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IMMANUEL KANT

Metaphysical Foundations of Natural Science

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IMMANUEL KANT

Metaphysical Foundations of Natural Science

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Introduction

Much of Kant's intellectual energy, throughout his long career, was devoted to issues in the philosophy of natural science. Kant was not a "philosopher of science" in the sense now familiar within the Anglo-American tradition – a specialist focused on the nature and methods of scientific inquiry, say, or on the foundations of some particular science, such as physics or biology. Kant was a generalist philosopher in the classical sense, concerned with all human thought as such (both practical and theoretical) and with the structure and character of all distinctively human activities and institutions (science, art, religion, law, morality, politics, and so on). Natural science, however, was a particularly central and important example of human thought. Indeed, for the eighteenth century as a whole, the age of Enlightenment and the triumph of Newtonianism, the recent culmination of the scientific revolution of the sixteenth and seventeenth centuries in the work of Newton had elevated natural science to previously undreamt of heights within the intellectual firmament. Thinkers as diverse as Voltaire, Hume, and Kant himself all took the Newtonian achievement in natural science as a model of the human intellect at its best, and as a model, more specifically, for their own philosophical activity.[1]

In the eighteenth century, in fact, philosophy as a discipline had not yet clearly split off from natural science, as is indicated by the circumstance that what is now called "natural science" was still often called "natural philosophy" at the time. Moreover, a great stage-setting debate within natural philosophy – the famous correspondence between Leibniz and

[1] See E. Cassirer, *The Philosophy of the Enlightenment* (Princeton: Princeton University Press, 1951); P. Gay, *The Enlightenment: An Interpretation*, 2 vols. (New York: Norton, 1977).

Clarke of 1715–17 – had paid equal attention to both technical problems in physics and natural science (such as the laws of impact and the nature of matter) and very general issues within metaphysics and even theology (such as the principle of sufficient reason and God's choice to create our world).[2] In mid-eighteenth-century Germany, in particular, the debate between Leibnizeans and Newtonians dominated the intellectual agenda within both natural science and metaphysics, and Kant himself was no exception. Indeed, his earliest writings were overwhelmingly concerned with problems of natural philosophy in general and the project of reconciling Leibniz and Newton in particular.[3]

Kant's early writings in natural philosophy

Two of Kant's most important "precritical" writings in this connection are the *Universal Natural History and Theory of the Heavens* of 1755 and the *Physical Monadology* of 1756. In the first work Kant developed one of the earliest versions of the "nebular hypothesis." He formulated the idea that the band of stars visible as the Milky Way consists of a rotating galaxy containing our solar system and that other visible clusters of stars also consist of such galaxies. Moreover, according to the hypothesis in question, all such galaxies originally arose from rotating clouds of gas or nebulae whose centrifugal force of rotation caused a gradual flattening out in a plane perpendicular to the axis of rotation as they cooled and formed individual stars and planets. The laws of such galaxy formation, for Kant, proceed entirely in accordance with "Newtonian principles." At the same time, however, since our solar system has the same nebular origin as all other galactic structures, we are able to explain one important feature of this system for which the Newtonians had invoked direct

[2] See H. Alexander, ed., *The Leibniz–Clarke Correspondence* (Manchester: Manchester University Press, 1956). A classical discussion of the underlying issues is A. Koyré, *From the Closed World to the Infinite Universe* (Baltimore: Johns Hopkins University Press, 1957).

[3] For an introduction to the situation in German philosophy before Kant see L. Beck, *Early German Philosophy* (Cambridge, Mass.: Harvard University Press, 1969). For Kant's own intellectual development see E. Cassirer, *Kant's Life and Thought* (New Haven: Yale University Press, 1981); and, for a more detailed recent treatment, M. Kuehn, *Kant* (Cambridge: Cambridge University Press, 2001). For Kant's early work in metaphysics and natural philosophy see A. Laywine, *Kant's Early Metaphysics and the Origins of the Critical Philosophy* (Atascadero, Calif.: Ridgeview, 1993); M. Schönfeld, *The Philosophy of the Young Kant* (Oxford: Oxford University Press, 2000); and the introduction to my *Kant and the Exact Sciences* (Cambridge, Mass.: Harvard University Press, 1992).

divine intervention – the fact that all the planets in our system orbit in approximately the same plane – from purely mechanical natural laws after all, precisely as the Leibnizeans had maintained.[4]

The question dominating the *Physical Monadology* concerned a specific metaphysical problem arising in the debate between the Leibnizeans and the Newtonians. If the ultimate constituents of matter are absolutely simple elementary substances or monads, as the Leibnizeans contended, how can this be reconciled with the geometrical infinite divisibility of space? It would appear that by dividing the space filled or occupied by any given piece of matter, however small, we would also eventually divide the elementary material substances found there as well – contrary to the assumed absolute simplicity of such substances. So how can an elementary constituent of matter or "physical monad" possibly fill the space it occupies without being infinitely divisible in turn? Kant's answer, in 1756, is that physical monads do not fill the space they occupy by being immediately present in all parts of this space; they are not to be conceived, for example, as bodies that are solid through and through. Physical monads are rather to be conceived as pointlike centers of attractive and repulsive forces, where the repulsive force, in particular, generates a region of solidity or impenetrability in the form of a tiny "sphere of activity" emanating from a central point. Geometrically dividing this region of impenetrability in no way divides the actual substance of the monad, but merely the "sphere of activity" in which the pointlike central source manifests its repulsive capacity to exclude other monads from the region in question. So the Leibnizean commitment to ultimate simple substances or monads is perfectly consistent with the infinite divisibility of space after all – but (and here is Kant's characteristic twist) it can only be maintained by explicitly adopting the Newtonian conception of forces acting at a distance (in this case a short-range repulsive force acting at a very small distance given by the radius of its "sphere of activity").[5]

[4] For a translation of part of Kant's work see the volume edited by M. Munitz, *Universal Natural History and Theory of the Heavens* (Ann Arbor: University of Michigan Press, 1969). As Kant explains in the preface, he was inspired by ideas of the English astronomers Bradley and Wright. Kant's contemporary (later friend and correspondent) Lambert published similar ideas, independently of Kant, in his *Cosmological Letters* of 1761. The nebular hypothesis was given its most developed formulation in the eighteenth century by Laplace in his *Système du monde* in 1796. It is now often known as the Kant–Laplace hypothesis.

