Alberto Vanzo

Kant on Experiment

Chapter 7 of *Rationis Defensor: Essays in Honour of Colin Cheyne*, ed. James Maclaurin (Dordrecht: Springer, 2012), 75–96. DOI: 10.1007/978-94-007-3983-3_7

In this paper I illustrate the relations in which experiments stand to hypotheses, laws, and principles in Immanuel Kant's natural philosophical methodology. My aim is not to provide a rational reconstruction of Kant's philosophy of experiment or to assess its internal coherence, but to illustrate it by contrasting it with an alternative conception of experiment that had a widespread following in the early modern period. This is the philosophy of experiment that was first sketched by Francis Bacon and later developed by Robert Boyle and Robert Hooke.

Needless to say, Bacon, Boyle, and Hooke are neither the first, nor the only philosophers to comment on the nature and functions of experiments before Kant. However, Bacon, Boyle, and Hooke provided a fairly elaborated and extremely influential set of reflections on the nature, types, and functions of experiments. Their philosophy of experiment embodies a set of beliefs and attitudes – such as the focus on fact-gathering and the rejection of hypotheses – that were widely held in the second half of the seventeenth century, among others, by many English natural philosophers and members of the Royal Society, the Florentine Accademia del Cimento, and the early French Academy of Sciences. A similar emphasis could be found in many British and French authors throughout the eighteenth century.[i]

Sketching a history of the anti-hypotheticalism that characterizes the Bacon-Boyle-Hooke view of experiment, Larry Laudan claims that it was endorsed by "most scientists and epistemologists" from the 1720s to the end of the eighteenth century. Laudan mentions Kant as one of the authors for whom "the method of hypothesis is fraught with difficulties" (Laudan 1981, p. 10). In contrast to Laudan, I will argue that Kant's view on the relations between experiments on the one hand and hypotheses, laws, and theories on the other hand, is best seen as an alternative to the aversion to hypotheses and sharp contrast between experiments and speculations that characterizes the Bacon-Hoyle-Hooke view of experiment.

Kant often emphasizes the importance of experiments for natural science. Experiments, together with observations, are "the single road of natural science" (Kant 1922, vol. 11, p. 142)[ii] and "the source" of physics (Kant 1936-1938, vol. 22, p. 331).[iii] They enable us to discover "the properties of object[s] of outer senses" (Kant 1922, p. 142 - trans. modified) and the laws of nature (Kant 1966f, pp. 815_{7-9}, and 898_{48}). Empirical physics entered "the highway of science" only when Galileo, Torricelli, and Stahl followed "the suggestion of the ingenious Francis Bacon" (Kant 1781/1787, Bxii; 1980, p. 107) and started performing experiments:

> When *Galileo* rolled balls of a weight chosen by himself down an inclined plane, or when *Torricelli* made the air bear a weight that he had previously thought to be equal to that of a known column of water, or when in a later time *Stahl* changed metals into calx and then changed the latter back into metal by first removing something and then putting it back again, a light dawned on all those who study nature [...] (Kant 1781/87, Bxiii)

Galileo's, Torricelli's, and Stahl's experiments are not only the basis for what Kant regarded as a scientific revolution ("a sudden revolution in the way of thinking," (Bxii). They are also the basis for a revolution in metaphysics, which Kant undertakes in the *Critique of Pure Reason*. Its method "consists in this: to seek the elements of pure reason in that *which admits of being confirmed or refuted through an experiment*" (Bxviii). Kant's "experiment of pure reason" (Bxxi n.; 1793, p. 291) aims to set metaphysics on the same "secure path of a science” (Kant 1781/1787, Bix) on which physics entered thanks to Galileo’s and Torricelli’s experiments. In the theoretical field, the experiment of pure reason will enable Kant to explain the nature, extent, and limits of a priori knowledge (Kant 1781/1787, B6, A3/B7, A57/B81; 1783, p. 276; Seigfried 1989). In the practical field, that experiment will clear the ground for the new foundations of morality which Kant articulates in the *Critique of Practical Reason* (Kant 1781/1787, Bxxiv–xxx; Sato, 2008).

Despite his claims on the importance of experiments, Kant was not an experimenter (Adickes 1924–25, vol. 1, pp. 6–11; vol. 2, pp. 484 and 487),[iv] although he was aware of many results of the experimental sciences of his day. Kant’s writings do not contain any accurate experimental report or discussion of the practical aspects of experiments. The Kantian corpus does not provide any detailed, self-contained discussion of what an experiment is, except for a claim that was customary among Kant’s German contemporaries (Lambert 1764, vol. 1, pp. 351–53; Erxleben 1772, §4). This is the claim that, by means of experiments, we *intervene* in nature, placing objects in states in which they would not otherwise be (Kant 1980, pp. 102–3).[v] By contrast, observations do not modify the state in which observed objects are. Accordingly, we can perform experiments on animals and the medium-sized objects that we have at hand, but not on distant stars and planets, because we cannot modify the state they are in.[vi]

Despite his apparent disinterest in the practical aspects of experiments, Kant provides reflections on three important topics in the philosophy of experiment. These are the relations of experiments to hypotheses, laws of nature, and the heuristic principles that guide scientific inquiry.[vii] I will reconstruct these relations in Sects. 7.2, 7.3 and 7.4 of the paper, after sketching the Bacon-Boyle-Hooke conception of experiment in Section 7.1.[viii] Some critical remarks are provided in Section 7.5.[ix]

7.1 *Bacon, Boyle, and Hooke*

According to Bacon, Boyle, and Hooke, the main function of experiments is not testing theories or enabling us to discover the laws of nature. It is providing data, factual information on the properties and behaviour of bodies in determinate circumstances.

Experiments aimed primarily to verify or falsify theories were eschewed because Bacon, Boyle, and Hooke conceived of natural philosophical inquiry as a two-stage process (Hooke 1705, p. 7). The first stage was the construction of natural histories, that is, structured collections of a large number of facts on designated topics (Boyle 1666). The second stage was the development of theories on the basis of the information collected. This second stage was to be initiated after the completion of the first stage (Boyle 1662, p. 12). Compiling natural histories was an enormous endeavor which would occupy many generations of researchers. As a consequence, theory construction was seen as a task which could only be accomplished in a distant future (Parker 1666, pp. 45−46).

To be sure, Boyle and Hooke claimed that it is useful to know the main theories which are available on a given topic in order to design experiments (Boyle 1666, p. 2; Hooke, 1705, p. 19). However, they were wary of drawing general conclusions from observations and experimental results. For instance, Boyle regarded the so-called Boyle's law as a generalization, observed to be true in specific places, but he was reticent to say that it is universally valid (Boyle 1662, p. 60).[x]

Bacon, Boyle, and Hooke held that one should perform experiments in a state of mind which is as free from theoretical assumptions as possible (e.g. Hooke, 1705, p. 20). Otherwise, one will easily fall prey to the prejudices (the famous Baconian *idola* (Bacon 1620, part 1, §61).)

which often thwart our endeavors to discover truth. Accordingly, Boyle and Hooke professed themselves adherents of experimental philosophy.[xi] They counseled against the premature formulation of theories, systems, and hypotheses (e.g. Hooke 1665, sig. A4).[xii] These were distinctive marks of speculative philosophy, as the adversary of experimental philosophy was called (Boyle 1662, p. 12; Hooke 1665, sig. a3, b1; Sprat 1667, p. 341; Anstey 2005; Gaukroger 2006, pp. 352–451).

The most frequent examples of speculative philosophy were Aristotelian and Epicurean natural philosophy and, later, Cartesian natural philosophy (Boyle 1666, p. 2).

