Transcendental Idealism and its Influence on Nineteenth Century Science

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1 Introduction

What was to eventually become Immanuel Kant's (1724–1804) doctrine of 'transcendental idealism' began as an attempt to make metaphysics—which was supposed to provide us with rationally certain knowledge of things as they exist in themselves, i.e., independently of any considerations concerning our cognitive access to them—more *scientific*. Kant hoped to provide metaphysics with a set of principles that would guarantee the legitimacy of its claims. Kant, however, would eventually convince himself that metaphysical knowledge of the kind he was seeking to ground is impossible to achieve. He was not the first to have drawn this conclusion. But Kant's particular way of reasoning to it was significant as it involved the working out of a framework (see Figures 1 and 2) that could be used to provide a conceptual grounding for the sciences.

Kant's philosophy had an enormous impact on science over the nineteenth century and beyond. But from the very beginning, not everyone who was influenced by Kant's system agreed (or even took themselves to agree with Kant) about what the main significance of it all really was. At the heart of the disagreement was the issue of whether or not to understand transcendental idealism as a doctrine having metaphysical significance in its own right. Over the course of this chapter we will see how the divide over this central interpretational issue was reflected in a divide over what it means to provide a foundation for science, particularly over whether this chiefly concerns ontological questions (about what exists) or methodological questions (about our method for investigating what exists). Each side of the divide influenced much of the science that was carried out over the century, particularly in the areas of mathematical physics and in the life sciences.

2 Kant's Transcendental Idealism

By the time of his *Inaugural Dissertation* (1770), Kant had settled on two basic methodological principles with which to turn metaphysics into a legitimate science. The first was a kind of generalized principle of causality through which one explains, *a priori* (i.e., even before considering any experience of them), how substances mutually interact (Kant 1770: §16). The other was the *principle of reduction* (ibid.: §25). Given that the goal of metaphysics is rationally certain cognition of the 'intelligible world' of things as they exist irrespective of how we happen to be able to apprehend them (ibid.: §4), the principle of reduction instructs us that the objects of metaphysics should not be conceived to include or in any way depend upon anything that refers to sensation, not even to space and time: the mere forms, according to Kant, through which our sensible representations are apprehended as ordered (ibid.: §13–15).

Although Kant was still hopeful, in 1770, that progress could be made in metaphysics in this way, by the time of the writing of the *Critique of Pure Reason* (or first *Critique*) in 1781, he no longer believed this to be true. Instead he became convinced of the doctrine he was to call *transcendental idealism* (A26–28/B42–44),[1] which declares that cognition of the intelligible world is, for us, impossible, and that cognition, for us, must be understood to be relative to the sensible conditions under which we, as rational subjects, are able to apprehend an object. For our cognition is *discursive* (Allison 2004: 11–19) in the sense that to know an object is to subsume our intuition of it under some concept; and since intuitions of external objects are mediated by our *faculty of sensibility*, while concepts arise from the spontaneous activity of our *faculty of understanding*, this entails that cognition requires the contribution of both (A51/B75). Metaphysical cognition, which must not refer to experience in any way, is therefore not possible for us.

If such cognition were possible, then besides analytic knowledge, obtained from unpacking (in the sense of the logic of Kant's time) what is entailed by a given concept, it would also include synthetic knowledge, wherein two or more distinct concepts are cognised as necessarily connected in some way. When Kant declares metaphysical cognition (which is, by hypothesis, *a priori*) to be impossible what he really means is the synthetic kind. There is, however, another kind of synthetic *a priori* knowledge that is not metaphysical. This is our knowledge of mathematics, most vividly illustrated by geometry. Simply analytically unpacking the concepts of a straight line, an angle, and the number three, according to Kant, will not allow us to cognise how the sum of a triangle's angles, for example, are related to a right angle. But by *constructing* a triangle via spatial intuition in accordance with Euclid's postulates, we can understand how the various aspects of that figure necessarily relate to one another (A715-717/B743-745).

Kant's goal in the first *Critique* is to explain how synthetic *a priori* knowledge is possible in general and to investigate its limits (B19). In both cases the answer is provided by *possible experience*. The forms of possible experience are, Kant argues, known *a priori*, and since it is through these forms that appearances are represented as ordered (A20–A22/B34–36), the kind of knowledge they yield is synthetic knowledge. Possible experience is also the limit of this kind of cognition insofar as it is only in reference to it that synthetic *a priori* cognition may be obtained. While traditional metaphysics will be disappointed by this, such cognition is far from trivial, and in the first part of the first *Critique*, Kant lays out a basic conceptual framework with which to characterize it (See Figure 1).

The experience of an object considered as such, according to Kant, is comprised of two distinct aspects: the intuition, mediated by sensibility, through which the object appears to us, and the concept of the understanding whereby we combine the various intuitions of it under a given rule. The two forms through which objects appear are space and time, associated with what

[1] I have followed the common convention to prefix page numbers from the first and second editions of the first *Critique* with 'A' and 'B', respectively.

Kant calls outer and inner sense, through which we intuit external objects and our own mental states, respectively (A22/B37). These forms are *pure*—Kant also calls them pure intuitions—since they refer to the form of an appearance in general rather than to whatever happens to be given in sensation (A20/B34–B35). Similarly, pure concepts are forms of thought (A51/B75). In what he calls *transcendental logic*, which unlike general logic does not abstract completely away from the content of the propositions it relates, these pure forms are called the *categories*: of *Quantity* (*unity*, *plurality*, *allness*), of *Quality* (*reality*, *negation*, *limitation*), of *Relation* (*inherence*, *causality*, *community*), and of *Modality* (*possibility*, *existence*, *necessity*) (A80/B106); they correspond to the logical forms of judging (A79/B105) in relation to objects which can be given to us in intuition (A62/B87).

