thing that the Heath Green Paper wants to end. Against it Professor Swinnerton-Dyer's worryings about women as tutors look sublimely trivial. No-one insists that women must be eligible for every post, even if there is no visible harm in the idea: a Cambridge tutorship is merely an incidental plum of the profession. Research fellowships are another matter: they are the roots of the tree. They must be available to the sexes equally.

Miscellany

The Editors regret that the 3-day week means that this issue of the *Review* is both belated and abbreviated. They offer their apologies to their readers.

More about Shops

It is very bad new that Bowes and Bowes are closing down both their Science and their Modern Language Bookshops in Trinity Street. No doubt the reasons given are sufficient: the shops are not, and cannot be made, big enough to give Bowes an adequate return on the capital locked up in them.

Like everybody else, booksellers and publishers are the victims of inflation. Nevertheless, the loss to Cambridge will be felt; and what is to become of the vacated shops? Let us hope that the owners, Trinity College (fairly well shielded against inflation, after all) can find the sort of tenants who will add to the life and gaiety of Trinity Street, even if they cannot pay sky-high rents.

Our Spy

The ever-observant G. B. MacRide reports: 'There is always some absurdity to be seen in Cambridge streets. For instance, the medallion of William Pitt which adorns the Pitt Club in Jesus Lane now shines white against a background of Irish green. Considering that he was the architect of the Act of Union, I can only conclude that the green was applied by the local branch of the IRA. Then, why is it necessary for King's to set up a little notice, to the east of its bridge, reading TO THE CHAPEL, when the up-turned sow is clearly visible? Is it in case of fog? Mind you, the silliest notice of all is one I spotted recently at the railway station: PLEASE KEEP CLEAR OF FALLING MASONRY'.

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Worlds, selves, and theories

Mary Hesse

There are two *prima facie* conflicting attitudes towards natural science in contemporary culture. First there is the somewhat dismissive relativism of all shades of the radical wing: science is good (or more often bad) for technology and control, but as a system of knowledge claiming to discover features of the real world it is so underdetermined by the facts and so conditioned by its social environment as to constitute mythology rather than knowledge.[1] On the other hand there is continuing popular fascination with the more speculative ends of scientific theorizing—with the cosmology of the large and the fundamental physics of the small, and with the doubtfully scientific claims of parapsychology. The apparent conflict may, of course, be resolved by the cynical with the remark that fascination with speculative science is closely allied with the popularity of science fiction, and that all this does indeed constitute the culture-conditioned mythology of our time, which a reflective intelligence may note and even make use of, but not allow itself to be captured by.

Unfortunately in a climate of such cynicism, natural science is unlikely to flourish, even if it continues to be valued for its occasional golden egg. That is why it is a welcome sign to find increasingly serious philosophical interest being taken in the ontological problems of modern physics, for this shows that rationality allied with empiricism in natural science can still take the

[1] For different aspects of this view see Quine, Kuhn, Feyerabend, and Foucault. The issues are discussed in Ian Hacking's 'The Archeology of Knowedge', this *Review*, 93, 1972, 166, and in some of the papers in *Changing Perspectives in the History of Science*, ed. M. Teich and R. M. Young, reviewed by Ernan McMullin in this issue.

initiative in encouraging metaphysical shifts in our world-view which are not merely culturally determined. A recent collection of articles entitled *Paradigms and Paradoxes*[2] is a case in point. There, among other analyses of the current conceptual problems of modern physics, an article by C. A. Hooker outlines illuminatingly the theses of the post-seventeenth century conception of reality which have to be abandoned if modern physics, and particularly quantum theory, is to be taken seriously. Among these features of the ontology of classical physics are: the world consists of complex objects which are definite analysable structures of their elements and characterizable at definite space-time points; the states of the world are determined by its preceding states; there is in principle a descriptive theory which can be put into one-to-one correspondence with the world; and the states of the world are independent of their being observed.

The effects of being told that we must abandon these features of our world and knowledge have been somewhat blunted in the half century since quantum physics began by vague and inaccurate expressions of them in popular science literature, and indeed without further details they can hardly be made intelligible. It is therefore worth trying to spell out again just how revolutionary their consequences are for our picture of the world and the observer's place in it.