With their factual and experimental approach, Bacon, Boyle, and Hooke, together with the members of the Royal Society and the other adherents to the program of experimental philosophy, gave an extraordinary impulse to the natural sciences. However, their aversion to speculation and hypotheses eventually undermined the Baconian research program of constructing natural histories. In the absence of organic links between experiments and observations on the one hand, and natural philosophical theories and hypotheses on the other, the mere accumulation of facts did not lead to the substantial progress in the explanation of the newly observed phenomena that experimental philosophers were expecting. It also did not lead to the establishment of corpuscularianism which many "new philosophers" hoped would replace the traditional Aristotelian matter theory.[xiii] Therefore, it is not surprising that, after the publication of Newton's *Principia mathematica philosophiae naturalis* in 1687, British natural philosophers were quick to embrace the new Newtonian model of natural philosophical inquiry.

Experiments and observations in the *Principia* are not aimed at the compilation of natural histories. They are aimed at the establishment of mathematical and nomological explanations of natural phenomena. By contrast, determinate nomological explanations were not central to

Bacon's or Boyle's natural philosophical projects. Newton claimed that the principles and laws which are the core of natural philosophical theories are deduced or induced from the phenomena. However, Newton did not spell out in detail how this deduction or induction takes place. Moreover, Newton continued to decry hypotheses and speculation. Like Bacon, Boyle, and Hooke, Newton "did not feign hypotheses".[xiv] For Newton, as for Bacon and Boyle, experiments and hypotheses "were on different sides of the methodological divide" (Anstey unpublished). By contrast, according to Kant, experimental activity starts with the formulation of a hypothesis.

7.2 Experiments and Hypotheses

7.2.1 Experiments, Hypotheses, and Preliminary Judgements

Discussing "how we can discover the hidden qualities of natural bodies by means of experiment", Kant states:

> we must always first presuppose something here (*begin with a hypothesis*) from which to begin our course of investigation [...] For to venture forth blindly, trusting good luck until one stumbles over a stone and finds a piece of ore and subsequently a lode as well, is indeed bad advice for inquiry (Kant 1798a, pp. 223–24, italics added).

Unlike Bacon, Boyle, and Hooke, Kant holds that we neither can, nor should perform experiments in a theoretical void. Starting with a hypothesis is not only good experimental practice. It is also what every experimenter, more or less consciously, actually does: "[e]very man who makes experiments first makes hypotheses, in that he believes that this or that experiment will have these consequences" (Kant 1966f, p. 889).[xv]

Hypotheses are not only important for experiments. They are the starting point of every activity which requires one to make judgements on the basis of uncertain grounds. "Thus a doctor makes hypotheses when he cures the sick[;] he has to subsume everything under hypotheses, and see whether the consequences that he now has before his eyes follow therefrom" (Kant 1966a, p. 220). A businessman makes a hypothesis when he "finds a ground that is sufficient for undertaking something" (Kant 1966c, pp. 750–51). A general facing the enemy "must necessarily judge and decide something" on the basis of hypotheses (Kant 1966c, pp. 750–51).

Bacon or Boyle could object that hypotheses may derive from prejudices and therefore they must be eschewed. Kant would agree that hypotheses derive from prejudices. However, he would add that, in line of principle, there is nothing wrong in having pre-judices, understood in the etymological sense of preliminary judgements. On the contrary, preliminary judgements are necessary for invention and discovery:

> There has never been an inventor in the world, and there has never been anyone who invented something, who did not at the same time make a preliminary judgement concerning his invention and the invented thing. He was not certain of the thing, but *the judgement cleared the path for him to try, and to experiment* (Kant 1966a, p. 162, trans. modified and italics added).[xvi]

The hypotheses to be tested by means of experiments are "half-judgements" (Kant 1966f, p. 862), suppositions, and tentative assumptions about the properties and existence of objects and the laws and forces to which they are subjected.

Why should we believe that our inquiries always start with hypotheses and preliminary judgements? Kant's texts contain two sets of considerations in support of this claim. First, Kant formulates pragmatic considerations, which are independent from his transcendental philosophy. Kant sketches several brief descriptions of the activities of doctors, judges, miners, inventors, and experimenters. These descriptions are aimed to yield plausibility to the view that inquiries in all these fields are based on hypotheses and preliminary judgements.

Second, Kant's conception of the mind places a great emphasis on the active role of the human subject in shaping our experience of the world (Kant 1781/1787, A126). In Kant's view, we continuously subsume the objects that we come by under concepts, such as those of substance and causality (B161, B164). We do this by formulating judgements about those objects (B143), even though we are normally unaware of this mental activity. If one endorses this view of the mind, it will be much easier to admit that we constantly frame hypotheses and preliminary judgements than it would be for those philosophers who deny the existence of unconscious mental contents. According to Kant, the preliminary judgements and hypotheses which are at the basis of our experiments are part of the continuous flow of our spontaneous activity of judgement (Kant 1961, p. $243_{2-33,36}$; 1998b, 359_{189-90}).

7.2.2 Hypotheses and induction

Kant's concise explanations of the notion of hypothesis employ several technical terms. It is helpful to unpack them in three steps:

1. Hypotheses are judgements that we regard as true: they are "a holding to be true" [*Fürwahrhalten*].

2. We hold them to be true because they explain the reasons for given phenomena. The metaphysics treatises of Kant's eighteenth century German predecessors provided detailed treatments of the notion of reason in connection with the principle of sufficient reason (e.g. Crusius 1747, §§139–54). Adopting their terminology, Kant states that hypotheses illustrate the *Gründe*, that is, the causes or reasons of given

phenomena. Having in mind the distinction between sufficient and insufficient reasons (e.g. Crusius 1747, §143), Kant states that the reason expressed by a hypothesis must be sufficient to explain why the phenomena take place.

3. Hypotheses describe presuppositions [*Voraussetzungen*] (Kant 1966c, p. 746_5; 1998a, p. 146_{14}; 1800a, p. 84_8). They describe what must be preliminarily [*voraus*] posited [*gesetzt*], that is, exist or take place, for certain phenomena to take place.

The *Jäsche Logic* expresses all this as follows:

> *A hypothesis is a holding-to-be-true of the judgement 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*.
>
> All holding-to-be-true in hypotheses is thus grounded on the fact that the presupposition, as ground, is sufficient to explain other cognitions as consequences (1800a, pp. 84–85).[xvii]

For example, "I suppose that the earth has cavities, because on the basis of this [supposition] it is possible to explain how valleys arose; then I suppose the ground, because on the basis of it one can explain [its] consequences. This is a hypothesis" (Kant 1966d, p. 440).

The example makes clear that, when we formulate hypotheses, we follow a pattern of reasoning which leads us from certain events (the consequences) to their ground (*R* 2687 [1776–89?], vol. 16, p. 471; Kant 1966c, p. $746_{5–7}$). On the face of it, this pattern of reasoning would seem to be an abduction or an inference to the best explanation. Instead, Kant's discussions of hypotheses mention induction. Hypotheses "are not taken to be true apodictically, but *per inductionem*" (Kant 1966e, p. 558).[xviii] "Induction" is a technical term for Kant. It designates the ascription of a property to all members of a class, on the ground that it belongs to some of them.[xix]

Since Kant claims that hypotheses are the result of inductions, and the conclusions of inductions are universal judgements, Kant must hold that hypotheses are universal judgements. These are judgements of the form "all *S* are *P*". However, this claim is implausible. Kant himself makes many hypotheses on the constitution of individual objects or on the causes of just one event: for instance, the hypothesis that there is heated matter at the centre of the Earth (Kant 1800b, pp. 259–60; 1966f, p. $887_{7–8}$; 1998b, p. 377). In what follows, I will ignore this difficulty and presuppose Kant's claim that hypotheses are universal judgements derived by induction.