((Figure 1 goes around here))

Besides the categories, the understanding also provides us with a number of *synthetic a priori principles* (A159-235/B198-294) for what can be an object of experience at all (see Figure 2), which we uncover when we consider the rules, or *schemata* (see Figure 1), which govern the way that the categories are applied to pure intuition (A137–147/B176–187). Some of these principles are *constitutive* for appearances insofar as they tell us what an appearance of an object must be like if that appearance is to exist for us at all; specifically, that it must be of determinate extent (A163/B204), and have a particular degree of intensity (A166/B208). The remaining principles are *regulative* for appearances, in the sense that they connect given appearances together in time; specifically, as appearances of possible, actual, or necessary substances that interact with one another and evolve through time in accordance with the principle of cause and effect (A182–183/B225–226, A189/B232, A211/B256, A218/B265–266).

((Figure 2 goes around here))

The third faculty relevant to cognition is the faculty of *reason*. Reason is not itself directly involved in cognition; not, at any rate, the kind of cognition—which Kant calls *theoretical*—that is sought after both by science and by metaphysics in the traditional sense. But it nevertheless has a *practical* use (A796/B824) insofar as we need it to draw connections between the understanding's concepts. Although it is, in that sense, merely regulative for the understanding, Kant argues that the nature of our cognitive power makes it unavoidably seem (A295/B352) as though reason's principles are constitutive for the existence of objects. This has been a stumbling block for traditional metaphysics. But with the illusions of reason exposed (A341/B399–A404/B431) and the contradictions that follow from them avoided (A405/B432–A566/B594), Kant argues that the way becomes clear for a reconceptualisation of traditional metaphysics as a system of methodological principles for theoretical investigation (A643–668/B671–696).

3 Kant’s Metaphysical Foundations of Natural Science

Metaphysics in the traditional sense is, on the one hand, meant to be a fully general doctrine insofar as it is concerned with objects irrespective of their particular character or the way in which they are apprehended by us (Axii). On the other hand, the goal of traditional metaphysics is to provide us with a system of constitutive principles with which to ground those objects’ existence. We saw in the previous section how, according to Kant, we can maintain metaphysics as a fully general doctrine only by reconceptualizing it as a system of regulative or methodological principles. But a metaphysical system in the constitutive sense is also possible if we restrict its domain of applicability. Kant’s system of synthetic *a priori* principles is itself a kind of metaphysics in relation to our sensible experience in general. But it was specifically to the objects of *outer sense* that Kant turned his attention in his *Metaphysical Foundations of Natural Science* (1786).

Any doctrine that can be called a natural science has, according to Kant, a so-called ‘pure’ part. This is the part of that doctrine that considers its objects exclusively from the point of view of *a priori* principles, both in the mathematical sense and in the restricted metaphysical sense just discussed. Fundamental physics is, according to Kant, an example of a natural science that is completely pure. But there are also what Kant calls ‘applied’ (or ‘special’) natural sciences, which contain, additionally, an empirical part. Such sciences posit, on empirical grounds, the existence of particular kinds of entities, and describe these, at least in part, in terms of empirical generalizations rather than strict laws. Whether a natural science as a whole is pure or not, the concern of its mathematical part is with what is constructible in intuition given a mathematical representation of an object, while its metaphysical part contains, as we mentioned above, the principles relating to the existence of such a thing. These further divide into principles that make nature, in general, possible at all, and principles relating to particular natures, i.e., particular kinds of things; where the most general distinction one can make, in the latter case, is between corporeal and thinking nature (Kant 1786: 5). Empirical psychology, which pertains to thinking nature, is not, properly speaking, a natural science, according to Kant; since mathematics is not applicable to it, it can only be a historical doctrine. Therefore only a doctrine of corporeal nature can be a natural science in the proper sense, from which it follows that we can identify the mathematical and metaphysical principles of natural science with the mathematical and metaphysical principles for the possibility of matter, i.e., the matter of appearance, in general (ibid.: 7–8).

The mathematical principles of natural science had, for Kant, already been given by Isaac Newton. As for Kant’s metaphysical principles, these are divisible into four groups, corresponding to our use of the four groups of categories in relation to an object in *motion* (see Figure 2), which is the only way we can represent an object as affecting our senses (ibid.: 12). The pure doctrine that considers motion with respect to the categories of quantity is called *phoronomy*. Phoronomy governs the composition of relative motions considered as such, i.e., as a change, in the outer relations of a movable thing to a given space (ibid.: 17), that is described solely in terms of their respective velocities (ibid.: 15). To determine the motion resulting from the composition of two given (rectilinear) motions of a single point in a given space,[2] phoronomy dictates that we represent the first of these motions against the backdrop of

[2] We will come back to the question of non-rectilinear, i.e., circular, motions at the end of this section.

'absolute space', i.e., an abstract representation of some larger space that we might imagine the space the movable is situated in to be moving through (ibid.: 16). The second is represented as a motion of the movable's relative space in the direction opposite to it but with the same speed. For instance, consider a point on a shuffleboard disc that is moving uniformly with a certain speed towards the east along on the deck of a ship that is itself moving uniformly towards the west at the same speed. To determine the result of these motions as they relate to the point in question from the standpoint of the shore we (a) represent the first motion (i.e., of the disc, which is to the east) as a motion through absolute space, i.e., some space that we might imagine the Earth as a whole (our relative space in this example) to be moving through. We then (b) represent the point's relative space as also moving to the east, i.e., in the direction opposite to the motion of the ship. Since, in this case, both motions have identical speeds and directions, it follows that the point will not change its position with respect to the Earth. We can use a similar construction to determine the result of composing two motions (not necessarily of the same speed) in the same direction, or whose directions are related by some arbitrary angle (ibid.: 26–28).

The pure doctrine corresponding to the categories of quality is called *dynamics*. Dynamics, which presupposes phoronomy, governs how matter comes to fill or be moved out of a given space (ibid.: 33–34). This is accomplished through attractive and repulsive (ibid.: 35) *moving forces* (ibid.: 62). Repulsive forces, in particular those associated with each of the parts of a given, infinitely divisible (ibid.: 40) matter, determine the (continuously variable) degree to which that matter fills a space (ibid.: 36). Attractive force is prior to repulsive force insofar as it is the ground upon which we say that something is able to fill a space at all, and thus the ground upon which we can conceive of two given movables as being in contact. Since it is logically prior to contact, its action must, according to Kant, be conceived of as independent of contact, and thus independent of whether or not the space between two given matters is filled; i.e., attractive forces act immediately at a distance on other matters, beyond their surface of contact, and in principle through empty space (if such exists) (ibid.: 50, 62).