It is well known that the core of quantum theory is the Uncertainty Principle, according to which simultaneous determinations of the position and momentum of a quantum particle are impossible. It follows that no detailed predictions of the motions of quantum particles are possible, since no detailed information of the relevant variables can ever be available. Hence quantum physics is essentially indeterminist, in contrast to classical physics, where, in principle at least, it was possible to conceive all future states of the physical world as causally determined in detail by its present state. This much has entered the public consciousness with regard to quantum physics, but its impact has been small and diminishing, perhaps because in the lay mind the notion of total determinism was always rather remote. If people believe in determinism in matters of more immediate concern than galaxies and billiard balls, they tend to do so for reasons not drawn from physics. And unfortunately general understanding of the new physics ends with the statement of indeterminacy. The rest is bafflement, confusion, misinterpretation, and consequent indifference. But the consequences of quantum physics for our world picture are, at least in some very plausible interpretations, much more radical than mere future unpredictability, and impinge on firmly entrenched philosophical assumptions as well as upon those of physics.

First of all it is important to notice that two very serious misinterpretations are often associated with non-technical expositions of quantum theory, both of which have the effect of diminishing its radical character. The first is even to be found in the standard textbook of philosophy of science of the 1960s, Ernest Nagel's *Structure of Science*. Nagel says 'indeterminacy is not exhibited in any experimentally detectable behaviour of *macroscopic* objects. Indeed the theoretical indeterminism as calculated from quantum mechanics . . . is far smaller than the limits of experimental accuracy'.[3] So why need the layman bother? But Nagel's assertion is just false. It is certainly true that *most* macroscopic objects and systems we experience may be regarded from the point of view of quantum theory as large statistical aggregates of particles, whose behaviour is determinate to well within the limits of experimental accuracy. But there are innumerable kinds of system, both natural and artificial, where single quantum particles may trigger off chains of events in the macro-world which consequently share and amplify their indeterminism. A homely example is the selection of Premium Bond numbers. Natural examples with potentially enormous macroscopic effects are disintegrations of small numbers of radium atoms, and mutations caused by random radiation.

The second, and more serious, misinterpretation concerns the meaning of the Uncertainty Principle. This should be properly understood, not as a restriction on measurement and predictability only, but much more fundamentally as the assertion that quantum particles do not *have*, as characteristics of their nature, definite simultaneous values of positions and momenta, or of related physical variables. This might be expressed by saying that this is a matter of their *ontology* or existence, not of their *epistemology* or capacity for being known by us. Now at first sight this may not appear very startling, for two considerations appear to diminish its force. First one may ask, 'How can assertions be made about what exists, when that is admitted to be *beyond* the possibility of anything that can be known?' To which the answer is that it can be shown within quantum theory that *if* it is assumed that particles actually have simultaneous definite positions and momenta, though they cannot be observed, *then* contradictions arise in the theory. Since the theory is otherwise internally consistent, we must conclude that it asserts that these simultaneous values not only cannot be measured, but that they do not exist.

A second reason why the Uncertainty Principle might be thought to lack radical significance is that the conceptions of 'particles' and 'waves', which have been taken over in quantum theory from its classical predecessor, do not seem necessarily to be the only physical models that might be adopted in quantum physics. Everything I have said about the Uncertainty Principle has been in terms of *particle* variables such as position and momentum (and equivalent points could have been made in terms of the wave model). But might it not be possible to translate the language of quantum theory into some other model, such as for example theorists of 'hidden variables' have

[2] Ed. R. G. Colodny, Pittsburg, 1972. I should like to thank Graeme Robertson for discussions of this literature, but he is not responsible if I have made mistakes about physics.

