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Kant on the Fundamental Forces of Matter: Why Attraction and Repulsion?

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Abstract

This article addresses a simple question that has rarely been asked of Kant's philosophy of nature: why are attraction and repulsion the two fundamental forces of matter? Where proposals can be found in the literature, they are divergent. I provide a new answer, which has strong support from the historical context: Kant pursues a modified version of what I call the 'reduction method' that was much debated in the German metaphysical tradition. To this, Kant crucially adds his critical doctrine of regulative ideas, revealing an overlooked way that the Appendix to the *Critique* informs his philosophy of nature.

Keywords: *Metaphysical Foundations of Natural Science*; fundamental force; reduction; scientific method; metaphysics

1. Introduction

In the *Metaphysical Foundations of Natural Science* (1786; hereafter *MFNS*), Kant undertakes to determine the concept of matter in general, the object of outer senses, by 'carry[ing] it through' the four classes of the categories (4: 476).¹ This entails that the four chapters of *MFNS* present an increasingly determinate conception of matter in general, in which the quality, quantity, relation and modality of matter are respectively set out in the Phoronomy, Dynamics, Mechanics and Phenomenology chapters. Kant defines the concept of matter most fundamentally as the moveable; this is because, he asserts, it is only through motion that the senses can be affected (4: 476).² After matter as the moveable is first determined in the Phoronomy chapter as the moveable *in space*, the Dynamics adds the further determination that it is the moveable insofar as it *fills* space. It is in the Dynamics that Kant introduces the two original or fundamental forces (*ursprüngliche Kräfte* or *Grundkräfte*: 4: 500, 508) of repulsion and attraction as the ground of matter's property of filling space.³

Why are there two fundamental forces in Kant's account of the way that matter dynamically fills space, and why are these specifically repulsion and attraction? These simple questions have rarely been posed in the literature on *MFNS*, and, where they have, varying explanations have been proposed. I here provide an alternative explanation for the fundamentality of repulsion and attraction, which, I argue, has a stronger basis in Kant's other texts and the historical context.

I first review existing interpretations of whether and how Kant justifies repulsion and attraction as the fundamental forces of matter. This review finds that interpreters implicitly agree that Kant's argument is located neither in the Note to Explication 2 of the Dynamics, which gives a logical presentation of the fundamental forces in terms of two possible movements on a line, nor in the so-called 'balancing argument'. The commentators disagree, however, on where, if anywhere, Kant's justification may be found. In section 3, I defend an alternative account, oriented around a passage in the General Remark to the Dynamics in which Kant gives a compressed account of a method of *reduction* of empirical forces to the smallest possible number, whereby the natural philosopher arrives at fundamental repulsive and attractive force. I contend that Kant here indicates what I call the 'reduction method' that underpins his claims about fundamental repulsive and attractive forces in the Dynamics. In my view, Kant would have expected his audience to be familiar with this method, so I gloss the passage in the General Remark with extensive reference to the historical background and Kant's other writings and lecture notes. I finally turn, in section 4, to the Appendix to the Transcendental Dialectic of the first *Critique*, which completes the picture and makes possible a reconstruction of what I claim is Kant's presupposed argument for attraction and repulsion as the two fundamental forces of matter.

2. Previous interpretations

Although neither emphasizes the issue, the two pre-eminent commentators on *MFNS*, Konstantin Pollok and Michael Friedman, give opposed accounts of Kant's justification for attraction and repulsion as the fundamental forces of matter. A third interpretation is suggested by Daniel Warren, and one could add a purely historical explanation for Kant's position. My account will differ from all four of these interpretations.

According to Pollok, the fundamental nature of repulsion and attraction is grounded in the priority of repulsive force. Repulsion is the 'first force', not temporally but according to the genesis of concepts (*begriffsgenetisch*), because it is 'the first way that matter manifests itself to our senses as something real in space' (Pollok 1997: L). Pollok aligns repulsion with the category of the real and attraction with the category of limitation, following Kant's own suggestion (4: 523). However, this leads Pollok to suggest that Kant's argument for the two fundamental forces ultimately rests on empirical perception of repulsion: first we perceive repulsive force, then the so-called 'balancing argument' entails that attractive force is the second fundamental force. Repulsion would be empirically necessary, whereas attraction would have 'metaphysical necessity' (Pollok 2001: 278). Pollok considers the undeclared 'physiological fact' of repulsion a 'weakness' in Kant's grounding of the fundamental forces of matter (Pollok 2001: 278; cf. 279).

Implicit in Pollok's account is the claim that Kant's balancing argument and his reference to a logical difference between attractive and repulsive force cannot *alone* justify the existence of the two fundamental forces. I agree, and it is worth expanding on the point. The balancing argument, appearing in Propositions 5 and 6 of the Dynamics, has two sides that mirror one another, each in the form of a *reductio*.⁴ On the one hand, matter cannot possess only repulsive force with no counteracting

force, because it would expand limitlessly and ‘disperse itself to infinity’, so there would be no determinate bodies and, ‘properly speaking, no matter would exist at all’ (4: 508). A counteracting ‘original attraction’ must therefore be attributed to matter ‘as a fundamental force belonging to its essence’ (4: 509). On the other hand, matter cannot have only attractive force: if this were the case, matter would collapse into itself ‘and coalesce into a mathematical point’, again entailing that ‘space would be empty, and thus without any matter’ (4: 511).

Kant’s balancing argument is preceded by a merely logical presentation. After defining attractive and repulsive force as the causes by which a matter draws others to it or drives them away, Kant states in the note to Explication 2 that ‘[o]nly these two moving forces of matter can be thought’ (4: 498). This is because when a part of matter impresses motion on another, it does so as if both are points, and the motion can be pictured as taking place on a straight line between two points, on which only the convergence or divergence of the two parts of matter are logically possible. The force causing convergence is attraction and the force causing divergence is repulsion.

Does the balancing argument, and the preceding logical argument, serve to justify the existence of two fundamental forces and precisely attraction and repulsion? In my view, the answer is no. Each half of the balancing argument defends the claim that one of the fundamental forces cannot be posited without the other, but in the balancing argument Kant does not show, nor does he claim to show, that either of these forces must be posited at all, nor that no other fundamental forces should be posited alongside them. Neither does the merely logical presentation help in this regard. The fact that there are only two possible motions between two points does not rule out these motions being the result of a single force, for example a fundamental ‘motive force’ operating in two directions, nor their being the product of the complex interaction of, say, ten fundamental forces. Despite Kant’s hopeful language, this Explication does not reveal anything about the forces at work in these two motions, and the note remains merely a definition of attractive and repulsive force.⁵ For these reasons, it is understandable that Pollok proposes that the justification for the two fundamental forces must be found elsewhere, in repulsion as a ‘physiological fact’.

However, we do not need to follow Pollok in identifying a weakness in the argument of *MFNS* if we take Kant to *reject* the view that the immediate perception of repulsion means it somehow has priority over attraction. When commenting on the introduction of attractive force as the ‘second essential fundamental force of matter’, Kant notes that it *seems* (*scheint*) that repulsion is more immediately comprehensible than attraction, because we can sense the resistance of physical bodies (4: 510). But this merely apparent priority of repulsion is a result of human limitations, specifically that we immediately sense pressure and impact: ‘it is therefore so difficult for us to understand [attraction] as a fundamental force’ and one ‘struggles’ to properly conceive of attraction as fundamental. Kant nevertheless insists that attraction belongs to the fundamental forces ‘just as much as repulsion’ (4: 510). The more compelling interpretation is therefore that he continues to hold the view he expressed in 1755: attraction and repulsion are ‘*equally* certain, *equally* simple, and *equally* original and universal’ (1: 234; my emphasis). If repulsion does not have priority over attraction, we need not take Kant to ground the fundamental forces on a covert ‘physiological fact’.

