Moritz Schlick and Bas van Fraassen: Two Different Perspectives on Causality and Quantum Mechanics

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Moritz Schlick's interpretation of the causality principle is based on Schlick's understanding of quantum mechanics and on his conviction that quantum mechanics strongly supports an empiricist reading of causation in his sense. The present paper compares the empiricist position held by Schlick with Bas van Fraassen's more recent conception of constructive empiricism. It is pointed out that the development from Schlick's understanding of logical empiricism to constructive empiricism reflects a difference between the understanding of quantum mechanics endorsed by Schlick and the understanding that had been established at the time of van Fraassen's writing.

1: Introduction

Moritz Schlick's ideas about causality and quantum mechanics dealt with a topic that was at the forefront of research in physics and philosophy of science at the time. In the present article, I want to discuss the plausibility of Schlick's ideas within the scientific context of the time and compare it with a view based on a modern understanding of quantum mechanics.

Schlick had already written about his understanding of causation in [Schlick 1920] before he set out to develop a new account of causation in "Die Kausalität in der gegenwärtigen Physik" [Schlick 1931]. The very substantial differences between the concepts of causality developed in the two papers are due to important philosophical as well as physical developments. Philosophically, [Schlick 1931] accounts for Schlick's shift from his earlier position of critical realism towards his endorsement of core tenets of logical empiricism. At the level of physics, his later paper was strongly inspired by the recent development and success of quantum mechanics. Unlike Carnap who, while being interested in scientific developments, preferred a philosophical discourse that remained independent from individual scientific statements, Schlick was a real expert regarding the physics of his time and tried to account for specific new developments in physics at a philosophical level. Schlick makes an attempt to account for philosophical as well as for scientific new developments and to build one coherent conception that can do justice to both of them. In his own understanding, he does find an interpretation that works for both sides and is strengthened by that fact.

The discussion of Schlick in the present paper will focus on [Schlick 1931] and on his verificationist perspective on causation. Schlick's attempts to reconcile logical empiricism

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and a strict verificationism with a realist stance, which shows e.g. in [Schlick 1932], will not be of importance for the present analysis.[2]

About half a century after Schlick, Bas van Fraassen who is equally interested in analysing philosophy of physics based on general empiricist conceptions presented his constructive empiricism [van Fraassen 1980]. The attempts of both authors to relate their respective understanding of empiricism to the topical understanding of quantum mechanics provide an instructive basis for comparing the compatibility of logical and constructive empiricism with quantum physics. While both positions have been developed primarily based on general philosophical reasoning, they seek to be coherent with the new developments in Physics. Van Fraassen's interest in quantum physics may suggest that he took his position's compatibility with the concepts of quantum mechanics to be an important issue. The question may be asked whether the development from Schlick's interpretation of logical empiricism towards van Fraassen's constructive empiricism is related to the development of the understanding of quantum physics that took place during that time span. The present paper will argue that connections between the physical and the general philosophical level of discussion can indeed be established.

2: Schlick on Natural Laws and Causality

Early logical empiricism held that statements acquire meaning only through the conditions of their verification. This idea, which was intended to offer the basis for a clear-cut distinction between meaningful scientific statements and metaphysics without cognitive content, had an unpleasant consequence, however: it threatened to render all general scientific statements meaningless. Scientific theories are based on general natural laws which quantify over all events or objects of a given kind. Verification as understood by logical empiricism, however, must be based on individual observations and therefore can only pertain to individual facts.

To give an example, let us consider the natural law "All freely falling massive objects on earth accelerate with rate g.". Verification can only be based on observations of the kind: the free-falling object A has accelerated with rate g at time t. Having measured accelerations with rate g consistently on many occasions will be considered a confirmation of the corresponding natural law by the scientific community. Inductive reasoning will lead from the set of confirming evidence to the prediction of future outcomes under comparable circumstances. The described set of measurements cannot constitute a verification of the law of acceleration, however. From the logical empiricist perspective, verification must be logically conclusive, which would require deductive inference from the set of observations to the general statement. This, however, obviously cannot be provided.