[3] *op. cit.* p. 316.

suggested, or even to abandon models of 'interphenomena' altogether, and content ourselves with a mathematical formalism linking phenomenal measurements only? The answer to this is, first, that both kinds of interpretation have persistently been tried without success, and, second, that the classical particle and wave models are very intimately involved in current quantum theory, so that to remove them would be equivalent to finding a totally new kind of theory such as is nowhere on the horizon. Curiously enough, even though the particle and wave models certainly contradict each other if taken each to be realistic descriptions of what exists (no entity can be at the same time *both* a particle *and* a wave), yet the 'complementary' use of the two models in different and carefully specified experimental circumstances is quite essential to the working of quantum theory, and has had impressive predictive success.

At present, therefore, quantum theory is firmly entrenched in essentially its present form, and, although of course it cannot be known for certain to be true, it must be taken as seriously as any currently acceptable theory, as the best statement science can currently make about the world. When the consequences of the theory are drawn out, however, they reveal a strange prospect. These consequences have largely been derived by means of 'thought-experiments', that is, applications of the theory to particular experimental setups, where the experiment is one that could undoubtedly be performed, and where its outcome can be clearly deduced from the theory. One such experiment, which brings out most of the strangeness of the ontology of quantum theory, is the paradox of the so-called 'Schrödinger cat'.[4]

Consider an experiment in which a single quantum particle can be emitted from a source S in such a way that it is known to have a probability of one half of moving to each of two holes A and B in an otherwise impermeable screen. Behind the screen, A opens on to an otherwise sealed box in which sits a cat and a lethal device directed at the cat which will be triggered off by the entry of the particle at A, while B opens on a sealed box which is quite empty. Initially we cannot see into either box. Now in accordance with the ontological interpretation of the Uncertainty Principle, it would be inconsistent to say *before making an observation* that the particle has actually entered A and not B, or conversely, but we can say only that the particle is *actually* in *both* these states (technically called a 'superposition' of states), with a probability of one half each. Already the logic of 'or' as applied to ordinary particles is violated, for while the quantum particle is in the sense defined *either* in state A *or* state B, it does not follow that it is *either* (in state A and not B) *or* (in state B and not A).

There is worse to come, however. Consider the lethal device and the cat, both of which are macroscopic objects. When the particle enters either A or B, assuming the mechanism is working as specified, the cat either dies or lives. If we do not open up the boxes we do not know which of these states the cat is in. And here arises the paradox, for on the one hand our deep-rooted classical assumptions demand that the cat is (in the ordinary sense of *or*) *either* dead *or* alive, whether we have observed its state or not. On the other hand, wherever quantum physics clashes with classical physics in making definite predictions in the macro-domain, there is good evidence that quantum physics is the more adequate theory of macro- as well as micro-objects. But then, if we make the very plausible *reducibility assumption* that quantum physics *is* the only currently acceptable universal theory, then we have to say of both gun and cat that they are in a superposition of states, with a probability of a half each.

At what point must the superposition of states be said to be collapsed into one or other classical state? Certainly no consciousness (no 'I') can be directly aware of such a superposition as a state of nature. So we undoubtedly have at the quantum particle end of the experiment a superposition of states, while at the end at which I observe the state of the cat there is undoubtedly for me a collapse into one state or other. But between these points there is a choice of interpretations: we may say that the collapse takes place (i) at the first macroscopic object (the gun), or (ii) at the first conscious observer (the cat (?), or the first human observer to open the box), or (iii) at myself. Interpretation (i) is the so-called Copenhagen interpretation, which is adopted by most working physicists. It has the advantage (if such it be thought) of brushing conceptual problems under the carpet and circumventing any challenge to orthodox ways of thinking about the macroscopic world. But it has the disadvantage of abandoning the reducibility assumption and leaving an *ad hoc* and quite unexplained hiatus between the situations to which only quantum theory is applicable, and those to which only classical physics is applicable. The kindest thing to be said about it is that it attempts to be conservative in a situation where conservativism is really impossible, for it entails abandoning the *methodological* tradition of looking for universalisable theories, in order to preserve intact the *classical ontology* of macroscopic objects. But an ontology that is not universalisable is not worth much.

[4] The best philosophical account of this thought-experiment is in Hilary Putnam's 'A philosopher looks at quantum mechanics' *Beyond the Edge of Certainty*, ed. R. G. Colodny, Pittsburg, 1965, p. 75.

