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Induction and certainty in the physics of Wolff and Crusius

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ABSTRACT

In this paper, we analyse conceptions of induction and certainty in Wolff and Crusius, highlighting their competing conceptions of physics. We discuss (i) the perspective of Wolff, who assigned induction an important role in physics, but argued that physics should be an axiomatic science containing certain statements, and (ii) the perspective of Crusius, who adopted parts of the ideal of axiomatic physics but criticized the scope of Wolff's ideal of certain science. Against interpretations that take Wolff's proofs in physics to be based on empirical statements that are *probable*, we show how inductively established statements, coupled with assumptions concerning the uniformity of nature, can be certain according to Wolff. We examine Crusius' little known work on physics and show that he attacked Wolff, arguing that many statements of physics are probable. We provide a discussion of the reception of methodological rules similar to Newton's *Regulae Philosophandi*, discussing different interpretations of such rules. We conclude by briefly hinting at how the debate between Wolff and Crusius provides historical context for understanding Kant's philosophy of natural science.

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1. Introduction

Several early modern theories of science were marked by a demanding ideal of science. According to this ideal, proper scientific knowledge should be certain rather than probable, and no mere probability can qualify as knowledge. A statement is absolutely certain, according to the traditional

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interpretation, if its negation implies a contradiction. The traditional ideal of science further requires that scientific statements constitute an axiomatic system. On this axiomatic conception of science (de Jong and Betti "Classical Model"), a science should be based on principles that are themselves certain, and all non-fundamental statements of that science should be derived from these principles. This conception of science has been ascribed to Spinoza (de Jong & Betti "Classical Model"), Wolff (van den Berg & Demarest "Axiomatic Natural Philosophy") and Kant (de Jong & Betti "Classical Model"; van den Berg *Kant on Proper Science*).

At first glance, this ideal of science seems unsuited for sciences other than deductive a priori sciences such as mathematics. It seems unclear how any empirical science could satisfy the ideal, since we tend to regard the statements of empirical sciences as contingent and empirically revisable. Concerns such as these have led contemporary philosophers not only to reject the axiomatic ideal of science, but also to question the notion that early modern authors ever truly adhered to this idea given their respect for empirical inquiry. For instance, it has been argued by Fisher (*Gassendi's Philosophy*) that Pierre Gassendi's empiricism leads him to a form of probabilism, by Cataldi Madonna ("Wahrscheinlichkeit") that in assigning an important role to empirical premises, Christian Wolff considered proofs in the empirical sciences to be merely highly probable rather than certain, and by Chignell ("Kantian Fallibilism") that Immanuel Kant's frequent insistence on certainty and necessity belies his fallibilism about empirical scientific knowledge.

In this paper, we investigate whether and how, according to some eighteenth-century philosophers, the axiomatic ideal of certain science could be satisfied by empirical sciences and by physics in particular. We do this by looking at a disagreement between two philosophers who played an important role in eighteenth-century Germany debates on the nature of scientific methodology: Christian Wolff and Christian August Crusius. These authors provide two competing perspectives on physics. On the first perspective, endorsed by Wolff, physics both can and should be a demonstrative and axiomatic science containing statements that are certain. Against interpretations such as that of Cataldi Madonna, according to which Wolff's proofs in physics were based on empirical statements that are merely *probable*, we reveal Wolff's reasons to regard inductively established statements, coupled with assumptions concerning the uniformity of nature, as certain. Building on recent research on Wolff by Frketich ("Reasoning from Essences") and Wells ("Science and the PSR"), we show how metaphysical assumptions concerning essence, empirical assumptions concerning experimentation and the nature and stability of objects, and methodological principles governing induction were interpreted in Wolffian science**.** The second perspective on physics we find in a neglected work by Crusius, in which Crusius accepts parts of the ideal of axiomatic physics, but argues that many statements of physics

which Wolff took to be certainties are in fact probable. We further show how some philosophers differed in their interpretations of methodological rules akin to Newton's *Regulae Philosophandi*, which were seen as crucial principles of physics in the eighteenth century. Finally, we briefly suggest that the debate between Wolff and Crusius on the status and nature of physics provides important historical context for understanding Kant's philosophy of natural science, even if Kant is not the focus of this paper and the exact relation between Wolff, Crusius, and Kant on the topic of natural science remains to be investigated.

In the second section, we discuss the topics of experience, induction, and certainty in Wolff's physics, investigating how, according to Wolff, metaphysical and empirical assumptions guarantee the certainty of inductive inferences. Section Three investigates certainty and induction in Newton, Wolff, and other Wolffian authors, focussing on the role of mathematics in science, while Section Four discusses the certainty that Wolff assigns to statements of physics. In Section Five we show that Crusius argued, against Wolff, that physics is mostly a probable science. Finally, in Section Six we briefly indicate how interpreters of Kant might benefit from knowledge of the debate between Wolff and Crusius.

