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Kant's theory of scientific hypotheses in its historical context

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ABSTRACT

This paper analyzes the historical context and systematic importance of Kant's hypothetical use of reason. It does so by investigating the role of hypotheses in Kant's philosophy of science. We first situate Kant's account of hypotheses in the context of eighteenth-century German philosophy of science, focusing on the works of Wolff, Meier, and Crusius. We contrast different conceptions of hypotheses of these authors and elucidate the different theories of probability informing them. We then adopt a more systematic perspective to discuss Kant's idea that scientific hypotheses must articulate real possibilities. We argue that Kant's views on the intelligibility of scientific hypotheses constitute a valuable perspective on scientific understanding and the constraints it imposes on scientific rationality.

1. Introduction

In this paper, we discuss Kant's position in the early modern controversy over the admissibility and the role of hypotheses in philosophy and science, which stemmed in part from Newton's criticism of Descartes. According to Descartes, we can establish the most general principles of natural philosophy with certainty, but we are usually not in a position to deduce the causes of more particular phenomena directly from these principles. In such cases, he proposes that we postulate a (mechanical or corpuscularian) explanation that is compatible with the general principles of natural philosophy and that can account for the phenomena. Descartes warns against directly concluding that such explanations are also correct, however, because as far as we know, the phenomena could have been brought about in other ways. Since such hypothetical explanations are underdetermined by both the phenomena and the general principles of natural philosophy, they do not attain the demonstrative certainty to which we aspire, even if they can become morally certain (Descartes, 1996).[1]

Although we find similar accounts in Hobbes (Hobbes, 1839, pp. 387–389; 1845: 3–4. See also Laudan, 1981, p. 43.), and in Gassendi's work (see Detel, 1978 and Fisher, 2005, chapter 6), the method of hypotheses came to be largely associated with Cartesianism. It was widely adopted among self-professed Cartesians,[2] and even British authors like Boyle who in many ways departed from Descartes seemed to draw extensively on the latter's presentation of the method of hypotheses (Laudan, 1981, chapter 4. On seventeenth century British accounts of hypotheses, see; Ducheyne, 2013). This association with Descartes is one of the main reasons why the method became controversial in the eighteenth century. In the Scholium generale to the *Principia Mathematica Philosophiae Naturalis*, Newton commented that:

> I have not as yet been able to deduce from phenomena the reason for these properties of gravity, and I do not feign hypotheses. For whatever is not deduced from the phenomena must be called a hypothesis; and hypotheses, whether metaphysical or physical, or based on occult qualities, or mechanical, have no place in experimental philosophy. In this experimental philosophy, propositions are deduced from the phenomena and are made general by induction. (Newton [1726] 1999, p. 943)

In insisting here that his law of gravitation is incontrovertible despite the absence of a mechanically plausible account of the physical cause underlying this law, Newton seems to proscribe the use of hypotheses altogether and to reject any method other than deduction from the phenomena. In part because of Newton's influential admonition, many eighteenth-century thinkers rejected recourse to hypotheses and instead defended induction as the proper scientific method. In the *Enquiry*

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[1] Descartes' presents this theory in the *Principles of Philosophy* (AT VIII: 325–329). On Descartes' theory of hypotheses, see Larmore, 1980; Laudan, 1981; Clarke, 1982, pp. 113–122 and 1998; Roux, 1998; Garber, 2001, part II.

[2] For the reception of Descartes' hypothetical method among the cartesians, see Clarke, 1989, chapter 5.

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Concerning the Principles of Morals, for instance, Hume claimed that in questions of fact "we can only expect success, by following the experimental method, and deducing general maxims from a comparison of particular instances," and that "the other scientifical method, where a general abstract principle is first established, and is afterwards branched out into a variety of inferences and conclusions, may be more perfect in itself, but suits less the imperfection of human nature, and is a common source of illusion and mistake in this as well as in other subjects" (Hume, 1998, p. 77. For Hume's relationship towards Newtonianism, see; Schliesser & Demeter, 2020). Similarly, Reid's *Inquiry into the Human Mind on the Principles of Common Sense* is replete with defenses of induction and attacks on the use of hypotheses (e.g., Reid, 1997, pp. 11–12 and 91–93). The main criticism of hypotheses in these authors was not so much that hypotheses lacked certainty, but rather that hypotheses were often prematurely treated as already established. In response to such criticisms, proponents of hypotheses in science sought to spell out precise criteria for the admissibility, the truth or probability, and the relative merit of hypotheses. In formulating such criteria, aspects of previous, seventeenth-century accounts of hypothetical explanation were often combined with emerging theories of probability. This strategy can be encountered, for instance, in the work of Christian Wolff and in several eighteenth-century German philosophers, including Georg Friedrich Meier, Christian August Crusius, and Immanuel Kant.

In spite of the importance of the debate on hypotheses in eighteenth-century philosophy, Kant's stance towards it has received little attention. An important exception is two papers by Robert Butts from the 1960s (Butts, 1961; 1962), in which Kant's account of hypotheses is analyzed and contrasted with Hempel's then-dominant account of scientific method. In this paper, we will revisit the topic in light of recent scholarship to show that Kant's account of hypotheses draws on treatments of hypotheses and probability in eighteenth-century German philosophy. In addition, recent work in the philosophy of science will allow us to provide a re-evaluation of Kant's views on hypotheses. In section 2, we discuss the related accounts of hypotheses offered by Christian Wolff, whose work formed the background of much of eighteenth-century German philosophy and science, and Meier, whose abridged Logic handbook Kant used as the basis for his lectures on Logic (Young, 1992: xvii). In section 3, we discuss the contrasting view proposed by Crusius, whose resistance to Wolffian orthodoxy influenced Kant (Tonelli, 1969: li-lii). We show that Kant drew on Wolff and Meier for an account of how hypotheses can play a role in an ideal of science that stresses certainty. We also argue that Kant drew on Crusius' idea of real possibility to demand that a hypothesis needs to be *really*, and not just *logically* possible. In the final section, we discuss how the demand of real possibility led Kant to an original account of the role of intelligibility in scientific explanation.

2. Wolff and Meier on probability and scientific hypotheses

Wolff adopts an axiomatic conception of science.[3] On this conception, a science consists in fundamental statements from which non-fundamental statements are deduced through strict *demonstrations* (Wolff [1728] 1963, p. 17). Wolff further requires that scientific cognition be *certain*, i.e., known to be true (Madonna, 1987, p. 19. Wolff [1728] 1963, p. 18).

Meier too adopted this conception of science (Van den Berg, 2021), insisting that science is *exhaustively certain* cognition (Meier, 1752, pp. 311–312), which he defines as a certain cognition of truth that arises when one knows all the marks of a truth (Meier, 1752, pp. 255–256.; Van den Berg, 2021). This type of certainty is obtained, for example, in mathematical demonstrations, in which one has knowledge of all the grounds of a truth (starting from axioms) (Meier, 1752, p. 256). Hence, Meier links the exhaustive certainty of a statement to its demonstration from certain principles.

