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The Significance of a Non-Reductionist Ontology for the Discipline of Physics: A Historical and Systematic Analysis

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Abstract An overview of the history of the concept of matter highlights the fact that alternative modes of explanation were successively employed. With the discovery of irrational numbers the initial conviction of the Pythagorean School collapsed and was replaced by an exploration of space as a principle of understanding. This legacy dominated the medieval period and had an after-effect well into modernity—for both Descartes and Kant still characterized matter in spatial terms. However, even before Galileo the mechanistic world view slowly entered the scene—the world as chaos, particles in motion. Elevating movement to become the guiding principle in our understanding of matter dominated the main tendency of modern physics until the (end of the) 19th century. The discovery of irreversible processes (radio-activity for example) directed 20th century physics towards an exploration of the meaning of energy-operation. It turned out that even within 20th century physics long-standing legacies prevailed, because an account of the nature of matter continued to be torn apart by atomistic and holistic views—confronted by the problem of constancy and change (radical transformability versus persistence). Concrete, material reality exceeds the scope of any single mode of explanation—an insight that also serves a better understanding of the wave-particle duality.

Keywords Arithmeticism · Law side · Factual side · Arithmetical and spatial addition · Straight line · Uniqueness and coherence

It is sufficient to consider, for example, the discussions concerning the nature of space and time, determinism, indeterminism and causality, the continuous

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> or discontinuous characteristics of matter and energy, the infinity or finiteness of the universe that have been produced by the developments of contemporary physics: even when they have been led by professional and outstanding physicists, they were of a genuine philosophical nature, as it can be easily seen if we consider that they also occupied the mind of several outstanding professional philosophers of our time. Moreover, they count among the most typical and classical questions of the philosophy of nature of all times, and the fact that they are still the object of lively discussions also after the acceptance, say, of relativity and quantum physics clearly indicates that they have not been *solved* by such theories, but simply further problematized as a consequence of them (Agazzi 2001:10).

1 Introduction

An understanding of modern physics is crucially dependent upon a clear distinction between the four most basic aspects of reality, namely number, space, movement and the physical aspect. The uniqueness and coherence of these fundamental aspects of reality are indispensible in an assessment of the implications of a non-reductionist ontology for the foundation of the discipline of physics.

Interestingly, the dominant philosophical orientation amongst the special sciences during the first half of the 20th century wanted to restrict science to the "positive facts" that were assumed to be the sole guide to "objective scientific truth." "Sense data," were supposed to be the only source of reliable knowledge, and this position supported the postulate of the *neutrality* of human rational endeavors. The latter conviction (!) erroneously labeled any ultimate commitment (conviction) operative within the domain of rationality as a *disturbing factor* that should be *eliminated* from science.

However, without an implicit *trust* or *faith* in reason this postulate itself cannot be maintained. All human beings are endowed with the capacity to think and to argue rationally, but they do this from one or another *diverging direction-giving orientations*. Consequently, despite the fact that positivism acknowledged that there are universal structural conditions for theory making, it never allowed that deep, extra-scientific convictions could be among them. This overlooks the point made by Stegmuller to the effect that there is no single domain in which a self-guarantee of human thinking exists—one already has to *believe* in something in order to *justify* something else (Stegmüller 1969:314).

An analysis of the *structure* of scientific activities therefore does not aim at *securing* a domain of the *good* by protecting it from the evil influence of direction-giving ultimate commitments, for any such analysis can only advance by implicitly proceeding from a particular life-orientation.

There are not simply 'scientific' people *liberated* from any and all supra-rational convictions, and "non-scientific" people blurred by the 'evil' of adhering to some or other *conviction*. Whatever the life-orientation of thinkers may be, they all equally share in the dimension of *rationality* (or: logicality) and all of them are inevitably in the *grip* of a more-than-rational *ultimate commitment*.[1]

The positivistic appeal to *sense data* is problematic, because the theoretical 'tools' employed in the *description* of what is observed always utilize *terms* that are not susceptible to "empirical observation" themselves. In order to demonstrate this point it will be instructive to consider the history of the concept of *matter*.

1.1 Historical Perspective on the Concept of Matter

The early Greek philosophers chose one or another fluid element as the principle material Origin of all else, such as *water* (Thales), *fire* (Heraclitus) and *air* (Anaximenes). Subsequently, the school of Pythagoras opposed the earlier theories by insisting that rationality could only be understood as mathematical relationships. On that ground they proposed that everything is number. Naturally this school went too far in its above-mentioned one-sided claim that *everything is number*. This thesis rests on the conviction that with the aid of the relation between integers, i.e., by merely using normal fractions, it is possible to describe the 'essence' of whatever there is in numerical terms.

However, soon the developments within Greek thought became sensitive to *spatial configurations*—such as the shape of the calyx leafs found in nature, for this shape appeared as an instantiation of a *regular pentagram*. An investigation of the geometrical properties of a regular pentagram led to the discovery that it is not possible to express the *ratio* between any side and any diagonal of the regular pentagram with the aid of normal fractions, i.e., in terms of the *ratio* of two whole numbers/integers: a/b. This limitation at once embodied the discovery of 'incommensurable' quantities—something completely unacceptable for the Pythagoreans because suddenly within the limiting and form-giving nature of number the *apeiron* (the unbounded-infinite) appeared, i.e., irrational numbers were discovered.

Flowing from the inherent tension in Greek thought between what *is limited* and what *is unlimited* (the *peras* and the *apeiron*) the discovery of irrational numbers (or in modern mathematical terms: real numbers) inspired the search for an alternative principle of explanation—one that could escape from the unbounded (infinite) present in number.

The alternative mode of explanation proposed was that of space. The spatial aspect allowed for the acceptance of *static forms* and it also opened the possibility of observing any spatial figure *at once*, without any *before* and *after*. The implication was that the acquisition of concepts is enclosed within the *now* (and in the school of Parmenides this resulted in the equation of *thought* and *being*).