Various ways of dealing with that problem have been suggested by exponents of logical empiricism in the early 1930s. Rudolf Carnap chose the path towards weakening the criterion of verification to an extent that would allow the notion of a gradual verification (confirmation) of natural laws.

Moritz Schlick rejected that strategy since he believed that any weakening of the criterion of verification would sacrifice the clear distinction between science and metaphysics. He therefore tried to develop a different strategy. He was ready to

[2] For wider discussions of Schick's works on causality see [Stöckler 1996], [Stöltzner 2008] and [Fox 2009].

acknowledge that natural laws and generalizing sentences of similar kinds are indeed not verifiable. In fact, Schlick claimed that they do not constitute statements at all. He rather took them to constitute instructions for the generation of statements (*Anweisungen zur Bildung von Aussagen*). In other words, they were akin to commands or advices. According to Schlick, the scientist uses those laws in order to create statements on her predictions of individual future outcomes of experiments. Those predictions have the status of statements because they can be verified by empirical data. The natural laws are just guidelines how to extract those statements based on inductive reasoning from other statements which have already been verified.

Schlick's understanding of natural laws plays directly into the more specific discussion on the status of the causality principle. The causality principle asserts that all events are fully determined by causal laws. It was widely considered an important and viable characterisation of classical physics. However, a closer look at the principle's meaning seems to lead into an unfortunate dilemma: either one takes the principle to be tautological or one has to introduce arbitrary restrictions to the definition of causal law which turn the causality principle from a statement of universal importance into a specific claim about the applicability of an arbitrarily chosen conception.

Schlick presents the problem in several steps in [Schlick 1931]. Causality denotes that a certain event in a given framework necessarily implies a specific consecutive event. The only way of understanding what this means, according to Schlick, leads through deploying the concept of a law. There has to be some kind of order ("Ordnung") that determines the next event's outcome based on the first event. The problem arises, however, that any imaginable sequence of events might be declared some kind of order. There is no clear-cut and fundamental distinction between order and non-order. The causality principle thus turns into a tautology.

One attempt to define the elusive distinction between order and non-order in a meaningful way relies on prediction. Following that idea, order allows for successful prediction while non-order does not. However, no fundamental principle seems at hand that prevents even the least orderly and most arbitrary statement about an imagined sequence of events from being predictively successful. A time traveller coming from the future could use her records for providing predictions of that kind. Being extremely lucky might lead towards the same predictions by chance. Using predictive success as a criterion for order thus does not prevent us from accepting any imaginable sequence of events as the consequence of some law.

In order to free the causality principle from the tautology threat, one has to introduce specific additional conditions which have to be met by natural laws. The most natural suggestion is to demand a certain degree of simplicity. The awkward nature of simplicity debates makes it obvious from the start, however, that any specific and precise condition introduced on that basis must be highly arbitrary and is likely to be threatened by counter-examples of laws from real science which do not meet the given condition. Entering that discussion or a discussion on any other more specific definition of natural law leads into arbitrary constructions of law concepts whose significance does not seem to range beyond its creator's set of predilections. Such constructions seem inadequate for providing a stable foundation for universally acceptable statements on the viability of the causality principle. Schlick considers that route unpromising.

What Schlick suggests instead is to apply his definition of scientific laws as instructions for generating statements. According to that idea, the principle of causality itself, which requires quantification over all events, does not constitute a statement with cognitive content at all. The question whether or not it is tautological thus does not arise. The causality principle may be taken to be a kind of meta-law, which means that it does not constitute immediate advice regarding the generation of individual statements but rather advice regarding the generation of laws. The claim that all events are fully determined by causal laws must be interpreted as the meta-theoretical advice to look for causal laws which can suggest successful predictions of individual and verifiable events.