Friedman offers an alternative account. Like Pollok, insofar as Friedman considers why these forces are fundamental he locates Kant's justification in the balancing argument and in the 'asymmetry' according to which repulsion precedes attraction (Friedman 2013: 180–94). But he suggests a different basis for the priority of repulsion. With reference to the *Jäsche Logik*, he characterizes Kant's position as follows: 'whereas the proposition that matter fills a space by impenetrability is analytic *a priori* (because part of the official definition of matter . . .), the proposition that matter possesses a fundamental force of attraction is synthetic *a priori*' (Friedman 2013: 171, n. 110).⁶ I take Friedman to be proposing that the starting point of the balancing argument is that repulsion is analytically contained in the very concept of matter. Elsewhere, he points to the support for this interpretation in *MFNS*: when first introducing attraction, Kant asks why, '[i]f attractive force is originally required even for the possibility of matter', is repulsion 'immediately given with the concept of a matter, whereas the former is not thought in the concept, but only adjoined to it through inferences?' (4: 509; Friedman 2001: 56). This passage appears to support Friedman's interpretation. However, it would be strange if a key claim of *MFNS* were analytic, because the project of carrying the concept of matter through the classes of categories adds synthetic determinations to the concept. I would therefore follow Dina Emundts when she argues that the ascription of fundamental forces to the concept of matter is a synthetic, not analytic judgement (Emundts 2004: 34, n. 30; 37).⁷ In any case, Pollok and Friedman appear to offer opposed accounts of the ultimate basis for the fundamentality of attraction and repulsion.⁸ For Pollok, their fundamentality is grounded on the immediate *perception* of repulsion, whereas Friedman considers repulsion to be analytically contained in the *concept* of matter.

A third interpretation can be found in a passing comment made by Daniel Warren. He contends that the Dynamics makes modest and deflationary claims about fundamental forces: we have no insight into how fundamental forces are possible, and we know nothing about their inner properties but only their relations (Warren 2001: 107–9). Warren argues, in my view entirely correctly, that Kant defends a faithfully Newtonian agnosticism about the metaphysical status and cause of attraction by claiming that fundamental repulsive force is *equally unknowable*.⁹ Having pointed to the unknowability of (the possibility of) both fundamental forces, though, Warren takes a further step:

The *MFNS* claims to establish that there must be fundamental attractive forces and that there must be fundamental repulsive forces, and that these forces have certain basic properties. But . . . I am not convinced that the *MFNS* should even be regarded as establishing how many fundamental forces – taking this to mean: how many fundamental force laws – there are, beyond having established that there must be at least two.¹⁰

In effect, Warren dismisses the problem of the justification of the fundamental character of attraction and repulsion by suggesting that Kant does not actually defend the view that these are the only fundamental forces of matter. He thus extends Kant's (Newtonian) agnosticism about the metaphysical status and cause of fundamental attractive and repulsive forces to the very question of the number of fundamental forces. For Warren, there may be more fundamental forces of matter; Kant claims no more than that there are 'at least two'. However, this reading must ignore

Kant's regular assertions, discussed below, that there *are* two fundamental forces of matter.

Alongside these three interpretations, one might propose a purely historical account. Attraction and repulsion were commonly depicted as the fundamental forces of matter in the seventeenth and eighteenth centuries, a view that Kant himself had long held. In various works of the 1750s and 1760s, particularly the *Physical Monadology* (1756) and *Negative Magnitudes* (1763), he presents attraction and repulsion as the two constitutive forces of the fundamental elements of bodies.¹¹ The account of the genesis of the universe and its physical laws in the *Universal Natural History* (1755) employs 'no forces other than those of attraction and repulsion to develop the great order of nature, two forces which are equally certain, equally simple, and equally original and universal'. These forces, Kant notes, 'have both been borrowed from Newtonian philosophy' (1: 234–5). Newtonian attraction is of course gravitational force. Michela Massimi has convincingly argued that, when referring to Newtonian *repulsive* force, Kant has in mind the work of speculative, experimental Newtonian chemists and life scientists like Stephen Hales and the Leiden school ('s Gravesande, Musschenbroek and Boerhaave) (Massimi 2011; cf. Carrier 1990: 175–80). Kant therefore apparently considered the scientific consensus of the day to be that attraction and repulsion are the two fundamental forces of matter.

Such an historical account is accurate as far as it goes, but it does not capture the full background to Kant's claim that attraction and repulsion are fundamental. Moreover, my account will seek to show that Kant does not simply *assume* that these are the fundamental forces of matter; rather, he has a sophisticated argument that can be reconstructed from a range of his writings and lecture notes.

3. The reduction method for attaining fundamental forces

I contend that Kant does justify his claim that there are two fundamental forces of matter, attraction and repulsion, and that he gives a very compressed sketch of an argument in the General Remark appended to the Dynamics chapter of *MFNS*. The passage briefly indicates a method by which diverse forces can be reduced to fundamental ones, which I will flesh out with reference to other texts by Kant and his predecessors. I will ultimately argue that the discussion of fundamental attractive and repulsive force in the main body of the Dynamics presupposes the result of Kant's version of this method.

Kant notes at the beginning of the General Remark that his Dynamics has the negative utility that the atomist view of matter can be discarded or at least 'demoted to the value of an hypothesis' (4: 524). Alongside this negative utility, however, is a positive one: 'the field of the natural scientist is thereby indirectly enlarged. For the conditions by which he formerly limited himself, and through which all original moving forces were philosophized away, now lose their validity' (4: 524). An advantage of the approach to natural philosophy propounded in the Dynamics, in Kant's eyes, is that fundamental forces remain part of physics: they cannot be 'philosophized away' as the atomists would have it.¹² At the end of the General Remark, Kant returns to this when contrasting the mechanical and dynamical modes of explanation (*Erklärungsarten*). The former is atomism, which posits absolutely impenetrable elements and a void between them; the latter proceeds 'by mere variety in combining the original forces

of repulsion and attraction to explain all differences of matters' (4: 532). Whilst acknowledging the mathematical advantages of atomism, Kant cautiously affirms the dynamical mode of natural-philosophical explanation through fundamental forces.¹³ He refutes the atomist view that the void is necessary for thinking the specific differences in density possessed by different parts of matter. These differences can be understood as based on different degrees of repulsive force; Kant thus believes he has saved the dynamical mode from disproof.¹⁴

This is the context in which Kant presents what I will argue is a compressed justification for his claim that attraction and repulsion are the fundamental forces of matter. He notes that 'no law of either attractive or repulsive force may be risked on a *priori* conjectures'. Why not? Kant gives an answer in what in my view is the key passage in *MFNS* for the issue at hand:

For it lies altogether beyond the horizon of our reason to comprehend original forces *a priori* with respect to their possibility; all natural philosophy consists, rather, in the reduction (*Zurückführung*) of given, apparently different forces to a smaller number of forces and faculties that explain the actions of the former, although this reduction (*Reduction*) proceeds only up to fundamental forces, beyond which our reason cannot go. (4: 534)

In this passage, which has not been given due attention in the literature,¹⁵ Kant very tersely provides all the elements of his argument. He points to what I call the 'reduction method' for attaining fundamental forces. In my view, Kant would have supposed his audience to be familiar with this reduction method, because variations on it are common among his predecessors in the German metaphysical tradition. This context has been largely forgotten today.¹⁶ The rest of this section therefore provides an extended gloss on this passage from the General Remark to the Dynamics, drawing on Kant's predecessors, notes from his lectures and his other writings.