It is known that on the basis of Babylonian observations Thales accurately predicted an eclipse of the sun in the year 585 B.C. He also had the remarkable geometrical skill of being able to calculate the height of a pyramid from a sun shadow of 45° (keeping in mind that a pyramid differs from something like a tree where it is possible to establish its height perpendicular to its base). Thales also

[1] A penetrating analysis is given by Clouser in terms of the hidden role of religious belief in theories (see Clouser 2005).

knew that the diagonals of a rectangular triangle are equidistant, and according to Lorenzen he provides the starting-point for geometry as a coherent theoretical system (Lorenzen 1960:45–46).

The important feature of this development is that the spatial figures of Greek geometry were *idealized*. It meant that a straight line, circle and square are not perceivable in a sensory way—they can merely be contemplated intellectually. Plato's account of human knowledge reflects this conviction because he explicitly states that the conclusions reached do not use "sensory objects":

> Then by the second section of the intelligible world you may understand me to mean all that unaided reasoning apprehends by the power of dialectic, when it treats its assumptions, not as first principles, but as *hypotheses* in the literal sense, things 'laid down' like a flight of steps up which it may mount all the way to something that is not hypothetical, the first principle of all; and having grasped this, may turn back and, holding on to the consequences which depend upon it, descend at last to a conclusion, never making use of any sensible object, but only of Forms, moving through Forms from one to another, and ending with Forms (*Politeia*, 510D).

Plato's dialogue Meno, where the leader of the conversation used leading questions in order to allow the conversation partner to produce a geometrical proof, caused Oskar Becker to remark that this gave birth to the appreciation of the *a priori* nature of mathematics (Becker 1965:X).

The effect of the discovery of irrational numbers was not only that mathematics was geometrized, but it also paved the way for a speculative theory of reality attempting to explain the entire universe in terms of a *spatial perspective*—as a substitute for the outdated arithmetical orientation of the Pythagoreans. The implication was that Greek thought now understood *matter* in terms of spatial extension. An entity is identified with the place it occupies. Something *is* its place.

It should be noted, however, that Parmenides hardly had an independent space concept at his disposal. He also did not contemplate the idea of an *empty space*. When something *is* its place, then the absence of something implies that the subject to which the predicate 'place' applies is not present. Herman Fränkel writes: "With the assertion of a complete filling of space… the existence of a mere empty space is rather denied than acknowledged." (Fränkel 1968:181, note 4.)

In its denial of movement, the school of Parmenides—especially as exemplified by the arguments of Zeno—formulated the consequences of over-emphasizing the spatial aspect as mode of explanation. If something indeed *is* its place then it can never move, for passing from one place to another place will entail a change of essence!

This metaphysical overextension of the *static* nature of space even motivated a remarkable denial of the spatial whole-parts relation.

In order to understand this properly we have to keep in mind what we have explained earlier, namely that whatever is continuously extended in a spatial sense allows for an infinite divisibility. The spatial whole-parts relation turns the original numerical meaning of succession—what I prefer to call the successive infinite[2]—'inwards,' it is embodied in the successive infinite divisibility of a continuum. Because the way numerical aspect is basic to the spatial aspect (as I argued in the article on mathematics), it turns out that the spatial part/whole relation can be endlessly divided.

The spatial metaphysics of Parmenides, by contrast, inspired Zeno to defend a view of *unitary wholeness* that *excludes* plurality. In other words, Zeno wants to *deny* the 'part'-element of the spatial whole-parts relationship while at the same time holding on to the 'wholeness' which entails it.

> His position is that reality is both *one* and *indivisible*. Yet, in order to *argue* for his position, he explored the whole-parts relation in his argument that is aimed at the *denial* of plurality! The reason why Zeno considers plurality to be self-contradictory is that plurality requires a *number* of (indivisible) units and because it also implies that reality is *divisible* (see Guthrie 1980:88). But divisibility threatens the wholeness of a *unit*, since anything divisible has to be a magnitude which must be infinitely divisible. The supposed *indivisibility* of a *unit* clashes with its *infinite divisibility*. "Hence, since plurality is a plurality of units, there can be no plurality either" (Guthrie 1980:89).

It was confusing two distinct modes of explanation (the quantitative and the spatial), and stripping from them their necessary connections, that cause such multiple distortions. The school of Parmenides did realize that space provides an original mode of explanation, but in the attempt to 'purify' space from number it dismissed a foundational condition of space, space, namely, a multiplicity. By ignoring the foundational role of a numerical multiplicity, Zeno distorted the meaning of number and also skewed the nature of space by questioning the divisibility of a spatial continuum. The infinite divisibility of a continuous whole within space is a reminder of the original successive meaning of number lying at the basis of space. Just as it is impossible to separate space from other aspects of reality, so too it is impossible to separate space from the numerical aspect. Even in the most extreme examples of arithmeticism in modern mathematics, aiming to reduce space to number, key features of space were ineliminable. In the case of axiomatic set theory for example it turned out that undefined ('primitive') terms derived from the spatial whole-parts relation were unavoidable, such as *set* or *element of* (see Fraenkel et al. 1973:21 ff).

The original numerical meaning of the number one as an integer analogically appears within the spatial aspect. This points to the fact that the unity of a space is constituted as a genuine *whole* or *totality*, a unitary whole allowing an *infinite divisibility*. The speculative (metaphysical) idea of a unitary whole *precluding* multiplicity robs both number and space from their unique meaning as well as from their mutual coherence.

[2] The traditional distinction is between the potential infinite and the actual infinite. The alternative distinction is that between the *successive infinite* and the *at once infinite*.

In respect of the nature of material things the most important consequence is that the Greek-Medieval legacy only acknowledges *concrete material extension*. Extension characterizes the nature of material things.