2. Experience, induction, and certainty in the Wolff's physics

Wolff endorses an axiomatic conception of science (See Anderson *Poverty of Conceptual Truth*; Wells "Science and the PSR"; van den Berg & Demarest "Axiomatic Natural Philosophy"), according to which a science consists in demonstrating certain statements from certain principles (Wolff, *Preliminary Discourse*, 17–18. Wolff *German Logic*, 172). Wolff also adopts the ideal of axiomatic physics, according to which non-fundamental statements in physics are deduced from principles (van den Berg & Demarest "Axiomatic Natural Philosophy"). In his *German Logic* (176–178), Wolff provides, as an example, a syllogistic demonstration of the statement that "air has an expansive force" (see Anderson "Wolffian Paradigm", 39–40; Anderson *Poverty of Conceptual Truth*, 91–93; van den Berg *Kant on Proper Science*, 31–33; van den Berg & Demarest "Axiomatic Natural Philosophy", 384–385; Frketich "Reasoning from Essences"; Frketich "Mathematical Method"), the premises of which are definitions and empirical statements. This example is meant to show that experimental results from physics can be presented deductively. However, it may be hard to see how the premises of such demonstrations could be certain rather than probable if experience and induction play a role in the justification of these premises (and we shall see that they do). For this reason, Cataldi Madonna ("Wahrscheinlichkeit", 34, 36, 38–39) has argued that, for Wolff, proofs in the empirical sciences yield statements that are merely probable, even though these probable statements approach

certainty. Against this interpretation, we will argue that, although Wolff does assign experience and induction an important role in physics, he remains committed to the ideal of certain science.

Wolff presents his mature views on the role of experience in science in the *Preliminary Discourse*, where he famously distinguishes between philosophical, mathematical, and historical or empirical knowledge (Wolff, *Preliminary Discourse*, 3–8). By empirical or historical knowledge he means knowledge obtained by the senses. According to Wolff, this kind of knowledge provides knowledge of facts, and is certain in the sense that it cannot be called into doubt. Philosophical knowledge, by contrast, provides knowledge of the *reasons* of facts and thereby offers explanations of why certain things obtain or occur. Finally, mathematical knowledge provides knowledge of quantity. Wolff is explicit that philosophical knowledge is based upon historical or empirical knowledge. He argues that experience establishes those things for which reasons can be given, and that history thereby provides the foundation of philosophical knowledge (Wolff, *Preliminary Discourse*, 6). More specifically, Wolff contends that experience or history provides the certain, firm, and unshaken foundation of philosophical knowledge, and that in abstract disciplines such as first philosophy, the fundamental notions must be derived from experience. Wolff even goes so far as to argue that mathematics presupposes experience because some of its axioms are derived from experience. Hence, experience plays a foundational role in Wolff's philosophical system.

Wolff's views on experience and induction in science are further articulated in his *German Logic* and his *Latin Logic* (480–484; on Wolff's concept of experience and method, see also Engelhard "Experience in Wolff" and Dyck "Before and Beyond Leibniz"). In these works, Wolff defines experience as cognition that is based on sensation (*German Logic*, 181). Although statements based on experience are statements about individual things, Wolff believes that one can form universal statements based on experience through an inductive generalization. Such an inductive generalization is unproblematic, according to Wolff, because one can know if and when nature is uniform if one attends to all the circumstances under which events occur *(German Logic*, 189. See also Gomez Tutor *Wissenschaftliche Methode bei Wolff*, 184–186). Wolff (*German Logic*, 189) argues that all things in nature have their effects and undergo changes because of (i) their essences and (ii) the circumstances to which they are subject. Wolff concludes from this that, as long as the essences of the objects remain the same and the objects are subject to the same circumstances (and Wolff thinks that we can know when these conditions obtain), the same objects or causes will have the same effects. This principle, which Frketich ("Reasoning from Essences") calls "Wolff's Generalisation Principle", effectively postulates a uniformity in nature (see also Wells, "Science and the PSR") and allows Wolff to

consider it legitimate, under specific conditions, to infer from a causal relationship in a particular case to a causal relationship that obtains universally for all cases in which objects with the same essences are subject to the same circumstances.

Wolff's belief that we can know (i) that the essence of an object remains the same, and (ii) whether an object is subject to the same circumstances as before, is based on his metaphysical conception of essences. Arguing in his *German Metaphysics* (I, 21–22) that the essence of an object is necessary, eternal, and unchangeable, Wolff regards the constancy and uniformity of the essence of objects as metaphysically guaranteed. In the *Latin Metaphysics* (126–127), Wolff even states explicitly that certainty in science depends on this necessity (and hence immutability) of the intrinsic possibility of things, which is grounded in their essences. Wolff further argues (*German Metaphysics*, 189) that experimentation allows us to find out which circumstances an object is subject to and whether these circumstances are the same as before, since experiments allow us to manipulate the circumstances to which an object is subject. In this sense, experimentation provides insight into the stability of nature. Hence, induction is unproblematic for Wolff because he believes it to be based on certain and unproblematic metaphysical assumptions and on empirical conditions that we can know to obtain in concrete cases. In this way, we can employ induction in science without giving up on the idea that the statements of science should be certain.

This analysis of induction in Wolff differs from analyses such as that of Anderson in several respects. According to Anderson (*Poverty of Conceptual Truth*, 92), Wolff illustrates the use of demonstrations in physics by means of the following syllogism:

(i) What expands when resistance is removed has expansive force (Major Premise)
(ii) The air expands inside the balloon when the resistance is removed (Minor Premise)
(iii) Hence, the air has expansive force (Conclusion)

Anderson remarks that Wolff's procedure here is fallacious as a response to problem of induction, since it involves inferring a universal statement (conclusion iii) from a singular empirical statement (minor premise ii) by exploiting the "standard rule that treats singular judgments as universal for purposes of inference, since they apply the predicate to the whole extension of the subject" (*Poverty of Conceptual Truth*, 92). However, Wolff nowhere says that he adopts this rule to justify induction. He does, however, as Anderson also notes, state that induction is unproblematic because we can know that the essence of objects and the circumstances to which objects are subject remain the same. As Anderson himself admits, (*Poverty of Conceptual*

Truth, 93) Wolff sees no problem with induction because he thinks that experience captures the essence of the things involved. However, Anderson does not fully discuss the importance of Wolff's views on essence for his account of induction, which has been investigated in detail by Dunlop ("Definitions and Empirical Justification in Wolff"), Frketich "Reasoning from Essences", Vanzo ("Wolff and Experimental Philosoph"), van den Berg (*Kant on Proper Science*, Chapter Three) and Wells ("Science and the PSR").

