaluation on offer. Opposed to it is what we might call the deconstructive account of science. This comes in two forms, a popularistic (indeed often, journalistic) condemnation of the failure of science to meet human needs, and a philosophical critique of science's ability actually to deliver knowledge at all.

The first form sees the scientific imperialism implicit in the hagiographical account as being destructive of human good, with its depersonalization of reality and its rejection of value. Science furnishes humanity with great resources of power, but since it does not trade in wisdom, we are left with the actual ecological disasters, and the potential military disasters, for which technology has provided the catalyst.

What is at issue in this part of the critique is the question of scientism, not of science itself. The hagiographies accord so unique a status to science that its legitimate claims to afford understanding are blown up into a universal competence that it cannot sustain. Physics is illegitimately promoted into metaphysics. Scientism – the claim that science is all – provides a grotesquely impoverished account of reality, which its critics are right to reject. But in doing so, many of them seem to be in danger of rejecting also science itself.[2] Within its self-limited domain of inquiry (roughly, the world treated impersonally; reality in the objective mode of an 'it') science has much to tell us that we should take with the utmost seriousness. Or, at least, that is what I think, but the philosophical critics of science would, in their more sophisticated deconstructive way, beg to differ.

Philosophical debate

The twentieth century has seen a very vigorous debate in the philosophy of science.[3] Few agreed conclusions have emerged but I think that all participants, at least, would acknowledge that science,

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both in its method and in its achievement, is a good deal more subtle than might appear on the surface. In particular, the story of clear theoretical prediction receiving unchallengeable experimental confirmation and so leading to certain truth is altogether too simplistic a tale. We cannot avoid facing the many necessary considerations that seem to complicate the issue.

The first is the unsustainability of a clear separation between theory and experiment, so that the one cannot in fact unambiguously confront the other. In 1984, two experimentalists in my old subject of elementary particle physics, Carlo Rubbia and Simon Van Der Meer, received the Nobel Prize for their discovery of W and Z particles, the mediators of the weak nuclear force. It was certainly a splendid achievement, but how was it done? Their very large research team employed a vast array of electronic detectors, linked together so that their signals could be evaluated through computerized analysis. The raw material of the experimental result was the registrations in these detectors, but data in that form are of no immediate significance. It is only when the patterns are interpreted *using current theoretical ideas* that one receives the message 'Here is a Z' or 'There is a W'. In other words, theory and experiment are inextricably intertwined in the scientific acquisition of *interpreted* experience. All scientific observation is a form of 'seeing as'; we have to interrogate the physical world from a chosen point of view. Of course, that point of view may prove in need of correction, but scientists find such revisions as difficult and uncongenial as anyone else. In the middle 1950s great effort was exercised by many physicists in trying to understand some puzzling coincidences in the behaviour of meson decays. They believed there must be two sorts of particle involved because they seemed to be seeing two different kinds of behaviour under spatial reflection. Yet, all the other properties of these supposedly different mesons were exactly the same. After about two years of increasingly desperate but unconvincing attempts at ingenious explanation of this strange coincidence, two American-Chinese, T. D. Lee and C. N. Yang, made the brilliantly simple suggestion that maybe particles in these types of decay did not have to have a unique form of behaviour under reflection. That meant there could be just one kind of meson involved, after all. Lee and Yang had made the great discovery –

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again of Nobel calibre – that what we call parity is not conserved in weak decays. They made their discovery by looking at those meson decays in a new way. They saw the physical world differently from the way in which their colleagues did. The need to adopt a point of view introduces a certain precariousness into the scientific enterprise. We have to beware of the tricks of an imposed perspective whilst being able to profit from the insight afforded by a well-chosen perspective.

Another problem arises from the fact that, though theory is indispensable to science, it is always underdetermined by data. After all, theories purport to speak in universal terms of what will happen at all times and in all places, but in our experimental sampling of physical experience we are only able to make limited encounter with what is going on. A particular aspect of this difficulty is the problem of induction, so trenchantly stated by David Hume in the eighteenth century. Why should past experience be the guide to future behaviour? The sun may have risen today, but I cannot *logically* deduce that it will rise again tomorrow. How many instances of Z-particle patterns did Rubbia and Van Der Meer have to see before they could really know there were such particles? In its assertion of universal knowledge, is not science going far beyond what it can, in all sobriety, actually claim to know?