Within the Aristotelian legacy it was believed that celestial bodies obey laws that are different from those that hold for entities on earth. In addition it was believed that the movement of anything required a *cause*. The problem of motion increasingly acquired a more prominent position, although it did not mean that the powerful influence of the classical space metaphysics immediately lost its hold. The power of this spatial orientation is indeed still evident in the thought of Descartes (1596–1650) and even Immanuel Kant (1724–1804). In their understanding of nature both these philosophers continued to assign a decisive role to *spatial extension*. For Descartes *extension* serves as the essential characteristic of material bodies—*res extensa*, for he writes: “That the nature of body consists not in weight, hardness, colour, and the like, but in extension alone” (Descartes 1965:200—Part I, IV). Kant (1787) characterization of material bodies is also oriented to space. When our understanding leaves aside everything accompanying their representation, such as substance, force, divisibility, etc., and likewise also separate that which belong to sensation, such as impenetrability, hardness, color, etc., then from this empirical intuition something else is left, namely extension and shape.[3]

It should not surprise us therefore that Descartes straightaway applied the feature of (mathematical) continuity to material things and even to atoms which since Greek antiquity, were supposed to be the last indivisible material particles. He holds that there cannot be atoms or material particles that are inherently non-divisible.

> We likewise discover that there cannot exist any atoms or parts of matter that are of their own nature indivisible (Descartes 1965:209; Part I, XX).

In this context (XX) he even introduces the idea of God in order to make acceptable the infinite divisibility of matter. He argues that although God can make a particle small enough that no creature can divide it this does not set any limits to the Divine capacity to divide. Therefore it should be assumed that matter is indeed infinitely divisible:

> Wherefore, absolutely speaking, the smallest extended particle is always divisible, since it is such of its very nature.

That Descartes continues to hold on to *extension* as the essential trait of matter embodies his connection with the long-standing Greek-Medieval tradition. However, what he has to say regarding the infinite divisibility of matter breathes the spirit of the early modern *functionalistic* orientation.[4] This new functionalistic attitude soon attempted to explain concrete things completely in *functional* terms. Yet Descartes at the same time did pay attention to motion, which he defined as the

[3] “So, wenn ich von der Vorstellung eines Körpers das, was der Verstand davon denkt, als Substanz, Kraft, Teil-barkeit usw., imgleichen, was davon zur Empfindung gehört, als Undurchdringlichkeit, Härte, Farbe usw. absondere, so bleibt mir aus dieser empirischen Anschauung noch etwas übrig, nämlich Ausdehnung und Gestalt” (Kant 1781/1787-B:35).

[4] Functionalism reduces entities to functions and substantialism reduces functions to entities.

"action by which a body passes from one place to another" (Descartes 1965:210; Part I, XXIV). This new point of view finds itself on the cross-road of the transition from the Medieval to the modern era.

Although Buridan (early 14th century) did contribute to the uprooting of the dominant position of spatial extension and the transition to the modern era, it should be kept in mind that the *impetus* idea itself cannot be equated with the nature of *inertia*. There is a conception that the mechanics of Buridan and classical physics are fundamentally similar, entailing that the *impetus theory* practically already brought to expression the *law of inertia*.

This convergence is first of all sought in the supposed correlation between the scholastic view of impetus and the dynamic element of inertial motion. In the second place it was believed that the assumption of *permanence* present in Buridan's view of impetus already discovered the law according to which motion not disturbed in any way will be everlasting (cf. Maier 1949:142).

It is indeed striking that an *impetus* that was transferred in a celestial sphere (supposed to follow a *circular* path) was supposed to be free from any resistance. Therefore it seemed proper to compare it with the underlying idea of inertia. But inertia concerns uniform (rectilinear) motion, not circular motion. In the case of the impetus theory there was a difference between what happened in the heavens and happened on earth. According to the Medieval Scholastic understanding a force without resistance cannot produce motion. But since *impetus* is artificially and forcefully superimposed upon some or other obstacle (i.e., an interfering force of motion), such an obstacle can only be overcome when the impetus itself is altered in the process of overcoming the resistance. Yet the decisive difference between these two views is given in that element of inertial movement from which one cannot abstract, namely the inertia of a mass-point.[5] It is possible to abstract from external obstacles and forces, but it is impossible to abstract from that which is crucial for inertia, namely the *mass* of whatever moves. According the classical mechanics the latter is the real factor in the continuation of movement (inertia). In the case of the impetus theory inertial mass serves as resistance (obstacle) for the movement of the impetus that caused it. Consequently there is an unbridgeable gap between the impetus theory and the basic idea if inertia, namely the possibility of an everlasting rectilinear motion.[6] The issue at stake is to arrive at a proper understanding of the unique and irreducible nature of distinct modal aspects of reality, also serving as modes of explanation—the main focus of a non-reductionist ontology.

The truly modern era in physics begins with Galileo, who formulated his law of inertia. Galileo formulated his law of inertia with the aid of a *thought experiment*. Suppose a body moves on a friction-free path extended into infinity, then this movement will simply continue endlessly. Opposed to the traditional Aristotelian-Scholastic conception according to which the movement of a body is dependent upon a *causing force*, the law of inertia implies the motion is something *given* and

[5] In classical mechanics the simplest subject is a mass-point.

[6] Maier writes: "Es gibt also gar keinen Ausweg: die Möglichkeit einer in infinitum daurenden gleichförmigen Bewegung des proiectum ist von Standpunkt der Impetustheorie aus grundsätzlich ausgeschlossen" (Maier 1949:148).

that therefore instead of trying to deduce or explain it should be accepted as a mode of explanation in its own right. Motion is original and unique and indeed, embodies a distinct *mode of explanation* different from those used by the Pythagoreans (number) and the Eleatic school of Parmenides (space). If motion does not need a causing force, then at most it is possible to speak of a *change* of motion (*acceleration* or *deceleration*)—and this does need a *physical force*. The well-known German physicist Von Weizsäcker remarks:

> Since the law of inertia has shown that no force is required for a change of place the most natural thing to do is to accept that force causes a change of speed, or, as Newton says, the magnitude of motion ('Bewegungsgröße') (Von Weizsäcker 2002:172).[7]

The idea of a uniform (rectilinear) motion on the one hand expands the inherent limitations attached to number and space as modes of explanation, and on the other it opens the way to consider another problem that already captured Greek thought. This problem concerns the relation between *persistence* (think about the nature of inertia) and *dynamics* (consider the change of motion requiring a physical force).