[5] See the translation in D. Walford, ed., *Immanuel Kant: Theoretical Philosophy, 1755–1770* (Cambridge: Cambridge University Press, 1992). It is noteworthy that this same solution to the

Kant's conception in the *Physical Monadology* is an early example of a "dynamical theory of matter," according to which the basic properties of solidity and impenetrability are not taken as primitive and self-explanatory, but are rather viewed as derived from an interplay of forces – here, more specifically, the two fundamental forces of attraction and repulsion, which together determine a limit or boundary beyond which repulsion (and thus impenetrability) is no longer effective and attraction (representing Newtonian gravitation) then takes over unhindered. This kind of theory exerted a powerful influence in the later part of the eighteenth century, in the work of such thinkers as Boscovich and Priestley, for example, and it can appropriately be viewed as an anticipation, of sorts, of the field-theoretic approach to physics developed in the nineteenth century, beginning with the work of Faraday and culminating in Maxwell's theory of electricity and magnetism. In this sense, Kant's own contributions to a dynamical theory of matter had a significant impact on the development of natural science itself, quite apart from the original more metaphysical setting within which it was first articulated.[6]

The context of the *Metaphysical Foundations*

The *Metaphysical Foundations of Natural Science* appeared in 1786, at the height of the most creative decade of Kant's "critical" period: the decade of the first edition of the *Critique of Pure Reason* (1781), the *Prolegomena to any Future Metaphysics* (1783), the *Groundwork of the Metaphysics of Morals* (1785), the second edition of the *Critique of Pure Reason* (1787), the *Critique of Practical Reason* (1788), and finally the *Critique of Judgement* (1790). The appearance of this work in 1786 shows, more specifically, that the deep (and in part extraordinarily innovative) concerns with fundamental questions in the natural science and natural philosophy of the time characteristic

problem of absolute simplicity of substance versus geometrical infinite divisibility of space is found in the *Inquiry Concerning the Distinctness of the Principles of Natural Theology and Morality* of 1764, where it appears as an "example of the only certain method for metaphysics illustrated by reference to our cognition of the nature of bodies": see Walford; ed., *Kant*, pp. 259–63.

6 For a discussion of the development and influence of eighteenth-century dynamical theories of matter see P. Harman, *Metaphysics and Natural Philosophy* (Brighton, Sussex: Harvester Press, 1982) and *Energy, Force, and Matter* (Cambridge: Cambridge University Press, 1982), as well as E. McMullin, *Newton on Matter and Activity* (Notre Dame: University of Notre Dame Press, 1978), chapter 5. Boscovich's *Theory of Natural Philosophy*, appearing in 1758, was much more widely influential than Kant's *Physical Monadology* – where it again appears that the work of Boscovich and Kant were entirely independent of one another.

of Kant's precritical period were also very salient in the critical period. In particular, the *Metaphysical Foundations* continues, and also attempts to integrate, two separate lines of thought from the precritical period: the extension of Newtonian gravitational astronomy to cosmology first suggested in the *Theory of the Heavens*, and the further development of a dynamical theory of matter as first sketched in the *Physical Monadology*. At the same time, however, Kant now frames both developments within the radically new context of his critical philosophy.

The critical version of the dynamical theory of matter is developed in the longest and most complicated part of the *Metaphysical Foundations*, the second chapter or Dynamics. As in the *Physical Monadology*, Kant here views the basic properties of matter – impenetrability, solidity, hardness, density, and so on – as arising from an interplay of the two fundamental forces of attraction and repulsion. In sharp contrast to the *Physical Monadology*, however, Kant abandons the idea of smallest elementary parts of matter or physical monads and argues instead that all parts of matter or material substances, just like the space they occupy, must be infinitely divisible. Indeed, in the course of developing this argument, he explicitly rejects the very theory of physical monads he had himself earlier defended in 1756. A space filled with matter or material substance, in Kant's new theory, now consists of an infinity or continuum of material points, each of which exerts the two fundamental forces of attraction and repulsion. The "balancing" of the two fundamental forces that had earlier determined a tiny (but finite) *volume* representing a "sphere of activity" of impenetrability around a single pointlike central source now determines a definite *density* of matter at each point in the space in question effected by the mutual interaction of attraction and repulsion.

Thus, in the *Metaphysical Foundations*, as in the *Critique of Pure Reason*, material or phenomenal substance is no longer viewed as simple and indivisible, but is instead a genuine continuum occupying all the (geometrical) points of the space it fills. Accordingly, the problem posed by the infinite divisibility of space that the *Physical Monadology* had attempted to solve by invoking finite "spheres of activity" is now solved, in the Dynamics of the *Metaphysical Foundations*, by invoking the transcendental idealism articulated in the Antinomy of Pure Reason of the first *Critique* – and, more specifically, the argument of the Second Antinomy resolving the apparent incompatibility between the infinite divisibility of space, on the one side, and the presumed absolute simplicity of the material or phenomenal substances found in space, on the other. Matter or material substance is infinitely *divisible* but never, in experience, ever infinitely *divided*; hence, since matter is a mere appearance or phenomenon and is thus given only in the "progress of experience," it consists neither in ultimate simple elements nor in an actual or completed infinity of ever smaller spatial parts. Therefore, it is only by viewing matter as a thing in itself or as noumenal substance (which would be necessarily simple) that we obtain a genuine contradiction or antinomy; and so, by an indirect proof or *reductio ad absurdum*, we have a further argument in support of Kant's characteristically critical doctrine of transcendental idealism.

The cosmological conception presented in the *Theory of the Heavens* had also included a striking vision of how the various galactic structures are distributed throughout the universe. The smallest such structure (due to nebular formation) is our own solar system, consisting of the sun surrounded by the six then known planets. The next larger structure is the Milky Way galaxy, in which our solar system as a whole orbits around a larger center together with a host of other stars and (possible) planetary systems. But the Milky Way galaxy itself, for Kant, is then part of an even larger rotating system consisting of a number of such galaxies; this system is part of a still larger rotating system; and so on *ad infinitum*. The universe as a whole therefore consists of an indefinitely extended sequence of ever larger rotating galactic structures, working its way out from our solar system orbiting around its central sun, through the Milky Way galaxy in which our solar system is itself orbiting around a galactic center, then through a rotating system of such galaxies, and so on. Moreover, this indefinitely extended sequence of galactic structures reflects a parallel indefinitely extended sequence of nebular galactic formation, as the structures in question precipitate out from an initial uniform distribution of gaseous material sequentially starting from the center.