3.1 '[A]ll natural philosophy consists . . . in the reduction of given, apparently different forces to a smaller number of forces and faculties . . .'

Kant regularly claims in his metaphysics lectures that all natural philosophy or physics is concerned with reducing, as far as possible, the number of forces that we posit to explain natural phenomena. The Volckmann metaphysics lecture notes (1784–5) record him stating that the human understanding cannot come to a fundamental force (*vim primitivam*). Rather,

[W]e seek only to reduce the derivative to fundamental forces, namely we search as to whether various derivative forces cannot be derived from one. Thus we test whether in all bodies we do not come upon a fundamental force. . . . All physics amounts to the reduction of the various forces, which we decrease (*abnehmen*) as far as possible to fundamental forces; the more we can do this, the more we have philosophy, and one therefore finally goes so far as to seek the fundamental forces of substance. (28: 432)¹⁷

Kant here applies the principle of parsimony, accepted by almost all natural scientists of the period,¹⁸ to the Leibnizian distinction between fundamental and derivative force.¹⁹ In doing so, he follows the Wolffian tradition. Wolff ignited a great controversy in eighteenth-century German metaphysics by claiming that the various activities of the human mind or soul could be reduced to a single 'representative force'.²⁰ An overview of the eighteenth-century 'faculty psychology' debates can be found in Lewis White Beck's classic study: figures including Sulzer, Mendelssohn, Jacobi and Tetens argued for between two and four fundamental faculties or forces of the soul (Beck 1996: 288, 329, 371, 416).

While German metaphysicians intensely debated the number and nature of fundamental forces, they consistently adopted Wolff's project of reducing the various psychological forces to a smaller number of fundamental ones (see Dyck 2008: 154–6). This is apparent in a late work in the tradition, Tetens' *Philosophische Versuche* (1777). The first chapter of the treatise, titled 'On the Efforts of the Philosophers to Derive Representations, Sensations and Thoughts from their Fundamental Force', notes that it is 'natural' to seek to reduce (*zurückführen*) various expressions of a force to a fundamental activity (*Grundtätigkeit*) (Tetens [1777] 2014: 16). Tetens calls his method 'observational' and credits it to Locke: one must 'compare, eliminate (*auflösen*)' observations of the soul's modifications in order to seek the simplest faculties and types of action (*Wirkungsarten*) (Tetens [1777] 2014: 1). This is the method, Tetens states, of the doctrine of nature.

Kant's conception of this method becomes clearer in his examples. The Volckmann notes state that 'at first one has as many forces as the effects one is aware of, until one seeks as far as possible to derive them from a foundation (*Grund*), e.g. the string of a piano has a tonal and elastic force, but one can derive the tonal from the elastic' (28: 432). Because the 'tonal force' of a piano string can be shown to be a specific instance of the more general elastic force, the former is derivative of the latter. The Mrongovius metaphysics notes (1782–3) give the example of the forces 'to illuminate and to warm'. Analysis shows that the accidents of 'lighting-force' and 'heating-force' do not really differ, so the two forces are actually derivative of a more fundamental force (29: 770). As with the forces of the piano string, the natural philosopher seeks to reduce the variety of given, that is, empirically cognized, physical forces as far as possible.²¹

Kant borrows the example of lighting- and heating-force from Wolff, who employs it to clarify an issue in psychology in his *Deutsche Metaphysik* (1719). When arguing that there is only a single force of the soul, a *vorstellende Kraft* or *vis repraesentiva* that activates the soul's various faculties, Wolff uses an analogy from natural science. Like the soul, a flame has a single force that we mistakenly take to be plural:

[T]here is nothing more in the flame of pure burning light than one single force, namely, the motive force due to which the flame has its movement. However, we give this single force several names because of the differences in its effects. For if we see that the light illuminates, we attribute a lighting force to it. When we perceive that its flame warms, one says that it has a warming force. (Wolff [1720] 1983: §746)

We thus tend to ascribe different forces to different effects of a single force: 'lighting force' and 'warming force' can be reduced to the more fundamental motive force. For Wolff there is a single force of bodies, namely motive force; and a single force of the soul, namely representative force (§753). The various, only apparently different forces of bodies and souls must, for Wolff, be reduced to a single fundamental force in each domain that is the ground of the various physical and psychological effects that we perceive.

Kant's general distinction between fundamental and derivative force is inherited from Wolff. A force is derivative if its activity can be shown to have its source in another force with a wider range of activities. A fundamental force is a force for which this is not possible.²² Strictly speaking, a derivative force is the result of erroneously taking a specific activity of a fundamental force to be a distinct force. This does not entail, though, either for philosophers in the German metaphysical tradition or for Kant, that one should avoid all mention of derivative forces: it can be useful in physics to speak of the magnetic force of a body, even if this is technically merely a name for an effect of fundamental repulsion or attraction. Natural philosophy should, however, set out the relations between derivative and fundamental forces according to which the former are reduced to the latter: as the next section will show, this is because natural philosophy is concerned with *explaining* the activities observed in nature.

Wolff's example reveals an important feature of the use of the reduction method in the German tradition: it is applicable both to the physical forces of bodies and the psychological forces of the mind. Kant defends such a view throughout the metaphysics lecture notes, most explicitly in the L₂ ontology (early 1790s):

All forces are classified into primitive or fundamental forces and into derivative or derived forces. We attempt to reduce the derivative forces <*vires derivativae*> to the primitive forces. All physics, of bodies as well as spirits, the latter of which is called psychology, amounts to this: deriving diverse forces, which we know only through observations, as much as possible from fundamental forces. (28: 564; my emphasis)

The reduction method thus guides both physicists and psychologists. We are of course focusing here on the fundamental forces of matter, but the wider context is important and will be relevant to the discussion of the Appendix to the *Critique* in section 4, below.

As noted, German metaphysicians after Wolff debated the 'smaller number' of forces to which Kant refers in the passage in *MFNS*: how many fundamental forces are there, that is, how far can the reduction method be pursued? On this question, Crusius' *Entwurf der nothwendigen Vernunft-Wahrheiten* (1745) takes an important position. In line with other Pietists, Crusius had theological grounds for insisting that there must be further fundamental forces of the soul than only Wolff's representative force: the importance of guilt and sin led the Pietist thinkers to add free will, desire, aversion and pleasure and pain to the fundamental forces (see Crusius [1745] 1964: §73). Crusius' theological commitments mean that he also denies we can have precise knowledge of the number and nature of the fundamental forces: the Pietists stressed our inability to fully comprehend the mysteries of God's creation (see Wundt 1984: 58–9). We cannot know precisely how many fundamental forces there are;

nevertheless, Crusius claims we can know that ‘there must be more than one’ because we have entirely heterogeneous types of representation (Crusius [1745] 1964: §444).