The important insight of Plato is that change can only be established on the basis of constancy (persistence)—i.e., without an enduring subject there is nothing to "hold on to," nothing to which the alleged changes can be attributed. Of course this insight does not force us to join the specualative account which Plato gave for it in his metaphysical theory of static, super-sensory ideal forms—it is true that his solution did form a lasting attraction for many scholars. Even Frege said that amidst the on-going flow of events something lasting, something with eternal durability must exist for otherwise the knowability of the world would be canceled and everything would collapse in confusion.[8]

The proper elaboration of Plato's insight, namely that change presupposes constancy, is found in Galileo's formulation of the law of inertia and in Einstien's theory of relativity. The core idea of Einstein's theory is the constancy of the velocity of light in a vacuum. Although he often merely speaks of "the principle of the constancy of the speed of light",[9] he naturally intends "the principle of the vacuum-velocity" ("das Prinzip der Vakuumlichtgeschwindigkeit"—see Einstein 1982:30–31; and also Einstein 1959:54). From this it follows that Einstein primarily aimed at a theory of *constancy*—whatever moves, moves relative to this element of constancy. It was merely a concession to the historicistic *Zeitgeist* at the beginning of the 20th century that he gave prominence to the term 'relativity'—all movement is relative to the constant *c*.

However, a certain ambiguity is still found in the thought of Descartes and his followers for in spite of the fact that they viewed *extension* as the essential property of matter, they also simultaneously pursued the kinematical ideal to explain

[7] "Da das Trägheitsgesetz gezeigt hat, daß keine Kraft nötig ist für eine Änderung des Orts, ist es das natürlichste, anzunehmen, die Kraft verursacht eine Änderung der Geschwindigkeit, oder, wie Newton sagt, der Bewegungsgröße".

[8] "Wenn in dem beständigen Flusse aller Dinge nichts Festes, Ewiges beharrte, würde die Erkennbarkeit der Welt aufhören und alles in Verwirrung stürtzen" (Frege 1884:VII—Einleitung).

[9] "das Prinzip der Konstanz der Lichgeschwindigkeit"—cf. Einstein 1982:32.

everything that exists and happens exclusively in terms of movement (cf. Maier 1949:143).[10] It is generally known that Thomas Hobbes took the full step to the exploration of movement as principle of explanation in his intended rational reconstruction of reality. According to the newly established natural science ideal he first demolished reality to a heap of chaos in order afterwards to build up, step by step, a new rationally ordered cosmos, guided by the key concept "moving body." His acquaintance with the mechanics of Galileo enabled him to exceed the limits of space as mode of explanation. Galileo himself embodies the long history of our understanding of matter up to this phase of its development because he explicitly explores the three modes of explanation thus far highlighted in our discussion. He accounts for arithmetical properties (countability), geometrical properties (form, size, position and contact) and kinematic features (motion).[11] Leibniz continues this legacy in his belief that physical events can be explained mechanisticlly in terms of magnitude, figure, and motion.[12]

As soon as the kinematic mode of explanation is acknowledged in its own right the necessity to find a cause for motion disappears. The classical opposition between *being at rest* and *moving* is therefore untenable, because from a kinematic perspective 'rest' is a state of movement (cf. Stafleu 1987:58). Unique and irreducible modes of explanation are not *opposites*—for they are mutually cohering and irreducible.[13]

Although Descartes and Newton did employ the concept *force*, it may in general be said that modern physics since Newton is characterized by its *mechanistic* main tendency. The mechanistic view consistently attempts to reduce all physical phenomena to a *kinematic perspective*. However, already in the course of the 19th century modern physics started to explore the nature of *energy*. The founder of physical chemistry, Wilhelm Ostwald, developed his so-called *Energetik* (energetics) that even influenced the later views of Heisenberg. Vogel refers to Heisenberg's work "Wandlungen in den Grundlagen der Naturwissenschaft" (Stuttgart 1949) where the latter explicitly speaks of energy as the basic stuff that constitutes matter in its threefold stable forms: electrons, protons and neutrons (Vogel 1961:37). Yet Ostwald's *Energetik* did not exert a lasting influence upon the physics of the 20th century, probably because it was attached to a specific view of continuity opposed to

[10] Maier remarks that "Descartes und seine Schule" indeed pursued a "rein phoronomisches Ideal" and attempted to explain "alles Sein und Geschehen in der Welt lediglich aus Bewegungen".

[11] "G. Galilei zählt als primäre Qualitäten der Materie arithmetische (Zählbarkeit), geometrische (Gestalt, Größe, Lage, Berührung) und kinematische Eigenschaften (Beweglichkeit) auf" (Hucklenbroich 1980:291).

[12] On October 9, 1687 Leibniz wrote in a letter that we "must always explain nature mathematically and mechanically" (Leibniz 1976:38). In a footnote the Editor of Leibniz's work writes that Leibniz's approval of the corpuscular philosophy of Boyle ought to be understood as "any philosophy which explains physical events mechanistically or in terms of magnitude, figure, and motion" (Leibniz 1976:349, note 14).

[13] For that reason we also number and space ought not to be seen as opposites as it was asserted by Lakoff en Núñez (2000:324) owing to their inability to appreciate the unique and mutually cohering nature of these aspects.

an atomistic approach. Niels Bohr particularly mentions the excessive skepsis found in the thought of Mach regarding the existence of atoms.[14]

The last prominent physicist who consistently adhered to the mechanistic approach was Heinrich Herz. Soon after Hertz's death in 1894 the work in which he attempted to restrict the discipline of physics to the concepts mass, space and time, reflecting the three most basic modes of explanation of reality, namely the modes of number, space and movement, appeared: "The Principles of Mechanics developed in a New Context." This caused him (and Russell) to view the concept of *force* as something intrinsically antinomous.