7.2.3 Hypotheses, Certainty, and Probability

The claim that hypotheses are the conclusions of inductive inferences is the basis for Kant's further claim that hypotheses cannot be certain.[xx] They do not enjoy the high epistemic status that early modern philosophers typically required for a statement to be part of the body of proper science, or *scientia*.

In Kant's vocabulary, to be certain of a statement means to know that it is necessarily true.[xxi] For Kant, we can never know that a hypothesis is necessarily true. For universal statements, necessary truth goes hand in hand with "true or strict" generality, "i.e., in such a way that no exception at all is allowed to be possible" (Kant 1781/1787, B3–4). However, we cannot know whether there is any exception to the state of affairs described by a hypothesis.

This is because hypotheses are universal statements established by induction on the basis of information gathered in the course of experience. However,

> Experience never gives its judgements true or strict but only assumed and comparative *universality* (*through induction*), so properly it must be said: as far as we have perceived, there is no exception to this or that rule (Kant 1781/1787, B3, italics added; see A24, A90/B124).

Experience cannot guarantee that a statement is necessarily true either, because necessity, together with strict universality, is a "secure" indication "of an *a priori* cognition" (B4; see A823/B851).

Kant's contemporary Johann Georg Daries, among others, held that some inductions are the source of strictly universal judgements, of whose truth we can be certain. They are the inductions that are based on the enumeration of all members of a class (Daries 1776, §135). However, according to Kant, experience never gives us any guarantee that our enumerations are complete. For every given genus about which we make a generalization, there could be some members that we have not yet experienced and that are counterexamples to our generalization. The inductive employment of reason for devising hypotheses

> is not properly *constitutive*, that is, not such that if one judges in all strictness the truth of the universal rule assumed as a hypothesis thereby follows; for how is one to know all possible consequences, which would prove the universality of the assumed principle if they followed from it? (Kant 1781/1787, A647/B675)

Therefore, "[h]ypotheses always remain hypotheses, that is, presuppositions, whose complete certainty we can never attain" (Kant 1800a, p. 85).[xxii] They can only be more or less probable.

7.2.4 The Three Requirements for a Good Hypothesis

Not every hypothesis should be regarded as a possible explanation of natural phenomena. Kant details three requirements that every hypothesis must satisfy. In the first place, we must be sure that whatever state of affairs the hypothesis adduces as an explanation for given phenomena can actually take place (Kant 1781/1787, A770/B798). To this end, the hypothesis must be consistent with the body of our knowledge. “If, for example, to explain earthquakes and volcanoes we assume a subterranean fire, then such a fire must be possible, if not as a flaming body, yet as a hot one (Kant 1800a, p. 84; see Kant 1998b, p. 377). Hence, we should not make the hypothesis that there are flames at the centre of the earth, because combustion would be impossible due to the lack of air (Kant 1800b, pp. 259–60). However, we can make the hypothesis that the centre of the earth is composed of heated matter, because a body can be heated in absence of air.[xxiii]

In the second place, we must make sure that the events to be explained really follow from the assumed hypothesis. Otherwise, the hypothesis is “a mere chimera” (Kant 1800a, p. 85; see 1966e, p. 559_{6-7}; 1998b, p. 378_{635-37}).[xxiv]

In the third place, a hypothesis must be sufficient to explain a whole set of phenomena, without the need to integrate it with further hypotheses.

> Thus *Tycho* Brahe’s hypothesis, for example, did not suffice for the explanation of many appearances; hence he assumed several new hypotheses to complete it. Now here it is to be surmised that the assumed hypothesis cannot be the real ground. The Copernican system, on the other hand, is a hypothesis from which everything can be explained that ought to be explained therefrom, *so far as it has yet occurred to us*. Here we do not need any *subsidiary hypotheses* (*hypotheses subsidiarias*) (Kant 1800a, pp. 85–86; see Kant 1781/1787, A774/B802; 1966e, p. 559).

The prohibition to use subsidiary hypotheses prevents natural scientists from framing a whole system out of hypotheses which integrate each other to form comprehensive explanations, but are not systematically related to experiments and observations. An example of such a system is Descartes’ vortex theory, which for Locke and Newton was a paradigm example of an unfounded speculative hypothesis (Anstey 2005, pp. 229–31). It is occasionally targeted in the Kantian corpus as well (Kant 1966a, p. 222; 1763, p. 144).[xxv]

Compliance with the three criteria ensures that we do not assume “mere chimeras” (Kant 1966f, p. 888_{23}), “empty figments of the brain” (1790, p. 466_{18}), “empty fictions” (1966c, p. 746_{19}), “romances of reason” (1966a, p. 220_{33}) or “daring adventure[s] of reason” (1790, p. 419 n.) as hypotheses. These are typical expressions of the anti-hypothetical rhetoric to be found in the writings by Boyle, Hooke, or Locke (e.g. Locke 1976–89, vol. 4, p. 628). They employed those expressions in their wholesale rejection of any hypothesis from the current stage of natural philosophy.

Kant, like his German contemporaries (e.g. Erxleben 1772, §9), employs the same expressions of seventeenth century British philosophers. However, unlike his British predecessors, Kant employs those expressions within a framework which is not hostile to hypotheses *per se*. Kant states that hypotheses, like castles in the air, are fictions, but not all fictions must be rejected. The power of imagination, kept “under the strict oversight of reason” (Kant 1781/1787, A770/B798), can give rise to useful “heuristic fictions” (1966a, p. 262_{28}). The three criteria laid out above discriminate castles in the air from heuristic fictions. The task of experiments is determining which heuristic fictions portray actual states of affairs, rather than mere possibilities.

7.3 Experiments and the Laws of Nature

Let us assume that we have a hypothesis which satisfies the three criteria and is confirmed by experiments. What use shall we make of it? We saw in the introduction that, according to Kant, experiments help us discover the laws of nature. Laws of nature are expressed by necessary statements. Kant regards this as an analytic truth: to say that something is a law is to say that it is necessary.[xxvi] Accordingly, in order to know that a statement expresses a law of nature, we must know that it is necessarily true. However, experiments cannot confer certainty to a hypothesis, because experience cannot establish that a statement is necessarily true.[xxvii] Therefore, just by means of experiments, we cannot prove that a hypothesis is a law of nature (Kant 1783, p. 294).

Does this mean that experiments will never enable us to achieve the purpose they are meant to serve, that is, discovering the laws of nature? Kant does not draw such a pessimistic conclusion. He holds that testing hypotheses by means of experiments is necessary, but not sufficient, to discover the laws of nature. Experimental confirmation of a hypothesis is only the first step toward the discovery of a law of nature.

To illustrate this point, let us consider Copernicus' heliocentric theory of planets. Copernicus' "first thought" was a preliminary judgement: "the observer revolve[s]," whereas "the stars [...] [are] at rest" (Kant 1781/1787, Bxvi). "Copernicus assumed" this thought "only as a hypothesis" (Bxxii n.) This hypothesis proved to be superior to the Ptolemaic hypothesis and to Tycho Brahe's hypothesis. Kant holds that, unlike the Tychonian hypothesis, the Copernican hypothesis does not require supplementary hypotheses (Kant 1966e, p. 559; 1800a, pp. 85–86). Unlike the Ptolemaic hypothesis, the Copernican hypothesis explains all the phenomena. This confers a high degree of probability to the Copernican hypothesis (Kant 1966f, p. 887), but it does not make it certain. What made it certain is the fact that it was subsumed 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 1781/1787, Bxxii n.)