Der Kausalsatz teilt uns nicht direkt eine Tatsache mit, etwa die Regelmäßigkeit der Welt, sondern er stellt eine Aufforderung, eine Vorschrift dar, Regelmäßigkeit zu suchen, die Ereignisse durch Gesetze zu beschreiben[3]. [Schlick 1931, p571]

Schlick's construction solves the problem of the delimitation of order from non-order. Seen from his perspective, it is not necessary to offer a rigid distinction between (sufficiently simple) laws and (overly complex) non-laws. The scientist can follow the advice given by the causality principle by looking for simple structures first and then adding complexity until she finds a law that is compatible with the known phenomena. The advice thus makes sense without offering any rigid definition of order.

3: Implications of Quantum Mechanics According to Schlick

The status of the causality principle was intensely debated in the context of quantum physics in 1920s and 1930s. Werner Heisenberg took quantum mechanics to be a refutation of the principle of causality. In his view, the uncertainty relation implied that no natural law could predict the outcome of future measurements based on the present state of the world. Thus, there was no strict causality relation between the present state of the world and future events.

Max Born, to the contrary, endorsed the tautology interpretation of the causality principle. Like Heisenberg, he took quantum mechanics to imply that it did not make physical sense to try to define a natural law that could implement a specific strict causality relation between the present state of the world and future events. Contra Heisenberg, however, he stressed the formal existence of a causality relation expressing the connection between old and new data. That causality expression was represented simply by the actual sequence of events. It could not be determined in advance based on the theory and the available data. This, however, could be interpreted in terms of the causal structure's lack of simplicity rather than in terms of the absence of a causal structure. Though the causality principle thus survived, applying the concept of causation lacked any significance with regard to a characterisation of the scientist's activity. In Born's view, the impossibility to translate the uncertainty relation into a clear refutation of the causality principle was a nice illustration of that principle's tautological character.

While Heisenberg's understanding seemed to be an accurate characterisation of the intuitive understanding of the canonical interpretation of quantum mechanics, Born's philosophical analysis appeared to be directly implied by a traditional and universal conception of causation.

[3] The causal sentence does not tell us a fact, like e.g. the regularity of the world, directly. Rather, it constitutes an instruction, a prescription for looking for regularity and for describing events by laws.

Schlick took the unsatisfactory state of the debate on quantum physics and causation to provide strong support for his position on causality. From his perspective, quantum physics clearly demonstrated the inadequate nature of the classical concepts of causation. In fact, it seemed to offer a physical argument that was in stupendous agreement with the philosophical arguments put forward by Schlick himself.

Schlick's reasoning relied on a strictly empiricist interpretation of quantum physics. According to that understanding, the indeterminacy of quantum mechanics is strictly identified with unpredictability: quantum mechanics is structurally incapable of providing precise predictions of future events. Ontological conceptualisations of indeterminacy which relate the term to an irreducible characteristic of the quantum state are rejected by Schlick as metaphysically contaminated. This take on quantum physics did not constitute a consensual position among quantum physicists at the time. It was apparently endorsed by some physicists, however. In particular, Schlick attributes a position along those lines to Arthur Eddington [Schlick 1931, p563].

Schlick then goes on to interpret this understanding of indeterminacy within the framework of his notion of a natural law. A natural law in Schlick's eyes is an advice for the generation of statements on individual events. If quantum physical laws are indeterminate laws, they give the advice NOT to generate statements which predict the outcomes of experiments in contradiction with the indeterminacy. The causality principle is located one level further up. It constitutes advice which kind of natural laws one should formulate. Specifically, it constitutes an advice to look for laws which give advice how to generate statements on the specific outcome of experiments based on previously collected data. Rejecting the causality principle due to the success of quantum mechanics then amounts to rejecting the advice to look for new laws which give advice how to build such statements. In other words, it means considering it a bad idea to try making precise predictions on future events in the given context.

Understood in this way, the causality principle is neither a statement that has been refuted by quantum physics as Heisenberg suggests nor is it tautological. It does not constitute a statement at all. It is not irrelevant either, however, since it conveys advice one can follow or reject. Whether one does or does not endorse the causality principle thus makes a significant difference with regard to scientific strategy.