The doctrine corresponding to the categories of relation is called *mechanics*. It is the analog of what, in the mathematical part of the doctrine of corporeal nature is known as Newtonian mechanics. It presupposes both phoronomy and dynamics insofar as it represents matter as such as something movable with moving force; and it considers how matters so represented communicate their motion to one another (ibid.: 75). The *quantity of matter* (in the mechanical sense) in a given space is simply the aggregate of the movables in it (ibid.: 76, 78). When these all move together with the same speed and in the same direction they exert their collective moving force externally as a *mass*. A given quantity of matter acting in mass at a given speed yields a quantity of motion (ibid.: 76–77) through which the given quantity of matter manifests itself in experience (ibid.: 79), thus providing a means (in fact, the only means) through which to estimate it (ibid.: 76). Besides this, mechanics dictates that in any change of a corporeal nature, the total quantity of matter will neither be diminished nor increase (ibid.: 80), that any such change must be due to an external cause (ibid.: 82), and that action and reaction must be equal to one another in every case of a communication of motion between movables (ibid.: 84).

Finally, the doctrine corresponding to the categories of modality is called *phenomenology*. It presupposes the doctrines of phoronomy, dynamics, and mechanics and determines the modality, with respect to each, through which a given motion may be represented as the motion of an object (ibid.: 93–94). Phoronomical principles merely determine possible motions.

In particular, given the rectilinear motion of a point relative to some space, it makes no difference, objectively, whether one represents that point as moving and the space as stationary, or vice versa (ibid.: 94). Dynamical principles serve to determine which motions of the object are actual. In particular, circular motion (as opposed to rectilinear motion), since it requires a continuously acting force (see Figure 4), is, according to Kant, a manifestation of the original moving forces of matter (ibid.: 96–97). The principles of mechanics, finally, determine which motions of the object are necessary insofar as they determine the necessary relations that obtain between movables, in particular according to the law of equal action and reaction (ibid.: 97).

((Figure 3 goes around here))

((Figure 4 goes around here))

4 Kant's Critique of Teleological Judgment

In the first *Critique*, Kant's concern had been to determine the conditions for the possibility of theoretical cognition. This, as we saw in Section 2, is the exclusive domain of the faculty of understanding. As for the faculty of reason, although theoretical cognition is not possible for it, it has, as we discussed, a practical use, both for science and for moral philosophy. The latter was the main concern of Kant's second *Critique* (1788), which need not concern us further here. The concern of Kant's third and final *Critique*, the other of Kant's works which was to have an enormous impact on nineteenth century science, was *judgment*. Judgment in general is the ability to subsume a given particular under some universal rule or concept; for instance when we judge that two appearances of some object are related to one another as cause and effect. In this case, and generally in the case of synthetic *a priori* principles which, recall, are purely formal and given *a priori* by the faculty of understanding, then the judgment in question is a determinative one; for the form that particular appearances must take for the principle to be applicable to them is given *a priori* along with the principle, and the power of judgment merely needs to determine whether or not the given appearances conform to it. In every other case judgment has to *reflect* on the empirical regularities that characterize the particular to find, for itself, a universal rule from which they can be seen to necessarily follow (ibid.: 179). The term 'fish', for example, at one time subsumed any concept corresponding to a type of animal living underwater. This example illustrates that the job of reflective judgment is never really done, and that novel empirical data continually prompt us to revise the way in which we systematically carve up the world.

Importantly, according to Kant, there are times when the power of judgment has no choice but to reflect upon certain material products of nature as though they had been purposely designed. These material products are what Kant calls *natural purposes*. A natural purpose, like a work of art, is such that it can only be conceived of in a lawlike way if the existence of all of its various parts, as well as their relations to one another, are understood to be based upon the idea of the thing as a whole (ibid.: 366–367, 373). Unlike a work of art, however—and indeed in a way that far surpasses any kind of art we are capable of (ibid.: 371)—a natural purpose is a self-organizing being, i.e., such that its parts reciprocally materially produce one another (ibid.: 373–374), so that each part is itself both a purpose in its own right and also a means by which the purposiveness of the whole organism is maintained (ibid.: 376). Kant illustrates this using the example of a tree, which he argues continually materially produces itself in three different senses: First, it produces seeds that give rise to other trees of the same species; second, it transforms other matter into food and thereby continually maintains itself as an individual and grows; and third, its various shoots and branches can be thought of as individual trees in their own right that mutually support and sustain one another (ibid.: 371–372).

Expressed as a thesis, this claim amounts to the following: “Some products of material nature cannot be judged to be possible in terms of merely mechanical laws”, but rather must be judged in teleological terms (ibid.: 387).[3] Importantly, however, this thesis does not require us to assume that organized natural beings have actually been designed (ibid.: 180–182). For as we just pointed out, the concept of a natural purpose is not the same as the concept of an intentionally designed work (e.g., of art), and in any case to make such an assertion we would have to be able to cognise the ultimate purpose of nature as a whole, which (for us) is impossible (ibid.: 378). This teleological principle is, rather, just a necessary subjective principle or methodological *maxim*; i.e., without the order described by the principle there would be nothing to guide us (ibid.: 386), in this case through an analogy with our own purposeful activity, as we investigate self-organizing natural beings (ibid.: 375, 383–384).

There is a second, subjective, principle that judgment is required to employ as it reflects upon the empirical regularities that it encounters in nature. This is the principle that: “All production of material things and their forms must be judged to be possible in terms of merely mechanical laws” (ibid.: 387),[4] i.e., according to laws given to judgment by the understanding as applied to matter in general. As we discussed in Section 3, these laws are objectively valid in relation to material cognition in the sense that it is only in accordance with them that the objective cognition of material objects is possible at all (ibid.: 386). Yet, as Kant had already argued in the first *Critique*, it does not follow from this that the objects of our empirical investigations are already determined in accordance with principles of the understanding in advance of our inquiry into them, or that we can know *a priori* that any particular endeavor to attain objective cognition in this sense will be successful (cf. A509/B537). Thus the requirement *that we reflect upon* material nature in accordance with the principle of mechanism does not amount to a constraint on the world as it exists in itself. It is, to reiterate, merely a necessary subjective principle or methodological maxim.