The same applies to the hypotheses that are confirmed by experiments. Experiments make them probable. The integration with a body of a priori laws and principles makes them certain. Thus

> Reason, in order to be taught by nature, must approach nature with its principles in one hand, *according to which alone the agreement among appearances can count as laws*, and, in the other hand, the experiments thought out in accordance with these principles [...] (Kant 1781/1787, Bxiii, italics added).

What principles must we employ to transform appearances into laws and how can we carry out this process? To answer these questions, we must enter the complex territory of Kant's theory of the laws of nature. Two caveats are in place here. First, my outline will be highly selective. I will reconstruct Kant's theory only to the extent which is necessary to understand how experiments enable us to discover new laws of nature. Second, my comments apply more neatly to Kant's view of physical laws than to his view of biological laws. I privilege physical laws because most of Kant's references to specific experiments relate to the field of physics, and not to biology.[xxviii]

There are laws of nature at three levels. At the first and highest level, we encounter the principles of pure reason. We can call them transcendental principles. They are eight highly general statements which describe features of our perception and features of natural objects and phenomena. For instance, a transcendental principle which describes features of our perception is: every sensation has a variable degree of intensity (Kant 1781/1787, B207). A principle which describes features of natural phenomena is the causal principle: "[a]ll alterations occur in accordance with the law of the connection of cause and effect" (B232). Among the transcendental principles, those which apply to natural objects and phenomena extend to physical phenomena and material objects, as well as to psychological phenomena (Kant 1783, p. 295). For example, the causal principle does not only apply to the alterations of material objects. It also applies to mental states. Every change in our mental states is determined by a cause.

According to Kant, the transcendental principles can be proven to be true a priori, at least given Kant's peculiar notion of a priori (Kitcher 2000, p. 17). This means that, although the proofs of the transcendental principles depend on premises concerning our cognitive capacities, they do not rely on any premise concerning *particular* experiences or features of objects that we can only know through experience. By contrast, a principle will be a posteriori in Kant's sense if its proof relies on assumptions concerning particular experiences or features of objects that we can only know through experience.

Kant prefers to call the transcendental principles principles, rather than laws, in order to stress that they lie at the basis of the system of our knowledge. To the extent that they concern natural objects, the transcendental principles are the most basic laws of nature (Kant 1783, p. 319). "[T]hey are not themselves grounded in higher and more general cognitions" (Kant 1781/1787, A148/B188).

At the second level, there are the metaphysical principles of natural science. Among these are Newton's laws of inertia and of action and reaction. Unlike the transcendental principles, the metaphysical principles do not apply to psychological phenomena, but only to material bodies. Like the transcendental principles, the metaphysical principles are known a priori.

This does not mean that experience or experiments are irrelevant to the metaphysical principles. First, we must have experience of the external world in order to acquire the concept of material body, without which we cannot even formulate the metaphysical principles. Second, experience might be necessary in order to discover them. Kant could well agree that we cannot discover the law of action and reaction without making appropriate experiences, such as the pendulum experiments that Newton details in the *Principia*.[xxix]

However, those experiments are not sufficient for us to *prove* the metaphysical principles. They cannot be, to use Locke's famous expression, "Principles that Matter of Fact justifie" (Locke 1693, p. 248). This is because, being laws, they apply necessarily to every object that exists in space and time. Yet experience, experiments, and matters of fact cannot confer necessity to any judgement. Even if we discover the metaphysical principles empirically, we must prove them a priori, as Kant attempts to do in the *Metaphysical Foundations of Natural Science*. If no a priori proof were available, we would have to deny that they are laws in the proper sense of the term.

At the third level, we find the empirical laws of nature. They apply to specific material objects and physical phenomena. We discover the empirical laws of nature a posteriori, on the basis of observations and experiments (Kant 1781/1787, B263). We can prove them only by making reference to observations or experiments. Therefore, the empirical laws of nature, unlike the transcendental and metaphysical principles, are established only a posteriori.

Empirical laws of nature raise the same difficulty that we encountered earlier with reference to experiments. On the one hand, empirical laws "can only be known [...] empirically" and therefore, at least from the point of view of our understanding, "are contingent" (Kant 1790, p. 184, see pp.179–80). On the other hand, empirical laws, being laws, must contain an element of necessity. Our understanding must think of them "as laws (i.e., as necessary)" (1790, 184). How can we confer necessity to laws that we can know "only empirically"? Since necessity cannot be established a posteriori, it must be established a priori. In Kant's view, we have reason to regard empirical rules as necessary laws if we can relate them to the transcendental and metaphysical principles (Friedman 1992, p. 174). In order to confer necessity to an empirical rule, we must show that it follows from the a priori principles, in addition to empirical premises.[xxx] Let us consider three examples to see how this process unfolds.

1. We have determined certain empirical regularities concerning the melting of wax and we want to formulate an empirical law of nature. We could then prove that the statements describing those regularities follow from a priori principles, such as the causal law and the law of action and reaction, together with empirical statements describing properties of wax.

2. We have formulated statements describing how a billiard ball moves when it is hit by other balls. We could then derive those statements from the causal principle, metaphysical principles, and information on the weight and shape of billiard balls.

3. Faced with Kepler's laws of planetary motion, we could prove that they follow from metaphysical principles such as the law of inertia and the law of action and reaction (Friedman 1992, pp. 175−80).

In each of these cases, we start from empirical regularities which we have established a posteriori. Then we attempt to subsume them under a priori principles. If we succeed in this attempt, we will have reason to regard the statements describing those regularities as "something radically new" (Friedman 1992, p. 178), that is, as descriptions of necessary features of reality.[xxxi]

The process which leads from a hypothesis to an empirical law of nature is represented in Fig. 7.1. The point of departure for this process is a hypothesis which is derived by induction. To begin with, we should assess whether the hypothesis satisfies the three requirements discussed in Section 7.2.4. If it does not, we must abandon it. Otherwise, we must approach it holding, in Kant's words, experiments in one hand and principles in the other (Kant

1781/1787, Bxiii). First, we must perform experiments or carry out observations to confirm or disprove the hypothesis. Then, if the hypothesis is confirmed, we must attempt to relate it to the principles which are the basis of natural science. If we succeed in doing so, then the hypothesis could be an empirical law of nature.