In relation to Wolff and Crusius, Kant takes a nuanced position. He remains within the Wolffian tradition by affirming the reduction method for the investigation of the forces of bodies and the mind. Following Crusius and others, he dismisses Wolff’s view that the reduction method allows us to identify a *single* fundamental force of bodies or the soul. Contrary to Crusius, though, Kant claims that we *can* know the determinate number of fundamental forces, whether physical or psychological.²³

3.2 ‘... that explain the actions of the former ...’

Let us return to the example borrowed from Wolff in the Mrongovius notes. After stating his standard definition of ‘force’ as the ground, in a substance, of the inherence of accidents,²⁴ Kant states,

Force is thus not a new accident, but rather the accidents <accidentia> are effects produced by the force. Sometimes the accidents <accidentia> do not differ really, then the forces also differ only logically, e.g. to illuminate and to warm. All forces are called derivative <derivatives> which differ logically from others, or where the difference can be cancelled through analysis. (29: 770)

Two or more forces are derivative if they only differ logically, not really; an indicator of this is that the accidents produced by the forces are the same.²⁵ For example, close consideration of ‘lighting-force’ and ‘warming-force’ reveals that they produce the same accidents of a substance, so ‘the difference can be cancelled through analysis’ and they must derive from a more fundamental force.

Kant’s reference in this passage to logical and real difference shows how he clarifies Wolff’s example through a distinction that seems to be inspired by Crusius. In the *Entwurf*, Crusius distinguishes between ideal grounds, which are the basis of thoughts, and real grounds, which bring about or make possible things outside of our thoughts (*ausserhalb den Gedanken*) (Crusius [1745] 1964: §34).²⁶ Kant knew Crusius’ distinction well: in *Negative Magnitudes* (1763), he makes a distinction between real and logical grounds that, whilst distinct from Crusius’ distinction between real and ideal grounds, nevertheless follows his emphasis on the ‘real’ as that which is outside of thought.²⁷ It is therefore notable that Crusius employs his real/ideal distinction as one of the ‘eight marks’ that characterize fundamental forces in the *Entwurf*.²⁸ A characteristic mark of fundamental forces is that they differ by more than just degree and direction, so they are really and not just ideally differentiated (Crusius [1745] 1964: §73). Although the Mrongovius notes do not refer to degree and direction, Kant similarly states that fundamental forces are *really* differentiated, whereas derivative forces differ only in thought.

Real differences between forces cannot be cancelled by analysis. An example is the different ways that the fundamental forces of matter act. In the *MFNS*, repulsion is a ‘surface force’ that acts only on contact; attraction is a ‘penetrating force’ that acts at a distance (4: 516). These differences enable Kant to (tentatively) propose mathematical laws of the two forces: ‘original attraction of matter would act

in inverse ratio to the squares of the distance at all distances, the original repulsion in inverse ratio to the cubes of the infinitely small distances' (4: 521).²⁹ These factors – different ways of acting and different mathematical laws – indicate the real difference of attraction and repulsion, suggesting that they are fundamental because we cannot cancel their differences by analysis to reduce them to a more fundamental force.

We have so far considered only signs, like Crusius' characteristic marks, that suggest that forces may be fundamental or derivative: two forces are likely to derive from a common more fundamental force if they produce the same accident or their differences can be cancelled out through analysis. What, then, is the relation between the fundamental forces and the derivative forces that are only logically differentiated from them? The key point, which Kant states in the passage from the General Remark that we are glossing, is that fundamental forces *explain* derivative ones. Crusius is again in the background. When introducing the notion of a fundamental force, Crusius refers to misguided uses of the concept of force: 'man has the force to write, to compose poetry. The stomach has the force to digest. Magnets have the force to attract iron, etc.' (Crusius [1745] 1964: §70).³⁰ These alleged explanations are in fact mere tautologies, so 'nothing yet has been explained'. Crusius is here making a standard critique of 'occult qualities'.³¹ He continues, 'if one intends to explain the causes of things, then one must have insight into an actual (*wirkliche*) causal connection between [the cause] and its effects' (Crusius [1745] 1964: §70). Such an actual (or real) causal connection is provided, Crusius claims, by a fundamental force.

Kant adopts Crusius' conception of the relation between fundamental and derivative forces as one of causal explanation. The opening of the General Remark to the Dynamics states that the possibility of fundamental forces 'can never be comprehended (*eingesehen*)' (4: 524).³² The possibility of derivative forces, by contrast, can be located in the fundamental forces from which they derive. The main body of the Dynamics makes this clear:

That the possibility of the fundamental forces should be made conceivable is a completely impossible demand; for they are called fundamental forces precisely because they cannot be derived from any other, that is, they can in no way be understood (*begriffen*). (4: 513)

Kant here indicates that to derive a force from a more fundamental one is to comprehend the possibility of the derivative force. Conversely, the natural-philosophical method of reducing derivative to fundamental forces identifies explanatory causal relations. Fundamental forces are those that can be shown to cause the activities that we misrecognize as distinct derivative forces, and which allow the latter to be comprehended. If a force is to be designated as fundamental, there must be no other force that can be shown to cause its activities or serves to explain its possibility.

This explanatory relation is key, as the next subsection will show. Before turning to this, I wish to contend that this relation differs from that of the subordination of species under genera. In this, I am contesting a proposal made by Glezer (2018: 182–8). Glezer relates the passage from the General Remark on which we are focusing (4: 534) to Kant's discussion, in the Appendix to the Transcendental Dialectic, of how Newton's derivation of the law of universal gravitation is an example of the role of regulative

principles of reason in scientific inquiry (A662–3/B690–1). I agree that regulative ideas play an important role in Kant's conception of the reduction method and will return to this in section 4. I do not however follow Glezer's suggestion that the reduction of derivative to fundamental forces mentioned in the General Remark can be understood as an instance of the subordination of species under genera as outlined in the Appendix.³³

In my view, the reduction method and the genera–species relation represent two distinct approaches to the systematic unity of nature in the Appendix. A footnote to *On the Use of Teleological Principles in Philosophy* (1788) can support my point. Kant here rejects Wolff's claims that the soul has a single representative force and that matter has a single motive force. He states that the argument for the latter would be that 'repulsion and attraction both stand under the common concept of movement': however, 'one desires to know whether the former could also be *derived* from the latter, which is impossible' (8: 181n.; my emphasis). It is impossible to know whether repulsion and attraction could be derived from movement because, 'with respect to their specific difference, the *lower* concepts can never be derived from the *higher* ones' (8: 181n.).

On my reading of this note, Kant presents Wolff as a representative of the view that fundamental motive force stands to the various derivative forces of matter as a genus stands to species: in a relation of subordination. Kant argues by contrast that attraction and repulsion are indeed 'lower' concepts than movement, as they are species of the genus 'movement', but this does not mean that the difference between attraction and repulsion can be *derived* from movement. For Kant, who is here again close to Crusius, to designate the single fundamental force of matter as 'motive force' is to indulge in tautological non-explanation.³⁴ The reduction method, in Kant's hands, is concerned not with the taxonomic classification of concepts but with causal, explanatory relations between forces. It seeks to show, for example, not that 'tonal force' is a species of the genus 'elastic force' but that tonal force is *derived* from elastic force, and so has its condition of possibility in the latter, and conversely that elastic force *explains* tonal force.

3.3 '... although this reduction proceeds only up to fundamental forces, beyond which our reason cannot go.'

