SECCION MONOGRAFICA

CAUSALITY IN PHYSICS

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PRESENTATION

This monograph section of *Theoria* is devoted to the notion of causation in modern physics. The four long essays and short epilogue contained in this volume constitute a representative sample of recent work by philosophers of physics on causality. All the contributions to this volume share a healthy respect for science, and what science may be able to tell us about causation: these essays look for a notion of causation that can make sense of modern physical science. And, as is the norm in contemporary philosophy of physics, the discussions engage with science in its own terms, and not through the distorting lens of rational reconstruction. Although these are philosophical essays and are primarily aimed at a philosophical readership, they may also interest scientists.

The contributions discuss a range of physical theories in non-relativistic quantum mechanics, quantum field theory and general relativity. Other branches of physics that are touched upon include classical electrodynamics and mechanics, and special relativity. In spite of this broad range of subject matters, there is one deep philosophical thread that runs through the volume: a preoccupation with the notion of causal continuity, the idea that causes propagate in continuous paths ("wordlines") in space-time. This is reflected in the contributors' more or less explicit engagement with process or transfer theories of causation, which take causal continuity as basic.

Phil Dowe's and Erik Curiel's contributions are explicit discussions of transfer or process theories of causation. Their results pull in opposite directions. Dowe rebuts objections to, and hence provides arguments for, his own version of a transfer theory, the conserved quantity theory; Curiel argues that no transfer or process theory of causation can make sense within General Relativity. Their claims are perhaps not as incompatible as they may seem. The conserved quantity theory takes conservation laws to the essential component of causality: causal relations only properly obtain in the presence of a conservation law. More specifically a causal process, at least in the actual world, is the worldline of an object which possesses a conserved quantity, in accordance with the conservation law in question.

But Dowe is very careful not to assert that the *meaning* of the word "cause" necessarily involves such conservation laws. Instead he accepts there have been and continue to be many notions of "cause". In particular, Dowe accepts that it is neither likely nor necessary that our common sense notion of causation will turn out to involve conservation laws. But Dowe is interested in the notion of causation that makes sense of currently accepted science -because current science is the best guide we have to reality-, and not in our *common sense* notion of causation. He takes it that what is required is an *empirical* analysis of causation, not merely *conceptual* analysis. So he takes the science *very* seriously indeed. At this stage one may object that science does not operate in a conceptual vacuum. For a start, those that were once special scientific concepts, have often ended up as part of our ordinary conceptual repertoire (consider, for instance, the notion of infinite, which is nowadays part of any educated person's conceptual repertoire; or the concepts of atom, molecule, or even DNA). And similarly scientific concepts do not typically come out of no-where, nor are they created *sui generis*, but are typically refinements of everyday concepts. So the task of empirical analysis cannot be so clearly distinct from conceptual analysis.

Dowe is well aware of this potential objection -he explicitly refers to the 'historical', or 'genealogical' connection of scientific to ordinary concepts. He seems to think that what distinguishes the concepts of science is their belonging in empirically well-confirmed scientific theories (cf. his remarks at the end of section 2.) And he does not think that the empirical warrant that scientific concepts may acquire will transfer automatically to the ordinary concepts that have historically preceded them. So he is only prepared to give up his conserved quantity theory if it fails to fit in with established physics; if his theory fails to fit with the ordinary concept of "cause", then so much the worse for the ordinary concept of "cause".

There seem to be at least two difficulties with this argument: first, it is not clear that all scientific concepts must be inherent in scientific theories. For example experimental and theoretical physicists often use the same term to refer to slightly (occasionally radically) different concepts (the term '*radiation*' is one; perhaps the term '*electron*' is another). There is a sense in which every concept requires a 'theory', but this need not be an explicit and well-tested scientific *theory*, even for those concepts that figure in science. The second difficulty is that restricting the analysis of the concept of cause to well-established scientific theories does not seem to preclude conceptual conflict. Different theories may employ different, incompatible, concepts. And some concepts (perhaps "cause" is one of them) may be well defined in certain theories but not others. Dowe gives no principled prescription for resolving such conflicts, and this open-mindedness may well turn out to be an advantage for his conserved quantity theory of causation.