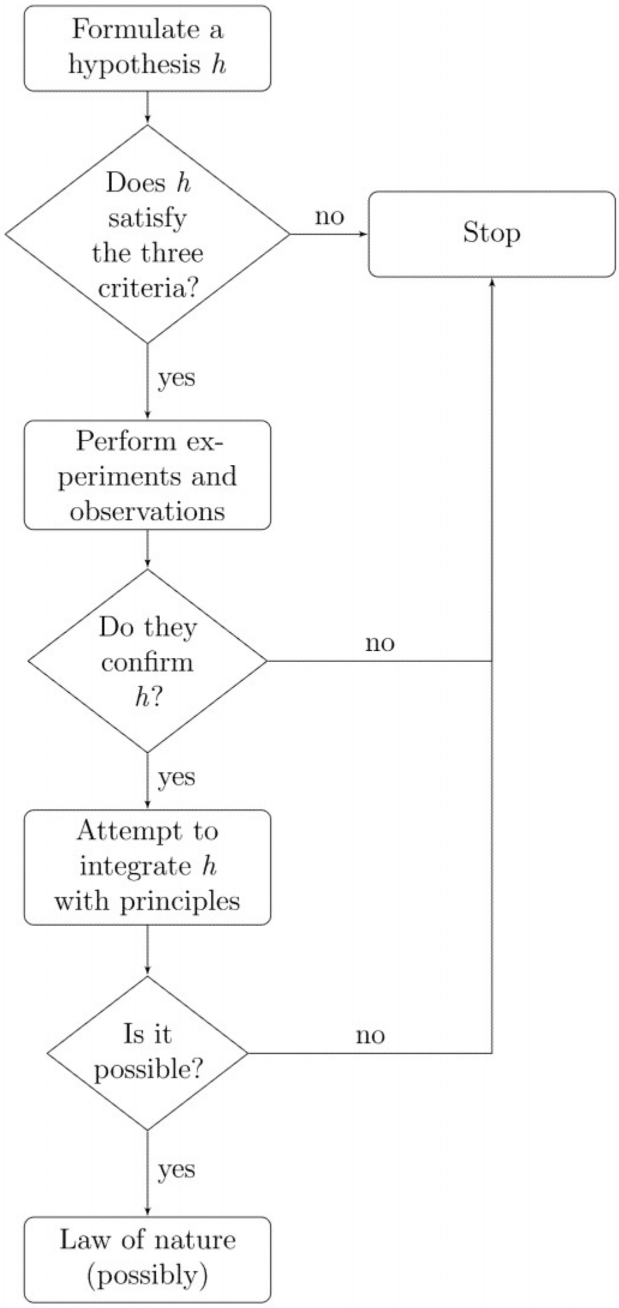

Fig. 7.1: Process from hypotheses to empirical laws

I stated that it *could* be a law of nature, and not that it will certainly be a law of nature, because other operations may be involved in our search for natural laws. For instance, we may have to choose between two incompatible hypotheses, both of which are confirmed by the observational evidence and can be integrated with a priori principles. Alternatively, we may have to submit our experiments, hypotheses, and explanations to the scientific community. We may be entitled to claim that a hypothesis is a law of nature only when some degree of intersubjective agreement is reached. This would conform to Kant's repeated claim that people's agreement, and especially the agreement of the learned community, with our opinions provides a reason to hold them true (Kant 1781/1787, A820−21/B848−49; 1783, p. 298).

7.4 Experiments and Heuristic Principles

In the previous section we have seen that, for Kant, principles play a role *after* we perform experiments. They enable us to convert experimentally confirmed hypotheses into laws of nature. However, there are also principles which play a role *before* we perform experiments. They are principles that we follow in order to formulate hypotheses to be tested by means of experiments. When we perform experiments, "we must always first presuppose something here (begin with a hypothesis) from which to begin our course of investigation, *and this must come about as a result of principles*" (Kant 1798a, p. 223 – italics added; see 1942, p. 199_{1-3}).

What principles is Kant referring to? To the extent that we are aware of them, the transcendental and metaphysical principles are involved in the formulation and assessment of hypotheses. We should only accept hypotheses that are consistent with those principles. In addition, three other principles guide the formulation of hypotheses. They are the principles of homogeneity, specification, and affinity. Kant calls them the principles of the hypothetical use of reason.

The principle of homogeneity states that “one should not multiply beginnings (principles) without necessity” (Kant 1781/1787, A652/B680). Kant takes it to mean that one must always search for higher genera for all the species that one knows. As an example, Kant mentions the hypothesis that every salt is either an acid, or an alkali, and the attempts “to regard this distinction as merely a variety or varied expression of one and the same fundamental material” (A652−53/B680−81). The principle of homogeneity is a methodological principle which presupposes a metaphysical principle: namely, that natural entities belong to common kinds.

The principle of specification prohibits one from assuming that there are lowest species, that is, species which cannot in turn have sub-species. This is a presupposition of natural inquiry, as Kant explains by taking different types of soil as an example:

> That there are absorbent earths of different species (chalky earths and muriatic earths) needed for its discovery a foregoing rule of reason that made it a task for the understanding to seek for varieties, by presupposing nature to be so abundant that it presumes them. For we have an understanding only under the presupposition of varieties in nature, just as we have one only under the condition that nature’s objects have in themselves a sameness of kind, because it is just the manifoldness of what can be grasped together under a concept that constitutes use of this concept and the business of the understanding. (A657/B685)

The principle of affinity derives from the combination of the principles of homogeneity and specification. It states that “there is a continuum of forms” (A659/B687): “there are no species or subspecies that are proximate [...], but intervening species are always possible, whose difference from the first and second species is smaller than their difference from each other” (A659−60/B687−88; see A228−29/B281). This appears to be a metaphysical principle, but it has a methodological significance: one must always allow for the possibility that there are intermediate species between the species that one already knows. In this instance, as was the case for the two previous principles, we have a methodological prescription (always look for intermediate species), which depends on a metaphysical presupposition (there is a continuum of forms).

The principles of the hypothetical use of reason, like the metaphysical principles of natural science, are not inductive generalizations that we form on the basis of experience. We do not derive them from the discovery that known genera have lower species, that lower species belong to higher genera, and that there are intermediate species between any two known species. In Kant's view, we would not find higher genera, lower species, and intermediate species in the first place, unless we previously assumed the principles of the hypothetical use of reason as guides for the formulation of hypotheses (A660/B688). For instance, we perform experiments to test the hypothesis that several phenomena obey the same law because we assume that there is a higher genus for every given set of phenomena.[xxxii]

We do not have to be fully conscious of this assumption in order to formulate hypotheses and to test them with experiments. We often exercise our mental powers according to rules of which we are unaware. "The exercise of our powers [...] takes place according to certain rules that we follow, *unconscious* of them as first, until we gradually arrive at cognition of them through experiments and lengthy use of our powers" (Kant 1800a, p. 11; see 1966e, p. 502; 1966f, p. 790). This applies, for instance, to the rules of grammar, which we discover long time after we started following them. The same applies to the principles of the hypothetical use of reason.

Although we often follow these principles unconsciously, Kant does not think that we always follow them (Kant 1786, p. 472). They "do not say what happens, i.e., in accordance with which rule our powers of cognition actually perform their role and how things are judged, but rather how they ought to be judged" (Kant 1790, p. 182). They are rules or maxims that must guide the formulation of hypotheses (Kant 1781/1787, A666/B694). Like hypotheses, the principles of the hypothetical use of reason are "heuristic fictions" (A661/B689) which precede and guide experimental activity.

To be sure, the principles of the hypothetical use of reason are not the sole presuppositions of experimental activity. Kant argues for the existence of other regulative principles that direct empirical research. They are: the assumption that we cannot have sensory perceptions of any absolute or insurmountable temporal or spatial limits (A508–9/B536–37); the assumption that nature is organized as if it were designed by an intelligent being (A826/B854); and the assumption that living beings are constituted as if they obeyed final causes (Kant 1790, p. 387).[xxxiii] Moreover, the principles of the hypothetical use of reason are not *only* presuppositions of experimental activity. They also underlie the systematic organization of cognitions. We employ those principles when we formulate a hypothesis which explains several phenomena, even if we are unable to perform experiments or observations to test it. If the hypothesis provides the best explanation of the phenomena, we should accept it despite the absence of experimental or observational confirmation. However, if experiments confirm the hypothesis, we have "a powerful reason to take as well grounded the unity that is hypothetically thought-out" (Kant 1781/1787, A661/B689).

7.5 Conclusion

According to Bacon, Boyle, and Hooke, experiments serve mainly to collect data in view of the future construction of natural philosophical theories. Experiments were not typically assigned the function of testing theories and hypotheses. On the contrary, the experimenter's prior natural philosophical beliefs and persuasions were looked upon with suspicion, as potential sources of prejudices which could contaminate his experimental activity. On the whole, data collection and experimentation were seen as theory-free activities.