Finally, we come to the key aspect of the reduction method through which, I am arguing, Kant arrives at the fundamental forces of matter. This line in the General Remark is one of many places in which Kant states that fundamental forces mark a limit of our cognitive capacities. *Dreams of a Spirit-Seer* (1766) connects this point to the reduction method:

[I]n the relations of cause and effect, substance and action, philosophy, to start with, serves to unravel the complex phenomena and reduce them to simpler representations. But when one eventually arrives at *relations which are fundamental*, then *the business of philosophy is at an end*. It is impossible for reason ever to understand how something can be a cause, or *have a force* ... (2: 370; my emphasis)

The reduction of the number of forces as far as possible – here referred to in terms of reducing complex phenomena to simpler representations – is curtailed when we reach fundamental forces, because comprehending the possibility of fundamental relations is beyond the capacity of reason. The *Critique of Practical Reason* (1788) states that ‘all human insight is at an end as soon as we have arrived at fundamental forces or fundamental faculties; for there is nothing through which their possibility can be conceived, but just as little may they be arbitrarily invented or assumed’ (5: 46–7). Likewise, the L_1 metaphysics lecture notes assert that ‘one cannot comprehend any fundamental force. One has already philosophized enough if one only *comes up to the fundamental force*’ (28: 280). In the main body of the Dynamics of *MFNS*, Kant states that fundamental attraction and repulsion are equally incomprehensible as regards their possibility (4: 513).³⁵

It is entirely consistent with the findings of the previous subsection that one cannot comprehend the possibility of fundamental forces, because, as we have seen, to explain a force is to show how it is derived from a more fundamental one. Fundamental forces, by definition, cannot be reduced to more fundamental ones, so their possibility is inherently inexplicable. A further consideration must be added to this, however. The passage above from *Dreams of a Spirit-Seer* continues by saying that the relations manifested by forces, which as we have seen are causal and explanatory, ‘can only be derived from experience’ (2: 370). This point is made more clearly in the Inaugural Dissertation (1770). Because the existence of forces cannot be proved or disproved through the principle of contradiction, forces tend to proliferate in metaphysical systems: ‘Freed from the obstacle of inconsistency, [forces] burst forth in a horde from any architectonic mind, or, if you prefer, any mind which inclines to chimeras’ (2: 416). Accordingly, Kant advocates the following rule (2: 416–17): ‘One may not, therefore, accept any original force as possible unless it has been given by experience; nor can its possibility be conceived *a priori* by any perspicacity of the understanding.’

In the works of 1766 and 1770, then, Kant insists that forces may *only* be cognized *a posteriori*; any *a priori* claims about the existence or possibility of forces are prone to illusion. He regularly repeats this point in the *Critique* and the lecture notes.³⁶ The most striking aspect of his position, as stated clearly in the above passages from *Dreams* and the Dissertation, is that the possibility of *even fundamental forces* can only be known empirically.³⁷ Fundamental attractive and repulsive forces are not *a priori* concepts or ideas, but can only be said to be possible if they are given in experience. This will be key to my reconstruction, in the next section, of Kant’s fully fledged account of how attraction and repulsion mark the limit of the reduction method in the domain of physics.

This section has sought to elucidate Kant’s brief reference to the reduction method of natural philosophy in the General Remark to Dynamics in *MFNS*, filling in the background that would have been familiar to his audience. It will be evident that Kant draws heavily yet selectively from his predecessors to develop the distinctive claim that the reduction method, applied to the forces of matter, arrives at fundamental repulsion and attraction, which mark our cognitive limits. For a full understanding of Kant’s claims here, and to appreciate the novelty of the way he transforms the reduction method inherited from the German metaphysical tradition, we should look outside of the *MFNS* to his doctrine of regulative ideas. This final element will show

that, in Kant's hands, the reduction method is not a pre-critical relic, and it will explain why he maintains that physical forces cannot be reduced *beyond* the two fundamental attractive and repulsive forces.

4. Fundamental force as a regulative idea guiding the reduction method

After outlining his conception of a regulative idea as a *focus imaginarius* in the Appendix to the Transcendental Dialectic of the *Critique*, Kant proposes 'to illustrate this through one case in which reason is used' (A648/B677). This case is the concept of force. Kant is here primarily concerned with the (fundamental) forces of the soul or mind, following the post-Wolffian debates mentioned above. 'At first glance', he writes, we might assume as many forces as there are effects (*Wirkungen*); but a 'logical maxim' encourages us to 'reduce this apparent variety as much as possible by discovering hidden identity through comparison'. The various effects of the mind, often mistakenly conceived of as distinct forces, include 'sensation, consciousness, imagination, memory, wit, the power to distinguish, pleasure, desire, etc.' (A649/B677). We can try to logically reduce these by combining different forces of the mind, for example imagination combined with consciousness might be reducible to 'memory, wit, the power to distinguish, or perhaps even understanding and reason' (A649/B677).³⁸

We can recognize here the reduction method alluded to in the General Remark to Dynamics and clarified in the passages discussed above. It is formulated in the Appendix as follows:

The logical principle of reason demands this unity as far as it is possible to bring it about, and the more appearances of this force and that force are found to be identical, the more probable it becomes that they are nothing but various expressions of one and the same force, which can be called (comparatively) their fundamental force. One proceeds in just the same way with the rest of the forces. (A649/B677)

This passage gives less detail than the metaphysics lectures on how the reduction method proceeds, noting only that it is probable that two forces are expressions of a more fundamental one if their appearances are identical. But Kant continues: 'These comparatively fundamental forces must once again be compared with one another, so as to discover their unanimity and thereby bring them close to a single radical (*radikale*), i.e., absolutely fundamental force' (A649/B677). The new addition is that reason seeks a *single* fundamental force. Moreover, the 'idea of a **fundamental force**' is a *regulative idea* guiding reason's reduction method.³⁹ Logic does not ascertain whether such a thing exists, but this idea is 'at least the problem set by a systematic representation of the manifoldness of forces' (A649/B677).

This account in the Appendix might be thought to be far from our original question about the nature and number of the fundamental forces of *matter*. But Kant evidently considers his claims to also apply to physical forces:

For even without our having attempted to find the unanimity among the many forces, or indeed even when all such attempts to discover it have failed, we nevertheless presuppose that such a thing will be found; and it is not only,

as in the case cited, on account of the unity of substance that reason presupposes systematic unity among manifold forces, but rather reason does so even where many forces, though to a certain degree of the same kind, are found, as *with matter in general*, where particular natural laws stand under more general ones; and the parsimony of principles is not merely a principle of economy for reason, but becomes an inner law of its nature. (A650/B678; my emphasis)

Here, the ‘case cited’ is the regulative unity of the soul provided by the idea of a fundamental force, which Kant explicitly connects to the case of ‘matter in general’ (*Materie überhaupt*). Corey Dyck reads this passage as seeking to guard against the confusion of the forces of the soul and the body (Dyck 2014: 216). This is true: Kant describes the forces of the soul and of bodies as two different cases. However, both souls and bodies possess ‘many forces, though to a certain degree of the same kind’: the reduction method in both domains seeks to identify the hidden identities among apparently distinct forces. What distinguishes bodily from mental forces is that, in the domain of physics, ‘particular natural laws stand under more general ones’, whereas the notion of law is not key to the hierarchy of cognitive forces. So, although physical and psychological forces must be distinguished from one another, Kant indicates a deeper connection between the two domains in that both are subject to ‘the parsimony of principles’ or the reduction of forces to the smallest possible number of fundamental ones. The applicability of the reduction method, guided by the regulative idea of a fundamental force, is common to these entirely different domains of forces.⁴⁰

In the *Mrongovius* notes, Kant reflects on the implications of introducing the regulative idea of a single fundamental force into natural-philosophical method:

In natural science one has good reason to regard the attracting and repelling forces as primitive forces. Can there be in one substance many or only one fundamental force? For our reason there must be several because we cannot reduce everything to one, but the unity of each substance requires there to be only one fundamental force. (29: 773/822)

On the one hand, the idea of the unity of substance means that matter should have a single fundamental force; on the other hand, we *cannot* pursue the reduction method to the point of reaching a single force.⁴¹ It is beyond our cognitive capacities to reduce physical forces beyond attraction and repulsion; these are therefore fundamental forces.