The *Metaphysical Foundations*, unlike the *Theory of the Heavens*, is not a work of cosmology. But the cosmological vision of the *Theory of the Heavens* is still centrally present there, transposed, as it were, into a more epistemological key. The very first explication of the *Metaphysical Foundations*, in the first chapter or Phoronomy, defines matter as the *movable* in space; and, as Kant immediately points out, this inevitably raises the difficult question of relative versus absolute motion, relative versus absolute space. Kant firmly rejects the Newtonian conception of absolute space as an actual "object of experience," and he suggests, instead, that it can be conceived along the lines of what he himself calls an "idea of reason." In this sense, "absolute space" signifies nothing but an indefinitely extended sequence of ever larger "relative spaces," such that any given relative space in the sequence, viewed initially as at rest, can be then viewed as moving with respect to a still larger relative space found later in the sequence. In the final chapter or Phenomenology, which concerns the question of how matter, as movable, is possible as an object of experience, Kant returns to this theme and develops it more concretely. He characterizes absolute space explicitly as an "idea of reason" and, in this context, describes a procedure for "reducing all motion and rest to absolute space." This procedure then generates a determinate distinction between true and merely apparent motion – despite the acknowledged relativity of all motion as such to some given empirically specified relative space. The procedure begins by considering our position on the earth, indicates how the earth's state of true rotation can nonetheless be empirically determined, and concludes by considering the cosmos as a whole, together with the "common center of gravity of all matter," as the ultimate relative space for correctly determining all true motion and rest.

What Kant appears to be envisioning, then, is an epistemological translation of the cosmological conception of the *Theory of the Heavens*. In order to determine the true motions in the material, and thus empirically accessible universe, we begin with our parochial perspective here on earth, quickly move to the point of view of our solar system (where the earth is now seen to be really in a state of motion), then move to the perspective of the Milky Way galaxy (where the solar system, in turn, is itself seen to be in motion), and so on *ad infinitum* through an ever widening sequence of ever larger galactic structures serving as ever more expansive relative spaces. What Kant calls the "common center of gravity of all matter," relative to which all the motions in the cosmos as a whole can now be determinately considered, is never actually reached in this sequence; it is rather to be viewed as a forever unattainable regulative idea of reason towards which our sequence of (always empirically accessible) relative spaces is converging. In this way, in particular, we obtain an empirically meaningful surrogate for Newtonian absolute space using precisely the methods used by Newton himself (in determining the true motions in the solar system in the *Principia*, for example). At the same time, we preserve the fundamental Leibnizean insight that any position in space, and therefore all motion and rest, must ultimately be determined, in experience, from empirically accessible spatiotemporal relations between bodies.[7]

Kant's conception of absolute space in the *Metaphysical Foundations* therefore corresponds – in the more specific context of a consideration of matter as the *movable* in space – to his famous attempt in the *Critique of Pure Reason* to depict his own doctrine of the transcendental ideality of space as the only possible middle ground between the two untenable extreme positions of Newtonian "absolutism" and Leibnizean "relationalism." It also corresponds, even more directly, to Kant's conception of the extent of the material or empirical world in space articulated in the First Antinomy, according to which there is indeed no limit to this extent at any particular finite boundary, but, at the same time, the world cannot be conceived as an actually infinite completed totality nonetheless. In the end, there is only the purely regulative requirement or demand that, in the "progress of experience," we must always *seek* for further matter beyond any given finite limit and, accordingly, accept no given such boundary as definitive. We must seek, in the terminology of the *Metaphysical Foundations*, for ever larger relative spaces encompassing any given relative space; and, in this way, Kant's conception of absolute space as an idea of reason is the complement, from the point of view of the critical doctrine of transcendental idealism, of his new version of the dynamical theory of matter as consisting of a potential (but not actual) infinity of ever smaller spatial parts. Both are thus now firmly embedded, as we have said, within the radically new critical perspective of "transcendental philosophy."

Structure of the work: motion and the dynamical theory of matter

Even more obviously, however, there is a quite explicit correspondence between the first *Critique* and the *Metaphysical Foundations* in the very structure of the latter work. It consists of four main parts or chapters which, as Kant explains in the Preface, are coordinated, respectively, with

[7] For further discussion (in connection, specifically, with Newton's argument for determining the true motions in the solar system in Book III of the *Principia*) see my contribution to P. Guyer, ed., *The Cambridge Companion to Kant* (Cambridge: Cambridge University Press, 1992); and (for even more details) my *Kant and the Exact Sciences* (note 3 above).

the four main headings of the table of pure concepts of the understanding – the categories of quantity, quality, relation, and modality:

> The concept of matter had therefore to be carried through all four of the indicated functions of the concepts of the understanding (in four chapters), where in each a new determination of this concept was added . . . The *first* considers *motion* as a pure *quantum* in accordance with its composition, without any quality of the movable, and may be called **phoronomy**. The *second* takes into consideration motion as belonging to the *quality* of matter, under the name of an original moving force, and is therefore called **dynamics**. The *third* considers matter with this quality as in *relation* to another through its own inherent motion, and therefore appears under the name of **mechanics**. The *fourth* chapter, however, determines matter's motion or rest merely in relation to the mode of representation or *modality*, and thus as appearance of the outer senses, and is called **phenomenology**. (Ak 4:476–77)

Hence, the *Metaphysical Foundations* is explicitly constructed and organized by the guiding "architectonic" of the critical period – the structure first given by what Kant calls the table of logical functions of a possible judgment.[8]

Thus, the first chapter or Phoronomy subsumes the concept of matter as the movable in space under the categories of quantity by showing how it is possible to consider such motion as a mathematical magnitude – to show, more specifically, how the concept of speed or velocity first acquires a mathematical structure. This, according to the general concept of quantity or magnitude considered in the first *Critique*, requires that we show how any two magnitudes falling under a common magnitude kind (two lengths, areas, or volumes, for example) may be composed or added together so that a new magnitude having the properties of the mathematical sum of the two then results. Our problem, in the present case, is therefore to show how any two speeds or velocities may be summed or