Now, although both of these maxims are necessary given the nature of our cognition, according to Kant (1786: 404, 407–408, 413), they appear to result in an 'antinomy', or conflict—at the very least a logical one (“must be judged” and “cannot be judged” are clearly logically contradictory). Kant calls this the *antinomy of teleological judgment*, which he then endeavors to resolve. The upshot of Kant’s resolution of this antinomy is as follows. First, it does not follow from the fact that something must be *reflected upon* in some manner, *X*, that it is fully *explainable* in those terms (ibid.: 388). Thus the assertion that a given object must be judged according to *X* is compatible, from an ontological point of view, with the statement that it must be judged

[3] The translation is Pluhar’s.

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according to *Y*, even when *X* and *Y*, construed ontologically, disagree in some way *Z*, as long as *Z* is not a disagreement we can resolve on the basis of a possible experience. Since neither (ibid.: 388, 411) the ontological construal of the mechanistic maxim, that all production of material things *is* possible in purely mechanical terms, nor (ibid.: 389, 396, 406–408) the ontological construal of the teleological maxim, that some production of material things *is not* possible in these terms, are determinable by us through a possible experience,[5] the merely logical contradiction between them is harmless for the methodological purposes that they are actually required for in the practice of science (ibid.: 412–413).

This said, even in the case of a material process that must be thought of in teleological terms, without any corresponding mechanism it would make no sense to call it a natural process in the first place (ibid.: 413). In other words an account of a natural process may be teleological only in the sense that the mechanical part of the account, which we are anyway required to develop as far as we possibly can, must be *subordinated* to whatever purposes we posit (ibid.: 413–415). It is never the case that we can omit any part of the mechanism through which a given natural purpose is continually realized and maintained.

5 Kant's Successors

As I mentioned at the beginning of this chapter, not everyone who was influenced by Kant's philosophy agreed regarding what its main significance was. The central point of disagreement —which persists to this day among commentators on Kant—was over whether transcendental idealism is best understood as having primarily ontological or methodological significance. Although the methodological interpreters were arguably more faithful to Kant's own motivations, it is perhaps overly simplistic to say that the ontological interpreters of Kant's doctrine were wrong. For Kant's doctrine most assuredly does place constraints on what we can and cannot say about nature as it exists in itself, even if those constraints ultimately stem from fundamental methodological considerations. But in any case, as we will see in the rest of this chapter, both sides of the divide were to have a great impact on the development of nineteenth century science.

On an ontological reading, the main significance of transcendental idealism lies in the positive assertion that things, as they exist in themselves, are not spatiotemporal and thus not constrained by Kant's synthetic *a priori* principles. But from this perspective it is clear that Kant's arguments for transcendental idealism are lacking, for as many have pointed out over the years, it does not follow (compare Kant's argument at A26/B42) from the fact that space and time are the necessary conditions attaching to our sensibility, that they cannot also be determinations of things in themselves. Indeed the latter seems to be a natural explanation of the former fact.

Naturphilosophie (which is the German word for "nature philosophy"), one of intellectual traditions that emerged after Kant, can be understood as beginning from this way of thinking and following it through. Not just a philosophical doctrine, it characterized much of the practice of early nineteenth century empirical science (Beiser 2006: 9; Richards 2013: 109;

[5] In the case of the teleological maxim this amounts to saying that the concept of a natural purpose is transcendent for determinative judgment (Kant 1790: 396).

Schnädelbach 1984: 78). Building on Kant's dynamical theory of matter (see Section 3) as well as on Kant's concept of a natural purpose (see Section 4), *Naturphilosophie* reinterprets the latter, not just (as we explained in the previous section) as a principle that judgment must use to reflect upon nature, but as constitutive (see Section 2) of nature as it exists in itself (Friedman 2006: 57–58; Williams 1966: 46–47); for, it was argued, only under the assumption that nature, as a whole, is actually an organism, and that the subjective and objective aspects of our experience are both just different manifestations of the same organic principle, is it possible to conceive of how we can come to achieve knowledge of nature through sensibility in the first place (Schelling 1799: 113–140). We will return to *Naturphilosophie* in Section 7.

On the second, methodological,[6] reading of transcendental idealism, its primary significance lies in what it asserts about the kind of *a priori* theoretical cognition—understood in the sense of what we can say with mathematical certainty—that is possible for us, given the constraints imposed by the structure of our cognitive faculties. The so-called *neo-Kantians*, whose views were generally regarded as closer to Kant's own, although they were also concerned with metaphysical questions, can be understood as pursuing this line of thinking (Beiser 2014: 6). Such an interpretation is methodological in the sense that it understands the central lesson of transcendental idealism to be that we must abandon the old idea that to know something objectively is to know it absolutely independently of the way it is apprehended. Rather, the standard for objective cognition is reconceptualised to be that to which all finite rational cognisers such as ourselves must agree (Allison 2004: ch. 2).

Now, although, on this reading, transcendental idealism's significance is primarily methodological, there is a kind of ontological posit at its core. But this does not refer to the mind-independent world (i.e., the world as it exists in itself, which is what one traditionally means by ontology). It is a posit about the structure of our cognition. And it was precisely in regard to the characterization of this structure that many neo-Kantian thinkers diverged from Kant. Historically, philosophers have grouped the neo-Kantians into two main traditions. The earlier, so-called psychological, tradition has its roots in the ideas of Jakob Friedrich Fries (1773–1843) and Johann Friedrich Herbart (1776–1841).[7] Herbart and Fries, like Kant, conceived of philosophy as essentially concerned with the concepts and presuppositions of experience (Beiser 2014: 92), but they differed from Kant insofar as they readily drew on insights from the empirical psychology of their day, and moreover contributed to this field themselves (Beiser 2014: 33–38, 134–41; Leary 1982).