Why are we incapable of pursuing the reduction method to the point of reaching the *single* fundamental force of matter? Although Kant never explicitly makes this argument, I contend that his position can be reconstructed as follows, on the basis of the passages examined above.

1. No force can be cognized other than *a posteriori* with regard to its possibility (as Kant consistently claims from 1766 on; see section 3.3).
2. Fundamental forces can only be cognized *a posteriori* with regard to their possibility (as Kant also consistently claims and which follows from 1).

3. We can analyse various physical forces to reduce them as far as possible to comparatively fundamental ones, which causally explain derivative forces (the reduction method, outlined in section 3 above).
4. The regulative idea of a single fundamental force guides this reduction (as Kant claims in the Appendix, discussed in this section). For the sake of systematic unity, reason must assume there is a single fundamental force of matter.
5. By pursuing the reduction method (following 3) we reach the two forces of attraction and repulsion. There is no more fundamental force given in experience from which attraction and repulsion can be shown to be derived, i.e. which causes their effects.⁴²
6. We may not think up such a single fundamental force *a priori* (following 2).
7. It is due to the limitations of our cognition that we cannot pursue the reduction method beyond two fundamental physical forces (following 4–6). That is, as beings not in possession of intuitive understanding, we cannot cognize the possibility of any force other than *a posteriori*, and it is an empirical fact that we experience no force from which attraction and repulsion can be shown to be derived.
8. Attraction and repulsion are, *for us*, the two fundamental forces of matter (following 3 and 7).

If we take it to be a background presupposition, I propose that this reconstructed argument makes sense of Kant's consistent claim that attraction and repulsion are the fundamental forces of matter (and the same argument can be applied, *mutatis mutandis*, to the forces of the soul). The key steps are 2 and 5. Fundamental forces are empirical, due to the limits on the concept of force that Kant introduces in *Dreams of a Spirit-Seer* and the Inaugural Dissertation and reiterates in the *Critique*. Further to this point, ample textual evidence for which is given above, I infer that Kant holds the view that no more fundamental force than attraction and repulsion is given in experience. I propose that Kant considers this to be simply an empirical fact. If we were to experience a force that explained the possibility of attraction and repulsion, then this would be the single fundamental force of physical bodies. However, we encounter no such force in experience. This is why, as discussed in sections 3.2 and 3.3, Kant asserts that the two fundamental forces of matter cannot be understood (4: 513; cf. 4: 524). As forces are causally explained by comparatively fundamental ones, the most fundamental physical forces are incomprehensible; this, Kant claims, is the case with attraction and repulsion. It is ultimately the interplay between the regulative idea of a single fundamental force and the inherent (sensible) limitations of our cognition, which put a stop to the reduction method at a certain point – in the case of physics, when we reach two forces – that is the basis of Kant's claim that attraction and repulsion are the two fundamental forces of matter.

5. Conclusion

This article has sought to reconstruct Kant's version of the reduction method, which, I argue, justifies his claim that repulsion and attraction are the fundamental forces of

matter. Kant provides a sophisticated synthesis of positions held by his predecessors in the German metaphysical tradition. Moreover, by transforming Wolff's single fundamental force into a regulative idea that guides the reduction method, Kant adds a distinctively 'critical' slant. This entails that, in the domain of physics, fundamental attraction and repulsion, which remain empirical forces, ultimately indicate our cognitive limits, 'beyond which our reason cannot go'.

A consequence of my account of Kant's fully fledged conception of the reduction method is that the reduction of empirical forces to fundamental attraction and repulsion underpins his claims in the Dynamics of *MFNS* but it is not carried out in the 1786 work.⁴³ I have argued that the claims about the fundamental forces in *MFNS* instead *presuppose* the results of the reduction method as outlined in the metaphysics notes and further clarified in the Appendix. Accordingly, the General Remark of the *MFNS* makes only passing reference to the reduction method. This might be considered a weakness in the 1786 work, but more importantly it reveals overlooked connections between *MFNS* and the *Critique*.

The Appendix contends that reason's demand for systematic unity leads it to posit the regulative idea of a single fundamental force, an idea that guides the reduction method of physics and psychology. On my reading, the core claims about fundamental forces made in the rational physics of *MFNS*, no less than in empirical physics and psychology, are an outcome of reason's desire for a parsimony of principles as outlined in the Appendix.⁴⁴ This does not however mitigate the *a priori* status of *MFNS*: the work remains 'a genuine *metaphysics of corporeal nature*' (4: 472) because the reduction method conjoins *a priori* and *posteriori* reasoning. An *a priori* logical analysis of the multitude of physical forces enables us to reduce them to the smallest possible number of fundamental forces. But, in line with a defining characteristic of Kant's conception of force, these fundamental forces can only be cognized *a posteriori* with regard to their possibility. It is well known that *MFNS* has a complex task: to provide an *a priori* exposition of matter in general, which is at once a mere concept and 'intrinsically empirical' (4: 472). The complexity of its task stems at least in part from the subtlety of Kant's transformation of the concept of fundamental force that he inherits from the metaphysical tradition.⁴⁵

Notes

1 For an account of the progressive determination of the concept of matter in *MFNS*, see Watkins 1998. Kant's works are cited according to the Akademie Ausgabe pagination, except for the *Critique of Pure Reason*, referred to by the standard A/B pagination. I have been guided by, but have frequently modified, the Cambridge edition of Kant's works for passages translated therein (see note 3 for consistent changes).

2 On this, see Pollok 2001: 149–65; Blomme 2015: 497; McLear 2018.

3 Kant uses *ursprüngliche Kraft* and *Grundkraft* interchangeably, and the metaphysics lecture notes add the Latin synonym *primitive Kraft*. I translate these as *original*, *fundamental* and *primitive* force respectively, and I use 'fundamental force' as the general term. Fundamental force is contrasted by Kant with derivative force (*abgeleitete/derivative Kraft*). Some background to these terms will be given in section 3. I consistently translate *Kraft* as 'force' and *Vermögen* as 'faculty'. For a defence of this consistent translation of *Kraft*, see Dyck 2014: 200, n. 1. Kant distinguishes between faculty and force as, respectively, the possibility and actuality of an activity. On this, see note 20 below.