[8] The particularly close connection between the *Metaphysical Foundations* and the first *Critique* in this regard is further emphasized in the second (1787) edition of the *Critique*, where Kant remarks, as a comment to the table of categories, that (B109–10) "[this] table contains all elementary concepts of the understanding completely, and even the form of a system of such concepts in the human understanding; and it therefore gives an indication of all the *moments* of a prospective speculative science, and even their *ordering*, as I have also attempted to show elsewhere* [**Metaphysical Foundations of Natural Science*]."

added together; and, since motion must always be defined with respect to one or another "relative space" (what we would now call a reference frame), it is also necessary carefully to consider the (possibly different) such spaces involved. Kant's main contention, in the single proposition of the Phoronomy, is that the addition or composition in question cannot be carried out in a single relative space or reference frame. Rather, we must consider two different spaces or reference frames, such that the moving body has the first velocity with respect to one of the spaces, while this space, in turn, moves with the second velocity with respect to a second relative space: the motion of the body with respect to this second space or reference frame then has the desired sum of the two original velocities. Moreover, this whole "construction," for Kant, rests on a principle of the relativity of motion (according to which the two different reference frames in question are in an important sense equivalent); and it thus depends essentially on Kant's characteristic conception of the relativity of space and of motion already discussed above in connection with the consideration of absolute versus relative space at the very beginning of the Phoronomy.

In the Phoronomy, as Kant explains, the moving "body" or piece of "matter" in question is considered as having only the properties of speed and direction, and is thus entirely bereft of all empirically given "qualities" – mass, density, force, and so on – possessed by real physical bodies or bits of matter. Indeed, the "bodies" of the Phoronomy, as Kant explicitly points out, can, in this respect, be considered as mere mathematical points. The role of the second chapter or Dynamics, therefore, is precisely to explain how such empirical qualitative features are first introduced: how it is possible, in the words of the first explication, that matter, as the movable, then *fills* a space. The answer to this question turns out to be long and complicated, and to invoke the full resources, as we have already suggested, of Kant's critical version of the dynamical theory of matter. Matter fills the space it occupies by a continuous "balancing" of the two fundamental forces of attraction and repulsion exerted by all the continuum of points in the space in question. Repulsive force, however, has priority here; for, as Kant also says in the first explication, to fill a space, in the first instance, means to resist penetration (by other matter) into this space. Accordingly, the main body of the Dynamics chapter is organized into two symmetrical parts, where the first four propositions and accompanying remarks discuss the fundamental force of repulsion and the last four focus on the fundamental force of attraction.

Kant argues, in the first four propositions, that the impenetrability effected by repulsive force must be conceived as relative rather than as absolute. Matter is not a perfectly hard or impenetrable solid that resists penetration or compression absolutely; it is rather an essentially elastic continuum exerting expansive force or pressure against any attempt to compress it into a smaller space. The more it is compressed the more it resists, but there is no matter that cannot be compressed at all. Matter is thus what Kant calls an originally elastic or expansive medium (a concept he illustrates by the air filling the barrel of an air pump). Moreover, since Kant now defines material substance (such as air or any other "elastic fluid," for example) as that which is movable independently of any other matter, and since the originally expansive elasticity characteristic of such a substance can only arise, Kant argues, from repulsive forces exerted by *every* point in the space it fills, it follows that material substance is found in *all* of the parts of this same space (for each part exerts repulsive force against its neighboring parts and is thereby physically separable from them). Material substance must now be conceived, therefore, as essentially divisible to infinity, and Kant's critical version of the dynamical theory, as we have already explained, is thus in explicit opposition here to his earlier precritical theory developed in the *Physical Monadology* – where matter is only finitely divisible into elementary corpuscles or physical monads representing ultimate simple substances.

Kant introduces the fundamental force of attraction, in the next four propositions, by his critical version of the "balancing" argument. If matter had only the fundamental force of repulsion, Kant argues, it would expand itself to infinity by its own internal pressure – and, in this case, matter would have zero density everywhere, and space would turn out to be empty. In order that matter be really possible as that which fills a space, therefore, there must be something that resists this internal pressure. This, Kant concludes, can only be a second fundamental force essentially opposed to the fundamental force of repulsion: namely, a fundamental force of attraction. In order for matter to fill the space it occupies to a determinate degree – to have a determinate density or "quantity of matter" within this space – there must thus be a continuous "balancing," at each point of the space in question, of both fundamental forces.[9] In the remainder of the second part of the Dynamics Kant then explains that the properties of the fundamental force of attraction are precisely those of Newtonian universal gravitation: in particular, it acts immediately at a distance independently of any intervening matter (in Kant's terminology, it is a "penetrating" rather than a "surface" force), and it acts in this way between each part of matter in the universe and any other part at arbitrary distances to infinity. Kant connects this discussion, both implicitly and explicitly, with some of the main steps in Newton's own argument for universal gravitation presented in Book III of the *Principia*.

The eight propositions of the Dynamics describing the properties of the two fundamental forces are, as Kant explains, concerned only with completely "universal" properties of all matter in general and as such – properties or qualities "comprehensible a priori" by his own "metaphysical" treatment. These properties include original elasticity due to the fundamental force of repulsion and weight due to the fundamental force of attraction, together with the closely related properties of density and "quantity of matter." Nothing else, Kant suggests, can be comprehended a priori, and so all other properties of matter than these belong to a "physical" rather than properly "metaphysical" discussion. Nevertheless, in the long General Remark that concludes the Dynamics, Kant indicates, in a more or less speculative spirit, how some of the main headings of a physical treatment of the particular properties of matter responsible for its "specific variety" might be set up. He here discusses the distinction between fluid and solid matter, the property of cohesion (or attraction in contact), rigidity, elasticity in the sense of "spring force," and, finally, some of the key concepts of the discipline of chemistry (which, according to the Preface, is not yet a genuine science in the strict sense). Kant concludes this discussion with some important methodological remarks concerning the general approach one should take to all such properly physical questions. In general, the "metaphysical-dynamical" approach, which views matter as a true dynamical continuum and eschews absolutely hard elementary corpuscles and empty space, is to be preferred

[9] Again, as I pointed out above, this contrasts with Kant's precritical presentation of an analogous "balancing" argument in the *Physical Monadology*, according to which the interplay of attraction and repulsion determines a tiny (but) finite *volume* – what Kant calls the "sphere of activity" of impenetrability – around a pointlike central source.

to the opposing "mathematical-mechanical" approach, which postulates precisely an interspersing of hard elementary corpuscles and empty space from the very beginning (to explain differences of density) – and, in its extreme form, thereby attempts to dispense with all genuinely dynamical forces originally inherent in matter.