In the context of early nineteenth century academic philosophy, however, Fries and Herbart were comparatively minor figures. This was the period of the ascendancy of *Naturphilosophie*, which arguably achieved its peak influence through the work of G. W. F. Hegel (1770–1831), but fell into decline after his death.[8] In Germany this culminated in the so-called identity crisis of philosophy (Schnädelbach 1984: 5, 103)—the struggle to find a new role for philosophy in the

[6] Allison (2004: 35) uses the term 'metaphilosophical' (and also, equivalently, 'epistemological' and 'conceptual'). I am using the term 'methodological' to emphasize that the lesson of transcendental idealism is not solely philosophical but equally applicable to science, which in any case was not as sharply distinguished from philosophy at the time as it tends to be now.

[7] See, especially, Fries' *Neue oder Anthropologische Kritik der Vernunft* (1828) as well as Herbart's *Psychologie als Wissenschaft* (1824) and *Allgemeine Metaphysik* (1828).

light of the rise of the empirical sciences—and the subsequent rebirth of neo-Kantianism, which attempted to rehabilitate philosophy by reconceiving its role as the study of the foundations of scientific knowledge (Beiser (2014: 6); Schnädelbach (1984: 103–108)). Eventually the neo-Kantian movement was to coalesce into three main schools:[9] the Southwestern, Baden, or Heidelberg school, whose main representative in the nineteenth century was Wilhelm Windelband (1848–1915); the Marburg school, whose main nineteenth century representative was Hermann Cohen (1842–1918); and the Berlin school whose key figures during the nineteenth century were Alois Riehl (1844–1924) and Benno Erdmann (1851–1921).

As a rule, these three neo-Kantian schools repudiated psychologism, which in the present context is the idea that Kant's synthetic *a priori* principles have their basis in the nature of specifically human cognition and are valid only for it (Beiser 2014: 80), and which seeks to illuminate and in some cases even revise Kant's principles in the light of advances in empirical psychology (and eventually also in physiology). The later neo-Kantian schools argued, instead, for what has come to be known as the epistemological (a.k.a. logical) interpretation of Kant's philosophy. Arguably the most paradigmatic view of this sort was that of the Marburg school, which ultimately diverged significantly from Kant's in the sense that they denied Kant's basic distinction between sensibility and thought. For Cohen, intuition is viewed as a mere abstraction meant to capture the logical role played by sensibility in cognition (Cohen 1871: 90–91), while the idea of the "thing-in-itself" is understood, not as an empty metaphysical concept, but as a regulative or limiting one determinable in accordance with the Anticipations of Perception (see Figure 2), whose role in Kant's system, Cohen explained, is to provide us with the means, as explicated formally through the methods of the calculus, with which to determine the real (Cohen 1883; for further discussion, see Richardson 2006: 219–21).

6 Neo-Kantianism and Physical Geometry

Transcendental idealism's initial impact on the development of nineteenth century science came mainly through scientists themselves rather than through academic philosophers. In the early part of the century, the period which saw the ascendance of *Naturphilosophie*, this was partly because the distinction between philosophy and science was a fluid one (Beiser 2006: 10; Friedman 2006: 63–68; Richards 2013; Schnädelbach 1984: 78; Williams 1966: 32–63). Even after *Naturphilosophie*'s decline, it was primarily natural scientists who initially developed the neo-Kantian response to philosophy's mid-century identity crisis (see Section 5). At the vanguard of this movement was Hermann von Helmholtz (1821–1894). Helmholtz had read Kant at an early age (Cahan 2018: 44, 67), and Kant left a lasting impression on his thought. Drawing on

[8] Both Fries's and Herbart's contributions to psychology were well regarded at the time (Leary 1982: 221, Beiser 2014: 141). Herbart's work, in particular, was to have an important influence on the philosopher-scientist Hermann von Helmholtz (1821–1894), who we will discuss in Section 6. Although they were both rather marginal figures in academic philosophical circles, Fries had achieved some degree of fame early in his career before being eclipsed by Hegel (Beiser 2014: 53, 93).

[9] A fourth, neo-Friesian, school of neo-Kantianism (Beiser 2014: 2) was to form in the early twentieth century under the leadership of Leonard Nelson (1882–1927).

contemporary empirical research in physiology and psychology, especially the physiology of sense perception as exemplified by the research of Johannes Müller, Helmholtz (1855) carefully demonstrated how cognitive and physiological processes can be determinative of the nature of our representations. That in general there is such a dependence was, according to Helmholtz, just what Kant himself had aimed to show (Helmholtz 1855: 19); and Helmholtz explained how Müller had demonstrated that the very same physical stimulus is perceived qualitatively differently depending on the specific sense organ it impinges upon.

Helmholtz (1868: 185–187) argued that sensation does not represent its object directly in the way that an image does. Rather, our sensations of objects are like signs or symbols. By this he meant that whereas an image—a statue of a human being, for instance—replicates the specific shape and proportions of the person in question (perhaps on a larger or smaller scale), a symbol for a person (the word 'Alice', for instance), need not conform to its object in any way. But although symbols are not copies of reality in the way that a statue is, it is nevertheless possible to describe, in an objective way, exact mathematical relations obtaining between them. Those relations can therefore be understood to constitute a representation of reality even if the signs themselves do not; though it would be a mistake to understand this way of representing reality as in some sense mind-independent, for the signs themselves represent the *interactions* between our sense organs and external things rather than the things themselves (Lenoir 2006: 146).

Helmholtz later applied these insights in his investigations into the foundations of geometry. Kant had argued, in the first *Critique*, that although it was possible to consistently conceive of a geometry that was not Euclidean, there was nevertheless no way to construct a non-Euclidean figure via spatial intuition (A220–21/B268) in the way we discussed in Section 2, and thus no possible experience through which non-Euclidean spatial relations could come to be known. Helmholtz, in a critique of Kant, argued that Kant's notion of spatial intuition had in fact been insufficiently fleshed out, and that it could be subjected to further analysis in the light of Helmholtz's work on sense perception.

