NATURE AND THE GREEKS

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SCIENCE AND HUMANISM

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Erwin Schrödinger

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With a foreword by

Roger Penrose

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FOREWORD

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by Roger Penrose

I vividly recall reading Erwin Schrödinger's slim volume *Science and Humanism* some forty years ago, probably at a time while I was still a research student in Cambridge. It had a powerful influence on my subsequent thinking. *Nature and the Greeks*, although based on slightly earlier lectures, was not published until somewhat later, and I have to confess that I did not come across it then. Having only now read it for the first time, I find a remarkable work, of a similar force and elegance.

The two volumes go well together. Their themes relate closely to each other, being concerned with the nature of reality and with the ways in which reality has been humanly perceived since antiquity. Both books are beautifully written, and they have a particular value in enabling us to share in some of the insights of one of the most profound thinkers of this century. Not only was Schrödinger a great physicist, having given us the equation that bears his name – an equation which, according to the principles of quantum mechanics, governs the behaviour of the very basic constituents of all matter – but he thought deeply on questions of philosophy, human history and on many other issues of social importance.

In each of these works Schrödinger starts by discussing pertinent social issues concerning the role of science and of scientists in society. He makes it clear that, whereas there is no doubt that science has had a profound influence on the modern world, this influence is by no means the real reason for doing science; nor is it clear that this influence is itself always positive. However, his main purpose is not just to discuss issues of this kind. He is primarily concerned with the very nature of physical reality, of humanity's place in relation to this 'reality' and with the historical question of how great thinkers of the past have come to terms with these issues. Schrödinger clearly believes that there is more to the study of ancient history than mere factual curiosity and a concern with the origins of present-day thinking. His fascinatingly insightful study of the views of the philosopher/

scientists of antiquity, in *Nature and the Greeks*, makes clear that he also believes there is something directly to be gained from the Greeks' own insights, and what led them to their views, despite the undoubtedly enormous advances that modern science has made over what had been available to them at the time. Have we really made any progress at all concerning the really deep question: 'Whence come I and whither go I'? Schrödinger evidently believes not, though he appears to remain optimistic that genuine insights into such issues may become available to us in the future.

Having himself been one of the prime movers in the revolutionary changes that have taken place in our understanding of Nature at the scale of its tiniest ingredients, he is well placed to understand the importance of these changes in relation to what had been the views of physicists and philosophers immediately before him. Moreover, in my personal view, the more 'objective' philosophical standpoints of Schrödinger and Einstein with respect to quantum mechanics, are immeasurably superior to 'subjective' ones of Heisenberg and Bohr. While it is often held that the remarkable successes of quantum physics have led us to doubt the very existence of an 'objective reality' at the quantum level of molecules, atoms and their constituent particles, the extraordinary precision of the quantum formalism – which means, essentially, of the Schrödinger equation – signals to us that there must indeed be a 'reality' at the quantum level, albeit an unfamiliar one, in order that there can be a 'something' so accurately described by that very formalism.

Yet the formalism itself reveals a quantum-level reality that is strikingly different from the one that we experience at ordinary macroscopic scales. In a masterly way, Schrödinger paints for us a picture of that reality. I vividly recall, from my reading of *Science and Humanism* of forty years ago, Schrödinger's description of an iron letter-weight in the shape of a Great Dane that he had known as a small child, and that he retrieved after many years, having had to leave it behind in Austria when the Nazis came. What does it mean to say that it is the *same* dog as he had had before? There is no meaning to be attached to the 'sameness' of any of its individual particles. Schrödinger points out a remarkable irony. For over two thousand years, since the time of Leucippus and Democritus, there had been the fundamental idea that matter is composed of basic individual units, with empty space in between. Yet, this had been essentially a postulate, based on indirect inferences of widely differing acceptability. Then just as the first *direct* evidence of the atomistic nature of matter was beginning to come to light (such as in the Wilson cloud chamber and other experimental devices), quantum theory pulled the rug from beneath us. The particles that the theory revealed to us were not at all like the hard grains that we had come to expect, but were spread out in incomprehensible ways; worse still, they had no individuality whatever!

What is the present status of the particles that were known in Schrödinger's day? Electrons are still thought of as indivisible, but they belong to a larger family of particles, collectively called *leptons*. Protons, on the other hand, are not indivisible, being regarded as composed of still smaller units: the *quarks*. Modern particle physics is described in terms of these new kinds of element (quarks, leptons, gluons), which are the basic elements of what is referred to as the 'standard model'. In this model, the quarks and leptons are taken as structureless point-like objects. Are these the true atomic elements that physicists from the time of Leucippus and Democritus had sought?

I doubt that many present-day physicists would hold firmly to such a view. One prevalent line of thinking pins faith on the ideas of *string theory* according to which the basic units would not be point-like at all, but little loops referred to as 'strings'. These, however, would be far far tinier than the scales that are currently accessible to modern experimental techniques. There are some recent experimental indications that quarks may exhibit structure at much larger scales than those that would be required for string theory – in contradiction with the point-like expectations of the standard model. One must be cautious about drawing such conclusions, however, pending further results which may confirm or contradict them. This notwithstanding, it is fully to be expected that we are yet far from a final understanding of these matters.

In both of these books, Schrödinger shows himself to be deeply troubled, moreover, by the actual continuous nature of our pictures of space and time. According to quantum theory, the state of a material particle can undergo discontinuous jumps. In his attempts to reconcile this odd behaviour with the desirable feature that an individual particle ought really to retain some rudimentary sort of identity, Schrödinger is guided to the idea that it should be space itself, rather than the particles, which is discontinuous. I cannot help remarking, here, that this 'oddness' in the behaviour of quantum particles is now known to be even weirder than was imagined in Schrödinger's day. Schrödinger himself had pointed out, in 1935 (as a follow-up from some work by Einstein, Podolsky and Rosen), the puzzling phenomenon of *quantum entanglement*, according to which, in a system composed of more than one particle, the individual particles are not actually individual, but must be thought of as constituting an indivisible whole. In the mid-1960s John Bell showed that this entanglement could actually be directly measured, with consequences for our picture of reality that have still, in my opinion, not been adequately resolved.

Schrödinger, with considerable insight, goes back to ancient Greek times to try to examine the underlying reasons for our present firm beliefs in space-time continuity. He considers the picture of continuity that mathematicians, over the intervening centuries, have finally come to, and he points out the puzzling, almost paradoxical nature of this very picture. I had referred earlier to the powerful influence that Schrödinger had had on my own thinking. The idea that space and time are, at root, not what they 'seem' to be – perhaps themselves being discrete rather than continuous – is indeed something that took hold of me at that time, and the influence from Schrödinger's writings was great. I spent much time in trying to construct a theory in which spatial notions arose from an entirely discrete combinatorial structure. Although these attempts had some success, the thrust of underlying mathematical conceptions has been, instead, to drive us in the direction of that curiously elegant form of continuity that is provided by *complex numbers* (numbers in which $\sqrt{-1}$ features). Complex numbers are fundamental to quantum theory (and $\sqrt{-1}$ occurs explicitly in Schrödinger's equation). They are fundamental to the 'twistor theory' that my own deliberations led me to, and they are fundamental also to string theory. Moreover, they are fundamental to the deepest results of number theory (such as in Wiles's recent proof of Fermat's last theorem), which is the epitome of discrete mathematics. Perhaps, in complex numbers will ultimately be found the resolution between the discrete and continuous in physics that Schrödinger found so profoundly puzzling. Only time will tell.

Roger Penrose, March 1996