Cambridge University Press
978-1-107-03149-4 - Causal Reasoning in Physics
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CHAPTER 1

Introduction

1. From Helmholtz to Russell: a very brief historical sketch

Is there a place for causal reasoning in physics? Many readers might think that the answer to this question must obviously be "yes." Since it is the aim of science to explain the natural world, one might argue, and since the search for explanations is just a search for causes, causal reasoning obviously plays an important role in physics. Since physics is arguably the most fundamental science, it must be concerned with discovering the most fundamental causal relations.

Indeed, that physics is concerned with the search for causes appears to have been a widely held view in the late eighteenth century and up until the middle of the nineteenth century. For example, the German physicist Hermann von Helmholtz (1821–1894), in a public lecture, characterized the aim of physics as follows:

> Our demand to understand natural phenomena, that is, to discover their laws, is a different way of expressing the demand that we are to search for the forces that are the causes of the phenomena. The lawfulness of nature is conceived of as causal relationship, as soon as we recognize nature's independence from our thought and from our will. Thus when we ask about the progress of science as a whole, we will have to judge it according to the extent in which the recognition and the knowledge of causal connections, encompassing all natural phenomena, have progressed. (Helmholtz, 1896, 40, my translation)

For Helmholtz the centrality of causes is underwritten by a conception of forces as causes of motion. In his talk Helmholtz attempted to develop a unified conception of science with mechanics at its foundation:

> If motion is the primary change, which forms the basis of all other changes in the world, then all elementary forces are forces of motion; and the ultimate

> aim of science is to find those motions and their forces that form the basis of all other changes – that is, for science to dissolve into mechanics. (Helmholtz, 379)

Thus, for Helmholtz the ultimate aim of science is to find the basic forces, and these forces are understood as causes of fundamental motions. Indeed, a conception of forces as causes of motion appears to have been widely endorsed up until the middle of the nineteenth century. The physicist Gustav Theodor Fechner (1801–1897), for example, puts this view as follows: "that physicists often speak of force simply as the cause of motion" (Fechner 1864, 126, my translation).

Yet the view of physics as a search for causes was increasingly questioned in the last decades of the nineteenth century, and there now exists a long and distinguished tradition denying that causal notions can play a legitimate role in physics.[1] In the introduction to his *Vorlesungen zur Mechanik* (Lectures on Mechanics), Gustav Kirchhoff (1824–1887) criticizes the definition of forces as the causes of motion (and the very conception of science as the search for the basic forces as causes championed by Helmholtz) as being infected by unacceptable vagueness:

> It is customary to define mechanics as the science of *forces* and to define forces as the *causes* that produce motion or *strive* to produce motion . . . [but this definition] is infected by the vagueness from which the notions of cause of striving cannot be freed . . . Given the precision that otherwise characterizes inferences in mechanics, it appears to be desirable to remove such obscurities even if this were possible only through a restriction of its purpose. For this reason I take the task of the science of mechanics to be to describe the motions found in nature, and to describe them completely and as simply as possible. By this I mean that the aim is to state *what* the phenomena are which occur, rather than to determine their *causes*. (Kirchhoff, 1876, p. v, my translation; italics in the original)

The term "force" still plays a role in Kirchhoff's treatment, but forces are defined implicitly through the equations of mechanics: "In order to remove any obscurity it is sufficient to define the notion of forces only insofar as every theorem in mechanics which speaks of forces can be translated into equations" (*ibid.*, p. vi).

That the concept of cause is inherently and irredeemably vague is a criticism that has often been repeated since. In the early twenty-first century

[1] For a more detailed and excellent discussion (in German) of the history of the role of causal notions in physics in the nineteenth century, see Hüttemann (2013). My brief survey here follows Hüttemann's discussion in broad outline.

we find this view defended, for example, by the philosophers of physics John Earman and John Norton. Earman derides appeals to causal notions in physics by maintaining that the contest of conflicting intuitions about causal notions "may generate many learned philosophical articles," but that "a putative fundamental law of physics must be stated as a mathematical relation without the use of words that require a PhD in philosophy to apply (and two other PhDs to referee the application, and a third to break the tie in the inevitable disagreement of the first two)" (Earman 2011, 494). He insists that explanations in physics may not involve any causal "philosophy-speak" (Earman 2011, 494). Norton expresses a similar view, claiming that "the conditions of applicability [of causal notions] are obscure" (Norton 2009, 481).