Space, for Helmholtz, is the field that we construct in order to perceive things as we locally interact with our surroundings, the result of complex physiological and psychological processes that are scientifically describable in a lawlike way (Beiser 2014: 204; Friedman 2013: 85). As DiSalle (2006a: 128–129) explains, Helmholtz (1870) was able to show that the first four Euclidean postulates, which circumscribe the general conditions under which constructions with straightedge and compass are possible, presuppose a more general principle: that of the free mobility of rigid bodies. Informally, this is the idea, which one can trace back to Herbart (Lenoir 2006: 151–152, 159), that physically moving a rigid body around in space will not thereby deform it.

As for Euclid's fifth, the so-called parallel postulate: This, by contrast, describes a global feature of space that is not determined by this general condition on the constructibility of figures. In particular, Euclid's five postulates together describe a geometry in which the curvature is everywhere zero, in other words, a flat plain. But the 'principle of free mobility' is consistent, not just with Euclidean geometry, but with any geometry in which the curvature of space is globally constant, such as elliptic geometry (of constant positive curvature) and hyperbolic geometry (of constant negative curvature). Helmholtz described how the iteration of a number of basic local constructions (in accordance with postulates I–IV) would result in a series of sense impressions through which one could become acquainted with the global structure of a non-Euclidean space. Note how this presupposes that whether or not a given space is Euclidean is a matter of fact, decidable through experience rather than *a priori*. Helmholtz's analysis of how this is done highlights the role played by the conditions for the possibility of measurement (Lenoir 2006: 180, 201), made precise through the concept of a rigid body, as the basis for the pre-relativistic belief that the global geometry of space is Euclidean in the first place (DiSalle 2006a: 134–136).

We note here that despite his disagreement with Kant over the *a priori* status of the Euclidean axioms, this very divergence may be seen as a vindication of the basic idea at the core of Kant's transcendental idealism. For, as we have seen, it had been Kant's goal to identify the general conditions under which our representations of the objects of our experience are constrained. With respect to objects as they are represented in space, Helmholtz was able to show, through his physiological analysis of the facts that lie at the basis of sense perception, that underlying Kant's own account of the basic conditions of geometrical representation lay the principle of the free mobility, specifically, of a rigid body (DiSalle 2006a: 138), and thus he was able to show how dynamical principles of physics (upon which the concept of rigidity is predicated) are instrumental in enabling us to determine the geometry of a given space (DiSalle 2006b: 91).

It is useful to, following DiSalle (2006b: 89–94), contrast Helmholtz's views with those of his contemporaries, Henri Poincaré and Bernhard Riemann. Beginning with Poincaré, who was also a Kantian of a sort: The lesson he drew from Helmholtz's analyses of the principle of free mobility was very different from the one drawn by Helmholtz. In accordance with his hierarchical view of science (Friedman 1999: ch. 4), physical theory, for Poincaré, must in general be understood to be formulated against the already-settled backdrop of a particular conception of space and of the geometry which describes it. Although the principle of free mobility must be satisfied by any geometry capable of being given an intuitive interpretation, physical considerations, such as those implicit in the determination of the rigidity of a physical object, cannot come into play in this decision, since to do so would, so to speak, be to put the cart before the horse. It follows that one must conventionally choose, among the possible geometries consistent with the principle of free mobility, the one that is in some sense 'simplest'. Riemann, like Helmholtz, had also been substantively influenced by Herbart (Banks 2005; Scholz 1982). And like Helmholtz, he also took the question of physical geometry to be an empirically resolvable question that should be informed, in particular, by dynamical considerations. But unlike both Helmholtz and Poincaré, who took the principle of free mobility to be a condition of the very possibility of physical geometry as such, Riemann was willing to accept even this principle only provisionally until such time as a deeper understanding of the nature of dynamical interactions between bodies could be had.

7 The influence of *Naturphilosophie*

Naturphilosophie, as we discussed in Section 5, begins with Kant's dynamical theory of matter (Section 3), as well as with his concept of a natural purpose (Section 4), but goes beyond them insofar as it rejects Kant's distinction in kind between the sensible and intelligible aspects of our cognition. This further implies a rejection of Kant's distinction between what we can know through the understanding and through reason, since it is only the understanding's application to sensibility that distinguishes it from reason in the first place. Recall from Section 5 that the Marburg neo-Kantians had also rejected the distinction in kind between sensibility and understanding. But whereas, for the Marburg school, what this entailed was that the principles of the understanding are, like the principles of reason, not constitutive for our experience but merely regulative; for *Naturphilosophie* it was precisely the opposite: reason's principles, like the understanding's, are constitutive, and moreover not only for experience; for the reasons we discussed in Section 5 they were held to be constitutive of nature as it exists in itself.

As Friedman (2006: 57–58) explains, the faculty of reason is both infinitary, in the sense that in its regulative use it describes a progressive process of approximation to the infinitely distant goal of the cognition of the unity and systematicity of the natural world (Kant 1790: 185–186), as well as dialectical, in the sense that its use gives rise to antinomies that can only be resolved by recognizing that reason by its very nature transcends experience (A565–567/B593–595). Thus if this process is to be reinterpreted as constitutive, not just for our consideration of nature, but for its very existence, then it follows that our account of the infinitary dialectical progress of reason must have a material counterpart in an account, which is to be provided by *Naturphilosophie*, of how nature itself successively unfolds and evolves, through the fundamental attractive and repulsive forces from which apparently inert matter is constituted in itself, into an organic form (see also Beiser 2006: 20–21).

Naturphilosophie, through F. W. J. Schelling (1775–1854), influenced the thought of his close personal acquaintance, the polymath Johann Wolfgang von Goethe (1749–1832). This influence was mutual, as his correspondence with Goethe helped Schelling to clarify certain details of his own view (Richards 2013: 111–112). Kant had held that only mechanical accounts of natural processes could constitute explanations of them in the proper sense. It followed, for Kant, that domains of inquiry such as biology (as it existed in Kant's time), where appeals to purposes are essential and irreducible to mechanical causation, as he argued in his third Critique, could not claim to be scientific. But Goethe argued, against this, that appealing to the idea of a purpose in the life sciences is actually no different than the appeal to a mechanical cause insofar as both are done out of necessity; i.e., appealing to purposes is, for Goethe, just as necessary in the explanation of organic processes as appealing to mechanical causes is necessary in the explanation of the possibility of material experience as such. Moreover, insofar as nature as a whole must ultimately be viewed as a systematic unity and in that sense, organic, nature's mechanism must ultimately be subordinated to and for the purpose of the systematic idea of it as a whole (Richards 2013: 109).