By contrast, according to Kant, experiments cannot serve to build a base of data which are independent from theories. This is because experiments are always conceived of and carried out in the light of our assumptions, expectations, and heuristic principles. These assumptions and principles depend in part on the nature of the human mind and in part on the experimenter's convictions and purposes. They give rise to preliminary judgements and hypotheses which guide us in the design and performance of experiments.

Kant's emphasis on the importance of preliminary judgements and hypotheses for experiments goes hand in hand with his denial of the Baconian view that prejudices always play a negative function. According to Kant, prejudices (or more precisely, preliminary judgements) are indispensable for many human activities, including experimentation. However, it is necessary to test and assess them in order to either reject them as false, or else to transform them from mere opinions to certain truths.

On the whole, compared with Bacon, Boyle, and Hooke, Kant has elaborate views on the one hand, on how our theoretical and pre-theoretical assumptions bear on experimental practice, and on the other hand, on how the results of experimental activity can be integrated within the body of our theories in order to advance our knowledge of nature. However, Kant seems to have overstated the dependence of experiments on theories.

First, *pace* Kant, some experiments are performed in absence of a clear theoretical framework. Their aim is not testing hypotheses, but exploring new areas of inquiry or circumscribing new phenomena (Steinle 1997). Kant must have read the discussion of these *exploratory* experiments in a work that he knew well, Johann Heinrich Lambert's *New Organon* (1764, vol. 1, p. 355). However, Kant never discusses exploratory experiments.

Second, as a consequence of his disregard for exploratory experiments, Kant overlooks the benefits of the creative interplay of experiments designed to test theories and hypotheses with experiments which have a life of their own. Bacon, Boyle, and Hooke also overlooked the benefits of that interplay, but for the opposite reason: namely, because they focused too much on experiments having a life of their own.

Third, some experiments test hypotheses which contrast with our currently accepted theories. They lead us to replace them with new theories, incompatible with the previous ones. Kant does not provide any account of how these *revolutionary* experiments lead to theory change or revision.[xxxiv] On the contrary, he requires that our hypotheses are coherent with the body of our previous knowledge[xxxv] and that experimental results are integrated within a given system, based on the a priori foundations of natural science.[xxxvi]

In response to this criticism, Kant could emphasize that exploratory and revolutionary experiments are never wholly independent from our theoretical and pre-theoretical beliefs and hypotheses. However, he should have acknowledged that they enjoy a certain degree of freedom from our theoretical assumptions. This makes them more than handmaids to theory, hypothesis-testing procedures, or preliminaries to the addition of new laws of nature to a static, ever-growing body of natural philosophical knowledge, firmly resting on unshakable Newtonian foundations.

As is well known, developments in science have shaken those foundations and made space for more dynamic conceptions of scientific progress. These conceptions make it easier than it would have been for Kant to accommodate the interaction between theory-testing experiments and exploratory experiments and to explain the roles of experiments for theory change and revision. Arguably, the evolution of Kant's philosophical views points in this direction. The completeness and coherence of the system of natural science becomes more and more a regulative ideal when Kant moves from the Newtonian focus of the *Metaphysical Foundations of Natural Science* to the thorny status of teleological biological explanations in the *Critique of the Power of Judgement* and the reconsideration of chemistry in the *Opus Postumum*. Yet despite these developments, Kant never retracted the claim that he uncovered and enumerated the definitive a priori foundations of natural science.

At any rate, in order to acknowledge the roles of experiments for exploring new territories and establishing new theories, it was necessary to highlight the existence of fecund relations between experiments and theories. Highlighting these relations is a significant contribution of Kant's philosophy of experiment, especially if compared with the views of his British predecessors.[xxxvii]

References

Adickes, E. 1924–25. *Kant als Naturforscher*, 2 Vols. Berlin: de Gruyter.

Anstey, P.R. 2005. Experimental versus speculative natural philosophy. *The science of nature in the seventeenth century: Patterns of change in early modern natural philosophy*, ed. P.R. Anstey and J. Schuster, 215–42. Dordrecht: Springer.

Anstey P.R. Unpublished. The Bacon-Boyle-Hooke view of experiment. Unpublished manuscript.

Bacon, F. 1620. Novum organon. In *The Oxford Francis Bacon*, Vol. 11, ed. G. Rees and M. Wakely (2004), 48–448. Oxford: Oxford University Press.

Birch, T. 1756–57. *The History of the Royal Society of London for improving of natural knowledge, from its first rise*, 4 Vols. London.

Boyle, R. 1662. Defence against Linus. *The works of Robert Boyle*, ed. M. Hunter and E.B. Davis (1999), Vol. 3, 3–107. London: Pickering and Chatto.

Boyle, R. 1666. The text of Robert Boyle's 'Designe about Natural History'. In *Robert Boyle occasional papers*, no. 3, ed. M. Hunter and P.R. Anstey (2008). Retrieved 22 November 2011, from http://www.bbk.ac.uk/boyle/researchers/works/Occasional_Papers/occasional_paper_3.pdf.

Butts, R.E. 1961. Hypothesis and explanation in Kant's philosophy of science. *Archiv für Geschichte der Philosophie* 43: 153–70.

Butts, R.E. 1962. Kant on hypotheses in the 'Doctrine of Method' and in the *Logik*. *Archive für Geschichte der Philosophie* 44: 185–203.

Capozzi, M. 2001. *Kant e la logica*, Vol. 1. Naples: Bibliopolis.

Conrad, E. 1994. *Kants Logikvorlesungen als neuer Schlüssel zur Architektonik der Kritik der reinen Vernunft: Die Ausarbeitung der Gliederungsentwürfe in den Logikvorlesungen als Auseinandersetzung mit der Tradition*. Stuttgart: Frommann-Holzboog.

Crusius, C.A. 1747. *Weg zur Gewißheit und Zuverlässigkeit der menschlichen Erkenntniss*. Leipzig: Gleditsch.

D'Alembert, J. 1751. Discours Préliminaire. In *Encyclopédie, ou Dictionnaire raisonné des sciences, des arts et des métiers*, Vol. 1, ed. D. Diderot and J. d'Alembert (1751–77), ixlv. Paris: Briasson.

Daries, J.G. 1776. *Weg zur Wahrheit*. Frankfurt a.O.: Strauß.

Erxleben, J.C.P. 1772. *Anfangsgründe der Naturlehre*. Göttingen: Dieterich.

Friedman, M. 1992. Causal laws and the foundations of natural science. In *The Cambridge companion to Kant*, ed. P. Guyer, 161–99. Cambridge: Cambridge University Press.

Gaukroger, S. 2006. *The emergence of a scientific culture: Science and the shaping of modernity, 1210–1685*. Oxford: Oxford University Press.

Gloy, K. 1996. Kants Philosophie und das Experiment. In *Kant in der Diskussion der Moderne*, ed. G. Schönrich and Y. Kato, 64–91. Frankfurt a.M.: Suhrkamp.

Gloy, K. 2009. Die Bedeutung des Experiments bei Kant für die neuzeutliche Naturwissenschaft. In *Kants Philosophie der Natur: Ihre Entwicklung im Opus postumum und ihre Wirkung*, ed. E.-O. Onnasch, 189–201. Berlin: de Gruyter.

Guyer, P. 1990. Reason and reflective judgment: Kant on the significance of systematicity. *Noûs* 24: 17–43.

Hennings, J.C. 1774. *Kritisch historisches Lehrbuch der theoretischen Philosophie.* Leipzig: Weygand.