As has been noted by Dunlop ("Definitions and Empirical Justification in Wolff", 172), Wolff argues in his logic that we can manipulate the circumstances of an object to find out empirically whether a property is an attribute, i.e. a necessary intrinsic property of a thing that pertains to a thing at all times, or merely a mode or an accident, i.e. a property that the thing can fail to have while remaining the same thing. For example, according to Wolff (*German Logic*, 183–184) we can infer that softness is no attribute of a piece of wax from the fact that the wax becomes hard if it is moved from a hot to a cold place. Similarly, he deems it valid to infer that hardness is an attribute of a stone if it remains hard when subjected to varying circumstances. Wolff believes that the ground for why objects have certain attributes rather than others is the essence of these objects (Wolff *German Metaphysics*, 18–19; 23. See also van den Berg *Kant on Proper Science*, 61).

In the case of composite objects, Wolff believes this essence to consist in (i) the parts of the object, and (ii) the mode of composition of the parts (Wolff *German Metaphysics*, 29; 348). For example, we know the essence of the eye if we know the parts of which it is made up and the way in which these parts are put together (Wolff *German Metaphysics*, 23; see also van den Berg *Kant on Proper Science*, 59–60). This knowledge in turn allows us to explain why an eye has the attribute of enabling sight. Admittedly, Wolff claims that, since the way in which the parts of a composite object are composed is accidental to these parts, the essence of a composite being consists of nothing but mere accidents. Vanzo ("Wolff and Experimental Philosophy", 248) has inferred from this that "[w]hen Wolff discusses the essence of composite beings, he backtracks from his earlier claim that essences are necessary". In admitting that the essence of composite things consists in modes, and that modes are contingent and mutable, and can even cease to exist, Wolff commits himself, so Vanzo argues, to essences of composite things being contingent, mutable, and perishable. We believe this interpretation to be mistaken. First of all, it is very unlikely that Wolff would contradict his thesis that the essences of things are necessary and immutable within the scope of a few pages without further comment. Secondly, Wolff can be read here as making the different point that composite things can begin and cease to exist without substances or their parts beginning and ceasing to exist, because composite things are not substances, but rather ways in which substances relate in virtue of their respective contingent and

mutable properties (modes) (Wolff *Latin Logic*, 592), and because it is not essential to the substances of which composite things are composed that they relate in such a manner that they constitute that composite thing or even a composite thing of that particular kind. In contrast, it is necessary rather than contingent for the composite thing to consist of such parts composed in such a way, and that could be the sense in which the essence of a composite thing is necessary and immutable according to Wolff. Hence, Wolff's claim that the essences of composite things consist in mere modes can be made fully compatible with his earlier claim that the essences of things are necessary and immutable.

We do agree with Vanzo's claim that Wolff thinks we can come to know the essence of composite objects, i.e. the parts and mode of composition of these parts, in an empirical manner (Vanzo "Wolff and Experimental Philosophy", 247–249). This is evident from Wolff's discussion of the methodology of the life sciences, in which he claims that we can come to know the essence of organisms through anatomical analysis of their parts and of the mode of composition of these parts (Wolff *Würckungen der Natur*, 600–601; see also van den Berg *Kant on Proper Science,* 66–69, and van den Berg & Demarest "Axiomatic Natural Philosophy"). Hence, we can come to know the essence of objects that provides the explanatory ground for the attributes of these objects empirically. It is therefore unsurprising that induction poses no special epistemological problems for Wolff. After all, if we can know the essence and attributes of particular objects empirically, i.e. if we can know empirically the necessary properties of objects that apply to all individuals of a certain kind, we can unproblematically generalize what we know of the essence of particular objects to other objects of the same kind. As Frketich ("Reasoning from Essences", 140) remarks, as soon as one shows that, for example, elasticity is an essential property of a specific instance of air, one shows that elasticity is a property of every instance of air (See also Wells "Science and the PSR"). It is therefore by appealing to his views on essences that Wolff justifies inductive inferences, and the corresponding inference, in the example of the expansive force of the air, from the singular minor premise to the universal conclusion.

3. Wolff and Newton on certainty and inductive inference

In this section, we argue that Wolff's views on certainty and induction can be further elucidated by comparing them to Newton's views on these topics. It is important to keep in mind, however, that recent research on Wolff has demonstrated that there are fundamental differences between the philosophical views of these two authors. Stan ("Newton and Wolff") has shown that Wolff was sceptical about the existence of gravitation, taking gravity to be unprovable. One reason for this scepticism, as Dunlop ("Newtonian

Science in Wolff") and Wells have stressed ("Science and the PSR"), is that, according to Wolff, only metaphysics can prove that which is assumed by mathematics. Since Newtonian science lacks a proper metaphysical foundation, Wolff did not take Newton to have provided proper physical explanations. Wolff does not, however, reject Newton's use of mathematics in physics. In fact, as we will argue in what follows, Wolff's views on the role of mathematics in physics are quite similar to those of Newton (see on this topic also Demarest & van den Berg "Kant's Theory of Hypotheses", 14). To see this, we will first briefly describe the role Newton assigns to mathematics in physics and then compare these views to Wolff.