The Latin designation of *mass* during the medieval period was "quantitas materiae" (see Maier 1949:144). From this it appears that number (quantitas) plays a key role in the concept *mass*. Mass concerns a *physical* quantity, but it is also possible to observe the quantity of energy from the perspective of the *kinematical* modality. In this case the technical expression is *kinetic energy* that indicates the action capacity inherent to a moving body (see Maier 1949:142).

As soon as the physical aspect of reality surfaced it opened up the way for 20th century physics to explore it as an independent mode of explanation and to arrive at an even more nuanced understanding of reality. For example, in his *protophysics* Paul Lorenzen distinguishes four units of measurement reflecting the first four modes of explanation: *mass*, *length*, *duration* and *charge* (Lorenzen 1976:1 ff.).

A decade after Max Planck discovered his "Wirkungsquantum" he explicitly addressed the intrinsic untenability of the mechanical understanding of reality.

> The conception of nature that rendered the most significant service to physics up till the present is undoubtedly the mechanical. If we consider that this standpoint proceeds from the assumption that all qualitative differences are ultimately explicable by motions, then we may well define the mechanistic conception as the conviction that all physical processes could be *reduced completely to the motions* (the italics are mine – DFMS) of unchangeable, similar mass-points or mass-elements.[15]

Writing on the foundations of physics, David Hilbert refers to the mechanistic ideal of unity in physics but immediately adds the remark that we now finally have to free ourselves from this untenable ideal (cf. Hilbert 1970: 258).[16]

Einstein is equally explicit in his negative attitude towards "the mechanistic framework of classical physics" (see Einstein 1985:146).

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[14] See Niels Bohr, Atomtheorie und Naturbeschreibung (Berlin 1931:60 and p. 12), quoted by Vogel 1961:35). It should be kept in mind that the views of Mach ought to be understood against the background of the position of Ostwald.

[15] "Diejenige Naturanschauung, die bisher der Physik die wichtigsten Dienste geleistet hat, ist unstreitig die mechanische. Bedenken wir, daß dieselbe darauf ausgeht, alle qualitativen Unterschiede in letzter Linie zu erklären durch Bewegungen, so dürfen wir die mechanische Naturanschauung wohl definieren als die Ansicht, daß alle physikalischen Vorgänge sich vollständig auf Bewegungen von unveränderlichen, gleichartigen Massenpunkten oder Massenelementen zurückführen lassen" (Planck 1973:53).

[16] It is therefore strange that the contemporary physical scientist from Cambridge, Stephen Hawking, still writes: "The eventual goal of science is to provide a single theory that describes the whole universe" (Hawking 1988:10).

Eventually the distinction between the kinematic and physical aspects of reality thus became common knowledge. According to Janich the scope of an exact distinction between *phoronomic* (subsequently called *kinematic*) and *dynamic* arguments could be explained in terms of an example. Modern physics has to employ a dynamic interpretation of the statement that a body can alter its speed only continuously. Given certain conditions a body can never accelerate in a discontinuous way, that is to say, it cannot change its speed through an infinitely large acceleration, because that will require an infinite force.[17]

The idea of an attracting force, initially conceived of in connection with magnetism, eventually brought Newton to the insight that magnetism is a force that cannot be explained through motion, although in its own right, foundational to the physical aspect, motion is a mode of explanation. Stafleu points out that the rejection of the Aristotelian distinction between the physics of celestial bodies and the physics of things on earth paved the way, in the footsteps of Galileo and Descartes, to realize that the same physical laws apply to both domains, i.e., that physical laws display modal universality (i.e., they hold universally) (Stafleu 1987:73). He also remarks that Newton (just as Kepler) indeed already appreciated *force* positively as a principle of explanation that is distinct from motion as an original principle of explanation (see Stafleu 1987:76). Stafleu summarizes this process through which the physical aspect emerged as an equally original mode of explanation as follows:

> In Newtonian mechanics, a force is considered a relation between two bodies, irreducible to other relations like quantity of matter, spatial distance, or relative motion. Though an actual force may partly depend on mass or spatial distance, as is the case with gravitational force, or on relative motion, as is the case with friction, a force is conceptually different from numerical, spatial or kinematic relations (Stafleu 1987:79).

Since the introduction of the atom theory of Niels Bohr in 1913, and actually already since the discovery of radio-activity in 1896 and the discovery of the energy quantum h, modern physics realized that matter is indeed characterized by physical energy operation. It is therefore understandable that 20th century physics eventually had to come to a general acknowledgement of the decisive significance of *energy operation* for the nature and understanding of the physical world, as it is strikingly captured in Einstein's famous formula:

$$E = mc^2.$$

[17] "Die Tragweite einer strengen Unterscheidung phoronomischer (im folgenden kinematisch genannt) und dynamischer Argumente möchte ich an einem Beispiel erlautern, das… aus der Protophysik stammt. Die Aussage "ein Körper kann seine Geschwindigkeit nur stetig ändern" kann von der modernen Physik nur dynamisch verstanden werden. Geschwindigkeitänderungen sind Beschleunigung, d.h. als Zweite Ableitung des Weges nach der Zeit definiert. Zeit wird von der Physik als ein Parameter behandelt, an dessen Erzeugung durch eine Parametermaschine ("Uhr") de facto bestimmte Homogenitätserwartungen geknüpft sind … Bezogen auf den Gang einer angeblich so ausgewählten Parametermaschine kann eine Körper seine Geschwindigkeit deshalb nicht unstetig, d.h. mit unendlich große Beschleunigung änderen, weil dazu eine unendlich große Kraft erforderlich wäre" (Janich 1975:68–69).