4 For discussions of the balancing argument, see Pollok 2001: 273–83; Warren 2010; Friedman 2013: 180–94; Smith 2013.

5 Pollok (2001: 238) remarks that this passage, appearing in an Explication not a Proposition, only provides conceptual preparation for Kant's balancing argument and is not part of it. He adds: 'Über den Status der beiden Kräfte . . . und insbesondere ihr Verhältnis zueinander in einer dynamistischen Materietheorie ist mit dieser *Erklärung* noch nichts ausgemacht' (240).

6 See 9: 111. Friedman (2013: 172, n. 110) suggests that this maps onto the examples Kant uses to clarify his distinction between analytic and synthetic judgements in the Introduction to the first Critique: 'all bodies are extended' and 'all bodies are heavy' respectively (A7/B11).

7 The apparent contradiction with 4: 509 can be resolved if we note that Kant talks here of 'a matter', and the *Jäsche Logik* and the *Critique* likewise refer to the extension and attraction (or, in the *Critique*, heaviness) of *bodies*, not of the forces of *matter in general* that are at stake in the Dynamics. When discussing this point, Friedman conflates the fundamental forces of matter (repulsion and attraction) with properties of bodies (impenetrability and weight) (see Friedman 2013: 107). In my view, Kant holds that impenetrability belongs analytically to the concept of body but not that repulsive force belongs analytically to the concept of matter in general: like attractive force, it must be added synthetically.

8 Friedman (2013: 178) goes on to examine the relation between attraction and repulsion in what he calls 'Kant's progressive constructive procedure for successively applying mathematical concepts to empirically given nature'. In Friedman's reconstruction, repulsive force 'mediates' the first application of mathematics and the categories of quantity to objects of outer experience (2013: 175, 177, 179–80). This reconstruction does not seem to pertain to the question with which I am concerned, of why attraction and repulsion are the (only) fundamental forces of matter. As far as I can tell, Friedman does not specify the relation between his claims about the analytic containment of impenetrability/repulsion in the concept of matter and his reconstruction of Kant's progressive constructive procedure.

9 Warren 2001: 110. I further discuss this unknowability below.

10 Warren 2001: 115–16, n. 18. It should be noted that Warren's proposal comes in a footnote and part is in parentheses: I am not suggesting that it is a central part of his account but that he points to a view that can feasibly be held and which I wish to contest.

11 See 1: 477–85 and 2: 179–80.

12 Kant is conceivably thinking here of d'Alembert, whose *Traité de dynamique* sought to expel forces from physics because they are 'êtres obscurs et métaphysiques qui ne sont capables que de répandre les ténèbres sur une science claire par elle-même' (d'Alembert 1743: xvi). D'Alembert advocated replacing 'force' with the clear and distinct concepts of number, extension, impenetrability and motion.

13 Kant sides with the dynamical mode because atomism takes unwarranted liberties in 'assum[ing] empty interstices and fundamental particles of determinate shapes, neither of which are determinable or discoverable by any experiment' (4: 533). Atomism thus employs 'principles that are just as metaphysical [as the metaphysical foundations Kant outlines], but have *not been brought to the test of criticism*' (4: 524; my emphasis). Atomism is therefore pre-critical or dogmatic, in the terms of the *Critique* (cf. Bxxxv).

14 Kant thus seeks to refute only the *negative* claim of atomism 'that it is impossible to think a specific difference in the density of matters without interposition of empty spaces' (4: 533).

15 Pollok (2001: 381–2) discusses this passage only briefly as an instance of Kant drawing 'die Grenzlinie zwischen dem Bereich, der den metaphysischen Teil der Materietheorie ausmacht, und dem Bereich, der der empirischen Erforschung überlassen werden muß': the metaphysical domain includes the 'Reduktionismus' which 'führt schließlich zu Grundkräften als Erklärungsprinzipien aller Erscheinungen'; left over to the empirical domain is '[d]ie konkrete Bestimmtheit dieser Kräfte'. This is correct, but on my interpretation the passage has more systematic significance than Pollok allows, and more needs to be said about the reduction method. Friedman (2013: 225–6) considers the passage only insofar as Kant here 'explains the relationship between his metaphysical investigation of the dynamical concept of matter and the application of mathematical construction to this concept'. Friedman does not reflect on the reduction method or its significance for the fundamental forces of matter in *MFNS*. Warren (2001: 107–8) discusses it briefly, noting that 'Kant is describing an explanatory regress'.

16 I am therefore following a now well-established approach in historical Kant scholarship: reconstructing what would have been common knowledge for Kant's audience, schooled as they were in the German metaphysical tradition. See Watkins 2005: 5–8, 252; Dyck 2014: 2–3.

17 Elsewhere in the lecture notes, Kant calls the reduction method ‘the main rule of the philosopher’ (28: 262) and claims, ‘All natural philosophy occupies itself with the reduction of forces to a single fundamental force which we cannot further explain’ (29: 772; see also 28: 512, 564).

18 For example, d’Alembert’s ‘Discours préliminaire’ to the *Encyclopédie*, of which Kant owned a German translation, states, ‘c’est par l’étude réfléchie des phénomènes, par la comparaison que nous ferons des uns avec les autres, par l’art de réduire, autant qu’il sera possible, in grande nombre de phénomènes à un seul qui puisse en être regardé comme le principe’. This reduction ‘constitue le véritable esprit systématique’ (d’Alembert [1751] 2011: 83).

19 The *locus classicus* is Leibniz’s *Specimen dynamicum* of 1795. Kant knew the essay: he cites it in the original Latin in his first work and adds that ‘Leibniz ... was the first to teach that an essential force (*wesentliche Kraft*) inheres in a body and belongs to it even prior to extension’ (1: 17).

20 Wolff [1720] 1983: §§753–4; see Henrich [1955] 1994: 21–3 and Howard 2019: 93–7. For Wolff, ‘faculty’ and ‘force’ designate the possibility and actuality of an activity, respectively; in the subsequent tradition the terms are often used interchangeably. On the distinction in Kant, see Heßbrüggen-Walter 2004: 136–42 and Dyck 2014: 200–2, 206, n. 23.

21 My references to empirical cognition of forces should be clarified, for, as Watkins (2004: 476) puts it with regard to attraction and repulsion, ‘Since one can see nothing beyond the effects of these forces, there is no empirical content to physical forces *per se* (as opposed to their effects, which contain all such content)’. McLear (2018: 4984) makes the same point and cites Kant’s statement in the *Critique* that ‘acquaintance with moving forces’ comes to the same thing as ‘with certain successive appearances (as motions) which indicate such forces’ (A207/B252). There is no doubt that, for Kant, we only cognize forces through their effects, motions. As we know, though, it is only through motion that the senses can be affected (see note 2, above), and so strictly speaking this is the case for all empirical cognition. It is therefore legitimate to say within the critical framework that we cognize forces, and that they can be empirical, insofar as we subsume appearances under the predicable (or second-order concept) of force in a judgement (see A82/B108).

22 See Heßbrüggen-Walter 2004: 158–9; Dyck 2014: 202. On the nominalism of the German tradition with regard to derivative forces, see Heßbrüggen-Walter 2004: 58–9.

23 For Kant’s account of the number of fundamental forces of the soul or mind, which he regularly designates as cognition, pleasure and displeasure, and desire, see 5: 196–8, 20: 205–6, 28: 262, 584. The first Introduction to the third *Critique* criticizes philosophers who seek (like Wolff) ‘to reduce all faculties to the mere faculty of cognition’ (20: 206).