The use of mathematics in Newton's *Principia* has been described by Cohen as the Newtonian Style. According to Cohen ("A Guide to *Principia*", 148–155), Newton starts his analysis in the *Principia* by presenting mathematical constructs that are derived from nature simplified. In a second stage, the conditions of the mathematical construct are compared with the physical world, and Newton introduces factors that make the original mathematical construct more closely an analogue of physical systems. In a third stage, we apply the mathematical analysis to nature. We can illustrate this final stage by looking at the first steps of Newton's argument for universal gravitation, provided in Book III of the *Principia*. In the first proposition of Book III, Newton refers to the *mathematical* proposition that every body that moves in a curved line describing areas around an unmoving or uniformly moving point proportional to the times, is subject to a centripetal force toward that point (*Principia*, 446). He then refers to phenomenon 1, an *empirical proposition*, which states that the satellites of Jupiter describe areas proportional to the times with respect to Jupiter (*Principia*, 797), to conclude that the satellites of Jupiter are subject to centripetal forces or that the forces by which the satellites are maintained in their orbits are directed to Jupiter (*Principia*, 802). Note that this is a deductively valid argument. Walsh ("Principles") argues in line with this analysis that mathematics allowed Newton to reason deductively from axioms to theorems without loss of certainty, and that Newton therefore believed that mathematics was a source of certainty in natural philosophy. It was because of the use of mathematics that we could obtain certainty in natural philosophy.

Wolff, like Newton, seems to have believed that mathematics was a source of certainty in natural philosophy. In the *Preliminary Discourse*, for instance, he states that "the certitude of physical knowledge depends in many ways on mathematics" (Wolff *Preliminary Discourse*, 15). Moreover, he seems to believe that this is because mathematics allows for deductive demonstrations in natural philosophy. In his account in the *Preliminary Discourse* of how Newton transformed Hooke's mere hypothesis of gravity into certain knowledge, Wolff argues that Newton *demonstrated*, i.e. deductively proved from

certain premises, this and other conjectures of Hooke because Newton had a special talent for mathematics. As Wolff puts the point:

> […] 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, *Preliminary Discourse*, 101–102)

Hence, as was the case for Newton, Wolff seems to think the application of mathematics in natural science secures certainty because mathematics enables deductive demonstrations from certain premises in natural science.

Besides mathematics, Newton also ascribed an important role to induction in natural philosophy. In addition, Newton took induction to be governed by his four *Regulae Philosophandi*, which functioned as his maxims of scientific reasoning (Biener "Newton's Regulae Philosophandi"), and include a maxim of economy (rule 1), according to which "no more causes of natural things should be admitted than are both true and sufficient to explain their phenomena" (Newton, *Principia*, 794), and a maxim of causal reasoning (rule 2), stating that "the causes assigned to natural effects of the same kind must be, so far as possible, the same" (*Principia*, 795). The function of the *Regulae* as maxims of scientific reasoning can be illustrated by the arguments from Book III of the *Principia*. Recall that Newton used mathematics to prove that the forces by which the satellites of Jupiter are maintained in their orbits are directed to Jupiter (*Principia*, 802). Newton uses a similar procedure to prove that these forces are inversely as the square of the distances of their places from the centre (*Principia*, 802). In Proposition 2, Newton demonstrates that the forces by which the *primary planets* are maintained in their orbits are directed toward the sun and are inverse-square forces (*Principia*, 802). Proposition 3 then establishes that the force by which the *moon* is maintained in its orbit is an inverse-square force directed toward the earth (*Principia*, 802). Proposition 4 demonstrates that the "moon gravitates toward the earth and by the force of gravity is always drawn back from rectilinear motion and kept in its orbit" (*Principia*, 803). In Proposition 5, Newton then inductively generalizes this conclusion, proving that the satellites of Jupiter gravitate toward Jupiter, the satellites of Saturn gravitate toward Saturn,

and the primary planets gravitate toward the sun (*Principia*, 805). To justify this inductive inference, Newton refers to the previously demonstrated propositions and the second rule of philosophizing. Since the revolutions of the satellites around Jupiter and Saturn and the planets around the sun are phenomena of the same kind as the revolution of the moon around the earth, we can use rule 2 to infer that they depend on causes of the same kind (*Principia*, 806). Although he believes the practice of induction to be justified by the *Regulae*, Newton stresses that propositions obtained by induction remain fallible and hence merely probable, a conviction he expresses in rule 4, which states that propositions gathered by induction "should be considered either exactly true or very nearly true notwithstanding any contrary hypotheses, until yet other phenomena make such propositions either more exact or liable to exceptions" (*Principia*, 796).

Some philosophers and scientists in the period took Newton's *Regulae* to be certain, as opposed to merely probable truths, which allowed them to also view propositions that were inductively proven on the basis of such rules as certain (as opposed to probable). Such a view may not have been uncommon, since Ducheyne ("Gravesande's Appropriation of Newton") has argued that the Newtonian Gravesande attempted to *prove* Newton's *Regulae* in order to establish that they provide certainty rather than merely high probability. In the Wolffian tradition, we seem to find a similar view articulated by Baumgarten. Baumgarten articulates his version of these principles on which they are identical to Newton's *Regulae* on the basis of the following metaphysical principle:

> When the same, similar, equal, or congruent principle [principium] is posited (that is to say, efficient, deficient or occasional causes), then the same, similar, equal, or congruent consequences [principiata], causes, effects, occasions, etc. are posited as well; and vice versa.
>
> (Baumgarten *Metaphysica*, 100; our translation)

This necessary metaphysical rule corresponds to Newton's 2nd rule, and part of the bijection even articulates the same content as Newton's rule, which states that similar effects must have the same causes. Insofar as (part of) this rule is identical in content to Newton's Rule, it can fulfil the same methodological role as Newton's rule. Since Baumgarten believed that principles similar to Newton's *Regulae* are certain metaphysical truths, he probably also believed that the physical propositions proven on the basis of these principles are certain as well. Hence, as was the case for Wolff, Baumgarten did not consider induction to pose an obstacle for certainty.