Interpretation (ii) might be thought more acceptable in not dichotomizing the physical world, but consider what happens in this interpretation if 'you' look into the box and do not tell me the result. Why should I then assume that quantum theory stops short of your brain, so that *it* is now in one of the classical states 'observing cat dead' or 'observing cat alive'? Consistently with the reducibility assumption I must suppose that your brain too is in a superposition of states, until you *tell* me the result of your experiment, and then, assuming I believe you, this is equivalent to my own observation. The only interpretation consistent with the reducibility assumption for all macro-objects, including brains, is (iii). This is not a solipsistic interpretation, because no doubt is thrown on the ability of consciousnesses to communicate with each other and share knowledge of what then becomes their common world. But until knowledge is thus shared, according to quantum theory 'my' world is *ontologically* different from 'yours', for it would be inconsistent of me to assume that the experiment and you who have observed it are in definite classic states until I am told of it or observe it for myself. The world we can know in common *exists* only when I thus observe it.

It was considerations such as these that led Niels Bohr into an interpretation of quantum theory that is certainly the most interesting and perceptive so far.[5] Bohr concluded that the models of classical physics are not to be taken as real representations of *any* objects in the external world, but rather as necessary forms of human perception, in somewhat the same sense that the Kantian categories are necessary while not themselves being features of the world-in-itself. Unlike Kant, however, Bohr implies that the world-in-itself can be described insofar as quantum theory itself describes it in terms of superpositions of states. Bohr's metaphysics entails a radical departure from the 'objective' world of classical physics. He himself attempted to relate this interpretation to an ontology older than quantum physics, which he described none too clearly in terms of the artificiality of the subject-object distinction, and the inevitable distortion of reality that occurs when man 'objectifies' his world, that is, sets himself over against the world in order to know it. Max Jammer[6] has usefully traced these attempts to delineate the new metaphysics to two sources in Bohr's intellectual background. The first was his reading of William James, where he found the notion of 'complementarity' between thought as introspected, and as knowable objectively in terms of brain processes, each distorting the other and precluding complete description in either terminology. The second was the continuing Kierkegaardian tradition in the Copenhagen of Bohr's youth. To refer to these sources in attempting to understand Bohr is perhaps to try to explain the obscure by the more obscure, and indeed Bohr himself claims that the clear requirement in physics for a non-classical ontology of subject and object helps to *remove* the mystification inherent in alternative metaphysics. Many writers in the phenomenological tradition have since repaid the debt by referring to the Uncertainty Principle as a scientific example of their own accounts of the distortion of reality produced by objectification of the world.

We are still far from understanding either Bohr or quantum physics, let alone devising a clear alternative to classical ontology. But whichever of the currently viable interpretations of quantum theory is adopted, it is certain that we can no longer suppose that natural science gives us a potentially complete and detailed account of the objective world, with ourselves as detached and unproblematic observers within it. Physics itself forces us to question that complacent ontology.

[5] Most accessibly in Bohr's, *Atomic Theory and the Description of Nature* Cambridge paperback, 1961.

[6] *The Conceptual development of Quantum Mechanics*, New York, 1966.

Black Holes

Bernard Carr

General Relativity makes the remarkable prediction that there could be many regions of space where gravity is so strong that nothing, not even light, can escape. These regions are called 'Black Holes' and their intriguing properties make them one of the most exciting topics in modern physics. In fact the notion of a black hole is not new: as long ago as 1795 the French mathematician Pierre Laplace realized that an object on the surface of a sufficiently compressed star would have to travel faster than light (which according to relativity is impossible) to overcome the star's gravitational attraction. However, only in the last 30 years has it been realized that such conditions are likely to arise in the real universe and only in the last few years has there been any observational evidence for black holes. The observational evidence is not conclusive so we still cannot be certain that black holes really exist. However, because a large fraction of the universe could already be in black holes, it is possible that processes involving black holes may dominate all others in determining the structure of our universe. That is why black holes could play a crucial role in furthering our understanding of the universe.