Schlick's understanding may seem fairly convincing at first sight. As we will see in the next section, however, the foundational debate on deterministic alternative interpretations of quantum mechanics significantly changes that perception.

4: Hidden Variables and Bell's Inequalities

From very early on, quantum physicists thought about the question as to whether the indeterminacy interpretation of quantum physics was unavoidable. Louis de Broglie [de Broglie 1930] in particular tried to develop a hidden variables theory, i.e. a formulation of quantum physics which retained the principle that future events could not be precisely predicted based on earlier experimental data but nevertheless contained an ontological component that conformed to the principle of causality based on a tractable set of natural laws. What he was looking for was determinacy at an ontological level combined with indeterminacy at the epistemic level.

De Broglie's ideas did not attract much interest during the first decades of quantum physics. Already the possibility to formulate a question of the given kind in a scientifically meaningful way demonstrates, however, that Schlick's approach to the causality principle is uncomfortably narrow. For Schlick, a theory's scientific statements do not have meaning beyond the theory's predictive qualities. Ontological statements which cannot be expressed in terms of predictions are either meaningless or must be reduced to purely mathematical statements about the theory's structure. Such purely mathematical statements, however, must be entirely unrelated to the concepts of indeterminacy and causality since the latter, according to Schlick's understanding, are empirical rather than mathematical concepts. From Schlick's perspective, the question posed by de Broglie may be asked at a purely mathematical level about some structural properties of quantum physics but cannot have a meaningful rational reconstruction in terms of causality or the concept of indeterminacy.

De Broglie suggests that the answer to the question whether or not an, as he would put it, deterministic interpretation of quantum mechanics exists clarifies an essential characteristic of the theory with regard to its causal structure. Schlick, based on his position, must deny the question's significance in this sense.

Note that finding the question interesting along the line suggested by de Broglie does not necessarily imply taking hidden variable theories to be physically meaningful. Even if one takes an empiricist stance and considers such theories physically uninteresting due to their lack of empirical implications, one may well be interested in the question as to whether or not quantum physics allows for hidden variables. The answer to this question just tells something about the structure of quantum mechanics.[4] If one decides to discuss the question, however, it seems perfectly natural to discuss it terms of determinacy versus indeterminacy, which simply denotes the intuitive framework of the analysis. It therefore turns out that Schlick's strictly empiricist definition of determinacy obstructs a full and intuitively accessible analysis of quantum mechanics. For that reason, once it had been established that the question of hidden parameters did constitute an important philosophical question regarding quantum mechanics, Schlick's perspective did not have a chance to survive. It is important to note that the analysis of hidden parameters in quantum mechanics did not just work against Schlick's radically empiricist understanding of causation in quantum physics. By providing an example where Schlick's reduction of causation to prediction did not allow an adequate characterisation of an important debate in physics, it actually worked against Schlick's theory of causation in general. Schlick's understanding of the causation principle as a form of advice to aim at empirical predictions (and, correspondingly, of the denial of the causation principle as an advice not to do so in some contexts) just did not seem capable of accounting for some important use physicists made of the term in their work. Schlick's concept thus was in danger of decoupling from the scientific discourse.

Going even further, by threatening the viability of Schlick's theory of causation, quantum mechanics arguably weakened his entire conception of natural laws as advices for the creation of statements.

The history of the debate on hidden parameters is, of course, well known. John von Neumann early on believed to be able to prove the inconsistency of hidden parameter models. This, however, turned out to be incorrect. In the 1950s, David Bohm started developing specific realizations of hidden parameter models [Bohm 1952]. In 1964, John Bell

[4] In terms of an analysis of mathematical structure, the debate on empirically equivalent alternative interpretations of quantum mechanics thus can be of interest even from Schlick's perspective, as was emphasised in [Stöltzner 2006].

showed that the class of local hidden parameter models was empirically inequivalent with canonical quantum mechanics [Bell 1966]. Later on, experiments carried out on those grounds confirmed canonical quantum mechanics against its local deterministic rival.