Because Baumgarten, as an anonymous referee has stressed, was not merely a Wolffian and developed his own distinct views as well, we cannot infer from the fact that Baumgarten held this view that Wolff did as well. Wolff's generalization principle only expresses half of the bijection in the

above statement by Baumgarten, namely that the same causes will lead to the same effects. This of course already warrants a fair amount of induction, as Wolff himself stresses and as we have seen in the previous section. It is unclear whether Wolff also held the converse claim that the same effects must be due to the same causes, but it is in any case interesting to see how Baumgarten, working within Wolff's tradition, could have developed in a Wolffian vein and cast what to Newton was a methodological rule as a metaphysical truth. How controversial this move could be will become clear from our discussion of Crusius below, who interpreted, as we shall see, Newton's *Regulae* as probable propositions, and used this interpretation to argue that parts of natural science are probable.

4. Wolff on the certainty of physical knowledge

In the first section, we argued that Wolff took himself to have demonstrated metaphysically the necessity and immutability of essences, and that Wolff believed we could arrive at knowledge of essences empirically. This allowed him to regard scientific proofs based on inductive statements as yielding certain knowledge. This result, however, may be considered problematic, since Wolff argues (*German Metaphysics*, 622) that the laws of nature established in what he calls dogmatic physics or the science of things possible through bodies (Wolff, *Preliminary Discourse*, 35) are contingent (see Vanzo "Wolff and Experimental Philosophy", 247). If these laws and the statement that follow from them are contingent, however, it seems that their opposite must be possible, and that hence they cannot have the absolute necessity to which Wolffian science lays claim. For this reason, Cataldi Madonna has argued that Wolff ultimately regarded empirical statements of physics as merely probable because statements the opposite of which is still possible are, according to Wolff, probable statements (Cataldi Madonna, "Wahrscheinlichkeit", 34). In this section, we argue that this interpretation goes too far, since Wolff does insist that the statements of physics are necessary, even though he distinguishes this necessity from absolute necessity.

Perinetti ("Ways to Certainty", 268–271) has argued that early modern philosophers distinguished between different kinds of necessities. One such distinction is that between metaphysical and physical necessity. According to Perinetti, a statement is *metaphysically certain* if the statement cannot be negated without contradiction, i.e. if it is an absolutely necessary truth, whereas a statement is a *physical certainty* if it is derived from physical principles ("Ways to Certainty" 268). Statements that are physically certain express *physical necessities*. According to Perinetti ("Ways to Certainty", 270), Leibniz argued that a statement p is a physical necessity, even though it is contingent, if "the negation of p contravenes the laws of nature". Wolff seems to

employ this distinction as well. In his *German Metaphysics* (II, 352–354), Wolff states that something is absolutely necessary if it has the ground of necessity in itself, and also calls this kind of necessity mathematical or metaphysical necessity because it is the necessity of statements in mathematics and of (some) statements in metaphysics. Wolff contrasts metaphysical necessity with what he calls conditional necessity, where the necessity lies in the conditions, not in the thing itself. Wolff claims that the latter conditional necessity is also called the *necessity of nature* because it is grounded in the course and laws of nature, i.e. in the connections between objects (*German Metaphysics*, 352–354). This necessity constitutes some kind of physical necessity and can be attributed to statements of physics. Though contingent in the sense that their opposite is not impossible in itself, statements of physics can thus be taken to be physically necessary and physically certain. The knowledge of the conditions that make something physically necessary can be arrived at, Wolff holds, on the basis of experience. In the *Preliminary Discourse* (53), Wolff argues that the principles of dogmatic physics, which provide the reason why something must occur, must be derived from experience. Since such principles are not always evident by observation, recourse must be taken to experimentation. Experimentation also provides confirmation of physical statements that have been deduced from said principles. By means of experience in the form of observation and experimentation, therefore, Wolff believes we can arrive at knowledge of physical necessities.

Our interpretation of Wolff's views on induction elucidates his stated views on demonstration in the empirical sciences. In the first place, it clarifies the aptitude of the previously mentioned example of deductive demonstration of the expansive force of the air from the *Deutsche Logik*. This complex deductive proof, which formalizes the reasoning behind an experiment Wolff describes in his experimental physics, can be reconstructed as follows (we rely on the presentation from van den Berg *Kant on Proper Science* and van den Berg & Demarest "Axiomatic Natural Science"; for other discussions of the example, see Anderson "Wolffian Paradigm" and *Poverty of Conceptual Truth*, Frketich "Reasoning from Essences" and "Mathematical Method", and Wells "Science and the PSR"):

(1) [1] What continuously endeavours to expand has an expansive force [definition of expansive force]
(2) [2] What begins to expand when resistance is removed continuously endeavours to expand [proposition based on experience]
(3) [3] Hence, what begins to expand when resistance is removed has an expansive force [conclusion from (1) and (2)].
(4) [4] What expands a bladder when resistance is removed must also expand itself [proposition based on experience].

(5) [5] The air expands the bladder when resistance is removed [from experiment].
(6) [6] Hence, the air must expand itself, when resistance is removed [conclusion from (4) and (5)].
(7) [3] What begins to expand when resistance is removed has an expansive force.
(8) [6] The air begins to expand when resistance is removed.
(9) [7] Hence, the air has an expansive force. [Q.E.D.]