The third chapter or Mechanics considers matter (the movable in space) insofar as it has a "moving force" *as* a movable thing. Whereas the moving forces considered in the Dynamics – the fundamental forces of attraction and repulsion – are present or inherent in the bodies exerting them entirely independently of the state of motion of these bodies, now, in the Mechanics, we consider these same moving forces as involved in what Kant calls the communication of motion from one body to another. A paradigmatic instance of such communication of motion is impact, whereby one body transfers motion to another in virtue of their forces of impenetrability and loses as much motion through the impact as the impacted body gains. Kant makes it clear, however, that the very same phenomenon takes place in cases of attraction – where, for example, the attracting body produces a motion in the attracted body and, at the same time, is also in motion itself due to the (mechanical) resistance of the attracted body. In all such cases of the communication of motion, quite generally, the operative mechanical quantity is momentum (or mass times velocity), and any change of momentum produced by one body on another is precisely counterbalanced by an equal and opposite change of momentum experienced by the first body. *Both* bodies involved must necessarily be viewed as in motion, and the total momentum is necessarily conserved.

The fundamental importance of the concept of momentum here affords Kant an opportunity to explain more precisely the central concept of quantity of matter, which had been introduced into the Dynamics in connection with the density of matter. Quantity of matter is now officially defined, in the second explication of the Mechanics, as the (continuously extended and infinitely divisible) "aggregate of movables" in a given space. In accordance with the discussion in the Dynamics, in particular, the same quantity of matter present in a larger space can be brought into a smaller space by compression, where it is then correspondingly more dense than it was before (and vice versa for expansion). Quantity of matter, as in Newton, can thus be conceived as depending on both volume and density. But this concept, Kant explains, affords us no universally applicable measure of the quantity of matter, for matters of specifically different kinds (water and mercury, for example) cannot be transformed into one another by compression.[10] The only universally valid way to estimate quantity of matter, according to Kant's first proposition of the Mechanics, involves considering the momenta, and thus possible motions, of the bodies in question. As Kant explains, more precisely, quantity of matter manifests itself in experience only by the quantity of motion (i.e., momentum) at a given speed. Thus, for example, when we compare the quantities of matter of two substances in equilibrium on a balance, the two press down on the balance with equal gravitational forces and therefore manifest equal changes of momentum; but since, by Galileo's law of fall, their initial speeds (and thus accelerations) are equal, it follows that their masses or quantities of matter must be equal as well. And, more generally, it is only in the context of the communication of motion – and thus "mechanically" – that mass or quantity of matter can be validly estimated.

Instantiating the categories in space

Kant then moves, in the last three propositions of the Mechanics, to the main business of the chapter: establishing what he calls the three "laws of mechanics." These are, first, a principle of the conservation of the total quantity of matter in the universe, second, a version of the law of inertia, and third, the law of the equality of action and reaction. Here we find a very explicit correspondence, as promised, between the subject matter of the Mechanics and the categories of relation. In particular, the principle of the conservation of the total quantity of matter corresponds to the more general "transcendental" principle established in the first *Critique* – the permanence of *substance* in all changes in the (phenomenal) world; the law of inertia corresponds to the category, and accompanying principle, of *causality*; and the law of the equality of action and reaction corresponds to the category, and accompanying principle, of thoroughgoing dynamical interaction or *community*. Thus, in considering material substances or bodies as interacting with one another through their fundamental forces and, as a result, thereby standing in relation to one another in a community

[10] This particular point, in the context of the specific example of water and mercury, is made in Kant's earlier discussion of density in the first number of the General Remark to Dynamics (see 4:525–26).

of their inherent motions (i.e., momenta), we are, at the same time, applying the categories or pure concepts of relation to these same bodies.

It is in precisely this context, in fact, that Kant makes his most explicit and developed remarks about the relationship between the very general "transcendental" principles established in the first *Critique* and the more specific "metaphysical" principles established in the *Metaphysical Foundations* – remarks which are especially salient in the second (1787) edition of the first *Critique*. For example, in the second edition Introduction, Kant formulates the question of how pure natural science is possible, and he then adds a footnote instancing the laws of "the permanence of the same quantity of matter, of inertia, [and] of the equality of action and reaction" as clear and uncontroversial examples of such pure natural science (B20). Later, even more strikingly, he adds an entirely new section to the chapter on the system of principles of pure understanding, a "General Remark to the System of Principles." Here Kant first argues that the pure categories, without corresponding (spatiotemporal) intuitions, remain mere empty forms of thought, and he then argues for the "even more remarkable" conclusion that the categories require "not merely intuitions, but always even *outer intuitions*" (see B291–94). In order to have a permanent intuition corresponding to the category of substance, for example, we require "an intuition *in space* (of matter)." In order to instantiate the category of causality we require an intuition of change or alteration, and this intuition can only be "that of the motion of a point in space, whose existence in different places (as a sequence of opposed determinations) first makes alteration intuitive for us." Finally, we can similarly make the possibility of community comprehensible to ourselves only when we "represent it in space, and thus in outer intuition" – "for the latter already contains in itself a priori formal outer relations as conditions for the possibility of real relations (in action and reaction, and therefore community)."[11]

[11] Further changes in the second edition of the first *Critique* also clearly reflect the importance (and influence) of the intervening *Metaphysical Foundations*. Thus, for example, the second edition reformulates the First Analogy so that it now expresses a *conservation law* for the total quantity of substance (B224): "In all change of the appearances substance is permanent, and its quantum in nature is neither increased nor diminished." And there are parallel, if less dramatic changes made to the other two Analogies. Moreover, the Refutation of Idealism added to the second edition explains that "we have nothing permanent that could underlie the concept of a substance, as intuition, except merely *matter*" (B278), and thus it mirrors the above cited General Remark (which, in turn, explicitly refers to the Refutation of Idealism). Compare also note 8 above.