Hooke, R. 1665. *Micrographia: Some physiological descriptions of minute bodies made by magnifying glasses with observations and inquiries thereupon*. London: Jo. Martyn and Ja. Allestry.

Hooke, R. 1705. A general scheme, or idea of the present state of natural philosophy. In *The posthumous works of Robert Hooke*, ed. R. Waller, 1–70. London: Sam. Smith and

Benj. Walford.

Hume, D. 1740. An abstract of a book lately published; entituled, a treatise of human nature. In *A treatise of human nature*, ed. D.F. Norton and M.J. Norton (2000). Oxford: Oxford University Press.

Kant, I. 1747. Gedanken von der wahren Schätzung der lebendigen Kräfte. In *Kant* 1900−, Vol. 1, 1−181.

Kant, I. 1763. Der einzig mögliche Beweisgrund zu einer Demonstration des Daseins Gottes. In *Kant* 1900−, Vol. 2, 63−163.

Kant, I. 1781/1787. *Kritik der reinen Vernunft*, ed. J. Timmermann (1996). Hamburg: Meiner.

Kant, I. 1783. Prolegomena zu einer jeden künftigen Metaphysik, die als Wissenschaft wird auftreten können. In *Kant* 1900−, Vol. 4, 253−383.

Kant, I. 1786. Metaphysische Anfangsgründe der Naturwissenschaft. In *Kant* 1900−, Vol. 4, 465−565.

Kant, I. 1790. Kritik der Urteilskraft. In *Kant* 1900−, Vol. 5, 165−485.

Kant, I. 1793. Welches sind die wirklichen Fortschritte, die die Metaphysik seit Leibnizens und Wolf's Zeiten in Deutschland gemacht hat? In *Kant* 1900−, Vol. 20, 253−351.

Kant, I. 1798a. Anthropologie in pragmatischer Hinsicht. In *Kant* 1900−, Vol. 7, 117−333.

Kant, I. 1798b. Der Streit der Fakultäten. In *Kant* 1900−, Vol. 7, 1−115.

Kant, I. 1800a. Immanuel Kants Logik: Ein Handbuch zu Vorlesungen. In *Kant* 1900−, Vol. 9, 1−150.

Kant, I. 1800b. Immanuel Kants physische Geographie. In *Kant* 1900−, Vol. 9, 151−436.

Kant, I. 1900− . *Kant's gesammelte Schriften*, ed. Königlich Preußische (Deutsche) Akademie der Wissenschaften, Berlin: Reimer (later: de Gruyter).

Kant, I. 1922. Briefwechsel. In *Kant* 1900–, Vols. 10–13.

Kant, I. 1936–1938. Opus postumum. In *Kant* 1900–, Vols. 21, 22.

Kant, I. 1942. Erste Einleitung in die Kritik der Urteilskraft. In *Kant* 1900–, Vol. 20, 193–251.

Kant, I. 1961. Vorlesung Philosophische Enziklopädie. In *Kant* 1900–, Vol. 29, 3–45.

Kant, I. 1966a. Logik Blomberg. In *Kant* 1900–, Vol. 24, 16–301.

Kant, I. 1966b. Logik Busolt. In *Kant* 1900–, Vol. 24, 608–86.

Kant, I. 1966c. Logik Dohna-Wundlacken. In *Kant* 1900–, Vol. 24, 687–784.

Kant, I. 1966d. Logik Philippi. In *Kant* 1900–, Vol. 24, 303–496.

Kant, I. 1966e. Logik Pölitz. In *Kant* 1900–, Vol. 24, 502–602.

Kant, I. 1966f. Wiener Logik. In *Kant* 1900–, Vol. 24, 790–940.

Kant, I. 1980. Danziger Physik. In *Kant* 1900–, Vol. 29, 97–169.

Kant, I. 1998a. Logik Bauch. In *Logik-Vorlesung. Unveröffentlichte Nachschriften*, ed. T. Pinder, Vol. 1. Hamburg: Meiner.

Kant, I. 1998b. Logik Hechsel. In *Logik-Vorlesung. Unveröffentlichte Nachschriften*, ed. T. Pinder, Vol. 2, 269–499. Hamburg: Meiner.

Kitcher, P. 2000. *Kant's transcendental psychology*. New York: Oxford University Press.

Kreines, J. 2008. Kant on the laws of nature: Laws, necessitation, and the limitation of our knowledge. *European Journal of Philosophy* 17: 527–58.

La Rocca, C. 2003. Giudizi provvisori: Sulla logica euristica del processo conoscitivo. *Soggetto e mondo: Studi su Kant*, 79–119. Venice: Marsilio.

Lambert, J.H. 1764. *Neues Organon oder Gedanken über die Erforschung und Bezeichnung des Wahren und dessen Unterscheidung vom Irrthum und Schein*, 2 Vols. Leipzig: Wendler.

Laudan, L. 1981. The sources of modern methodology: Two models of change. In *Science and hypothesis: Historical essays on scientific methodology*. Dordrecht: Reidel.

Locke, J. 1693. *Some thoughts concerning education*, ed. J.W. Yolton and J.S. Yolton (1989). Oxford: Oxford University Press.

Locke, J. 1976‒89. *The correspondence of John Locke*, ed. S. De Beer. Oxford: Clarendon.

Malzkorn, W. 2000. Kant and the dynamics of science. *Philosophia naturalis* 37: 77‒95.

Newton, I. 1687. *The Principia: Mathematical principles of batural philosophy*, ed. I.B. Cohen and A.M. Whitman (1999). Berkeley: University of California Press.

Newton, I. 1714/15. An Account of the Book Entituled Commercium Epistolicum Collinii & aliorum, De Analysi promota. *Philosophical Transactions of the Royal Society of London* 342: 173‒224.

Parker, S. 1666. *Free and impartial censure of the Platonick philosophie: Being a letter written to his much honoured friend Mr. N.B.* Oxford: Hall.

Power, H. 1664. *Experimental Philosophy*. London: John Martin and James Allestry.

Reid, T. 2001. *Essays on the intellectual powers of man: A critical edition*, ed. K. Haakonssen and D.R. Brookes. Edinburgh: Edinburgh University Press.

Sato, T. 2008. Chemical affinity in Kant's practical philosophy. In *Recht und Frieden in der Philosophie Kants: Akten des X. Internationalen Kant-Kongresses*, Vol. 3, ed. V. Rohden et al., 359‒68. Berlin: de Gruyter.

Seigfried, H. 1989. Transcendental experiments. In *Proceedings of the sixth international Kant congress*, Vol. 2, ed. G. Funke and T. M. Seebohm, 341‒50. Washington, D.C.: Center for Advanced Research in Phenomenology and University Press of America.

Sprat, T. 1667. *The history of the Royal Society of London for the improving of natural knowledge*. London: J. Martyn.

Steinle, F. 1997. Entering new fields: Exploratory uses of experimentation. *Philosophy of Science* 64 (Suppl):: S65‒S74.

Turnbull, G. 1740. *The principles of moral philosophy: An enquiry into the wise and good* *government of the moral world*. London: J. Noon.

Walch, J.G. 1775. *Philosophisches Lexicon*, 4th ed., ed. J.C. Hennings. Leipzig: Gleditsch.