24 For this definition of ‘force’, see also A648/B676, 8: 181, 224, 28: 431, 564. Kant consistently criticizes Baumgarten’s view that substance is a force; instead, one should say that substance *has* a force (8: 224, 29: 771). On this, see Watkins 2005: 257–62.

25 Kant reiterates this a little later in the Mrongovius transcript: ‘Forces are derivative whose accidents are one with the accident of another force. A primitive force is one whose accidents are not one with the accident of another force, or which cannot be reduced to a higher one’ (29: 772).

26 On Crusius’ conception of real grounds and real connection, see Watkins 2005: 83–9.

27 For Kant, logical grounds and logical opposition result from the laws of identity and contradiction, whereas real grounds and real opposition can only be understood through experience, not through reason alone (see Watkins 2005: 163–4). Kant differs from Crusius, he states, in that the latter’s ideal grounds can also be real, whereas logical grounds cannot overlap with real grounds (2: 203). While I agree with Watkins (2005: 162–3) that Kant’s distinction between real and logical grounds seems original, I do not agree that it follows that Kant’s conception of a real ground is original: Kant could well have taken this from Crusius and newly differentiated it from a logical ground.

28 Crusius [1745] 1964: §§71–8; see Howard 2019: 96–7.

29 Tentatively in that, having stated that constructing the determinate degree of matter’s filling space is a ‘purely mathematical task’ because ‘one needs a law of the ratio of both original attraction and repulsion at various distances of matter and its parts from one another’ (4: 517), Kant adds, ‘I cannot forebear adding a small preliminary suggestion on behalf of the attempt at such a perhaps possible construction’ (4: 518). This suggestion is the inverse-square and inverse-cube laws of attraction and repulsion (4: 521). He notes, though, that the law of fundamental repulsive force should not ‘be viewed as necessarily belonging to the goals of my metaphysical treatment of matter’, because the latter should be free from the ‘conflicts and doubts’ that could trouble the mathematical law (5: 523).

30 For §70 I draw on Watkins' translation in Watkins 2009: 153–4, slightly modified.

31 Compare Locke ([1689] 1894: II.xxi.17), who mocks the view that the 'singing Faculty sings, and the dancing Faculty dances', and Leibniz (1989: 306), who derides those who posit a 'faculty of clockness' by which clocks tell time or a 'fractive faculty' of mills.

32 In this paragraph I follow a helpful discussion in Warren 2001: 107.

33 Glezer admittedly suggests this in cautious terms: the passage in the General Remark is 'reminiscent of' and 'parallels' the account of genus–species relations in the Appendix (Glezer 2018: 182, 186–7).

34 In the passage quoted above from §70 of the *Entwurf*, when Crusius argues that one must examine fundamental forces in order to have knowledge of actual causal connections, he adds that 'subsuming (*Subsumiren*) and other existential connections are not sufficient here'. I take Crusius to be here rejecting taxonomical relations of subordination. In his first publication, Kant already argued that 'motive force' cannot explain repulsion and attraction because it is a tautology, an occult quality (1: 18).

35 Following the line quoted in the previous section, claiming that the possibility of fundamental forces 'can in no way be understood', Kant adds, 'But the original attractive force is in no way more *incomprehensible* (*unbegreiflicher*) than the original repulsion. It simply does not present itself so immediately to the senses as impenetrability' (4: 513). As far as I know, commentators have not yet pointed out that Kant here follows an argument previously made by Pierre Louis Maupertuis in *Discours sur les différentes figures des astres* (1732). Against contemporaries sceptical about Newtonian attraction, Maupertuis argues that the latter cannot be disproved by contrasting it with the more immediately sensed repulsion, because repulsion is just as *incomprehensible* as attraction: 'des Philosophes n'auront garde de croire que la force impulsive soit plus concevable que l'attractive. Qu'est-ce que cette force impulsive? comment réside-t-elle dans les corps?' (Maupertuis [1732] 1751: 98). Kant makes regular reference to Maupertuis' work in the 1750s and 1760s. For more on Maupertuis' argument, see Downing 2012.

36 See A206–7/B252, A222/B269, A770/B798, 28: 279–80, 29: 78.

37 See also 29: 772: 'All fundamental forces must be given through experience'.

38 See a corresponding discussion in the L_1 psychology notes: 28: 262.

39 Kant's reference to the *logical maxim* guiding the reduction method, his reference, previously discussed, to the *analysis* of forces, and the fact that *reason* pursues the reduction method, make clear that although all of the forces involved, including the fundamental ones, are only cognized *a posteriori* with regard to their possibility, the method itself proceeds *a priori*. This point is overlooked by Glezer (2018: 187).

40 Kant's assertion that there should be a methodological continuity in the treatment of forces in physics and psychology has been widely overlooked in the literature. Exceptions are brief discussions by Heimsoeth (1956: 72–3, 1969: 575) and Dyck (2008: 159, n. 27).

41 Kant makes the same point with regard to the forces of the soul in the L_1 notes: 28: 261–2.

42 In the paragraph following this reconstructed argument, I expand on what I take to be Kant's view that it is an empirical fact that there is no single physical force more fundamental than attraction and repulsion. As to Kant's contention that there are not *more* than two fundamental forces of matter – that is, that his reduction method reaches two forces – indirect evidence can be found in his attempts to show that the derivative forces of matter are all derived from fundamental attraction and repulsion. The General Remark to the Dynamics makes such an attempt with regard to various properties of matter: density, cohesion, fluidity and rigidity, friction, elasticity, and chemical dissolution and decomposition; Kant often calls these derivative forces (4: 526, 529–30, 530–1). Kant is here concerned with the explanation of the 'specific variety' of matter 'from [the] fundamental forces', although he notes that he cannot (here) achieve this explanation completely, so he will only outline four 'moments' on which the specific variety of matter is based (4: 525). See also the next note. For a helpful discussion of Kant's comments on density and cohesion in the General Remark, see Carrier 2001: 210–15. I here leave aside the complexities introduced in the *Opus Postumum* with regard to the attempt to show that all physical forces are derived from attraction and repulsion. See Carrier 2001: 214–15 and Emundts 2004. I thank an anonymous reviewer for pressing me to address these points.

43 Similarly, the reduction method is presupposed, rather than carried out, in the physics lecture notes. The *Berliner Physik* begins with the two fundamental forces of matter (29: 77–8) then discusses a range of derivative forces (29: 78–91), sometimes stating how they are derivative of fundamental forces (e.g. gravity, impenetrability, elasticity), in other cases not doing so (e.g. magnetic force). This is also the structure

of the *Danziger Physik* (although less clearly, because these notes avoid the vocabulary of fundamental and derivative force).

44 McNulty (2019) suggests another way in which regulative ideas inform the claims of *MFNS*: absolute impenetrability and empty space can be considered as regulative ideas guiding the mechanical philosophy of nature, which Kant finds less preferable than its dynamical equivalent but refuses to rule out entirely.

45 For helpful critical comments on earlier drafts of this article, I would like to thank the two anonymous referees for this journal, Michael Bennett McNulty, James Messina, Rudolf Meer and the audience of the 2019 International Kant Congress in Oslo. This research was supported by the Research Foundation – Flanders (FWO).

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Cite this article: Howard, S. (2021). Kant on the Fundamental Forces of Matter: Why Attraction and Repulsion? *Kantian Review* 26, 413–433. <https://doi.org/10.1017/S1369415421000042>