It was also realized that physical processes are *irreversible*. In itself this observation also justifies the distinction between the kinematic and the physical aspects of reality. Both Planck and Einstein knew that from a purely kinematic perspective all processes are *reversible*. Einstein refers to Boltzmann who realized that thermodynamic processes are irreversible.[18] Already in 1824 Carnot discovered irreversible processes. Since 1850 Clausius and Thompson independently developed the second main law of thermodynamics, known as the law of non-decreasing entropy. This law accounts for the fundamental irreversibility of natural processes within any *closed system*. The term *entropy* itself was introduced by Clausius only in 1865. In 1852 Thomson explains that according to this law all available energy strives towards uniform dissipation (see Apolin 1964:440; Steffens 1979:140 ff.). Planck remarks that "the irreversibility of natural processes" confronted "the mechanical conception of nature" with "insurmountable problems" (Planck 1973:55).

It is only on the basis of an insight into the foundational position of the kinematic aspect in respect of the physical aspect that an appropriate designation of the first law of thermodynamics is made possible. Although we are used to employ the familiar designation of it as the law of *energy conservation* there is an element of ambiguity attached to the term 'conservation'—as if energy is "held on to." When, on the law-side, the retrocipation from the physical aspect to the kinematic aspect is captured by the phrase *energy constancy* this ambiguity disappears and then we have at hand a concise and precise formulation of this law.

2 The Mystery of Matter

The preceding historical sketch was intended to make clear that although each one of the four modes of explanation open up a legitimate angle of approach to physics none of them can claim to be the *exclusive* and/or *exhaustive* source of our knowledge of material things. Whatever their worth, they merely provide us with a *partial* perspective, one that will always be co-determined by a *totality view* exceeding the scope of any specific mode of explanation. Such a totality perspective actually exceeds the scope of any special science since it inevitably rests upon some or other philosophical view of reality.

The impressive power of theoretical thinking first of all derives from exploring the *universality*, of specific modal aspects. The philosophically informed physicist Von Weizsäcker implicitly draws upon this insight when he appreciates quantum theory as the *central theory* of contemporary physics. His explanation highlights the modal universality of the physical aspect, for this modal universality is not restricted by the typical nature of any (type of) entity—it cuts across all typical differences. We have noted that Von Weizsäcker says:

[18] "Er hat damit das Wesen der im Sinne der Thermodynamik "nicht umkehrbaren" Vorgänge erkannt. Vom molekular-mechanischen Gesichtspunkte aus gesehen sind dagegen alle Vorgänge umkehrbar" (Einstein 1959:42).

> Quantum theory, formulated sufficiently abstract, is a universal theory for all classes of entities (Von Weiszäcker 1993:128).[19]

In addition to this appeal to modal universality Von Weizsäcker also explicitly articulates the fundamental philosophical insight that *everything coheres with everything*: ("Alles hängt mit allem zusammen"—Von Weiszäcker 1993:134).

The universality of each of the four modes of explanation we've been discussing entails that the scope of each is *unspecified*. This means that whatever concretely exists functions within every one of these modes of reality.

No single entity 'escapes' from having a (typically specified) function within each modal aspect of reality. This applies to the first four modal aspects in particular. This insight explains why, as we saw in our reflections on the history of physics, every one of them at some time was elevated to being the sole explanatory principle of physical reality.

For example, although the formulation of the law of gravity by Newton highlights the universality of the physical aspect, his entire *Principia Mathematica* is still permeated by geometrical language and arguments. This shows its dependence upon the Greek-Medieval space metaphysics preventing him from employing his own calculus. Although the concepts employed by him do take motion and dynamics into account, the general framework continued to be *geometrical* in nature.

In the case of the modal universality of the physical aspect the implication is that every (modal-functional) physical law holds for whatever actively (i.e., as a subject) functions in the physical aspect. In connection with the way in which Helmholtz formulated the first main law of thermodynamics—the law of *energy constancy* as we prefer to designate it—Steffens remarks that for "… Helmholtz the law of the conservation of force" includes "all known physical phenomena" (Steffens 1979:137).

In connection with the question regarding the nature of *matter* this insight leads us towards an understanding of the coherence between the first four modes of explanation.

In our discussion of the earliest phase of the development of Greek thought we alluded to attempts to come to an understanding of what *matter* is. We saw that initially this urge was closely related to the principle of origin sought by some of the prominent pre-Socratic philosophers, mentioning the choices of Thales (water), Anaximines (air), Heraclitus (fire) or the infinite-unbounded chosen by Anaximander. These elements were thought of as flowing, dynamic principles of origin, because at this early stage of Greek thought the basic motive of form, measure and harmony played a subordinate role. Nonetheless the dialectical struggle between form and the formless was played out in terms of the same basic ontic modes of reality that provided merely a *partial* perspective on material things. Perhaps this is one way to understand the mystery entailed in the question what matter is. For if the aspects as modes of explanation make possible only *partial answers* from functionally distinct angles of approach, then merely making an appeal to these

[19] "Die Quantentheorie, hinreichend abstrakt formuliert, ist eine universale Theorie für alle Gegenstandsklassen".

angles of approach will never solve the problem. It is therefore not surprising that Stegmüller believes that one of the most difficult questions facing science in the 20th century is indeed the concept of matter, which he considers to be mysterious in the utmost sense.[20]

Of course what Stegmüller has in mind is first of all the old adage that here are no jumps in nature, that it is *continuous* (“*natura non facit saltus*”). Yet we have seen that there is an important difference between physical space and mathematical space—the former is discontinuous since it is bound to the quantum-structure of energy and the latter is continuous and therefore allows for an infinite divisibility. Stegmüller writes:

> In the preceding sections we have repeatedly established how much precisely those disciplines that are focused on the largest bodily structures as such, astronomy, astrophysics and cosmology, remained dependent upon knowledge of the smallest. In fact presently we often cannot even say if the scientific puzzle or theoretical dilemma that here appears poses a challenge merely for the disciplines concerned with the largest or also at once a challenge for the disciplines concerned with matter. One can defend the mean assertion that the contemporary “matter experts” in a certain sense are forced into a worse acknowledgement than Goethe’s Faust. They are not only “not wiser than before,” namely in respect of the time when they commenced their research, but they simply not once have gotten wiser than those first thinkers who more than 2000 years ago attempted to provide a speculative foundation for matter.[21]

When Stegmüller continues his explanation of the problems attached to an understanding of the nature of matter the first four aspects of reality suddenly acquire a new actuality. In the first place he distinguishes two global basic conceptions regarding the nature of matter, and he points out that currently these conceptions once again, as previously, occupy a prominent place in the discussions. He calls these two basic conceptions the *atomistic conception* and the *continuity conception*.[22] Laugwitz also points out that insofar as physics subjects itself to

[20] “Und daß *auf der anderen Seite* ausgerechnet der Materiebegriff der schwierigste, unbewältigste und rätselhafteste Begriff überhaupt für die Wissenschaft dieses Jahrhunderts blieb” (Stegmüller 1987:90).

[21] “Wir haben in den früheren Abschnitten mehrmals festgestellt, wie sehr gerade auch diejenigen Wissenschaften, welche sich mit den größten körperlichen Gebilden überhaupt beschäftigen: die Astronomie, die Astrophysik und die Kosmologie, auf das “Wissen vom Kleinsten” angewiesen bleiben, ja daß wir heute sogar oft nicht einmal sagen können, ob ein hier auftretendes wissenschaftliches Rätsel oder theoretisches Dilemma als bloße Herausforderung der “Wissenschaften vom Größten” allein aufzufassen ist oder als eine simultane Herausforderung sowohl dieser Wissenschaften *als auch* der Wissenschaften von der Materie. Es ließe sich die boshafte Behauptung verfechten, daß die heutigen “Materie-Experten” in einem gewissen Sinn zu einem schlimmeren Eingeständnis gezwungen sind als Goethes Faust. Sie sind nicht nur “nicht klüger als zuvor”, nämlich als zu der Zeit, da sie zu forschen anfingen, sondern sie sind nicht einmal klüger geworden als jene ersten Denker, welche vor über 2000 Jahren die Materie rein spekulativ zu ergründen versuchten” (Stegmüller 1987:91).

[22] “Selbst die beiden großen Grundkonzepte über die Natur der Materie stehen heute nach wie vor zur Diskussion, wenn auch mannigfaltig verschleiert hinter Bergen von Formeln. Diese beiden Grundkonzepte kann man als die *atomistische Auffassung* und als die *Kontinuumsauffassung* der Materie bezeichnen” (Stegmüller 1987:91).

auxiliary means from mathematics it cannot escape from the polarity between continuity and discreteness.[23]

Suddenly the question concerning the infinite divisibility of matter once again occupies a central position, thus highlighting anew the important distinction between *physical space* and *mathematical space*. It is clear that this distinction between 'atomism' and 'continuity' is based upon number and space as the two most basic modes of explanation of reality. But this is not yet the end of the dependence upon unique modes of explanation. For according to Stegmüller these two conceptions were designed in order to bring to a solution the following two problems (Stegmüller 1987:91):

(i) The apparent *indestructibility* of matter, and
(ii) The apparent or real limitless transformability of matter.

When these two problems are assessed in relation to one another it is immediately clear that they depend upon the third and fourth ontic modes of explanation given in reality, namely on the meaning of kinematic persistence ('immutability') and physical changefulness ('transformability').[24]

As soon as we do this, the key points of our historical survey of physics are again brought into play a decisive conditioning role in our theoretical reflections. The "thing-ness" of material entities once and for all transcends the limited nature of the unique angles of approach (modes of existence and modes of explanation) that served our understanding of matter. Things function at once within all these modes and yet, in spite of this aspectual many-sidedness, things are never exhausted by any one of these modal aspects. And it seems that the *mystery* surrounding material entities derives from this multi-aspectual *but-at-once more-than-merely* aspectual nature of such entities.

It is precisely this more-than-merely-aspectual-nature of material things that sheds a negative light on any *monistic* attempt to develop a "theory of everything." Greene, for example, wants a framework that will combine all insights into a seamless whole, into a 'single theory that, in principle' is capable of describing all phenomena (Greene 2003:viii). He indeed presents "super string theory" as the "Unified Theory of Everything" (Greene 2003:15; cf. also pp. 364–370, 385–386). However, he does not realize that although he has a *purely physical theory* in mind, the *meaning* of the physical aspect of reality inherently points beyond itself to its inter-modal coherence with other aspects, first of all with those aspects that are foundational to the physical aspect (namely the aspects of number, space, and movement). Even the way in which he phrases his goal cannot escape from terms that have their original seat within some of these aspects. Just consider his reference to a "seamless whole" and his use of the quantitative meaning of number while

[23] "Die Physik, insofern sie sich mathematischer Hilfsmittel bedient oder sich gar der Mathematik unterwirft, kann an der Polarität von Kontinuierlichem und Diskretem nicht vorbei" (Laugwitz 1986:9).

[24] The physicist Rollwagen holds the view that the "dualism" of wave and particle introduced a new dimension, namely the "possibility of the … mutual transformation of elementary energy-structures" (Rollwagen 1962:10).

referring to a "single theory." The idea of "everything" also makes an appeal to the quantitative meaning of the *one* and the *many*. Likewise the idea of a "seamless whole" reflects the core meaning of space (i.e., *continuous extension*) which underlies our awareness of *wholeness* and of *coherence* ("seamless").

The undeniable interconnectedness of all aspects of reality disqualifies each and every claim to (modal) *purity*—at least when this 'purity' is meant to refer to the meaning of an aspect stripped of its coherence with other aspects.