Goethe's work in morphology, especially his theory of the archetype, i.e., of the structure that all of the various parts of an organism are to be understood as transformations of, was to have an important influence on the subsequent development of biology. Through the efforts of Goethe's disciples, including Carl Gustav Carus and Alexander von Humboldt, Goethe's ideas were ultimately to have a key influence on Charles Darwin (1809–1882) (Richards 2013: 113–117). As Richards relates, Darwin, who had become familiar with Goethe's ideas on morphology through William Whewell and M. F. G. Pictet, brought with him during his journey on the *Beagle* a number of Humboldt's works. What Goethe had called an archetype became, for Darwin, the form that was inherited by the members of a given species from their ultimate evolutionary progenitor. It is a widespread view among life scientists, Darwin banished teleology, in the constitutive sense, from biology. For although teleological thinking has maintained its methodological importance, the theory of natural selection, these scientists claim, is ultimately materialistic and operates by mechanical means (Richards 2013: 130). The historical Darwin himself, however, continued to appeal to the concept of purpose in his own expositions of the theory (Richards 2013: 129).

Biology was not the only field of inquiry for which *Naturphilosophie* was to have a formative influence during the nineteenth century. Kant's dynamical conception of matter, as the filling of space through fundamental forces of attraction and repulsion, suggests a kind of field theory in the emphasis that it lays upon the diffusion of force through a given space (Williams 1966: 43). But the further step, which for Schelling had been natural in the face of contemporary developments in the study of chemical, electrical, and magnetic phenomena (Friedman 2006: 66), of understanding all of these effects to be the result of a process whose starting point is the opposition between the two types of fundamental force (Friedman 2006: 62), was not one which the more conservative Kant, who in the *Metaphysical Foundations* had denied scientific status to the chemistry of his day (on the grounds that there was no mathematics in it; see Section 3), would have been prepared to take.

Schelling's ideas were to inspire the development of the kernel of a field theory of electromagnetism by Hans Christian Oersted (1777–1851) (Stauffer 1957: 34; Williams 1966: ch. II), which was then further developed by Michael Faraday and finally systematized by James Clerk Maxwell (Williams 1966: chs. III–V). Oersted's explicitly stated methodology, as Friedman (2006: 64–66) explains, is grounded in the idea—which is the central pillar of Schelling's metaphysics—that our account of the progress of reason must ultimately be mirrored by an account of how material nature itself successively unfolds and evolves. By the middle of the century, however, Helmholtz had formulated the principle of conservation of energy, which allowed him to argue that all material phenomena are explainable mechanistically; i.e., such that all material action can ultimately be traced, as Kant had maintained, to dynamical forces of attraction and repulsion, without any appeal to their dialectical extension along the lines argued for by Schelling (Friedman 2013: 81–83).

Despite Helmholtz's efforts, however, it took some time for these and related ideas to be fully abandoned by scientists. The related view called *vitalism* (which, it is worth remarking, was never defended by Schelling; see Kabeshkin 2017), which argued that the forces responsible for the maintenance and generation of living matter are fundamentally different from those governing inorganic matter, remained popular among the scientists of the nineteenth and early twentieth centuries. Lord Kelvin (a.k.a. William Thomson), for instance, exempted them in his formulation of the Second Law of Thermodynamics, which he explicitly qualified to be only applicable to "inanimate material agency" (Thomson 1851: 265). Vitalistic ideas remained especially popular in chemistry and biology, becoming largely discredited only in the twentieth century as purely mechanical accounts of organic phenomena came to be seen as empirically more successful (Bechtel and Richardson 1998).

On the one hand, we can see in the examples of the nineteenth century development of biology and field theory a vindication of Kant's methodological interpretation of the principle of natural purpose. In both cases, the grand metaphysical picture provided by *Naturphilosophie*, in which the ontological interpretation of Kant's principle of natural purpose had figured so centrally, clearly guided the development of these respective theories. And yet in both cases, this teleological foundation eventually gave way to a mechanistic one, even if, especially in the case of biology, teleological reasoning still has an important heuristic role to play to this day. On the other hand, one can doubt whether a merely methodological understanding of the principle of natural purpose would truly have been enough to motivate the particular empirical investigations of the scientists involved. Looking ahead from the nineteenth to the twentieth century, particularly in regards to the development of quantum theory, it was the question of how to interpret the principle of mechanism itself, either as an ontological or as a merely methodological principle, which was to come under scrutiny; and in addressing this question neo-Kantian thinkers were to play a significant role.

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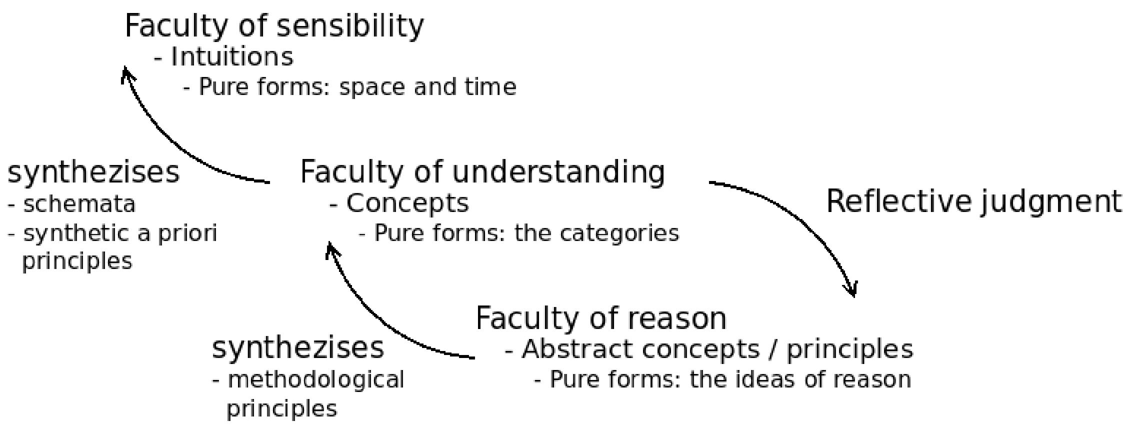

Figure 1. An overview of Kant’s system.