Whereas Kirchhoff's criticism of causal notions appears to be directed against a specific conception of cause as that which "produces" or "brings about" its effects (or "strives" to bring about its effects), later criticisms are directed against what appear to be less metaphysically loaded conceptions of "cause" as well. Thus, although the physicist Ernst Mach initially adopted John Stuart Mill's Humean regularity account of causation, according to which "the law of Causation . . . is but the familiar truth that invariability of succession is found by observation to obtain between every fact in nature and some other fact which has preceded it" (Mill 1875, III-v-§2), Mach later rejected the account and argued for a complete rejection of causal notions in physics as follows:

> When we speak of cause and effect, then we arbitrarily emphasize those aspects, the connections among which are the ones on which we have to focus, when we represent a fact from a certain perspective that is important to us. In nature there are no cause nor an effect. Nature exists only once. Repetitions of the same cases, in which *A* would always be linked with *B*, thus same effects under the same circumstances, thus the essence of the connection between cause and effect, exist only in the abstraction, which we undertake in order to represent the facts. (Mach 1901, 4.4.3, p. 513)

Mach here argues that causal regularities of the form "All *A*'s are followed by *B*'s" are the result of abstracting from the multitude of factors on which the occurrence of an event depends. The argument can be fleshed out in a bit more detail as follows. Imagine we are interested in representing the motion of a particular billiard ball *B* on a billiard table. In providing a mathematical model of the ball's motion, it may be useful to focus only on the motion of the cue ball and its collision with *B* as *the* "cause" of *B*'s motion and to abstract from the dependence of the ball's motion on any other factors, such as the gravitational forces exerted by the billiard players, nearby physical objects, or the sun. In many contexts it is appropriate to represent the motion of the ball in terms of a simple model that contains only the table and the balls on it, treats the collisions among balls as fully elastic and ignores gravitational forces. For a simple model, such as this, there will be regularities of the form "every ball at rest of mass *m* that is struck head-on by another ball with momentum *p* will move at velocity *v*." In principle, however, the motion of the ball depends on many other factors as well, which are ignored in the simple model. If we were to include these in our description of the collision event, we would find that the very complicated precise combination of factors on which the precise motion of ball *B* on a given occasion depends occurs exactly once. As Mach puts it, "nature exists only once." Thus, since the regularity "Whenever the full set of factors *F* occurs, they are followed by *B*" is instantiated only once, it is trivially true: corresponding to every true and complete description of the state of a system (or the world) at a time, and an event immediately succeeding that time, there is a true universal generalization of the form "The full set of factors *F* is followed by *B*."

For Mach this argument entails a complete elimination of the notion of cause: "If we aim to remove the traces of fetishism that are still attached to the notion of cause and if we realize that a cause can generally not be specified, but that a fact usually is determined by a whole systems of conditions, then this leads us to giving up the notion of cause completely" (Mach 1900, 433). The view that causal notions are in some sense perspectival, playing a role only in our representations ("Nachbildungen") of the world, and hence are not a legitimate part of physics, is a view that is also prominent among critics of causal notions in the late twentieth and early twenty-first centuries, as we will see in detail in subsequent chapters.

Mach's conclusion is that, in the advanced sciences, the concept of cause has been replaced by that of functional dependency:

> In the higher developed sciences the use of the concepts of cause and effect is more and more restricted and increasingly rare. The reason is that these concepts characterize a state of affairs only in a preliminary and incomplete manner and that they lack precision . . . As soon as one succeeds in characterizing the elements of events through measurable quantities [. . .], the dependencies among these elements can be represented much more completely and more precisely with the help of the concept of a function than through the indeterminate concepts of cause and effect. (Mach 1905, 278)

A functional dependency expresses the values some physical quantity (the "output") can take in terms of the values of other quantities (the "input").