In spite of their adherence to an axiomatic conception of science, Wolff and Meier do not dismiss the use of hypotheses, and Wolff rebukes those who do not want to admit anything in philosophy that is not already certain (Wolff [1729] 1983a, p. 187; Vanzo, 2015, p. 237). But if science is an axiomatic system of certain statements, how can hypotheses, which are probable (non-certain) statements that we assume to be true in order to explain things, have a place within science? We will argue, following Corr (1970, pp. 140–142), Dunlop (2013, pp. 465–466), and Vanzo (2015, pp. 235–236), that Wolff assigns hypotheses a place within science insofar as he takes them to be statements that lead us towards certainties,[4] and that Meier agreed with him in this.

Wolff defines hypotheses as (i) assumptions, that (ii) cannot yet be demonstrated, and (iii) provide a ground for phenomena (Wolff [1728] 1963, p. 67). Hence, hypotheses are non-demonstrated assumptions that may be demonstrated at a later stage of enquiry. Here, a demonstration must be understood as a syllogistic inference from certain principles (Wolff [1754] 1978, p. 172). Moreover, hypotheses specify a ground that explains why certain phenomena obtain and are thus explanatory. Wolff adds that because hypotheses "assume things which cannot yet be proven", they are "still quite uncertain" (Wolff [1728] 1963, p. 68). Finally, Wolff claims that hypotheses are opinions, i.e., they do not constitute knowledge, and are *probable* cognition (Wolff [1740] 1983b, p. 448; Leduc, 2017). Meier adopts a similar conception of hypotheses in his discussion of *opinion* (*Meinung*), which he defines as uncertain cognitions which we assume to be true, and which can be more or less probable through more or less inductive support (Meier, 1752, pp.304-307). Although he does not use the term "hypothesis" here, it is clear from his description of the copernican hypothesis as an opinion (1752, p. 301) and his discussion of what he calls *gelehrten Meinungen* in different sciences (1752, pp. 300–301) that Meier includes hypotheses under opinions. Meier uses the term "*gelehrte Meinung*", which could be translated as an "opinion as used in the sciences", for an opinion that specifies the ground of phenomena in the world, and is thus explanatory (1752, p. 300). The meaning of this term is very close to the traditional understanding of the term hypothesis.

Wolff's conception of hypotheses is informed by his theory of probability, which has been described by Madonna (1987) and Cantù (2018). Wolff's theory of probability is based on the distinction between partial and sufficient grounds for attributing the predicate of the statement to the subject of the statement, i.e., for the truth of the statement (Wolff [1740] 1983b, p. 436). Each of the grounds for attributing the predicate to the subject taken singly is a partial ground, and all the partial grounds taken together are the sufficient ground. In his Latin *Logic* (published in 1728), Wolff notes that if we know the *sufficient ground* of a truth, i.e., *all* partial grounds of the truth of a statement, we know this statement with certainty (Wolff [1740] 1983b, p. 435–436. Madonna, 1987, p. 19). If we only know some and not all partial grounds of a truth, however, we only know an *insufficient ground* (Wolff [1740] 1983b, pp. 436–437. Madonna, 1987, p. 19). A statement is called *probable* for a knower if they only know some partial grounds of the statement, i.e., if they only know an insufficient ground of the statement (Wolff [1740] 1983b, p. 437. Madonna, 1987, p. 19), and a statement is called more probable to the extent that the knower knows more partial grounds of the statement (Wolff [1740] 1983b: p. 437). If we know the sufficient ground of a statement, we can measure the probability of a statement in specific cases, because

[3] For more detail on Wolff's axiomatic conception of science, on which we draw in the following, see Van den Berg & Demarest, 2020. For a model of this conception, see De Jong & Betti, 2010. See also Anderson, 2015, chap. 3; Van den Berg, 2020; Van den Berg, Parisi, Oortwijn, & Betti, 2022; Van den Berg & Demarest, 2022.

[4] Our account of how hypotheses are transformed to certainties in Wolff draws on our Van den Berg & Demarest, 2022. See also Van den Berg & Demarest, 2020, p. 390. See for the development of Wolff's views on hypotheses, Leduc, 2017.

we are then in a position to know how many partial grounds are required for the truth of a statement. In this case, we can determine whether we know that all the partial grounds obtain, and if we do not, how many we know to obtain and how many are lacking (Wolff [1740] 1983b, p. 813). Since hypotheses are probable statements, we only know some and not all the partial grounds of their truth.

Meier's conception of probability differs from Wolff's. According to Meier, a probable statement is an uncertain statement p where we have more grounds for holding p to be true than for holding p to be false (Meier, 1752, pp. 280–281). The difference with Wolff's account is that Wolff calls a statement probable simply if it is held to be true for some insufficient ground. Unlike Meier, Wolff does not seem to require that, for a statement to count as probable, it also has to be probable to a sufficient degree. Given that he calls *gelehrte Meinungen* probable statements (1752, p. 307), Meier therefore takes *gelehrte Meinungen* to be uncertain statements where we have more grounds for affirming their truth than we have for affirming their falsity. We only know some of the partial grounds for their truth, since knowledge of all grounds for the truth of a statement would amount to us having exhaustive certain knowledge of this true statement, which we lack in the case of *gelehrte Meinungen* (Meier, 1752, pp. 280–281).

Having sketched Wolff's and Meier's accounts of probability, we turn to their views on the testing of hypotheses, which involves a method that we would now call hypothetico-deductive. According to Wolff, we test a hypothesis by *deducing* consequences from the hypothesis. Each of the consequences that can be deduced from the hypothesis is a condition for the truth of the hypothesis, i.e., a hypothesis is true if all of its consequences are. Wolff adds that for the consequences of a statement to count as evidence for the hypothesis, they need to be independent, in the sense that they do not imply each other (Wolff [1740] 1983b, p. 448). If independent consequences deduced from the hypothesis agree with experience and experiment, the probability of the hypothesis is increased (Wolff [1728] 1963, p. 67). In contrast, the hypothesis is improbable to the extent that some phenomenon cannot be deduced from it (Wolff [1740] 1983b, p. 450). And finally, if some of the things we deduce from the hypothesis are contrary to experience, the hypothesis is false (Wolff [1728] 1963, p. 67). Hypotheses should also satisfy certain additional conditions (see Vanzo, 2015, p. 237). A basic requirement is that a hypothesis should not be contradictory or lead to contradictions. But Wolff also requires that what is implied by the hypothesis really exists in nature. This, Wolff notes, constitutes a main difference between *mathematical* and *philosophical* hypotheses, namely that for a mathematical hypothesis, it suffices that the assumption does not lead to contradictions, whereas a philosophical hypothesis should correspond with what really exists in nature (Wolff [1729] 1983a, pp. 201–202).