The proof that local hidden parameter models are empirically distinguishable from canonical quantum mechanics and the eventual empirical refutation of those models on that basis further strengthens the case against Schlick's understanding of the causality principle. Schlick relates the meaning of the causation principle to an advice regarding the search for predictions in a specific context. Thereby, he goes beyond relating causality to observable features. He actually singles out one specific observable feature that is addressed by the causality principle: the question whether one should look for a certain class of empirical predictions. Since hidden parameter models do not aim at offering more precise predictions than canonical quantum physics, this question plays no role in their discussion. In Bell's analysis of local hidden parameter models, he deals with another empirically relevant aspect of causation. He asks whether the implementation of a certain type of deterministic system (i.e. the vindication of a causality principle) is empirically distinguishable from canonical quantum mechanics. By demonstrating that this is indeed the case, he establishes the empirical significance of the question of determinism (and thus also the question of causation) that goes beyond what Schlick is ready to acknowledge. What Bell shows is that determinism based on local hidden parameters can be tested in the context of quantum physics not by predicting the precise outcome of the determinate process but by looking at other experimental signatures. The complex of causation and determinacy thus becomes a part of the analysis of empirically relevant science without becoming expressible in terms of the range of the theories' predictions regarding the exact outcome of quantum processes. This, however, is at variance with Schlick's straightforward reduction of causation to prediction.

Quantum Mechanics and Constructive Empiricism

Today, logical empiricism has been replaced as the leading paradigm of empiricist thinking by van Fraassen's constructive empiricism, which was formulated in 1980 (van Fraassen 1980] within the framework of the by then popular realism debate. The core question to be answered by constructive empiricism is whether or not the success of scientific statements is in some way related to their truth.

Van Fraassen's position was motivated by the search for an empiricist position that could withstand the massive philosophical criticism that had led to the virtual abandonment of logical empiricism in the 1960s and 1970s. Constructive empiricism differs from its predecessor in a number of ways.

First, van Fraassen endorses a literal understanding of scientific statements. He assumes that we know what we are talking about when we distinguish, to give an example, the claim that electrons exist from a statement about a bundle of empirical phenomena explicable based on the concept of the electron. Thereby, he rejects the rigid theory of meaning that was defended by the logical empiricists and strongly criticised on various grounds by their opponents. Unlike the logical empiricists, van Fraassen can distinguish in a meaningful way between analysis at an ontological and at an epistemological level. (For the logical empiricist, such a distinction was empty because all meaningful analysis in the end had to be understood epistemologically.)

Having introduced the distinction, van Fraassen can participate in the modern debate on scientific realism. He thereby departs from the logical positivist position of Carnap and Hempel who reject the philosophical relevance of the realism debate based on denying that a realist position can have any significance beyond the purely pragmatic question of language choice.[5] Van Fraassen defends empiricism based on an analysis of scientific activity and reasoning. He introduces the concept of empirical adequacy that can be distinguished from truth based on a literal understanding of scientific statements. Nonlocal hidden parameters and the canonical interpretation of quantum mechanics, to pick up the scenario discussed above, are empirically equivalent and thus may be both empirically adequate. Nevertheless, in van Fraassen's understanding, it is possible to assume that one of the two interpretations is true and the other is false. Van Fraassen now does not ask the classical question whether we have reason to believe that our present theories are true or empirically adequate. He rather asks whether scientists aim at truth or empirical adequacy. He then goes on to argue that it makes more sense to attribute the aim of empirical adequacy to the scientist.

Based on his literal understanding of scientific theories, van Fraassen can state that we can know what we are talking about when discussing some theory's features even if they are not empirically testable. This wider theory of meaning allows meaningful talk about models in science without any immediate translation of that talk into verifiable observational sentences. Therefore, it opens the gates for van Fraassen's model theoretical account of scientific theories. Van Fraassen rejects natural laws as universal statements about the world just like Schlick. Scientific theories in his understanding constitute sets of models which are used to represent the phenomena. "A scientific theory is empirically adequate if it has a model such that all appearances [i.e. structures which can be described in experimental and measurement reports] are isomorphic to empirical substructures of that model." [van Fraassen 1980, p 64]

Constructive empiricism remains close to earlier empiricist conceptions in a number of respects. Van Fraassen's understanding of causality, in particular, does show resemblances with Schlick's account. In van Fraassen's understanding, causality is placed at the level of models. It characterises the model rather than the actual world. In this vein, one might call the causality principle a construction principle of a model, which would be an understanding reminiscent of Schlick's account.