The relation between the different quantities is a function, exactly if for each set of input values there corresponds exactly one output value. One prima facie advantage of expressing the relation between quantities in terms of functional dependencies among variables used to represent these quantities is that this appears to avoid the problem of trivialization: whereas the precise combination of values for the different input variables determining the value of the output variable may occur only once (and hence the corresponding causal regularity is trivially universally instantiated), the functional dependency relating input and output variables may be multiply instantiated.

Like Kirchhoff before him, Mach criticizes causal notions as being inherently vague. However, Mach's criticism of causal notions in physics and the sciences is more general and does not merely amount to a positivist or empiricist criticism of an overly metaphysical notion of causal "production" or of "bringing about." For Mach, even an empiricist Humean regularity notion of cause cannot be part of physics proper and has been replaced there by the more appropriate and more precise concept of functional dependency.

The English philosopher Bertrand Russell repeated many of Mach's criticisms in his famous and influential essay "On the Notion of Cause" (1912–13), which, at least in the English-speaking world, is much better known than Mach's earlier critique. Russell repeats both Mach's vagueness charge and the claim that even a regularity notion of causation is problematic, since true regularities would be instantiated at most once:

> The principle "same cause, same effect," which philosophers imagine to be vital to science, is therefore utterly otiose. As soon as the antecedents have been given sufficiently fully to enable the consequent to be calculated with some exactitude, the antecedents have become so complicated that it is very unlikely they will ever recur. (Russell 1912, 9)

Russell concludes, again following Mach, that the concept of cause in the advanced sciences has been replaced by the notion of functional dependency.

Russell's essay contains one additional criticism – a criticism that has often been repeated since. He points out that the notion of cause is time-asymmetric – effects do not precede their causes – whereas the laws of the basic theories of physics are time-symmetric: "the future 'determines' the past in exactly the same sense in which the past 'determines' the future" (Russell 1912, 15). From this contrast he concludes that physics is incompatible with causal notions. Appeals to the time symmetry of the dynamical equations constitute perhaps the predominant reason for why philosophers have, often without further argument, concluded that causal notions can play no role in physics. For example, the German philosopher of physics Erhard Scheibe maintains, after pointing to the contrast between time-symmetric laws and time-asymmetric causal relations, that "this suffices to seal the fate of event-causality" – of causation as a relation between pairs of events or event types (Scheibe 2006).

The overall lesson Russell draws from his discussion of causation in physics is that causal notions should be rejected *in general* as having no useful role in our conception of the world. In an oft-quoted passage, he says: "The law of causality, I believe, like much that passes muster among philosophers, is a relic of a bygone age, surviving, like the monarchy, only because it is erroneously supposed not to do harm" (Russell 1912, 1).

Although Russell's criticism of causal notions has received a lot of attention, in particular in the early years of the twenty-first century, the fact that he himself came to change his mind on the role of causal notions in science is much less frequently discussed. I will discuss Russell's later view briefly below (see Russell 1921; 1948; 1954). Yet not just Russell changed his mind; philosophy more generally seems to have moved away from a wholesale rejection of causal concepts of the kind that may have been fashionable during the heyday of logical positivism. Indeed, the position of many causal critics a century after the publication of Russell's essay seems to be closer to Mach's view than to the view Russell argued for in "On the Notion of Cause," since, unlike Russell, Mach appears to have allowed that causal relations can be a legitimate aspect of our partial and abstract representations of the phenomena. That causal notions can play a role in our representations of the phenomena from a particular perspective and in a particular context is a view with prominent defenders in the twenty-first century. The philosopher James Woodward, for example, argues in the essay "Causation with a Human Face" (Woodward 2007) – a paper we will discuss in detail in subsequent chapters – that it is precisely the fact that causation has a "human face" which constitutes the reason why causal notions do not sit well with our more fundamental theories of physics. Mach, however, as we saw, ultimately concluded from the perspectival character of causal notions that such notions ought to play no role in the more highly developed sciences, whereas Woodward and others want to draw a distinction between the "special sciences" on the one hand, in which causal reasoning is thought to play an important role, and physics on the other, which does not allow for a legitimate place for causal concepts.