Like Wolff, Meier adopts a hypothetico-deductive method according to which *gelehrte Meinungen* are assumed as probable cognitions to the extent that their deduced consequences conform to experience (Meier, 1752, p. 307). A *gelehrte Meinung* must be rejected if one of its consequences contradicts experience, and it can be accepted as probably true if the phenomena, or at least more than half the phenomena agree with it (ibid.). In addition, Meier warns that *gelehrte Meinungen* must not be taken to be certain and that we should only use such opinions if we lack appropriate certain knowledge (Meier, 1752, p. 304). As a guide for the proper use of *gelehrte Meinungen*, Meier notes that they should not be contradictory, should not imply contradictions, and should not contradict established truths (Meier, 1752, pp. 304–305).

Wolff and Meier, then, consider hypotheses to be probable cognitions that are acceptable to the extent that they serve to explain the phenomena and unacceptable to the extent that they fail to explain the phenomena or even contradict the phenomena. But what place can such hypotheses have within a conception of science according to which scientific cognition must be certain? Wolff suggests that we can use hypotheses as guides towards establishing certain truths (Corr, 1970, pp. 140–142. Dunlop, 2013, p. pp. 465–466, Vanzo, 2015, pp. 235–236), stating that "[p]hilosophy must use hypotheses insofar as they pave the way to the discovery of certain truth". (Wolff [1728] 1963, p. 67). Meier similarly states that opinions serve to guide us toward truth and certainty (Meier, 1752, pp. 307–308). Hypotheses, then, should lead us to the certain truths. But note that hypotheses cannot be transformed into certain statements through the hypothetico-deductive method sketched above. If we deduce consequences from hypotheses and thereby corroborate them, we only increase their probability, but can never demonstrate their certainty. Hence, it must be through a different method that we transform hypotheses into certain statements.

As an example of how we transform a hypothesis into a certain statement Wolff discusses Hooke's hypothesis that the primary planets gravitate toward the sun. According to Wolff, Newton *demonstrated* this hypothesis and thereby arrived at a certain truth (see Corr, 1970, p. 141, Dunlop, 2013, pp. 465–466, and Van den Berg & Demarest, 2022, on which we draw in the following). Wolff states the following:

> […] Robert Hooke maintained that the primary planets gravitate toward the sun, and because of the force of this gravitation, they are deflected from rectilinear motion. However, he could not demonstrate this hypothesis. But in his most excellent work entitled *The Mathematical Principles of Natural Philosophy*, Newton demonstrated with the greatest geometrical rigor that, because of their impressed force and gravitation toward the sun as a center in accordance with the laws which Kepler established by observation, the planets can be moved in no other orbit than an Apollonian ellipse. He also proved that the force by which the planets are deflected from rectilinear motion tends toward the sun as a center in accordance with the laws of gravity. Now it would be quite improper to try to belittle the discoveries of Newton by saying that the physical cause of celestial motion had been explained earlier by Hooke. For Newton's demonstrations require a special talent and acumen and a deep knowledge of geometry and mathematics (Wolff [1728] 1963, pp. 101–102).

Here, Wolff refers to Newton's deductions from the phenomena to show how Hooke's hypothesis came to be transformed into a demonstrated truth[5] with the aid of mathematics. The idea seems to be that Newton used mathematics to reason deductively from phenomena to certain consequences, such as the claim that the planets move in an Appolonian ellipse (on Newton's use of mathematics, see Walsh, 2017 and Cohen, 1999). Thus, Wolff takes the application of mathematics to physics to enable deductive demonstrations within the domain of physics. In addition, Wolff claims that the use of mathematics in physics secures *certainty* (Wolff [1728] 1963, p. 15. See also Dunlop, 2013, p. 466. Newton also thought that we can arrive at certain truths in physics. See Biener, 2018). According to Wolff, because Hooke's hypothesis was proven by means of mathematics, and, in addition, certain metaphysical principles (Van den Berg & Demarest, 2022), it was turned into a demonstrated, certain truth.

3. Crusius on probability and scientific hypotheses

In his *Weg zur Gewißheit und Zuverlässigkeit der menschlichen Erkenntnis* from 1747, Crusius discussed hypotheses against the background of his account of probability, which differs from that of Wolff and Meier. Crusius calls a statement probable if we have more reasons to take it to be true than we have for taking its contradictory to be true:

> In particular, in the case of probability, the ground of cognition consists in this, that a statement is more connected to the marks of truth than its contradictory; and since necessarily one of them is true, that one should be taken to be true which matches the marks of truth more closely. (Crusius [1747] 1965, p. 648) [6]

[5] Although Wolff accepted parts of Newton's theory, Stan (2012) shows that Wolff rejects the idea that action as a distance was the physical cause of gravity.

[6] All translations of this work in this article are ours.

Crusius stresses that probability consists in a relationship between a statement and its contradictory (which includes all the contraries of the statement) (Crusius [1747] 1965, p. 649), and notes that this is meant as a criticism of those who regard a statement as probable if the sufficient ground for the statement is not yet known to be true, but more than half of the sufficient ground for the statement is. Against this account, Crusius argues by means of a counterexample:

> It belongs to the nature of a square that we have four straight lines, four right angles, and finally an equality of the sides. Now, if I would be informed about a room that it has four sides and four right angles, it would have to be probable that it is square; because I would know two conditions that belong to a square, and only one condition would remain unknown. But no one would say this. For it is obviously equally possible that the room is oblong. (Crusius [1747] 1965, pp. 649-650)

Recall that according to Wolff a statement is called *probable* for a knower if they know some partial grounds of the statement and a statement is called more probable to the extent that the knower knows more partial grounds of the statement. Crusius' example provides a criticism of Wolff's idea that a statement is probable as soon as there is an insufficient reason to hold it. But this may also point towards a different account of probability in the two authors. For Wolff, a statement is probable as soon as there is some reason to hold it. But this may not in and of itself warrant that we hold it to be true. For Crusius, probability *is* linked with being warranted to hold the statement to be true. Wolff could respond that we are only warranted to hold the most probable statement to be true. And such a warrant does not exist in the example, because the statement is not more probable than its contraries.

Is Crusius's account also a criticism of Meier's account of probability? That depends on how we should understand Meier's account. Meier's account is relational: a statement is probable only if it is more likely that it is true than that it is false. Meier thus defines probability solely in terms of the statement itself. Crusius instead defines probability in terms of the probability of other statements: a statement is probable to Crusius if and only if its rivals are less probable. The difference here may be merely verbal though, as a statement is false if and only if its contradictory is true, and hence grounds to take the contradictory of a statement to be true are ipso facto grounds to take that statement itself to be false.