The new conceptual elements introduced have generally been acknowledged to allow more successful answers to a number of questions in general philosophy of science than logical empiricism. Van Fraassen's literal understanding of scientific statements and his semantic model theoretic approach were taken to offer a more adequate conception of how science in fact proceeded.

The previous discussion shows, however, that one of the most important new elements introduced by constructive empiricism, the literal understanding of scientific statements, can also be read in terms of a reaction to the altered character of the foundational debate in quantum mechanics. We have seen how the debate on hidden parameters from the 1950s and 1960s onwards strongly suggested an understanding of causation that was based on abstract conceptual considerations and could not be reduced to the question of the predictive range of quantum physics. Schlick's understanding of causation failed to account for the character of that debate. Van Fraassen, to the contrary,

[5] Schlick, it must be noted, did envision a reconciliation of logical empiricism with realism without sacrificing verificationism (see e. g. [Schlick 1932]).

can account for it based on his literal understanding of physical statements. Schlick decoupled universal laws from empirical confirmation by denying them the status of statements. Van Fraassen chooses a different strategy: he understands universal scientific statements as pertaining to models rather than to the world. At the level of models, however, the assertion that some model is a causal model, a determinate model or an indeterminate model does constitute a statement about the model's characteristics with cognitive content. Based on this construction, van Fraassen can take seriously the debates on ontology in the context of quantum mechanics without acknowledging a realist implication of those debates. He therefore can account for the full range of scientific analysis while remaining faithful to his empiricist stance.

Conclusion

The comparison between Schlick's understanding of the causality principle and van Fraassen's understanding of causation can indeed be related to a shift in the interpretation of quantum mechanics. While at Schlick's time the uncertainty principle and the indeterminacy of quantum mechanics could be understood in an uncompromisingly empiricist way in terms of the theory's predictive range, the later in depth analysis of hidden parameter models changed that situation. Bell's analysis and the subsequent empirical tests demonstrated that the attribution of stochastic properties to the quantum state itself, i.e. the distinction between indeterminacy due to our immutable lack of knowledge on the one hand and indeterminacy due the stochastic quality of the quantum state itself was in fact important for acquiring a full understanding of quantum physics. Based on that new understanding, even adherents to the canonical interpretation of quantum physics could not accept Schlick's strictly empiricist interpretation of quantum physics any more. Quantum mechanics thus had changed from being a potential supporter of Schlick's interpretation of the causality principle to providing a strong argument against it.

Van Fraassen's constructive empiricism is a position that accounts for the stronger emphasis on a characterisation of the quantum state in today's quantum physics. His emphasis on a literal understanding of concepts stands in full agreement with that approach. Van Fraassen's understanding of causation within his model theoretical approach allows for universal statements without requiring the assumption that they are verifiable by empirical data.

At a general philosophical level, van Fraassen aimed at developing an empiricist position that could withstand the criticisms which had been put forward against logical empiricism. The evolution from early logical empiricism towards van Fraassen's constructive empiricism at this level clearly reflects the results of a long process of analysis and criticism of empiricist ideas. The comparison of constructive empiricism with Schlick's version of logical empiricism carried out in the present work suggests that a similar story can be told at the level of philosophy of physics. Schlick's application of logical empiricist ideas were based on an understanding of quantum physics that was legitimate at the time. The modern foundational debate on quantum physics, however, does not fit well with Schlick's theory of causation in quantum physics. Van Fraassen's constructive empiricist take on causation has been strongly influenced by contemporary debates on quantum mechanics and thus avoids the problems faced by Schlick.

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