I have mentioned a number of anti-causal claims that have been prominent in discussions of causal notions in physics from the nineteenth century onward. Among these claims are the following: (i) the notions of cause and effect are inherently vague; (ii) this vagueness infects especially metaphysically rich notions of causal production; (iii) a regularity account of causation is problematic, since the set of factors on which a given effect depends is so large that the true causal regularities would be instantiated at most once; (iv) causal notions are part only of our abstract representations of the phenomena, and hence may be thought to be context- and interest-relative; and (v) the notion of cause is time-asymmetric, whereas the dynamical laws of the fundamental or established theories of physics are time-symmetric. In the following chapters I discuss these claims and several others to argue that they cannot be fashioned into arguments that succeed in showing that causal reasoning has no legitimate role to play in physics.

2. Distinct philosophical projects

The question whether there is a place for causal notions in physics can be asked within the context of several different philosophical projects.[2] The first such project is a metaphysical project interested in determining the metaphysical "grounds" for causal claims. The main division in the metaphysics of causation is between defenders of broadly Humean accounts and defenders of accounts that are broadly non-Humean. Humeans follow the Scottish philosopher David Hume (or at least follow Hume as he has traditionally been understood) in rejecting fundamental modalities. According to Humeans, the universe fundamentally is composed of a distribution of categorical properties and relations instantiated by fundamental entities throughout spacetime. This distribution is often referred to as "the Humean mosaic." For the Humean, all modal claims, including causal claims, are made true by features of the mosaic, such as regularities in the distribution of categorical properties. By contrast, non-Humeans believe that modal properties, such as necessitation relations or dispositional essences, are themselves fundamental properties. For example, one might hold that it is in the nature of objects with mass to attract other massive objects. Or one might hold that causal laws are a fundamental feature of reality and that it is in virtue of such laws that earlier states of the world produce or bring about later states.

[2] The distinctions I am drawing here are similar to ones Woodward drew in his Presidential Address at the 2012 Meeting of the Philosophy of Science Association in San Diego, CA.

Within the context of the metaphysical project, the question concerning the place of causal notions in physics becomes the question whether a certain metaphysical account of causation *receives support from*, *is at least compatible with*, or *is undermined* by certain central features of physics. The philosopher Tim Maudlin, for example, argues that the laws of physics are fundamentally causal laws governing how earlier states generate later states of a system (Maudlin 2007). Also, the philosopher Nancy Cartwright argues that the sciences, including physics, require a notion of causal capacities (Cartwright 1989; 1999). Much more common, however, at least among philosophers of physics, appear to be positions that agree with Kirchhoff's or Mach's skepticism and maintain that metaphysically rich notions of causation can have no legitimate place in a mathematized empirical science such as physics. At most a "thin," broadly Humean notion of causation may be compatible with physics, without however playing any useful role within that science.

A second philosophical project aims to offer a conceptual analysis, broadly construed, of claims of the form "A causes B." The core criterion of success within the context of this project is that an account of causation be able to reproduce commonsense causal claims – that is, that it be able to match our intuitions regarding what is assumed to be our "folk notion" of causation. David Lewis and his followers are engaged in this type of project, for which the central data are commonsense claims such as "Suzy's throwing the rock caused the bottle to break." Assessing the success of a given analysis involves examining how well the analysis handles cases of preemption, late preemption, trumping, or overdetermination – all well familiar from the literature on Lewis's counterfactual analysis of causation (see, e.g., Collins et al. 2004). My aim in what follows is not to offer a conceptual analysis of causal claims. Commonsense causal judgments will be relevant to my discussion only insofar as I will try to show that certain characteristic features that have been taken to be central to causal claims both in common sense and the special sciences are not incompatible with physics.