A further problem is provided by the cloudiness of our vision, the impurity of our encounters with the physical world. Rubbia and Van Der Meer were looking for Ws and Zs, but the production of these particles was only a small fraction of what was going on in their apparatus. Other, much more copious, interactions may occasionally produce an accidental mock-up of an event that looks like, but is not, a W pattern or a Z. Then there are cosmic rays wandering in from outer space, impinging on the detectors and 'doing their own thing', which again may occasionally produce false signals. If physicists are to understand what is actually happening, they must be able to strain out these unwanted contaminations. In the trade, this is called the problem of eliminating background events. There is no rule book to tell you how to do it. Judgement has to be exercised in order to guess where trouble might lie and then theory called upon to estimate the consequences and necessary corrections. There have been a number of embarrassing episodes

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in physics in which totally incorrect conclusions have been reached through errors about background effects.

Once one paints a realistic portrait of science 'warts and all', it becomes increasingly difficult to accord it a unique status as the sole reliable source of human knowledge. Yet, one also recognizes the cumulative fruitfulness of the history of science whereby, for instance, the successive levels of the structure of matter – from atoms to nuclei to protons and neutrons to quarks and gluons – have been unravelled. Does it not seem difficult to deny that here science is telling us something to be taken absolutely seriously about the structure of the physical world in which we live? Not everyone, however, has seen it that way. Some reject what they term a 'Whig view of history' in the account of scientific progress, emphasizing instead the occasions of discontinuity, as when Ptolemy gives way to Copernicus, or Newton is replaced by Einstein and Bohr. For Sir Isaac, the physical world was clear and determinate, its processes taking place within the even flow of an absolute time. For his twentieth century successors, the physical world is cloudy and fitful at its quantum roots, and the elapse of time and the judgement of simultaneity depend upon the state of motion of the observer. Such radical revision seems to put in question a triumphalist claim for the steady advance of scientific knowledge. And who knows what further revolutions of understanding may await us in the future?

Science's achievement

This sketch of the history and practice of science disabuses us of the notion that science has a straightforward technique for the ascertainment of certain truth about the physical world. Any realistic account will have to be much more nuanced than that in its conclusions. Two great questions face us: How can we rightly assess the achievements of science? Is there some discernible essence of the way it goes about attaining that achievement? In other words, what does it discover and how does it make these discoveries.

It is clearly not possible to claim that science establishes truth, pure and simple. Entry into some hitherto unexplored regime (of

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higher energy or shorter distance or whatever) is always liable to reveal new and surprising phenomena that will call for conceptual modification or even a totally new way of thinking. In that sense, the conclusions of science are necessarily provisional. Indeed, it is the possibility of finding the unexpected around the next experimental corner that motivates the expensive exploration of artificially created regimes (such as are produced in high energy accelerators), far beyond what is accessible to us through natural encounter with the physical world. Yet, when we consider a regime that has been well winnowed by the flail of experiment and the sieve of theory, then we do not expect to have to change our ideas radically about what is going on. Newton did not say the last word about the solar system – Einstein's theory of a general relativity is necessary to explain the fine detail of the behaviour of the planet Mercury – but his theory of gravity is sufficiently close to what is actually the case for us to be able to use it to send a space probe to Mars. If science does not attain absolute truth, surely it can lay claim to verisimilitude. Its established theories give reliable accounts of what is going on in a carefully delimited domain, to specified degrees of detail and accuracy. Scientists are mapmakers of the physical world. No map tells us all that could be said about a particular terrain, but it can faithfully represent the structure present on a certain scale. In the sense of an increasing verisimilitude, of ever better approximations to the truth of the matter, science affords us a tightening grasp of physical reality.