This demonstration is based on empirical definitions and propositions based on experience, and the conclusion follows deductively from the premises. Note that proposition [5], which describes the results of experiments with an air pump, refers to a particular and singular experiment. However, since the conclusions Wolff draws surely refer to air in general or all air (as was noted by Anderson *Poverty of Conceptual Truth*, 92) Wolff takes the inductive inference from a particular experiment to a general conclusion to be valid here. On our interpretation, Wolff considered this inference justified because we can assume the uniformity of nature on the basis of metaphysical and empirical grounds. A similar inductive justification can be given for propositions [2] and [5]. Note further that proposition [1] is a definition and is accordingly a fundamental truth of science according to Wolff, since he considered axioms to follow immediately from definitions, with theorems following from axioms in their turn. In this way, we can see how Wolff's demonstrations in physics consist in the deduction of certainties from statements that are certain because they are either fundamental definitional truths or empirical statements arrived at through a certainty-preserving inductive method. Hence, the above demonstration aptly illustrates Wolff's axiomatic conception of physics.

In addition, our account of induction in Wolff allows us to better understand his views on the role of metaphysical principles and experimental statements in the deductive demonstrations of physics. As is well known, Wolff believes that metaphysics provides concepts and statements that can be used in physical proofs. In his *Preliminary Discourse* (1728), for example, Wolff states that metaphysics, more specifically ontology, precedes physics by providing notions such as essence, necessity, composition, such that "if everything is to be demonstrated accurately in physics, then principles must be borrowed from metaphysics" (Wolff, *Preliminary Discourse*, 48). Thus, the possibility of providing demonstrations in physics is based on the foundational role of metaphysics. In addition, what Wolff calls experimental physics, which adopts the analytic method and reasons from effects to causes on the basis of experiments and observation, has a role to play in (what is sometimes called) dogmatic physics, which adopts the synthetic method and reasons from causes to effects employing the results of

experimental physics. Thus, in dogmatic physics, both statements from metaphysics and experimental physics are used.

The role of both metaphysical and experimental statements in making deductive demonstrations in physics possible becomes clear from an example from Wolff's *German Physics*. Distancing himself from many Newtonians, Wolff defines weight as the tendency of matter to move to the middle of the earth (Wolff *German Physics*, 119). He subsequently argues that matter with weight is moved by a matter that causes the weight of bodies (a *Schweermachende Materie*). More specifically, he argues, on the basis of the statement from experimental physics, that (i) heavy bodies that begin to fall move increasingly faster, and on the basis of the statement from metaphysics, that (ii) velocity only changes through an external impulse, that (iii) the matter that makes matter heavy continually impacts heavy matter (Wolff *German Physics*, 122–123). The statement from experimental physics is based on individual experiments, and must therefore be taken to be true, certain, and universally valid on the basis of induction, which, as we have seen, Wolff takes to be unproblematic because of metaphysical and empirical uniformity assumptions. The statement from metaphysics, in contrast, is taken to be true, certain, and universally valid on the basis of metaphysical proofs. Given that he takes these statements to be certain, Wolff can use them in deductive demonstrations in physics that secure scientific certainty, demonstrations that very often employ results from both experimental physics and metaphysics.

In conclusion, Wolff believes metaphysical principles to be indispensable in physics because they provide both certain essential premises and the principles of scientific reasoning that yield universal empirical truths. In this way, physics can take the form of an axiomatic system in which the certainty and necessity of each statement is guaranteed. Of course, as one anonymous referee pointed out, this does not mean that certainty and necessary truths can be had, according to Wolff, only in the context of such an axiomatic system. Wolff allows for introspection, and in his logic argues that introspection makes it certain that we have an understanding. Such knowledge need not be either de dicto necessary or included in an axiomatic system.

5. Probability in Christian August Crusius' physics

As Watkins has shown ("Laws of Motion", 315; *Metaphysics of Causality*, 81–85), followers of Wolff, such as Thümmig (1697–1728), Billfinger (1693–1750), and Reusch (1691–1758), as well as critics of Wolff, such as Crusius (1715–1775), followed Wolff by providing metaphysical justifications of some principles of physics. Throughout the eighteenth century, however, we can also discern a critique of the scope of Wolff's ideal of certain science, encapsulated in the argument that physics contains a great deal of

probable cognition (see van den Berg & Demarest "Axiomatic Natural Philosophy"). This argument is forcefully articulated by Crusius.

Crusius' critical stance towards the scope of the ideal of certainty is well established. Alexander, for instance, situates him in a tradition of German thinkers who argued that the scope of demonstrative knowledge in science was limited (Alexander "Pluraque credimus", 130–131, 141. See also van den Berg & Demarest, 390–391 and for a quantitative and qualitative analysis of this tradition Betti, van den Berg, Parisi & Oortwijn "spread of the mathematical method"). According to Alexander, Crusius stands in the tradition of Christian Thomasius and Andreas Rüdiger, who stressed that in many domains of science we can only attain probable belief and not apodeictic knowledge. In this context, Alexander discusses Crusius' views on probability, but focuses mostly on its relevance to hermeneutics (see also Gelfert "Enlightenment Contribution to Social Epistemology"), rather than on physics. Important work on Crusius' account of philosophical method and certainty has also been done by Prunea-Bretonnet ("Crusius and Kant on Distinctness"), and Zenker ("Crusius' Naturphilosophie") has situated Crusius' philosophy of nature in a tradition of thinkers that regarded physics as a merely probable science. A more detailed analysis of Crusius' account of the role of probability in physics, however, is still lacking.