Very often those pursuing the second project proceed by almost completely disregarding putatively causal claims in the sciences and the conditions under which such claims are asserted. An exception is philosophers who believe that commonsense causal claims can be grounded in, or can be reduced to, what is taken to be fundamental physics. A crucial role in such reductive accounts is usually afforded to the thermodynamic asymmetry that the entropy of a closed system does not increase. According to a tradition going back to Reichenbach (1956), causal claims – in particular the asymmetry of the causal relation – and the thermodynamic asymmetry have a common origin described by statistical physics. Barry Loewer (2007; 2008; 2012a; 2012b) and David Albert (2000; 2012), for example, defend an account of how it is that we possess a time-asymmetric concept of causal influence or control, by arguing that our commonsense concept tracks certain non-causal features of the world that are central to the foundations of thermodynamics. Loewer quite explicitly situates his account within Lewis's tradition of offering a broadly counterfactual analysis of commonsense causal judgments, arguing that an appeal to statistical physics can solve a problem Lewis's own theory has in accounting for the causal asymmetry.[3]

Loewer argues that counterfactuals reducible to the foundations of statistical physics are important to us because they "track the statistical mechanical probability distribution [grounding the entropy asymmetry] in ways that are important for the consequences of our decisions" (Loewer 2007, 323). There is a sense in which I agree with Loewer. The usefulness of causal relations in physics is intimately connected to a temporal asymmetry of our universe that can be captured in probabilistic terms. However, this connection does not imply that causal notions are reducible to non-causal features of physical systems. In particular, I argue that Albert and Loewer's attempt at such a reduction is unsuccessful. What we can learn about the relation between causal and statistical properties in physical systems does not allow us to distinguish between reductive accounts, such as Albert's and Loewer's, and metaphysically "richer" accounts of causation in physics, such as that of Maudlin (who appeals to the very same probabilistic asymmetries in support of his own account).

A third kind of project, finally, is what Woodward in his 2012 Presidential Address to the North American Philosophy of Science Association calls a "functional project" (Woodward unpublished). The functional project asks what if any the use of a certain concept is within a certain context. If it is to be legitimate to invoke causal reasoning in a certain domain, then causal notions have to be able to prove their usefulness in explanations or predictions, or in making our way about in the world. Thus, instead of asking for the metaphysical underpinnings of causal notions, the functional project asks what role, if any, causal notions play as part of our epistemic toolkit and as part of the representational resources. The legitimacy of causal notions or causal thinking is evaluated with respect to whether they serve a useful function, and any account of causation has to be defended with reference to the functional role of causal concepts.

[3] See Frisch (2005a) for a discussion of this difficulty.

Woodward takes his interventionist account (Woodward 2003) to be an example of this kind of project, arguing that identifying relationships that are exploitable for manipulation or control is one of the central goals of causal thinking. Here Woodward is appealing to a thesis developed in an influential paper by Nancy Cartwright – the thesis that the distinction between causal relations and mere correlations is needed to be able to discern ineffective from ineffective strategies (Cartwright 1979). In order to know whether a certain course of action would be effective in bringing about a desired outcome, it is not enough to know various *correlations* between outcomes of the desired kind and other kinds of events whose occurrence we might take to be under our control. We also need to have *causal* knowledge.

Cartwright's example is that people who carry a life insurance policy from TIAA-CREF, a company whose customers are primarily educators, tend to live longer. Merely being told that a correlation between carrying the insurance and life expectancy exists does not yet allow us to determine whether purchasing the life insurance is an effective strategy for increasing one's life expectancy. Rather, we need to know the causal structure underlying the correlation: we need to know whether purchasing the insurance has an effect on longevity or if, more plausibly, the two factors have common causes, such as the high level of education of the insurance members or their access to good health care. In the latter case, purchasing the life insurance would not be an effective strategy for increasing longevity.

As Woodward argues, the distinction between mere correlation and causal relations can be fruitfully characterized in terms of possible interventions into a system. Roughly, if two variables are related as cause and effect, interventions into the cause variable provide a way of manipulating the value of the effect variable. By contrast, if two variables are correlated but not causally related, then interventions into one variable will not affect the value of the other variable.

The very long title of Woodward's PSA presidential address includes the promise to offer "a defense of the legitimacy of causal thinking by reference to the only standard that matters – usefulness." One advantage of a functional account is that any such defense is relative to a specific domain or context. A concept may serve a useful function in one domain but not in others. Thus, one can, as many philosophers do, believe in the usefulness of causal notions both in common sense and in how the special sciences represent the world and nevertheless deny that causal notions have a legitimate function in physics. Thus, causal skeptics point to a list of putative features of representations in the special sciences that show