Given that Crusius stresses that a statement is probable only if it is more probable than its contradictory, his discussion of probability focuses more on the features that make a statement more likely than another statement than on the features that make a statement probable to begin with. Crusius introduces six "sources of probability" that can make a statement more probable than another statement:

1. That which can occur in more ways in the same circumstances is more probable than that which can occur in fewer ways (Crusius [1747] 1965, p. 661). For example, in rolling two 6-sided dice, a roll of a total of 7 is more probable than a roll of a total of 2, because there are 6 different ways in which one can roll a 7 in this way, whereas there is only one way to roll a total of 2.
2. A statement is more probable if it presupposes fewer coincidences (Crusius [1747] 1965, p. 665). For example, when we notice a specific harmony between phenomena, it is more likely that this harmony is due to a single cause than due to a mere coincidence of circumstances.
3. A statement is more probable if it has more "real possibility". Crusius suggests that something has real possibility, as opposed to mere logical possibility, if we know of the existence of causes or powers that can bring it about (Crusius [1747] 1965, p. 646). In this context, he distinguishes between mere "metaphysical" possibility and "physical" possibility. Something is merely metaphysically possible when God can bring it about, whereas it is physically possible if there are natural causes that can bring it about.
4. It is probable that what occurred in previous cases that are probably similar to the current case in relevant ways (Crusius [1747] 1965, p. 676), will also occur in the current case. For instance, it is more probable that similar effects will result from similar causes.
5. It is improbable that something will fail to occur in the present case if the circumstances of the current case were sufficient for its occurrence in previous cases. (Crusius [1747] 1965, p. 689). For if we have reasons to believe that these causes were sufficient to bring the effect about, we have reasons to believe they will also bring about the same effect now.
6. What corresponds better to the phenomena is more probable (Crusius [1747] 1965, pp. 691-692).

Crusius deals with hypotheses in his discussion of the sixth source of probability, where he defines them as follows: "[t]hat statement, however, that one assumes as a logical possibility, and wants to make probable through its harmony [*Übereinsteimmung*] with the phenomena, is called a hypothesis" (Crusius [1747] 1965, p. 691). A hypothesis is therefore a statement that is assumed for the sake of explaining the phenomena, but that is not yet established and that is made probable by the extent to which it matches the phenomena. Crusius proceeds to discuss ways in which we can judge hypotheses, given what we know about how to judge the probability of a statement.

Crusius suggests, first of all, that a hypothesis is probable if it matches the phenomena better than its contrary. According to Crusius, this follows because harmony with the phenomena is a sign of real possibility. Crusius reasons as follows: everything in the actual world is causally connected in some way. For this reason, true statements have to relate to each other in such a way that their objects stand in causal relationships to one another. If a statement is such that it does not relate to other statements in this way, then it cannot be true. If a statement does relate to other statements in this way, it is more probable to the extent that it relates to them in this way. Crusius therefore relies on his thesis that what has more "real" possibility is more probable. Here, we see that Crusius's distinctions between real and merely logical possibility, and between physical and merely metaphysical possibility are central to his account of hypothesis — a feature we will find in Kant's account of hypotheses as well.

Crusius also distinguishes between mere phenomena and harmonizing phenomena (Crusius [1747] 1965, p. 693). Mere phenomena are phenomena that merely match the hypothesis, whereas harmonizing phenomena are phenomena that also match each other in such a way that Crusius' rules of probability suggest that they derive from a single cause. The second source of probability, for instance, suggests that it is more probable that harmonizing phenomena stem from a single cause than from a mere coincidence of circumstances. A hypothesis is made more probable by a set of harmonizing phenomena than by separate phenomena, because in the former case it accounts not just for each of the phenomena, but also for the fact that they harmonize. Crusius proceeds to derive rules for determining the extent to which a phenomenon or a group of phenomena supports a certain hypothesis (Crusius [1747] 1965, pp. 697-704).

A third important guideline for judging hypotheses introduced by Crusius is that a hypothesis is less probable if more subsidiary (auxiliary) hypotheses are required for accounting for the phenomena. A theory that explains phenomena through one hypothesis rather than through a group of (independent) hypotheses, is more probable because in the latter case, it is assumed that many circumstances (the truth of several independent hypotheses) have to coincide for the phenomena to occur, whereas in the former case, no such coincidence is required. And as we saw, Crusius believes a statement to be more likely if it relies less on mere coincidence. Correspondingly, Crusius also tries to derive rules for determining the extent to which the use of subsidiary hypotheses decreases the probability of a hypothesis (Crusius [1747] 1965, pp. 705-710).

Crusius believes that the principles of probability that he expounds in his work can be applied in a wide variety of issues. One notable example is the following application of probability to natural theology:

> When one observes the regularity of organic natural bodies, there arises not just an incomprehensible manifold of presumptions of miracle [i.e., the assumption, that all these corresponding phenomena cannot be due to a mere coincidence]. For, since one finds in nature ever more regularity as one dissects these bodies, there arises the incomprehensibly high probability that one will find ever more grounds to postulate an intelligent cause as one continues one's investigations. (Crusius [1747] 1965, p. 732)

Here, we see that Crusius saw the argument from design as a highly probable hypothesis. The principle behind this reasoning is Crusius's claim that a hypothesis is more likely if it posits a single cause for a harmonizing group of phenomena than a coincidence of circumstances. This exemplifies not just Crusius's reasoning, but also his willingness to use canons of hypothetical reasoning in metaphysical debates.

In conclusion, we have seen that Crusius's account of hypotheses is distinct due to his specific treatment of the topic of probability, which he takes to consist in a relationship of the grounds of a statement to those of its contradictories rather than in the relationship between the partial grounds of a statement and its sufficient ground, as Wolff and Meier do. We have also seen that Crusius focuses heavily on the fact that real possibility makes a hypothesis superior and that he champions the use of probable and hypothetical reasoning in metaphysics. In the final section of this paper, we will see that Kant uses a similar notion of real possibility to criticize this willingness to blur scientific and philosophical reasoning.

4. Kant on scientific hypotheses

In the *Jäsche-Logik*, Kant defines hypotheses as follows:

> A hypothesis is a holding-to-be-true of the judgment of the truth of a ground for the sake of its sufficiency for given consequences, or more briefly, the holding-to-be-true of a presupposition as a ground (Kant, 1992, p. 586 [IX: 84]).[7]

Hence, a hypothesis is a judgment that we take to be true because it explains consequences that are derived from it. Hypotheses specify *grounds* for certain phenomena, and are therefore explanatory. In the first *Critique*, Kant makes clear that hypotheses are a special kind of opinion (*Meinung*) (Kant, 1999, p. 659 [A770/B798]), and thus do not constitute knowledge (*Wissen*). Finally, Kant remarks that hypotheses cannot become certain judgments through induction and that therefore, we never attain apodictic certainty through hypotheses, but "always only a greater or lesser degree of probability" (Kant, 1992, p. 586 [IX:84]). However, we shall see below that Kant follows Wolff in thinking that hypotheses can be transformed into certain truths.

Since Kant regards hypotheses as probable statements, understanding his account of hypotheses involves understanding his conception of probability. Kant defines probability as the holding-to-be-true of a judgment "based on insufficient grounds which have, however, a greater relation to the sufficient grounds than do the grounds of the opposite" (Kant, 1992, p. 583 [IX:81]). If we know the sufficient ground of a judgment, we have certain knowledge of this judgment. If we cognize a judgment as probable, we know only the insufficient grounds of this judgment, although these have a greater relation to the sufficient ground than the grounds of the opposite. Kant also distinguishes probability from what he calls plausibility, which is a "holding-to-be-true based on insufficient grounds insofar as these are greater than the grounds of the opposite" (ibid).

