Fundamental Physics and the Nature of Reality
Conclusion

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In our tour of fundamental physics, I have described the picture that modern physics has of the world. I have also, I hope, suggested that philosophy can help us understand the nature of science, and the nature of physics, with more sophistication. In this final meeting, we unite these two strands, and consider philosophical approaches to the question ‘what is the nature of these fundamental objects which appear in these successful physical theories?’

In the previous four blocks, we have looked at a number of fundamental physical theories, emphasising the basic notions in those theories, and the basic objects which they are composed of. It is now time to do explicitly what we have done implicitly, and consider to what extent, and in which way, these objects can actually be said to exist. Our discussion of the philosophy and sociology of science lays the ground for this, although it may have seemed an excursion at the time, partly because this is a question in the philosophy of science and it is useful to have that background, but also to help emphasise that the question is more subtle than might at first appear.

My description of the main positions here will be brief, not because the question is an easy one – it has a very large literature with many subtly different shades of meaning – but because I can hope to do no more than outline the main philosophical positions and problems.

Finally, in an appendix, I give a brief selection of some of the books I have found useful in preparing this course.

1 Realism and anti-realism

1.1 Scientific realism

The most straightforward and common-sense interpretation is also the most difficult to justify. *Scientific realism* (also known, somewhat pejoratively I think, as naïve realism) is the claim that the objects that science discusses exist, without qualification, in the world. This means that things like quarks and the curved spacetime we live in are deemed to actually exist, in that form, and that science has *discovered* these objects through its study of the world. This is probably the view held by most scientists, but despite this authority it is probably the least robust position to hold, and starts to crumble as soon as it is put under pressure.

The difficulties start to appear as soon as you ask what the really fundamental objects are. Are the quarks fundamental objects, for example, or should the fundamental objects instead be regarded as the quantum fields those quarks are excitations of? Also, before this century, a realist of this sort would be inclined to regard the gravitational field as a real thing, despite Newton's doubts about the elements of action-at-a-distance implied within it. When this model of gravitation was replaced by Einstein's, what happened to the reality of the gravitational field? Was it real in the ninteenth century and not real now? Or were we simply mistaken in our belief that the field existed, and now believe that it is Einstein's curved spacetime that is real (that is, did we discover that this field didn't *correspond* to anything in the real world)? Finally, how can we be sure that there is not some alternative theory, which we might have developed if physics (or science in general) had happened to take a different course in the past, which would have different fundamental objects, but which would explain the world just as successfully?

Realism in general, but most particularly this form, is fairly naturally linked with some form of reductionism.

1.2 Empiricism

The big difficulty that realism has, is that it has to believe that the world we perceive through our senses is an accurate representation of the world as it really is. The existence of optical illusions demonstrates that the impressions we get can sometimes deceive us – such illusions are of course resolvable, or removable, with measurement, but how can we be sure that we are not in the grip of some more subtle illusion or illusions, which cannot be so easily seen through. Perhaps we are deceived, for example, in believing that events in the world are causally linked to each other.

This problem has been approached many times in the history of philosophy, but the empiricists cut through the problem by declaring that the world of sense impressions is all that we *can* know, and that to discuss the world as it really is, is metaphysical. When this approach is applied to the philosophy of science (where it manifests itself as positivism), it results in the instrumentalist proposition that scientific theories are merely structures which relate our observations to each other, and allow us to predict what will happen in future. That is, our theories are seen as *instruments*, rather than insights, and they should not be judged in terms of their greater or lesser correspondence with the truth, but purely in terms of their usefulness. For the empiricists, it is unscientific, or metaphysical, to regard objects such as electrons or fields as actually existing in the world.

The approach is not idealist, however: an empiricist would not attempt to deny that objects such as ammeters or apples exist in the world, merely denying the objective existence of the electrons that purportedly make the ammeter swing, or the gravitational field that makes the apple fall. This distinction is the key to one of the major weaknesses of empiricism, however, as it suggests that we can straightforwardly distinguish objective things (such as ammeters) from theoretical ones (such as electrons), without using any theoretical concepts.

As a historical point, it is interesting to note that empiricism first emerged in the seventeenth and eighteenth centuries, associated with Berkeley, Locke and Hume, in the intellectual revolution engendered by the radical new approach to mechanics and cosmology that Kepler, Galileo and Newton were midwives to. In the philosophy of science, it has always been most closely associated with mechanics, and most naturally discussed within that context: whilst it is not unnatural to doubt the real existence of such mathematical objects as quarks and fields, it is much less natural to doubt the existence of molecules, DNA or tectonic plates. Having said that, the only place where it seems that empiricism is taken seriously by scientists is in the positivist Copenhagen interpretation of quantum mechanics, and even there, it is viewed with some discomfort. It is ironic that modern science, with its stereotypical contempt for philosophy in general and metaphysics in particular, should adopt as its interpretive world-view not empiricism, but an extreme form of realism which, in attaching extra-sensory meaning to the objects it studies, is unambiguously metaphysical.