This last passage added to the second edition of the *Critique* closely mirrors a corresponding passage in the Preface to the *Metaphysical Foundations* itself:

> It is also indeed very remarkable (but cannot be expounded in detail here) that general metaphysics, in all instances where it requires examples (intuitions) in order to provide meaning for its pure concepts of the understanding, must always take them from the general doctrine of body, and thus from the form and principles of outer intuition; and, if these are not exhibited completely, it gropes uncertainly and unsteadily among mere meaningless concepts . . . And so a separated metaphysics of corporeal nature does excellent and indispensable service for *general* metaphysics, in that the former furnishes examples (instances *in concreto*) in which to realize the concepts and propositions of the latter (properly speaking, transcendental philosophy), that is, to give a mere form of thought sense and meaning. (4:478)

Kant had already explained in the Preface that the special metaphysics of corporeal nature expounded in the *Metaphysical Foundations* differs from the general metaphysics articulated in the first *Critique* by limiting itself to the objects of specifically outer, that is spatial, intuition. It would appear, however, that there is nonetheless an especially close connection between the more general concepts and principles of the first *Critique* and the more specific concepts and principles of the *Metaphysical Foundations*. Indeed, Kant here suggests that the *only* way we can realize or instantiate concretely the abstract concepts and principles of transcendental philosophy is precisely by the objects of specifically outer intuition – by matter as the movable in space.

True and apparent motion

The fourth chapter or Phenomenology of the *Metaphysical Foundations* considers how matter as the movable in space can be an object of experience with regard to its state of motion – how, as Kant puts it, matter as the movable in space can be thought as *determined*, one way or another, by the predicate of motion. The underlying problem, as Kant makes clear, concerns the relativity of space and of motion first broached in the Phoronomy. In the Phoronomy, however, a principle of the thoroughgoing relativity of all motion appeared to hold unlimited sway, in that it was considered as all the same whether a body is viewed as being in motion (with respect to some empirically defined relative space or reference frame) or at rest (with respect to another such space or reference frame). Now, in the Phenomenology, the problem is precisely to explain how a body can be definitely and unequivocally characterized as being in one particular state to the exclusion of the other – how, in other words, we can apply a definite and unequivocal distinction between true and merely apparent motion. The main body of the Phenomenology consists of three propositions and accompanying remarks, which correspond, respectively, to the three categories of modality: possibility, actuality, and necessity. Thus, the rectilinear motion of a body with respect to a given (empirical) space, as distinct from the opposite motion of the space itself, is a merely *possible* (merely relative) predicate; the circular motion of a body, as distinct from the opposite motion of the (surrounding) space, is an *actual* (or true) predicate; and the mutual relative motions of two bodies, if either one is first assumed to be in motion relative to the other, is a *necessary* characterization of both bodies.

When Kant first articulates his principle of the relativity of motion in the Phoronomy, he already explains that it is subject to two important qualifications. In the first place, he says, he is assuming all the relevant motions to be rectilinear; for, "in regard to curvilinear motions, it is not in all respects the same whether I am authorized to view the body (the earth in its daily rotation, for example) as moved and the surrounding space (the starry heavens) to be at rest, or the latter as moved and the former as at rest, which will be specifically treated in what follows" (4:488; the "following" treatment of this case turns out to be the second proposition of the Phenomenology). In the second place, Kant explains, even the rectilinear motion of one body relative to another is not as completely arbitrary as it first appears. Whereas, "in phoronomy, where I consider the motion of a body only in relation to the space (which has no influence at all on the rest or motion of the body), it is completely undetermined and arbitrary how much speed, if any, I wish to ascribe to the one or the other," it later turns out, "in mechanics, where a moving body is to be considered in active relation to other bodies in the space of its motion, this will no longer be entirely the same, as will be shown in the proper place" (ibid.; thus the "proper place" in question turns out to be in the Mechanics). These two qualifications already introduced in the Phoronomy then correspond to the second and third propositions of the Phenomenology, where the second determines the actuality of circular (and more generally curvilinear) motion, and the third determines the necessity of equal and opposite motions of both bodies in accordance with the fourth proposition (the "Third Law of Mechanics") established in the Mechanics.[12]

The fourth proposition of the Mechanics, as we have already seen, formulates the equality of action and reaction: whenever one body acts on another by either the fundamental force of repulsion (as in cases of impact) or the fundamental force of attraction (as in universal gravitation), an equal and opposite reaction – that is, an equal and opposite motion or change of momentum – is experienced by the first body. *Both* bodies must necessarily be viewed as moving, and, as Kant emphasizes repeatedly, no motion at all can be communicated to a body absolutely at rest. Kant proves the proposition by showing how any motions arising in this way are to be "reduced to absolute space." In cases of impact, for example, there is a privileged frame of reference determined by the *center of mass* of the two bodies, such that both bodies are moving towards one another before the impact with equal and opposite momenta. The speed of the first body is to that of the second as the mass of the second body is to that of the first; and it is precisely this particular way of apportioning speeds between the two bodies that resolves the arbitrariness left open in cases of rectilinear motion by the Phoronomy. The true as opposed to merely apparent rectilinear motions, then, are precisely those involving equal and opposite motions (i.e., momenta) of both bodies involved in the communication of motion. The center of mass of the two bodies provides an empirically accessible surrogate for absolute space, and the motions determined with respect to any other frame of reference (relative to which one of the two bodies is initially at rest, for example) are merely relative or apparent. Moreover, as Kant also suggests in the Mechanics, the situation is quite similar in cases of attraction: here, too, the center of mass of the two interacting bodies, relative to which both bodies are necessarily in motion, provides us with a privileged frame of reference for describing the motions in question.

[12] More generally, Kant explains, the first proposition of the Phenomenology determines "the modality of motion" with respect to phoronomy, the second with respect to dynamics, and the third with respect to mechanics.