Zenker ("Crusius' Naturphilosophie") provides invaluable clues concerning the context of Crusius' views on physics. According to Zenker, Crusius' physics, as developed in his *Anleitung*, stands in a tradition of critics of the new physics as developed by Galilei, Descartes, and Newton. Such critics rejected the extreme mechanical worldview of the new physics and the mathematization of physics and instead went back to Aristotelean conceptions of physics according to which mathematics and physics are concerned with different domains of inquiry. In addition, critics of the new physics objected to the new physics that its practitioners employed empty concepts. According to Zenker, this line of criticism as developed in Germany can be traced to the work of Thomasius. Zenker argues that Crusius should be placed within this thomasian tradition, and his Anleitung should be read as an attempt to offer an alternative physics to the new mechanical physics, which he feared led to determinism, materialism, and eventually atheism.

In his *Anleitung*¸ Crusius argues that experience and experiment play a vital role in physics in allowing us to arrive at truths (*Anleitung*, 16–19). An experience, according to Crusius, is a statement in which the connection between the subject and the predicate is sensed immediately (*Weg zur Gewissheit*, 829; on Crusius' concept of experience, see also Heßbrüggen-Walter "Crusius on Experience"). From this definition, Crusius argues, it follows that universal statements cannot be experiences, since universal statements have an infinite scope, and we cannot perceive all the objects to which universal statements apply (*Weg zur Gewissheit*, 834). Hence,

universal statements based on experience can only be arrived at through some form of reasoning: induction. According to Crusius, if a set of experiences is of sufficient quantity, we can take a universal statement based on experience to be a *postulate of experience* (*Weg zur Gewissheit*, 834), i.e. a statement that we assume to be true even though it cannot be strictly proven (*Weg zur Gewissheit*, 64–65). Hence, although Crusius assigns induction a role in obtaining universal statements based on experience, he distances himself from Wolff in arguing that such statements are mere assumptions of truth rather than certainties.

In his Logic, Crusius provides an account of inductive arguments as instances of analogical arguments (*Weg zur Gewissheit*, 675; see also Alexander "Pluraque credimus", 143; on analogy, see also van den Berg "Kant and Analogy"). By means of an analogical argument, we infer that unperceived objects of the same kind as certain previously perceived objects are also similar to these previously perceived objects in some respect (*Weg zur Gewissheit*, 675–676). As an example, Crusius mentions the inductive argument that we can infer from the past effects of a medicine that a medicine of the same kind will have similar effects in the future (*Weg zur Gewissheit*, 677). Since Crusius treats inductive inferences as probable inferences that lead to probable conclusions, he takes induction to yield probable statements. Although in one passage Crusius claims that a universal statement based on induction and a large number of instances delivers complete certainty (*Weg zur Gewissheit*, 682), he means here that probable inferences can lead us to suspend doubt (*Weg zur Gewissheit*, 730–731), and the certainty he refers to is *moral certainty*, which, as Alexander ("Pluraque credimus", 158) notes, Crusius took to be the highest degree of probability yielding conviction (on moral certainty, see also Perinetti "Way to Certainty" and Prunea-Bretonnet "Crusius and Kant on Distinctness"). Hence, even though Crusius believed that statements based on induction can yield conviction, he still considered these statements to be merely probable.

Moral certainty constitutes, according to Crusius, one of three types of probability, the other two being probability in the strict sense (*das Wahrscheinliche in der engern und geringern Bedeutung*) and the credible (*das Glaubwürdige*) (all three types of probability are types of what we would now call subjective probability[1]). We speak of probability in the strict sense if we take something to be true more than we take its opposite to be true (*Weg zur Gewissheit*, 641). Thus, for example, if someone is prone to forgetfulness, we would sooner take it to be true that they have forgotten

[1]Today, it is customary to distinguish between subjective probabilities (typically degrees of belief) and objective probabilities (attributed to physical systems). The distinction was not yet in use in the eighteenth century, so we will only use these terms when they can be certainly, unproblematically and unambiguously applied to an author.

their keys than that they have been robbed, and hence the former statement is probable in the strict sense. We speak of the credible if we take something to be true to such an extent that we can confidently act on this information (*Weg zur Gewissheit*, 641). The credible therefore denotes that which we are able to believe to such a degree that we can unproblematically act on this information (Crusius *Entwurf*, 45). For example, since it is credible that our children will be hungry when they wake up tomorrow morning, we can prepare breakfast without doubting this information and our actions. Finally, there is moral certainty, which Crusius treats both as a form of probability and a form of certainty (Crusius *Entwurf*, 44–45). A statement is morally certain when, even if its opposite is not demonstrably impossible, it is not considered possible based on grounds of probability (*Weg zur Gewissheit*, 754–755). These different types of probability indicate, we submit, different degrees of (subjective) probability: credibility is a higher degree of probability than probability in the strict sense, and moral certainty again provides us with a higher degree of probability than credibility. However, these different types of probability are also introduced to describe different ways in which we evaluate a proposition (on these distinctions, see also Prunea-Bretonnet "Crusius and Kant on Distinctness").

Crusius took physics to be partly based on probable principles that he calls *presumptions* (*Präsumtionen*) (*Anleitung*, 60; see also van den Berg & Demarest "Axiomatic Natural Science" and Demarest & van den Berg "Kant's Theory of Hypotheses", 14–16; see also Alexander "Pluraque credimus", 143–147). A presumption is treated as a probable universal statement from which another probable statement is derived (*Weg zur Gewissheit*, 711). It is illuminating to look at some presumptions that Crusius discusses, especially the presumptions of physics. Crusius argues, for instance, that the presumption of the uniformity of nature, which he believes, like Wolff, to be the ground of induction, is merely probable, and not, as Wolff thought, a demonstrable certainty. He also argues (Crusius *Anleitung, 76*) that physics is based on the rule that natural events occur in accordance with stable and unchanging laws and that we must therefore assume the existence of such laws as a presumption, for without it we would not be able to practice physics. This indispensability of the assumption, of course, does not make the statement any more than merely probable.