So say I, and almost all other scientists with me, but not so all philosophers. The intertwining of interpretation with experience, together with the underdetermination of theory by experiment, has persuaded many of them that science's encounter with the physical world has about it a degree of elasticity that yields considerable room for explanatory manoeuvre. The theoretical insights of science are then seen as the imposition of a pattern of meaning on a veiled and elusive reality, rather than as reliable inferences from encounter with its actual nature.

The most extreme critics of this kind are those who see science as being largely, or even totally, a social construction. Thus, the sociologist Barry Barnes can propose that 'all knowledge generation and cultural growth should be regarded as endlessly dynamic and

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susceptible to alteration just as is human activity itself, with any actual change or advance a matter of agreement and not necessity'.[4] In his view, in the 1970s we did not *discover* quarks, we simply (unconsciously) agreed to view the world of ambiguous experience in a quark-like way. Physicists have the choice of what experiments are worth doing and how they should interpret them. In consequence, they can mould their encounter with the subatomic world into a shape that pleases their intellectual fancy. Anyone who does not go along with that self-imposed orthodoxy is excluded from the invisible college of scientists. That is the way the so-called 'Strong Programme' of the social determination of science sees the matter.

It is difficult to exaggerate how implausible this account seems to a high energy physicist. Far from the physical world proving to be like clay in our theoretical hands, it displays a diamond-like hardness, resistant to our expectations and imposing upon our minds its idiosyncratic and unanticipated structure. It is an immense struggle to find a theory that is economic and uncontrived and adequate to a wide swathe of experimental investigation. More than twenty years elapsed between Murray Gell-Mann's discovery of the strangeness quantum number and the articulation of the fully developed 'Standard Model' of the quark theory of matter.[5] They were years of continual experimental surprises and ceaseless theoretical struggles to make sense of what was going on. When finally a coherent picture emerged, it had all the feel of discovery and none of the feeling of pleasing construction. 'So *that's* what nature's like – who'd have thought it beforehand!'

Of course, it might seem possible that the physicists were mistaken and the philosophers and sociologists knew best, but I fear that the second-order commentators have paid too little attention to the accounts of their actual experience given by the first-order players. A part of that experience is the occasional critical experiment in which a definite indication from nature clearly points to the attainment of understanding through a particular kind of idea.

On the way to the discovery of quarks and gluons, there were crucial moments of insight derived from such critical experiments. One such was the discovery in the late 1960s of what is called deep inelastic scattering. When very high energy electrons are scattered

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by protons, some of them 'bounce back' in a surprising way. The historically minded would have thought of Rutherford and his colleagues in Manchester in 1911. Working at much lower energies, they had detected a similar bouncing back of α-particles when they impinged on a thin gold foil. Rutherford said it was as astonishing as if a 15 inch naval shell had recoiled on impact with a sheet of tissue paper. He went on to interpret it as indicating the presence of concentrated positive charge inside the gold atom. In a word, he had discovered the nucleus. It was possible to understand the Stanford electron experiments in a similar fashion, but now the little hard scattering centres proved to be identifiable with the quarks sitting inside the proton. Up to that point it had been possible to think of quarks as being no more than a kind of theoretical toy, a notional device to generate certain patterns in the ordering of matter; thereafter it became clearer and clearer that quarks must be reckoned as a new constituent level in the structure of the physical world. Some people liked that, others did not, but the physicists had been given a nudge by nature that no one could ignore, whatever their predilections. Of course, its recognition depended on interpretation. Matter is not stamped 'made of quarks'. But the interpretation was both so natural, and so effective in explaining the phenomena, that it could not be gainsaid. The origin of quark theory lies in the physical world and not in the minds of the physicists.

No one could deny, of course, that social factors operate in science. What experiments are considered worth doing (what experiments will in consequence be paid for), what theoretical ideas are fashionable (what in consequence most theorists will want to work on and solve) – all these are affected by social forces within the scientific community. I mentioned earlier the discovery of parity nonconservation. The experiments that confirmed Lee and Yang's ideas had been a practical possibility for many years. No one bothered to do them because they were considered uninteresting. Physicists thought they already knew what the answers would be. Such social factors certainly advance or retard the progress of scientific knowledge. But they do not determine what that knowledge shall be. When eventually the parity experiments were done, there could

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