Wartenberg, T.E. 1992. Reason and the practice of science. In *The Cambridge Companion to Kant*, ed. P. Guyer, 228–48. Cambridge: Cambridge University Press.

i For instance, Bacon's, Boyle's, and Hooke's attitude towards hypotheses was shared, among others, by Locke, Newton, Hume, Turnbull, d'Alembert, and Reid. See Locke (1976-89, vol. 4, pp. 563, 629), Newton (1687, pp.939-944; 1714/15, pp. 222-24). Hume (1740, §2), Turnbull (1740, p. 2); d'Alembert (1751-77, pp. i, v, vi, xxv); Reid, 2001, p. 50).

ii Translations are my own for those writings of Kant which have not been translated into English. All other translations are from the *Cambridge Edition of the Works of Immanuel Kant*. I have replaced American spelling with British spelling in quotations.

iii See Kant (1936–1938, vol. 22, pp. 299_{1-2} and 329_{32}–330_{3}). The expression "study of nature" in the *Opus postumum* is often followed by the explanation: "through observation and experiment" (see e.g. Kant 1936–1938, vol. 22, pp. 322_{17-18}, 328_{16}, 344_{15}, and 346_{25-26}).

iv Kant briefly describes an experiment that he performed in (1747, p. 153).

v This text classifies several types of experience, following a schema similar to those of Hennings (1774, pp. 151–52) and Walch (1775, cols. 1083–84).

vi Nevertheless, Kant often mentions observations and experiments in one breath. See e.g. Kant (1922, vol. 11, p. 142_{36}; *Reflexion* (henceforth *R*) 5645 (1780–88?), vol. 18, p. 288_{3}; Kant (1936–1938, vol. 21, pp. 15_{16-17} and 76_{28-29}). Kant often employs the term "experiment" in a loose sense, to refer to observations, e.g. in (1798b, p. 98; 1966b, p. 611).

vii Kant also has interesting views on the role of theoretical concepts for experimentation. I will not comment on this topic, as it is discussed in Wartenberg (1992, pp. 242–45). I will not discuss Kant's views on the role of experiments for the a priori inquiries that he develops in the first two *Critiques*. On this issue, see esp. Seigfried (1989), Gloy (1996, 2009), Sato (2008).

viii I follow Peter Anstey (2005, unpublished).

ix In reconstructing Kant's views, I will draw not only on the texts that Kant published, but also on his manuscript notes (the so-called *Reflexionen*) and on the notes of his lectures. These materials raise several philological problems: see Conrad (1994). In the face of those problems, when citing *Reflexionen* and lecture transcripts, I will mostly rely on statements which can be found in more than one source: several *Reflexionen* or lecture transcripts, or *Reflexionen* alongside Kant's works and letters. The following datings are assumed for the lectures on which the lecture transcripts are based. 1966c, 1966e, 1966f, 1980, and 1998b are based on lectures given from the early 1780s onwards. 1961 is based on lectures given between 1777 and 1782. 1966b and 1998a are based on lectures given in several different years, probably including pre-Critical materials. 1966a and 1966d are based on lecture given in the early 1770s.

x Boyle's law states there is an inverse proportional relationship between the pressure and volume of a gas in a closed system where the temperature is constant.

xi Bacon was posthumously recruited as the "Patriark of Experimental Philosophy" (Power 1664, p. 82).

xii On the origin of this passage, see Birch (1756–57, vol. 1, pp. 490–91).

xiii Boyle's endorsement of corpuscularianism is an example of indulgence in the sort of speculative hypotheses that experimental philosophers officially eschewed. Also, it should be granted that Bacon, Boyle, and Hooke regarded some experiments as tests for theories and hypotheses. My claim is only that they did not regard hypothesis-testing as the main function of experiments.

xiv See Newton (1687, vol. 2, p. 764; 1714/15, pp. 222–24).

xv See (Kant 1998b, p. 3776_{17-18}).

xvi See (Kant 1798a, pp. 223_{14-20} and 405_{8-11}). To be sure, Kant distinguishes between prejudices in the proper sense (*Vorurteile*) and preliminary or provisional judgements (*vorläufige Urteile*): see La Rocca (2003).

xvii See e.g. *R* 2678 (1764–75?), vol. 16, p. 465; *R* 2690 (ca 1780–89), vol. 16, p. 471; *R* 2694 (1790–1804), vol. 16, p. 472.

xviii See an addition (1770 or later) to *R* 2130, vol. 16, p. 246; 1800a, 9, p. 85_{15-16}.

xix See Kant (1966e, p. 594; 1998b, pp. 476–77; 1800a, pp. 132–33). The inductive pattern of reasoning which leads to the formulation of hypotheses is described in (Kant 1781/1787, A647/B675).

xx E.g. *R* 2681 (1776–89?), vol. 16, p. 469_{10-11}; *R* 2687 (1776–89?), vol. 16, p. 471). More precisely, hypotheses cannot be apodictically certain. On the distinction between apodictic and assertoric certainty, see Capozzi (2001, pp. 572–76). By "certainty" I will mean apodictic certainty in what follows.

xxi See (Kant 1966e, p. 517): certainty "is awareness of the necessity of truth". See also (Kant 1966e, p. 530; 1800a, p. 66).

xxii Based on Kant (1966e, p. 558); see *R* 2681 (1776–89?), vol. 16, p. 469.

xxiii Kant emphasizes that hypotheses must be consistent especially with that particular body of knowledge which is constituted by the "conditions of possible experience" (Kant 1781/1787, A771/B799), outlined in the first *Critique*.

xxiv The first *Critique* adds that we should be able to determine the consequences of a given hypothesis a priori (Kant 1781/1787, A774/B802). I take this to mean that, when we explain how certain events follow from the assumed hypothesis, we should show that they follow from it on the basis of a priori principles, such as the causal law and the law of action and reaction (see Butts 1961, p. 165). Empirical laws, besides a priori principles, might be involved in the explanation.

xxv A discussion of Kant's views on hypotheses which is rather different from the reconstruction provided here can be found in Butts (1962).

xxvi Kant associates the term "law" to necessity (e.g. 1781/1787, A126) and universality (e.g. 1783, p. 310). Kant (1781/1787, A126) qualifies laws as objective rules and other passages (e.g. 1783, p. 301) relate objectivity to necessity and universality.

xxvii See Sect. 7.2.3.

xxviii Kant also mentions several chemical experiments, but he denies that the empirical generalizations of chemistry can achieve the status of laws (1786, p. 468).

xxix E.g. Bk. 3, Prop. 6.

xxx This combination of [*a*] empirical and [*b*] a priori premises is reflected in Kant's statement that "the empirical laws can only [...] be found [*a*] by means of experience, and indeed [*b*] in accord with its original laws [a priori principles], in accordance with which experience itself first becomes possible" (Kant 1781/1787, A216/B263). Empirical laws can be inferred from the transcendental principles, but not "completely" (B165). "Experience must be added in order to come to know particular laws *at all*" (B165).

xxxi Typically, empirical laws outline necessary features of specific natural kinds: see Kreines (2008).

xxxii Kant argues that, in order to discover natural laws, we must assume that nature is ordered into genera and species, in conformity with the principles of the hypothetical use of reason (1790, p. 185). To show this, Kant explains how the principle of affinity was at work in the reasonings that lead to Newton's discovery of universal gravitation (Kant 1781/1787, A662–63/B690–91).

xxxiii See Guyer (1990).

xxxiv On the forms of scientific progress that are compatible with Kant's views, see Malzkorn (2000).

xxxv See Sect. 7.2.4.

xxxvi See Sect. 7.3.

xxxvii In acknowledging these relations, Kant could rely on the reflections of his German predecessors, from Wolff to Lambert. Reconstructing them and the extent to which they anticipate Kant's reflections is a task that I hope to take up on another occasion. For valuable comments on previous versions of this paper, I would like to thank Peter Anstey, Juan Manuel Gomez, Alan Musgrave, and Kirsten Walsh. The paper benefited from very helpful discussions of audiences at Budapest, Padua, and Sydney.