As was the case for his predecessors, Kant's method for testing hypotheses is hypothetico-deductive (see Falkenburg, 2000): we test an empirical hypothesis by assuming the hypothesis, deducing consequences from the hypothesis, and checking whether the deduced consequences agree with experience. As Kant writes in the *Wiener Logik*: "when something is accepted as a ground from which I can have insight into the sufficient ground of given consequences, then this a hypothesis" (Kant, 1992, p. 333 [XXIV:886]). An empirical hypothesis thus explains *given*, i.e., *empirical* consequences that follow from the hypothesis construed as a ground. Kant makes clear that we logically derive consequences from a hypothesis when he remarks that "I assume something, and then I see what other kinds of cognitions can be derived from this" (Kant, 1992, p. 334 [XXIV:886]). He illustrates this method of reasoning with hypotheses in the first *Critique* in explaining what he calls the hypothetical use of reason. The hypothetical use of reason operates by assuming a universal judgment problematically and determining whether certain particular cases follow from it. If these particular cases follow from the universal rule, the universality of the rule is inferred (Kant, 1999, p. 592 [A646-647/B674-675]). In such an inference, we infer from the truth of the consequence to the truth of the ground (Kant, 1992, p. 586 [IX:85]). According to Kant, such an inference can only yield a sufficient criterion of truth if all the possible consequences are known to be true. However, since we never know all the possible consequences of a hypothesis, the hypothetical (inductive) use of reason only allows us to obtain an analogue of certainty (ibid.).

Kant's hypothetico-deductive method also stipulates that we should not employ auxiliary hypotheses (Kant, 1999, p. 661 [A774/B802]). Like Crusius, Kant argues that auxiliary hypotheses impact negatively on the probability of the total hypothesis. In the *Jäsche Logik* Kant explains that, since the probability of a hypothesis is a function of the number of consequences that are derived from it, and since the invocation of auxiliary hypotheses implies that fewer consequences are derived from the single hypothesis under consideration, the use of auxiliary hypotheses means that a hypothesis loses much of its probability (see also Butts, 1962, p. 202). Hence, we must refrain from using auxiliary hypotheses.

Like Wolff and Meier, Kant believes hypotheses can lead to certainty, though he does not think certainty can be achieved inductively. In the *Blomberg Logik,* Kant states that hypotheses can be confirmed and become certain by relating them to their grounds:

> With all hypotheses one must necessarily secure acceptance and certainty for them in such a way that they can be confirmed and derived not merely a posteriori through relation to their consequences, but also a priori through the nexus, that is, through relation to their grounds (Kant, 1992, p. 175 [24: 221]).

The idea here seems to be that hypotheses can be transformed into certainties by situating them in a system of knowledge and deriving them a priori from their grounds.[8] Elsewhere Kant makes a similar point:

> It is also a principal ground of the truth of a hypothesis if one shows that the ground that one has fabricated for the sake of the sufficiency of the consequences deserves to be accepted on the basis of other causes. Here one shows from other grounds, namely, that what was fabricated must be accepted; thus one confirms the truth of the hypothesis (Kant, 1992, p. 177 [24: 223]).

Here, Kant notes again that a hypothesis is confirmed if the statement made probable by its accounting for the phenomena is then derived from

[7] Citations from Kant are from *The Cambridge Edition of the Works of Immanuel Kant* (ed. by Paul Guyer & Allen W. Wood), using the author-year system. The additions in square brackets refer to: for *Critique of Pure Reason* to the standard A/B page numbers of the first and second editions (Kant 1781/1787); for all other parts of Kant's oeuvre, to the respective volume and page numbers of the Academy edition of *Kant's Gesammelte Schriften* (Kant, 1900–). Thus, 'Kant, 1992, p. 586 [IX: 84]' points to: Logik-Jäsche, Academy edition, vol. IX, p. 84.

[8] Note that here the term 'a priori' has the traditional meaning of reasoning from grounds to consequences and does not denote something being justified independently of experience.

other grounds. Hence, once again, Kant seems to distinguish between justification a priori, i.e., derivation from grounds in a system of judgments, and justification a posteriori, i.e., justifying a hypothesis on the basis of the consequences derived from the hypothesis. It is through justification a priori that a hypothesis becomes certain.

This analysis is in line with Kant's comment from the first *Critique* that the Copernican hypothesis became a certainty by, as Vanzo (2012) explains, subsuming it under a body of laws:

> […] the central laws of the motion of the heavenly bodies established with certainty what *Copernicus* assumed at the beginning only as a hypothesis, and at the same time they proved the invisible force (of *Newtonian* attraction) that binds the universe [….] (Kant, 1999, p. 113 [Bxxii,n]).

In this passage, Kant probably alludes to the fact that Newton, in Book III of the *Principia*, justified the Copernican hypothesis on the basis of the theory of gravitation (Friedman, 1992, pp. 142, 170.; Van den Berg & Demarest, 2020, p. 390). According to Kant, the theory of gravitation is justified on the basis of a priori mathematical and metaphysical principles (Friedman, 1992, chapters 3 and 4). Hence, the Copernican hypothesis is shown to be derivable from a system of partly a priori laws (mathematical and metaphysical principles) and partly empirical laws (the law of gravity), and thus became a certainty. This is a good example of what Kant calls a priori justification in the *Blomberg Logik*. Hence, by deriving a hypothesis from established principles we can transform it into a certainty (for more details, see Vanzo, 2012).

5. Kant and the role of understanding in philosophy and science

We have seen that hypotheses, according to Kant, are merely probable, and derive their probability from their agreement with experience, and that they can become certain only by being deduced from certain principles and thereby ceasing to be a hypothesis. Kant therefore assigns hypotheses a similar function and status in science as Wolff and Meier did. Kant's account also shows similarities with that of Crusius. For one, as we saw, Kant too stresses the extent to which auxiliary hypotheses detract from the probability of a hypothesis. In this section we will show that, in addition, like Crusius, Kant attaches great importance to the real possibility of a hypothesis, but that Kant's conception of real possibility marks a clear departure between him and both Wolff and Crusius, since he uses it to prohibit the use of hypotheses in metaphysics and to restrict their use in science.

Both Wolff and Crusius allowed for metaphysical hypotheses. Wolff, for instance, spoke of hypotheses not just in physical but also in metaphysical contexts, treating the rival philosophical theories of mind-body interaction, namely physical influx, occasionalism, and pre-established harmony, as metaphysical hypotheses (see Wolff [1729] 1983, pp. 191–192; Leduc, 2017). And as we have seen, Crusius sought to use his theory of hypotheses to underpin a physico-theological proof for the existence of God. Kant, however, rejects the use of hypotheses in metaphysics. In the *Critique of Pure Reason*, Kant writes that "in this kind of inquiry it is in no way allowed to hold opinions, and that anything that even looks like a hypothesis is a forbidden commodity" (Kant, 1999, p. 102 [A:xv]). Kant defends this claim in part by insisting that metaphysics is supposed to be an a priori and therefore certain science. In the Doctrine of Method, however, Kant also explains that metaphysical hypotheses of the kind entertained by Wolff and Crusius are inadmissible because they lack real possibility:

> If the imagination is not simply to enthuse but is, under the strict oversight of reason, to invent, something must always be fully certain and not invented, or a mere opinion, and that is the possibility of the object itself (Kant, 1999, p. 659 [A770/B798]).