Curiel's contribution is a detailed and relentless critique of transfer theories (including those that, like Dowe's, ground causal relations on conservation laws) within General Relativity (GR). In Curiel's view only the integral formulation of conservation laws would be able to ground causal relations. But unlike other physical theories, including Special Relativity, GR does not provide an integral formulation for the global conservation of any quantity that sufficiently resembles energy. So, it seems, *energy can not be said to be conserved in GR*. And Curiel shows that energy is precisely what one would expect to be conserved if there was a well-defined notion of causality in GR; for in GR only energy could be said to propagate in the required way to make causal continuity plausible. As a consequence, the notion of causality itself does not make sense within GR. Curiel seems to have found just one of the types of conceptual conflict that I described above: while classical mechanics and special relativity admit a concept of cause that goes along with the conserved quantity account, General Relativity seems unable to do so.

Why should this worry Dowe? An obvious reason to worry is that GR is a very well established scientific theory, and Curiel is surely right that the conserved quantity theorist, who takes empirical analysis to heart, must also take his arguments to heart. But Dowe *has* an obvious way out: he can simply exempt general relativity from his conserved quantity account, by arguing that as this account is unable to provide a notion of causation that applies to general relativistic phenomena, then there is no notion of causation that applies to such phenomena. This would in no way be a shameful retreat; on the contrary, this response would express a sincere commitment to derive philosophical lessons from empirical science; and it would remain open-minded in cases of conceptual conflict. We would have indeed discovered by empirical means an important fact about causation, namely: it applies to all physical phenomena except for general relativistic phenomena.

Curiel will probably think this is not good enough; for he considers GR a *fundamental* theory, and takes this to mean that if there is no satisfactory concept of causality in GR then there is no satisfactory concept anywhere else. But Dowe need not follow suit here; he can instead take the line that there is no *fundamental* theory in just this sense. He can for instance adopt Nancy Cartwright's metaphysical pluralism -which takes different theories to be fundamentally *true* of different phenomena, without any strong expectation that a unified and consistent theoretical representation of all phenomena will ultimately emerge.[1]

Jordi Cat and Joseph Berkovitz do not concentrate on transfer or process theories *per se*; but they maintain the central preoccupation with causal *con-*

tinuity characteristic of these theories. Cat explicitly takes continuity as a basic feature of causation. It is in part because of this that the 'microcausality' condition of quantum field theory, which establishes that the commutator of spacelike separated observables must vanish, cannot be read as a causality condition. The Green's function, which represents the contribution of a source in a field at some space-time location to the field operator at another location, may also be taken to represent the transfer of a causal influence between the two locations. So the vanishing of the Green's function for spacelike separated operators may be seen to support a causal reading of the 'microcausality' condition. But, Cat argues, the Green's function can not be said to represent causal processes as collections of physical events or states in space-time. As a result it cannot be said to represent the continuous transmission of causal influence, so it cannot provide a causal grounding of the 'microcausality' condition.

This mistaken use of the Green's function is only one of the possible attempts to provide a substantial causal interpretation for the 'microcausality' condition that Cat's analysis shows to be inconsistent or impossible; and its implicit appeal to causal continuity is not Cat's only reason to reject it. Cat's analysis and ultimate rejection of causal readings of 'microcausality' is, to my knowledge, the first comprehensive study of such an important topic. Cat shows the causal reading of the 'microcausality' condition is motivated by a fundamentalist and reductionist attitude to quantum field theory. Instead he offers a deflationary reading that takes the 'microcausality' condition to be a mere boundary condition, a constraint on quantum field theoretic models of relativistic quantum phenomena.[2]