Categories	Synthetic a priori principles		Metaphysical principles of natural science
Of quantity	Axioms of intuition - Extension		Phoronomy - Composition of motions
		constitutive for appearances	
Of quality	Anticipations of perception - Intension		Dynamics - Moving forces
Of relation	Analogies of experience - Substance - Cause and effect - Interaction		Mechanics - Communication of motion
		regulative for appearances	
Of modality	Postulates of empirical thought as such - Modality		Phenomenology - Possible, actual, and necessary motions

Figure 2. Kant's synthetic a priori *principles and their corresponding categories and metaphysical principles of natural science.*

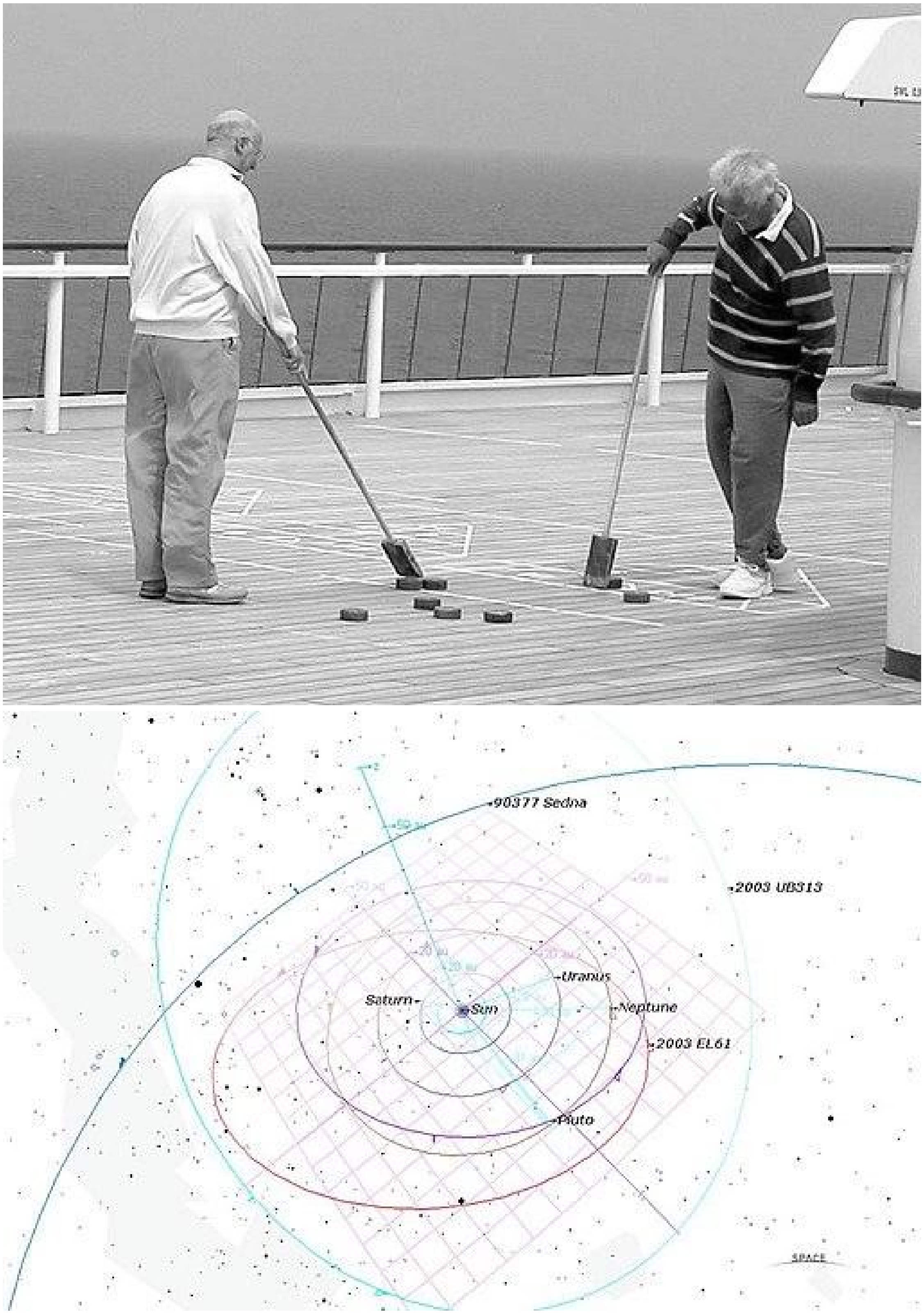

Figure 3. In a game of shuffleboard on a moving ship (viewed, e.g., from the shore), we use phoronomy to represent the discs' and the ship's velocities, dynamics to represent their associated attractive and repulsive forces, while mechanics governs their interactions. The same

is true in a representation of the planets in our solar system, where the forces of attraction between bodies are more significant.

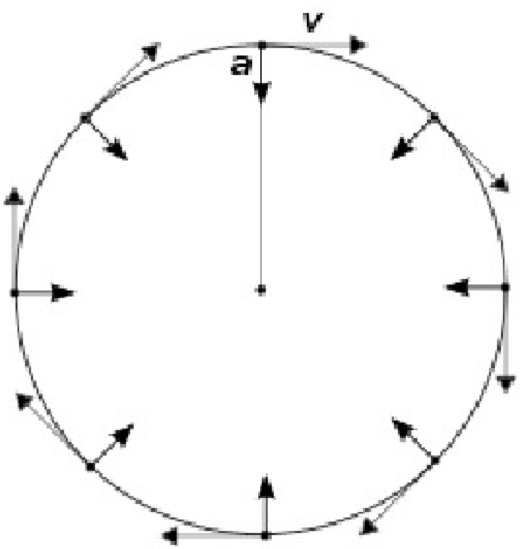

Figure 4. Circular motion requires a continuously acting moving force.

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