Mere logical possibility (internal consistency) does not suffice here; as Robert Butts (1961, 1962) has argued, Kant requires of hypotheses that they be *really* possible, i.e., that they conform to the conditions of possible experience:

> it is only possible for our reason to use the conditions of possible experience as conditions of the possibility of things; but it is by no means possible for it as it were to create new ones, independent of these conditions, for concepts of this sort, although free of contradiction, would nevertheless also be without object (Kant, 1999, p. 659 [A771/B799]).

Here, Kant recasts Crusius' notion of real possibility. For Crusius, a statement is more probable when it is really possible, i.e., if we know the forces it involves to exist in nature, than when it is merely metaphysically or logically possible. Kant uses a related distinction between that which is possible in experience and that which is merely logically possible:

> I can think whatever I like, as long as I do not contradict myself, i.e., as long as my concept is a possible thought, even if I cannot give any assurance whether or not there is a corresponding object somewhere within the sum total of all possibilities. But in order to ascribe objective validity to such a concept *(real possibility*, for the first sort of possibility was merely logical) something more is required. (Kant, 1999, p. 115 [B xxvi]; see also Kant, 1999, pp. 343–344 [A244/B302]; our stress)

Elsewhere in the first *Critique*, Kant notes that the (real) possibility of an object can be derived from experience (i.e., we experience an object and conclude it is possible) or guaranteed if it is consistent with the formal conditions of experience (Kant, 1999, p. 324 [A223/B270-271]). Accordingly, Kant states that "the postulate of the possibility of things thus requires that their concept agree with the formal conditions of an experience in general" (Kant, 1999, pp. 322–323 [A 220/B267]). In short: really possible objects must agree with the categories, the synthetic a priori principles of experience, and the forms of space and time (see for a clear account Guyer, 1998). Hypotheses must thus be consistent with the synthetic a priori principles of experience—the forms of intuition and the categories—as well as with established empirical laws (see also Butts, 1961, 1962).

Based on this criterion, Kant rejects hypotheses involving non-physical principles such as the simplicity of the soul or God, which are ideas of reason:

> A transcendental hypothesis, in which a mere idea of reason would be used for the explanation of things in nature, would thus be no explanation at all, since that which one does not adequately understand on the basis of known empirical principles would be explained by means of something about which one understands nothing at all. (Kant, 1999, p. 660 [A773-773/B800-801]).

Here, Kant dismisses the use of hypothetical reasoning in metaphysics. The reason for this is not that hypotheses lack certainty, since Kant believes that hypotheses can further science even if they are mere opinions. Instead, he argues that such philosophical hypotheses are inadmissible because they are not possible *in experience*. Kant thus insists that being really possible does not make a hypothesis more probable (as Crusius seems to have thought), but rather makes it admissible to begin with. In this way, Kant draws a sharp distinction between the domain of empirical enquiry, where hypotheses can play a role, and philosophy, where hypotheses have no dogmatic use, although they may have a polemic use, i.e., as a retort to another hypothesis that counter its unfounded claim to validity (See Kant, 1999, pp. 662–665 [A776-782/B804-810]). In this way, Kant's criterion of "real" possibility restricts hypotheses to the domain of scientific rationality.

However, Kant also uses this criterion to constrain the use of hypotheses in science. As Butts (1961, p. 168) saw, Kant's discussion of hypotheses suggests that he links explanation with *understanding*. According to Butts, what Kant needs is "a criterion for the adequacy of a hypothesis that separates explanations that make events intelligible from

those that do not" (ibid., p. 163). The fact that hypotheses articulate real possibilities guarantees that they make events intelligible. Hence, real possibility secures understanding (see also Butts, 1962). Kant seems to have attached great importance to understanding in scientific theorizing:

> since […] the category of the pure understanding does not serve for thinking up [*erdenken*] such a thing, but only for understanding [*verstehen*] it where it is encountered in experience, we cannot originally cook up, in accordance with these categories, a single object with any new and not empirically given property and ground a permissible hypothesis on it; […] Thus we are not allowed to think up any sort of new original forces, e.g., an understanding that is capable of intuiting its object without sense or *an attractive force without any contact*. (Kant, 1999, p. 659 [A770/B798]; our stress).

Here, Kant's requirement that a hypothesis be really possible rules out as unintelligible not only straightforwardly metaphysical hypotheses, but also hypotheses about new forces such as action at a distance. Hence, for Kant, understanding and intelligibility constrain scientific theorizing as well as metaphysical theorizing.

Kant's rejection of hypothesizing about fundamental forces is problematic for two reasons, and it is by looking at these reasons that we can better understand the role he assigns to hypotheses in science. On the one hand, in the *Metaphysical Foundations of Natural Science*, Kant accepted Newtonian attraction and criticized Newton's reticence towards accepting attraction as a fundamental force (Friedman, 1992, p. 139). So it is strange to see Kant reject gravity as unintelligible here. On the other hand, the scientific demand of intelligibility later came to be criticized heavily by positivists and logical positivists because they considered metaphysical qualms with scientific postulates to be irrelevant to science and detrimental to its progress. The classic example of this is, in fact, the resistance towards Newtonian attraction as "unintelligible". Instead, positivists often characterized understanding as a reduction to what is *familiar* to the person that does the understanding, and insisted that the task of science is simply to predict, or to explain by showing how the phenomenon can be derived from certain general statements and initial conditions. If they consider science to yield understanding at all, they reduce understanding to "rational expectation" (de Regt, 2017, p. 50), as Hempel does in the following passage:

> A D-N explanation […] shows that, given the particular circumstances and the laws in question, the occurrence of the [explanandum-] phenomenon was to be *expected*; and it is in this sense that the explanation enables us to *understand why* the phenomenon occurred. (Hempel, 1965, p.337, p.337)

Butts (1962, p. 201) already saw that, in insisting on a stronger conception of understanding and intelligibility, Kant's account of explanation differed markedly from the dominant Hempelian account of the 1960s. In this respect, Kant's conception of science fits better with a tradition in post-positivist philosophy of science, including authors such as Michael Friedman (1974) and Henk de Regt (2017), that stresses the importance of understanding in science.

In the Jäsche Logik, Kant distinguishes understanding (*verstehen*; *intelligere*) from comprehending (*begreifen*; *comprehendere*). To understand something is to "cognize something through the understanding by means of concepts, or to conceive [*concipiren*]", whereas to comprehend something is "to cognize something through reason or a priori to the degree that is sufficient for our purpose" (Kant, 1992, p. 570 [IX: 65). In the *Critique of pure Reason*, Kant remarks that "Concepts of reason serve for comprehension, just as concepts of the understanding serve for understanding (of perceptions)" (Kant, 1999, p. 395 [A311]). For something to be understandable, then, Kant believes that it has to accord with the conditions of experience, whereas we comprehend it when we know it based on principles. As we saw, a hypothesis is a purported principle on the basis of which we can comprehend phenomena, and this comprehension involves both explanation and intelligibility. Hence, Kant insists that the principles through which we explain phenomena should also be intelligible. But this raises the question of what precisely Kant understood by "intelligibility".