Crusius (*Anleitung*, 73) also discusses several presumptions that correspond to Newton's *Regulae*, arguing that they ground scientific reasoning but are nevertheless probable. Like Newton, he argued for a maxim of economy, stating that, if we can explain some effect from already known and comprehensible causes, we should not posit new and unknown causes. In addition, Crusius (*Anleitung*, 90) offers a maxim corresponding to Newton's second rule, which states that if the effects are similar, we can presume similar causes. The fact that Crusius took these rules to be merely

probable suggests that he also took the statements derived on the basis of these rules to be merely probable. Hence, in contrast to Baumgarten, who took rules like Newton's *Regulae* to be necessary metaphysical truths, Crusius took such statements to be merely probable statements that ground inferences that yield other merely probable truths. Crusius (*Anleitung*, 77–80) also took many other principles of physics, such as a variant of the law of continuity and the statement that "nature takes the shortest road", principles Wolff took to be certain (see Wolff *German Metaphysics*, II, 425; 440–441) to be merely probable. Finally, we may note that Crusius (*Anleitung*, 80) interprets probable statements as contingent statements. Hence, in contrast to Wolff, who took contingent statements of physics to be *physical certainties* that express *physical necessities*, Crusius took all contingent statements of physics to be merely probable.

In conclusion, Crusius argues that, within *empirical* science, the scope of certainty is far more restricted than Wolff took it to be, that our empirical knowledge is usually not demonstratively certain and that high probability, i.e. moral certainty, is often the highest degree of certainty we can obtain (Crusius *Anleitung*, 792). Such moral certainty yields not certainty but what Crusius (*Weg zur Gewissheit*, 799) calls rational belief (*Glaube*), which we also have (in cases where we lack moral certainty) if the probable statement we believe in is connected to our final ends. Gava has argued that Crusius' argument that, for statements that we do not *know* but *rationally believe*, "our ends can command our assent to a proposition if this proposition identifies conditions that are necessary for the realization of those ends" (Gava "Kant and Crusius on Belief", 62). This view anticipates Kant's argument that "when a proposition is left undecided by the evidence we have, we are rationally required to believe it if the latter describes conditions for the realization of certain ends in our practice" (Gava "Kant and Crusius on Belief", 61). An example of this is belief in the existence of God as a condition for the realization of the highest good (Gava "Kant and Crusius on Belief", 58). Crusius' views on physics suggest that, in the same way, we *must* rationally believe many presumptions grounding physics, such as Newton's *Regulae*, even if we cannot know them.

6. Scientific methodology and Kant's philosophy of natural science

In the writings of Wolff and Crusius, we have found two different assessments of the status of physical statements. The disagreement between the two authors concerns an issue that characterizes methodological reflections on physics throughout the eighteenth century. As van den Berg and Demarest ("Axiomatic Natural Philosophy", 390) have shown, even before Crusius' attacks on Wolff, the philosopher Georg Friedrich Walch (1693–1775), who

published the influential *Philosophisches Lexicon* in 1726, stressed that a body of statements is a science only if its statements are certain, and noted that various modern authors denied, against authors such as Aristotle and Descartes', that physics constitutes *scientia* in this sense. This debate on the status of physics is traced by van den Berg and Demarest to several eighteenth-century textbooks on physics.

Like the debate on physics between Wolff and Crusius, Kant's later reflections on natural science, too, can arguably be situated within the context of debates about the methodology and epistemic status of physics. In the *Metaphysical Foundations*, Kant famously argues that the statements of a proper natural science must be apodictically certain, and hence be based on a priori principles. Although we cannot analyse Kant's views within the scope of this paper, it seems to us that, in demanding that a science be apodictically certain, Kant mostly followed Wolff and the Wolffians. But, as McNulty ("Kant on Chemical Laws") has shown for the case of chemistry, Kant also argues that some sciences are based on regulative principles, such as chemical elements, which, according to McNulty, we cannot strictly speaking know, but only *believe*. Hence, like Crusius, Kant recognized that some postulates and principles of science are objects of belief, and, as Gava ("Kant and Crusius on Belief") has argued, derived his account of belief at least in part from Crusius. Kant therefore seems to have developed a position that mediates between the traditional options in this debate as well. We believe that our analysis of the disagreement between Wolff and Crusius provides a point of departure for new research on Kant's place in debates on early modern philosophy of scientific methodology, although we can only provide some pointers to this research here.

7. Conclusion

In this paper, we have addressed the question of how some eighteenth-century philosophers assessed the implications of the role of experience in physics for the status of physics as a true science by discussing the differing viewpoints of two major contributors to the eighteenth-century German debate, Wolff and Crusius. We argued, against interpretations that downplay Wolff's commitment to a demonstrative and axiomatic ideal of science, that Wolff took experience and induction to be certainty-preserving because he took the principles on which induction is based to be metaphysically and empirically grounded. We also argued that Crusius developed an opposing viewpoint on which some principles of physics are not certain, and are instead the objects of a belief that is rational because they are indispensable to science. We showed that, as a result, Crusius believed physics to contain (mostly) merely probable

statements. Finally, we suggested that Wolff and Crusius addressed central methodological and epistemological debates about physics and that their theories may shed light on Kant's later positions on the status of empirical sciences.

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