The case of attraction turns out to be rather more complicated, however. For the motions typically effected by attraction, in the guise of universal gravitation, are rotational or orbital motions rather than rectilinear motions. Here the two interacting bodies both orbit around a common central point, their mutual center of mass or center of gravity, but, unlike in the case of impact, they do not necessarily move along the straight line between them relative to this central point. Determining the center of mass lying on the straight line between them does not yet suffice, in any case, to determine the state of true or actual *rotational* motion – where the issue concerns whether this line itself rotates around its central point.[13] The solution to this problem is presented in Kant's second proposition of the Phenomenology, where he refers, in particular, to Newton's remarks in the Scholium to the Definitions of the *Principia* showing how the circular motion of two globes connected by a cord around a common center can be empirically determined from the resulting tension in the cord due to centrifugal force. And it is clear, from the context, that Newton intends this illustration as a model for his later argument in Book III of the *Principia* showing how the true (rotational and orbital) motions in the solar system can be determined via his theory of gravitation. Here the force of gravity takes the place of the connecting cord, and the various orbital motions around different common centers (the earth and its moon around their common center of gravity, the earth and the sun around their common center of gravity, and so on) are given a single unified representation by taking the common center of gravity of the sun and all the planets as determining the privileged frame of reference for considering all of these motions together.

Absolute space as an idea of reason

The General Remark to Phenomenology sketches Kant's procedure for "reducing all motion and rest to absolute space." The discussion suggests

[13] In the case of the orbital motions of two bodies around a common central point they do not move (rectilinearly) either towards or away from this point if the orbits are circular. If they are elliptical, however, then the resulting motion has two components: a rotational motion of the straight line connecting the two bodies around the central point plus a (rectilinear) oscillating motion of the bodies towards and away from this central point. In the course of its yearly elliptical orbit around the sun, for example, the earth moves closer to the sun (more precisely, to the common center of gravity of the earth–sun system) in one part of its orbit and farther from the sun in another part.

that we begin this procedure from our naïve perspective on the earth, initially taken to be in a state of rest. But all motions viewed from the point of view of the earth at rest are so far merely relative and, in accordance with the first proposition, therefore merely possible (for, once again, no body whatever can by truly or actually in a state of absolute rest). The next step is taken when we determine the state of true axial rotation of the earth (relative to the surrounding starry heavens), and this case, as Kant suggests, is analogous, in important respects, to the Newtonian example of the two (orbitally) rotating bodies connected by a cord. What Kant suggests, more specifically, is that we determine the true or actual axial rotation of the earth by observing how the earth's eastward rotation deflects a falling body from its downward rectilinear path towards the earth's center by what we now call Coriolis force. Here, then, we have a combined effect of gravitational and Coriolis forces, which is precisely parallel, as Kant also suggests, to the more familiar balancing of gravitational and centrifugal forces.[14] In all such cases, more generally, the actually observed motions result from the combination of a centrifugal tendency to proceed in a straight line tangent to the circular (or more generally curvilinear) motion in question, in accordance with the law of inertia, and a centripetal tendency to proceed in a straight line towards the center of circular (or more generally curvilinear) motion, in accordance with the law of gravitation. That gravitational attraction is here counterbalanced by circular (or curvilinear) *motion* – "without any dynamical repulsive cause" – is precisely what indicates the actuality of this motion.[15]

[14] It is worth noting, at this point, that two of Kant's most prescient and original contributions to natural science concerned effects arising from a combination of the earth's rotation and gravitational forces. *Whether the Earth has Undergone an Alteration of its Axial Rotation*, appearing in 1754 (and reprinted in the volume edited by Munitz cited in note 4 above), was the first work (by more than one hundred years) to take seriously the possibility that tidal friction arising from the attraction of the sun and the moon on the sea could produce nonuniformities in the earth's rate of rotation. Similarly, the *Theory of the Winds*, appearing in 1756, was the first work (by almost eighty years) to suggest an explanation of the directional tendency of the trade winds by the rotation of the earth – in terms of Coriolis forces due to this rotation, which upset the hydrostatic equilibrium in the atmosphere maintaining equal pressures at equal distances from the earth by a balancing of gravitational force and the air's expansive elasticity.

[15] Kant makes the remark about the absence of any "dynamical repulsive cause," and explicitly refers again to Newton's Scholium to the Definitions, at 4:562. The point is that the earth's gravitational attraction on the moon, for example, is balanced by the moon's orbital motion rather than any counteracting dynamical repulsive force – if the moon ceased orbiting it would drop in a straight line towards the earth. Similarly, in the case of Newton's example of the two globes, the tension in the cord is produced precisely by their mutual rotation and not by any repulsive force – if the rotation were to cease then so would the tension in the cord.

The remainder of Kant's discussion is unfortunately extremely compressed. He reminds us that mutually opposed and equal motions of any two bodies interacting by any "dynamical influences" whatsoever (he gives as examples "gravity or a tensed cord") are always necessary; he then moves rapidly, as we have already pointed out, to a consideration of "the common center of gravity of all matter." Thus, although Kant does explicitly refer, once again, to Newton's Scholium to the Definitions here (see note 15), he does not refer to the actual argument of Book III. Nevertheless, in light of Kant's earlier implicit and explicit references to the main steps in the argument of Book III in the Dynamics, it is plausible to suppose, as we have also already suggested, that Kant is in fact envisioning a cosmological extension of just this Newtonian argument. After determining the earth's state of true rotation, we then take up the perspective of the center of mass of the solar system, relative to which all rotational and orbital motions within this system can be given a unified representation within a single frame of reference; we proceed from there to the center of mass of the Milky Way galaxy, from there to the center of mass of a system of such galaxies, and so on *ad infinitum*. It is in precisely this way, as pointed out above, that we obtain an empirically meaningful surrogate for Newtonian absolute space, now reconceived as a regulative idea of reason, whereby all true or actual motions in the universe can be eventually effectively determined.[16]

Kant concludes the Phenomenology by reflecting on various concepts of *empty space*: phoronomical, dynamical, and mechanical. His main point, with reference to the earlier discussion in the Dynamics, is that there is no need to assume empty spaces interspersed within otherwise perfectly hard or solid matter to explain observed differences in density (and thus differences in quantity of matter). Kant concludes, therefore, by pointing, once again, to the indefinitely extended regress towards smaller and smaller parts of (continuously distributed) matter characteristic of Kant's critical version of the dynamical theory – which regress, as we have seen, is complementary, within his critical system, to the above progress towards larger and larger (rotating) systems of matter converging (in the limit) towards what he calls absolute space.

[16] See the discussion to which note 7 above is appended and, for further details and argument, the references cited there.