In his recent study on scientific understanding Henk de Regt (2017, p.160) distinguishes between *scientific* intelligibility and *metaphysical* intelligibility. By the latter, he means the harmony of a theory with "extant, or preferred, metaphysics" (de Regt, 2017, p. 160). Kant seems to argue that hypotheses must be *metaphysically* intelligible. The reason why Newtonian attraction is considered unintelligible in the above-quoted passage from Kant would therefore be that it is hard to account for on the extant metaphysics of matter. But Kant did not simply accept that this made attraction unintelligible. As Gerd Buchdahl (1970, p. 95) points out, one of the main tasks of the *Metaphysical Foundations* is to render attraction intelligible by making it essential rather than foreign to matter as such. In the latter work (Kant, 2004, p. 233 [IV:523]), Kant repeats his restriction that "to be authorized in erecting an hypothesis, it is unavoidably required that the possibility of what we suppose be completely certain, but with fundamental forces their possibility can never be comprehended," and adds that such forces "can be assumed only if they unavoidably belong to a concept that is demonstrably fundamental and not further derivable from any other (like that of the filling of space), and these, in general, are repulsive forces and the attractive forces that counteract them." Hence, Kant claims that action as a distance can be made intelligible by proving, in a transcendental fashion, that it is a fundamental force, and hence a non-hypothetical fundamental posit of natural science.

Kant therefore seems to have believed that attraction is unintelligible if it cannot be shown to follow from the nature of matter as such since we are not allowed to simply postulate fundamental forces. In other words, Kant agreed with Newton that we are not justified in "feigning" hypotheses, whether they are metaphysical or physical and whether they are mechanical or occult, in explaining attraction. But according to Kant, the resulting problem off accounting for attraction lies with the received matter theory, not with attraction as such. In offering a proof that the possibility of matter itself requires an attractive force (Kant, 2004, pp. 219–220 [IV:508]), Kant believed to have shown how attraction is really possible and hence intelligible. And in doing so, he elevated attraction from the status of an inadmissible, unintelligible hypothesis to a fundamental principle of natural science built into the concept of matter, and thereby our understanding of the material world, itself. In this way, Kant takes himself to have responded to both the Newtonian hesitance to introducing hypotheses and the Newtonian hesitance to admit gravity as a fundamental force (Kant, 2004, p. 226 [IV:515]).

According to de Regt (2017, p. 162), what is intelligible is not set in stone, since "[i]f application of conceptual tools leads to sustained scientific success, these tools will plausibly be 'canonized': they will come to be regarded as indispensable for achieving understanding". To some extent, Kant seems to agree, since we can revise some aspects of our underlying metaphysics to account for new scientific discoveries. In this way, philosophy can lead us to regard something as intelligible that was previously taken to be unintelligible as much as scientific practice can. To Kant, rendering something intelligible is not just harmonizing it with a familiar or extant metaphysics: it is harmonizing it with metaphysical foundations as such—in our case the fundamental concept of matter—and these metaphysical foundations can be revised through philosophical argument as well as through scientific progress.

6. Conclusion

In this paper, we situated Kant's account of hypotheses in the context of eighteenth-century German theories of hypothetical explanation. We showed how Wolff and Meier could allow hypotheses to play a role in science in spite of their shared insistence those scientific statements should be certain and that hypotheses are merely probable, and that Kant followed Wolff in insisting that hypotheses are made certain by being derived from certain principles. We also discussed Crusius's

account of how to weigh merely probable hypotheses against one another in terms of their degree of probability, and how the real possibility of a hypothesis made it more probable. We showed that Kant reinterpreted the notion of "real possibility" within his critical philosophy and made it a basic condition of hypotheses, namely that hypotheses have to be intelligible themselves in order to be able to explain what is explained through them. Because of this demand, and in contrast with his predecessors, Kant rejects the idea of metaphysical hypotheses: no theory about God or the soul can be used to explain phenomena, nor can such theories acquire probability from their accordance with the phenomena. This shows that, for Kant, hypotheses cannot be used in philosophy in the same way as they are used in science. In addition, Kant believes that the requirement of real possibility should constrain theorizing in science as well, as we showed through the example of the intelligibility of gravity. Kant objected both to introducing universal gravity as a hypothesis about the nature of matter and to introducing hypotheses about how universal gravity could be brought about. Hypotheses should explain the phenomena, and according to Kant, they can do so only to the extent that they also provide understanding, which involves real possibility. Kant's demand of intelligibility and real possibility, then, gives him a criterion to distinguish not just between physical and metaphysical theorizing, but also between proper and improper physical theorizing.