Empiricism's aim is to help demarcate scientific claims from non-scientific ones, by discussing the nature of a genuinely scientific approach. To this end, it declares that empirical adequacy – a theory's success in accurately describing and mathematically reproducing phenomena – is the sole warrant for a theory's acceptance, and further declares that science should not presume to discuss the 'truth' of a theory, whatever that means, as this is not a scientific concern.

The problems for empiricism as a philosophy of science are essentially the problems we discussed for the positivist interpretation of quantum mechanics. Recall the conflict between Ptolemy's epicycles and Kepler's ellipses: as long as the cosmological model based on epicycles managed to predict the motion of the planets accurately, which it did[1], it is not clear what would persuade an empiricist to switch theories. A realist might argue that Nature is simple, and that the notion of the planetary orbits being ellipses with the sun at one focus has fewer *ad hoc* assumptions in it, so we must have discovered a new truth about Nature. An empiricist, on the other hand, would have no reason to prefer one theory to the other, except that the ellipse theory was simpler to calculate with. This exaggerated argument is of course historically bogus, but it does illustrate that the empiricist cuts himself off from a range of

[1] Kepler knew from Tycho Brahe's data that there was a small but significant error, but this was at the very limit of observational accuracy at the time. In any case, it would still have been possible to add further epicycles to remove that error as well.

arguments which are both natural and useful to the realist.

Empiricism is not so easily dismissed as I might have suggested. However, the point I want to make is, I think, accurate. Empiricism's view of the nature of reality is that such a view is a metaphysical one, and as such, not one that science can be asked to provide. On the other hand actual working scientists, far from being empiricists, tend to be robustly naïve realists.

1.3 Social constructivism

The third extreme view of the problem is one that we met last week. Kuhn and Feyerabend talk of the instability of theories – the fact that theories, as well as the fundamental objects they include, are replaced by scientific revolutions, and that this replacement is complete when the scientific culture has formed a consensus around the new theory. They seize on this instability, and use it to deny a realist interpretation of the objects of these theories, instead talking of reality as *socially constructed.* A five-pound note, for example, has a real value, in the sense that I can go down to the shops and use it get real food; clearly, however, the note is real in a different way from that in which Ben Nevis, say, is real. The reality of the note's value – as opposed to the value of any other bits of paper with writing on them – is created by some process in society in the large[2]. In the philosophy of science, the social constructivists extend this argument from money and marriage to matter; they do not deny that there is some sort of reality to the world out there, but claim that rather than being themselves independently real and discovered by science, things like electrons and the gravitational field are real only in the sense that scientists have agreed to use those terms in discussing and manipulating those particular bits of Nature. The electron is real, therefore, in the same way that the note's value is.

[2] John Searle discusses this process in detail, in John R. Searle, *The Construction of Social Reality*, Penguin 1996. Searle would emphatically not approve of the extension of the process to science.

1.4 The middle ground

As an example of the middle ground between these various camps, I will briefly discuss Hilary Putnam's *internal realism*. Putnam distinguishes internal from metaphysical realism (essentially the 'scientific realism' we described above). Internal realism is objective, in the sense that the world is experienced the same way by different observers. There is also an element of pluralism to the theory, however, in the sense that the world admits of different 'mappings' – different, and potentially incompatible, explanatory schemes which explain how the world works. Bohr's Copenhagen interpretation and Bohm's hidden-variable theories are incompatible explanations of quantum mechanics; similarly Newton's and Einstein's gravitational theories are incompatible.

This internalism is not intended to be an empiricist theory, so my understanding of Putnam's idea is that the fundamental objects of *all* these incompatible theories can usefully and reasonably be regarded as real. If this understanding is correct, then internalism seems to be a sort of 'linguistic constructivism': there is something out there in Nature, but it is our decision to call a particular lump of that stuff an 'electron' which makes us see the world in those terms, and allows us to erect a theory to enable us to understand how these electrons move around.

In the same way, Ben Nevis only becomes a mountain, as opposed to a raised bit of Scottish landscape, when we decide to *call* it Ben Nevis. The tourist board has a different, incompatible, map of Scotland from the geographer: Ben Nevis also appears on their map, but as the same sort of thing as the border towns – a popular tourist attaction – and as a quite different thing from a similar mountain (to the geographer) not in a climbing area. The point here is that Ben Nevis really is a mountain, and it really is a tourist attraction, but that both of these are insightful constructions we place on something that really is just a bit of land higher (another human notion) than its surroundings.