Reading the *Metaphysical Foundations*

The *Metaphysical Foundations* is difficult to read, even by Kantian standards. The argument is often very compressed, and the text appears to have been written rather hastily. In addition, the quasimathematical style of presentation (which it shares with the *Physical Monadology* and some other precritical works) – its organization into definitions (explications), propositions, proofs, remarks, and so on – is quite formidable and creates further difficulties for the reader. It is therefore especially important in this case to supply some of the missing context on one's own. It helps a great deal, in particular, to connect the text with both other works in natural science and natural philosophy against the background of which Kant was writing, and with his own precritical writings that he is here in the process of revising and developing.

The author to whom Kant explicitly refers most often – far more often than any other – is Newton, and most such references are to the *Principia*. So it greatly helps to read the *Metaphysical Foundations* with the *Principia* ready to hand, and to track down all references, both explicit and implicit, to this work. Some of the more obvious implicit references are recorded in my notes, but it pays to be alert for other points of comparison as well. When Kant gives an official definition of something like "quantity of matter," for example, it is illuminating to consult Newton's definition of the same concept. In addition to the *Principia*, Kant also refers, both explicitly and implicitly, to the *Optics*; here again, one should be alert for such references as well, which are typically to the Queries at the end of the *Optics*. But Newton is not, of course, the only writer in natural science and natural philosophy to whom Kant refers and with whom he was quite familiar. He explicitly refers, for example, to Descartes, Euler, Kepler, Lambert, Leibniz, and Mariotte. In the case of Leibniz, the correspondence with Clarke was of course particularly salient, along with other Leibnizean texts with which Kant was familiar, such as the *Theodicy, New Essays Concerning Human Understanding*, and *Monadology*. In the case of Euler, his *Letters to a German Princess on Different Subjects in Natural Philosophy* (where, for example, he describes his important wave theory of light) exerted a deep influence on both the eighteenth-century discussion of such issues in general and on Kant's own thinking in particular.

Among Kant's precritical writings, as I have already explained, the *Theory of the Heavens* and *Physical Monadology* are especially central and important pieces of the background to the *Metaphysical Foundations*. Also important, however, are the *New Elucidation of the First Principles of Metaphysical Cognition* (1755), *The Only Possible Argument in Support of a Demonstration of the Existence of God* (1763), the *Attempt to Introduce the Concept of Negative Magnitudes into Philosophy* (1763), the *Inquiry Concerning the Distinctness of the Principles of Natural Theology and Morality* (1764), *Dreams of a Spirit-Seer* (1766), *Concerning the Ultimate Ground of the Differentiation of Directions in Space* (1768), and the *Inaugural Dissertation* (1770).[17] The *New Elucidation* and *Physical Monadology* constitute a particularly important pair of works here, for the *New Elucidation* stands to the *Physical Monadology* as the *Critique of Pure Reason* stands to the *Metaphysical Foundations*: the former work presents the more general metaphysical framework within which the more specific natural philosophical discussions in the latter then proceed. So here it is especially illuminating, for example, to consider how the concept of a "force of inertia," as discussed in both the *New Elucidation* and the *Physical Monadology*, is intertwined with the more general monadological conception of substance articulated in both works – and to read the explicit rejection of this concept in the Mechanics of the *Metaphysical Foundations* against this precritical background.

Some of the most obvious points of connection and correspondence between the *Critique of Pure Reason* and the *Metaphysical Foundations* have already been discussed above. And it is clear that the *Critique of Pure Reason*, more generally, provides the overarching philosophical context for the more specific issues in natural science and natural philosophy with which Kant is occupied in the *Metaphysical Foundations*. One should, therefore, be alert to this context at all times. For example, since, as we have seen, each main chapter of the *Metaphysical Foundations* corresponds to a heading of the principles of pure understanding as discussed in the Transcendental

[17] All of these are translated in the volume edited by Walford cited in note 5 above (with the exception of the *Theory of the Heavens*, for which see note 4). For a discussion of the natural philosophical significance of *Dreams of a Spirit-Seer* see the work of Laywine cited in note 3. Kant's correspondence with Lambert is especially important for Kant's intellectual development prior to and in connection with the *Inaugural Dissertation*; it is translated in A. Zweig, ed., *Correspondence* (Cambridge: Cambridge University Press, 1999). (In general, Lambert and his influence on Kant are helpfully described in the work of Beck cited in note 3.) Another particularly important precritical work (from the point of view of the *Metaphysical Foundations*), which has unfortunately not yet been translated into English, is the *Neuer Lehrbegriff der Bewegung und Ruhe* (*New System of Motion and Rest*) of 1758.

Analytic – the Axioms of Intuition, Anticipations of Perception, Analogies of Experience, and Postulates of Empirical Thought, respectively – one should always read the corresponding chapters of the *Metaphysical Foundations* in relation to these discussions in the Transcendental Analytic. But of course Kant's theory of space and time in the Transcendental Aesthetic is also very important, as well as such parts of the Transcendental Dialectic as the Antinomies of Pure Reason and the Appendix on the regulative use of reason. More generally, whenever Kant discusses space, motion, force, or matter in the first *Critique*, such discussions illuminate (and are illuminated by) the corresponding discussions of these concepts in the *Metaphysical Foundations*.

There is a final issue about reading the *Metaphysical Foundations* that concerns the structure and organization of the text itself. Although Kant is, in a sense, presenting a continuous linear argument, it is often the case that earlier arguments point towards later parts of the text for their completion and full articulation. Thus, as we have seen, Kant formulates a principle of the relativity of motion in the Phoronomy, but he also explicitly qualifies it there with respect to issues that are only later discussed in the Mechanics and Phenomenology. Similarly, he gives an argument for the infinite divisibility of material substance, and explicitly opposes the *Physical Monadology* in this regard, in the Dynamics; he returns to this question, and again opposes the *Physical Monadology* on the same issue, in the later discussion of quantity of matter and its conservation in the Mechanics – where, in particular, the concept or category of substance is now more explicitly salient. More generally, then, one should always be alert to the many and varied ways in which Kant anticipates later discussions earlier in the text and, conversely, refers back to earlier parts of the text in later discussions. In this sense, the text is more "dialectical" than linear, in that the meaning and point of what Kant is saying, at any given stage, only becomes fully articulated at a later stage. In the end, there is no alternative to reading and rereading Kant's text repeatedly, while patiently attempting to assemble all the pieces of the puzzle bit by bit; in my experience, however, it more than amply repays the effort.