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References

Anderson, R. L. (2015). *The poverty of conceptual truth. Kant's analytic/synthetic distinction and the limits of metaphysics*. Oxford: Oxford University Press.
Biener, Z. (2018). Newton's regulae philosophandi. In C. Smeenk, & E. Schliesser (Eds.), *Oxford handbook of Isaac Newton*. Oxford: Oxford University Press.
Buchdahl, G. (1970). Gravity and intelligibility: Newton to kant. In R. E. Butts, & J. W. Davis (Eds.), *The methodological heritage of Newton* (pp. 74–102). Oxford: Blackwell.
Butts, R. (1961). Hypothesis and explanation in Kant's philosophy of science. *Archiv für Geschichte der Philosophie, 43*(2), 153–170.
Butts, R. (1962). Kant on hypotheses in the "doctrine of method" and the Logik. *Archiv für Geschichte der Philosophie, 44*(2), 185–203.
Cantù, P. (2018). Mathematics. Systematical concepts. In R. Theis, & A. Aichele (Eds.), *Handbuch christian Wolff* (pp. 257–379). Wiesbaden: Springer.
Clarke, D. (1982). *Descartes' philosophy of science*. Manchester: Manchester University Press.
Clarke, D. (1989). *Occult powers and hypotheses. Cartesian natural philosophy under Louis XV*. Oxford: Clarendon.
Cohen, I. B. (1999). A guide to Newton's principia. In I. B. Cohen, & A. Whitman (Eds.), *The Principia: Mathematical principles of natural philosophy* (pp. 3–370). Berkeley: University of California Press.
Corr, C. A. (1970). Certitude and utility in the philosophy of Christian Wolff. *The Southwestern Journal of Philosophy, 1*(1/2), 133–142.
Crusius, C. A. (1747). *Tonelli, G. (Ed.), Weg zur Gewißheit und Zuverlässigkeit der menschlichen Erkenntnis. Hildesheim: Olms*, 1965.
De Jong, W. R., & Betti, A. (2010). The classical model of science: A millennia-old model of scientific rationality. *Synthese, 174*(2), 185–203.
Descartes, René (1996). *Adam, Charles, & Tannery, Paul (Eds.), Oeuvres de Descartes: Vol. 8. Paris: Vrin*.
Detel, W. (1978). *Scientia rerum natura occultarum. Methodologische Studien zur Physik Pierre Gassendis*. Berlin: De Gruyter.
de Regt, H. (2017). *Understanding scientific understanding*. Oxford: Oxford University Press.
Ducheyne, S. (2013). The status of theory and hypotheses. In P. Anstey (Ed.), *The oxford handbook of British philosophy in the seventeenth century*. Oxford: Oxford University Press.
Dunlop, K. (2013). Mathematical method and Newtonian science in the philosophy of Christian Wolff. *Studies In History and Philosophy of Science Part A, 44*, 457–469.
Falkenburg, B. (2000). *Kants Kosmologie. Die wissenschaftliche Revolution der Naturphilosophie im 18. Jahrhundert*. Frankfurt am Main: Vittorio Klostermann.
Fisher, S. (2005). *Pierre Gassendi's Philosophy and science. Atomism for empiricists*. Leiden: Brill.
Friedman, M. (1974). Explanation and scientific understanding. *The Journal of Philosophy, 71*(1), 5–19.
Friedman, M. (1992). *Kant and the exact sciences*. Cambridge, MA: Harvard University Press.
Garber, D. (2001). *Descartes embodied. Reading cartesian philosophy through cartesian science*. Cambridge: Cambridge University Press.
Guyer, P. (1998). The postulates of empirical thinking in general and the refutation of idealism (A218/B294-A292/B349). In G. Mohr, & M. Willascheck (Eds.), *Immanuel Kant: Kritik der reinen Vernunft* (pp. 297–324). Berlin: Akademie Verlag.
Hempel, C. (1965). *Aspects of scientific explanation and other essays in the philosophy of science*. New York: The Free Press.
Hobbes, T. (1839). *Molesworth, W. (Ed.), The English works of Thomas Hobbes: Vol. 1. London: Bohn*.
Hobbes, T. (1845). *Molesworth, W. (Ed.), The English works of Thomas Hobbes: Vol. 7. London: Bohn*.
Hume, D. (1998). In T. Beauchamp (Ed.), *An enquiry concerning the principles of Morals*. Oxford: Oxford University Press.
Kant, I. (1900). *Gesammelte Schriften. Academy edition* (Vol. 29). Berlin: De Gruyter.
Kant, I. (1992). *Young, M.J. (Ed.), Lectures on logic*. Cambridge: Cambridge University Press.
Kant, I. (1999). *Guyer, P., & Wood, A.W. (Eds.), Critique of pure reason*. Cambridge: Cambridge University Press.
Kant, I. (2004). *Allison, H., & Heath, P. (Eds.), Theoretical philosophy after 1781*. Cambridge: Cambridge University Press.
Larmore, C. (1980). Descartes' empirical epistemology. In Stephen Gaukroger (Ed.), *Descartes: Philosophy, mathematics and physics* (pp. 6–22). Sussex: Harvester Press.
Laudan, L. (1981). *Science and hypothesis. Historical essays on scientific methodology*. Dordrecht: Reidel.
Leduc, C. (2017). Wolff on hypothesis. In A. Pelletier (Ed.), *300 Years Christian Wolff's German logic* (pp. 77–97). Hildesheim: Olms.
Madonna, L. C. (1987). Wahrscheinlichkeit und wahrscheinliches Wissen in der Philosophie von Christian Wolff. *Studia Leibnitiana, 19*, 2–40.
Meier, G. F. (1752). *Vernunftlehre*. Halle: Gebauer.
Newton, I. (1726). *Cohen, I.B., & Whitman, A. (Eds.), The Principia: Mathematical principles of natural philosophy (3th ed.)*. Berkeley: University of California Press, 1999.
Reid, T. (1997). *Brookes, D.R. (Ed.), An inquiry into the human mind and the principles of common sense*. Edinburgh: Edinburgh University Press.
Roux, S. (1998). Le scepticisme et les hypothèses de la physique. *Revue de Synthèse, 4*(2–3), 211–255.
Schliesser, E., & Demeter, T. (2020). Hume's Newtonianism and anti-newtonianism. In E. N. Zalta (Ed.), *The stanford encyclopedia of philosophy (summer 2020 edition)*. https://plato.stanford.edu/archives/sum2020/entries/hume-newton.
Stan, M. (2012). Newton and Wolff: The Leibnizean reaction to the principia, 1716-1763. *The Southern Journal of Philosophy, 50*(3), 459–481.
Tonelli, G. (1969). *Einleitung. Tonelli, G. (Ed.), in Crusius, C.A. die philosophischen hauptwerke: Vol. 1 (pp. vii–lxv). Hildesheim: Olms*.
Van den Berg, H. (2020). Theoretical virtues in eighteenth-century debates on animal cognition. *History & Philosophy of the Life Sciences, 42*(3), 37.
Van den Berg, H. (2021). Kant's ideal of systematicity in historical context. *Kantian Review, 26*(2), 261–286.
Van den Berg, H., & Demarest, B. (2020). Axiomatic natural philosophy and the emergence of biology as a science. *Journal of the History of Biology, 53*, 379–422.
Van den Berg, H., & Demarest, B. (2022). *Induction, probability, and certainty in eighteenth-century German philosophy of physics: Wolff, Crusius, and kant* (Ongoing draft).
Van den Berg, H., Parisi, M. P., Oortwijn, Y., & Betti, A. (2022). *The spread of the mathematical method in eighteenth-century Germany: A quantitative investigation* (Ongoing draft).
Vanzo, A. (2012). Kant on experiment. In Maclaurin James (Ed.), *Rationis defensor: Essays in honor of colin Cheyne* (pp. 75–96). Dordrecht: Springer.
Vanzo, A. (2015). Christian Wolff and experimental philosophy. In D. Garber, & D. Rutherford (Eds.), *Oxford Studies in early modern philosophy* (Vol. II, pp. 225–255). Oxford: Oxford University Press.
Walsh, K. (2017). Principles in Newton's natural philosophy. In P. Anstey (Ed.), *The idea of principles in early modern thought: Interdisciplinary perspectives* (pp. 194–223). New York: Routledge.
Wolff, C. (1728). *1963. Preliminary Discourse on Philosophy in General (trans.R.J. Blackwell)*. Indianapolis: Bobbs-Merril.
Wolff, C. (1729). *1983a. Horae subsecivae Marburgensis I. Hildesheim: Olms*.
Wolff, C. (1740). *1983b. Philosophia rationalis sive Logica (3 vols.). Hildesheim: Olms*.
Wolff, C. (1754). *Vernunfftige Gedancken von den Kräften des menschlichen Verstandes und ihrem richtigen Gebrauche in Erkäntniss der Wahrheit*. Hildesheim: Olms, 1978.
Young, J. M. (1992). *Translator's introduction. Young, M.J. (Ed.), Kant, I. Lectures on logic (pp. xv–xxxii)*. Cambridge: Cambridge University Press.