This point of view has several variants and, it seems, several names. These variants are all realist in the senses that they assume that the world has an organisation independent of our theories, and that our theories are more than merely tools to relate our observations. However, this approach avoids subscribing to a correspondence notion of truth, in which a theory is true to the extent that it corresponds to reality; since we can never perceive reality except through some theory, we can never reasonably assess that degree of correspondence.[3]

[3] A similar point of view, under the name of 'unrepresentative realism' is discussed and defended in [Chalmers, 1982].

2 And so. . .

That is all we have time for. I hope you have found the course interesting and informative, and that I have achieved some of the aims I set out to. That is, I hope I have gone some way towards persuading you that it is not such bizarre exotica as superstrings and unified field theories that are the fundamental objects in physics, but instead a set of background concepts which include quantum mechanics and relativity, and that these concepts are broadly intelligible without mathematics. In going on to talk about the philosophy and sociology of science, I hope I have also succeeded in my rather subversive aim of persuading you to question the huge epistemological and moral authority which is sometimes arrogated to science.

It is a foundational principle of science that informed criticism burns away the rotten and the useless. I believe that science is special, both in its ability to generate reliable statements about the natural world, and in its spinal position near the centre of our society and culture. I also believe that it has grown indolent on its technological pickings, and that sympathetic criticism can help restore it to that intellectual health which allowed it to climb to that privileged position in the first place.

3 Booklist

Introductions to the physics

[Schwartz and McGuinness, 1999] is a lighthearted, but nonetheless very thorough, description of Special Relativity. It's very accessible, but not very detailed. [Gamow, 1965] is a whimsical account of the phenomena of relativity and quantum mechanics, which is entertaining, even if it is a little old-fashioned. Beyond these two, there seems a shortage of books which make serious popular (ie, non-mathematical) attempts to introduce special relativity.

[Polkinghorne, 1984] is a very straight account of quantum theory and its meaning. It's a little mathematical in places, but the author never relies on the maths to do anything more than amplify.

[Davies, 1984] is a roller-coaster ride through some of the more exotic parts of particle physics and cosmology. It's hard going in places, but rewarding and accurate.

History, philosophy and sociology of science

[Chalmers, 1982] is a very readable introduction to the philosophy of science, which covers all of the important areas, and includes some of Chalmers' own ideas as well. [Richards, 1987] is another general introduction to both the philosophy and the sociology of science, but is unfortunately out of print right now. Covering the same field, [Hilgevoord, 1994] is an excellent collection of essays based on talks given at an Erasmus symposium in 1992. The scope of the essays is very similar to the scope of the philosophy of science parts of this course.

[Collins and Pinch, 1993] is a series of case studies of scientific experiments and controversies, showing an unexpected, but accurate, view of how science actually works.

[Gregory, 1988] describes the view that physicists do not discover the world, but rather invent, through language, a physical world which matches the external one. [Atkins, 1992] is a provocative and slightly eccentric book, which takes an exhilirating gallop round the fundamentals of the natural sciences, to leave you gasping at the conclusion that the universe has that of necessity in it, that it could slide unbidden and uncreated into existence.

[Koestler, 1968] gives a very good account of the revolution in physics that Copernicus, Galileo and Kepler achieved between them. Good for both the history and the sociology of the time.

More advanced material

The Principle of Relativity [Lorentz et al., 1952] is a collection of (translations of) original papers on the Special and General theories, including Einstein's paper of 1905 [Einstein, 1905], but also some earlier papers by Lorentz suggesting interpretations of the Michelson-Morley experiment. The first few sections, at least, of the 1905 paper are worth reading as a current introduction to SR.

[Taylor and Wheeler, 1992] is a more advanced book. It's an undergraduate textbook, and so it doesn't pull any punches when it comes to the maths. The level of maths required is, however, relatively modest, so if you can cope with that and are prepared for some hard thought, you will benefit from the book's immense insight.

[Open University, 1998] is a third-level Open University course on special and general relativity. It is relatively unmathematical, at least compared with other accounts, but is nonetheless conceptually very demanding and exhaustive. I'd also recommend this to anyone who has had a conventional introduction to SR and GR.

[Baggott, 1992] gives a very thorough account of quantum mechanics and its interpretation, with a good bibliography. Baggott does not pull any punches when he discusses the mathematical formalism of the theory, and although this does not assume much more than a familiarity with calculus, this is enough to classify the book as 'advanced' here. Nonetheless, the book concentrates on the interpretation, rather than the mechanics, and even if you skipped all the mathematics, the later chapters of the book would, I think, be both intelligible and illuminating.

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