Similarly Joseph Berkovitz provides a much-needed analysis of the different types of non-locality present in different versions or interpretations of non-relativistic quantum mechanics. What is nice about Berkovitz's paper is his insistence that non-locality cannot be discussed in the abstract, independently of particular formulations of physical theories. Berkovitz believes that attempts to characterise non-locality in general (for instance by focusing on the well-known conditions of outcome and parameter independence) are unconvincing. This attitude is very much of a piece with the overall tenor of the volume which, as I have already emphasised, aims to conduct the philosophical task of conceptual analysis *within* science. Berkovitz therefore considers the concept of action-at-a-distance as it appears in four currently much-debated quantum theories: the Bohm theory in its minimal and non-minimal versions, the modal interpretation, and the dynamical theory of state-vector reduction. It turns out that there is no unique concept of non-locality, or action-at-a-distance, that is a uniform part of each and every one of these formulations of non-relativistic quantum mechanics.

Berkovitz explicitly refers to causal continuity (in section 7 of his paper) and interestingly he comes to question its universal validity; he even shows that the non-minimal version of Bohm's theory meaningfully represents causal influences that are not continuous in space-time. But he must assume causal continuity when he rules out common causes that do not screen off in the EPR experiment (in the final section of his paper). For it is difficult to see how else one could rule out common causes that act at a distance, i.e. across gaps in space-time, in order to generate the measurement outcomes that give rise to the quantum statistics in the EPR experiment.

It is certainly possible that the world that we live in contains such causes. In fact, one could argue that the strange quantum phenomena that Berkovitz describes precisely argue for their existence. But, causes acting across space-time gaps cannot even be ruled out in quantum mechanics! The quantum state itself could represent such a non-screening-off common cause. Berkovitz's PCC principle cannot rule out such a common cause, for PCC merely requires that the union of all the partial and common causes screen-off measurement outcome events from each other; it does not require that the common cause, individually taken, screens off. It is true that if the common cause in the EPR experiment propagated continuously, there would be some, no matter how small, region of space-time lying in the back light cone of each measurement outcome event that would screen-off *that* event from the outcome event in the other wing. But this is not true for a common cause that does not propagate continuously in space-time -for such a cause does not require any intermediate event "along the way" to screen-off the later effect from the original causal event.

This scenario also shows that Fine's non-factorisable models (which Berkovitz too quickly dismisses in the same paragraph in the same section) are not so implausible. There is one clear sense in which these models would fail to be local (i.e. the cause acts across space-time gaps!), but they would be local in the intended sense: all physical interactions would take place at a specified space-time point. Although such models are not theories in their own right, and cannot count as serious competitors to the quantum theories that Berkovitz describes, they at least show that the common assumption that the non-locality inherent in the quantum theories is also inherent in the world simply won't fly. Not just because quantum mechanics may turn out to be empirically inadequate after all (and this, though unlikely, is certainly *possible*); but because causation may be represented within the quantum theories themselves.

Berkovitz also kindly refers to the Cartwright/Suárez model of superluminal connections between the wings of an EPR experiment.[3] This model would be separable and non-holistic, in Berkovitz's own terms. Berkovitz believes all such models to be physically implausible. Certainly such models are not countenanced by quantum mechanics, which typically provides a Hamiltonian for the EPR interactions that lacks any term representing a direct-causal connection between the separated particles. But I nonetheless remain optimistic about the ultimate fate of direct-cause models for EPR, because these models *could* be seen to emerge as a natural extension of quantum mechanics. But this is a story for another occasion. Berkovitz makes a powerful case for discussing the philosophical issue of non-locality *within* quantum mechanics itself; and on this critical issue we are in full agreement.

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Notes

1 See Cartwright, Nancy: 1999, *The Dappled World: A Study of the Boundaries of Science*, Cambridge University Press. Cartwright's epilogue to this volume is also very pertinent here.

2 As noted by Nancy Cartwright in her epilogue, Cat's attitude to fundamentalism is opposite to that of Curiel. Cat is critical of the assumption that there are fundamental theories that we must turn to for a description of the true causal relations. It may be that this critical attitude is just what Dowe needs to avoid Curiel's argument against the conserved quantity theory.

3 Cartwright, Nancy and Suárez, Mauricio: 'A Causal Model for EPR', forthcoming in *Reverberations of The Shaky Game*, University of Chicago Press.

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