3 Systematic Distinctions

It is striking that the battle-field between *universality* and *individuality* is served by our basic intuitions of *number* and *space*. The idea of *being distinct* (at least partially) pre-supposes the *discrete* meaning of number while understanding *universality* pre-supposes the spatial awareness of *everywhere*. Of course the numerical point of entry—or mode of explanation—can be complemented in yet another way by the spatial angle of approach, namely when its articulation at once also highlights *numerical analogies* within space.[25]

In addition the core meaning of the first four aspects of reality may be employed in such a way that they are strectched beyond the boundaries of these modes, in which case we encounter the (idea-)statements[26] philosophy can formulate about the universe. These statements are not contradicting each other but rather entail and complement each other:

(i) Everything is unique;
(ii) Everything coheres with everything else;
(iii) Everything remains identical to itself; and
(iv) Everything changes. Only if these statements did not rest upon irreducible modal points of entry they would have been contradictory.

At this point we may unite the main contours of our historical overview by pointing out that most of the issues mentioned converge towards an understanding of the role of the four aspects underlying the last mentioned four statements about reality. Ultimately no view on physical laws and individual physical entities can side-step the first four modes of explanation of the world—for in both instances one encounters a mixture of conceptual terms and a concept-transcending usage of modal terms. In order to articulate this claim we now focus on the nature of *natural laws*.

[25] Within the philosophy of Dooyeweerd and Vollenhoven the coherence between the multiple irreducible aspects of reality is accounted for by referring to these interconnections as modal analogies (retrocipations and anticipations). In this context the original numerical meaning of succession (one, another one and so on without an end, endlessly) is turned "inwards" by the spatial meaning of continuity—seen in the *endless divisibility* of a continuous whole.

[26] When terms derived from specific modal aspects are employed in order to refer to whatever exceeds the boundaries of such an aspect, they are used in a concept-transcending way, yielding *idea-knowledge*.

4 Physical Laws as "Law of Nature"

Cassirer mentions an element present in the ancient Greek understanding of *law*—namely that *nomos* constitutes a principle of *ordering* through which motion and the diversity within reality is arranged (Cassirer 1911:375). During the early modern period a reaction to the traditional Aristotelian-Thomistic view led to a natural scientific orientation that treated law predominantly within a *relational coherence*. This approach became dominant within the discipline of physics.

This new accent is an effect of a fundamental switch, one in which the focus is not any longer on the *substance* of things (their *essence*), but merely on the *way* in which we experience them. Galileo is therefore no longer interested in the 'essence' of things but instead asks *how* they appear to us. What is revolutionary in his view, according to Herold, is that in the absence of thinking about essences (that proceeded from configurations of motion with distinct degrees of perfection) everything in principle is equal in the face of the law—amply demonstrated in his remark that he did not study the pedigree of geometrical figures (see Herold 1974:502).

Natural laws are (i) *necessary*,[27] (ii) they constitute an *ordering* in the sense of a *relational coherence* regulating *motion* and *diversity* within reality, and (iii) they are concerned with the *how* and not the concrete *what* of things.

During the early modern era these ideas developed within the context of the dominance of the modern ideal to understand the universe in terms of the (mathematical) natural sciences (also known as the natural science ideal). In the thought of Hobbes science, understood as (natural) philosophy, opened the way to view individual things in relation to what is *universal*. His emphasis on the *truth* entailed in universal propositions (see Herold 1974:503) reveals his nominalistic affinity that projected a human element into the universality of a natural law. Particularly Newton (in his *Principia Mathematica*, 1, 15) started to explore more extensively the view that a law must be understood as a *mathematically conceivable rule*. While taking distance from the idea of a God-given law the French Enlightenment, particularly D'Alembert, derived from the relations between bodies governed by law the *validity* of the latter (Herold 1974:505).

In the thought of Kant (1783) the feature of necessity (*Notwendigkeit*) is accompanied by what he claims to be the *universal-validity* of a law. Insofar as rules are objective they are designated as *laws*. We have seen that Kant derived these laws in an a priori way from human understanding that furnishes phenomena with the law to which they are subjected, i.e., understanding creates their lawfulness or law-conformity (*Gesetzmäßigkeit*) (see also Kant 1781-A:126). Kant's aim is to render comprehensible the "objective validity of the pure concepts a priori" of the categories of understanding (Kant 1781-A:128).

Hegel explored a further dimension in his science of logic when he focuses on determining law (*Gesetz*) as what remains the *same* in what *changes* (Hegel 1957-2:122). Cassirer assumes "ultimate logical invariants" that are not affected by their

[27] Stegmüller considers it to be "Hume's great achievement to have banished the concept of necessity from the concept of cause" (Stegmüller 1977:36).

changing material content. He speaks of "identity and permanence" that lie "at the basis of scientific laws" (Cassirer 1953:325). He actually got quite close to an understanding of the conditioning role of the first four modal aspects of reality in connection with an articulation of the nature of natural laws:

> There is no objectivity outside of the frame of number and magnitude, permanence and change, causality and interaction: all these determinations are only the ultimate invariants of experience itself, and thus of all reality, that can be established in it and by it (Cassirer 1953:309).

The "ultimate invariants of experience itself" are actually referring to the conditioning role of the most basic modal aspects of reality—they are indeed those "determinations" co-responsible for the way in which we experience reality.

Without acknowledging the ontic structural configuration of reality and in particular the ontic order of successive modal functions, we are left afloat without an anchoring guideline in our attempts to define the nature of natural laws. But once the underlying and conditioning role of these (ontic) modes of reality is acknowledged another challenge faces theoretical analysis, namely to distinguish between (i) elementary and (ii) compound basic concepts.

(i) Every scholarly discipline that finds its field of investigation delimited by a specific aspect of reality employs basic concepts reflecting the inter-connections between its delimiting aspect and other aspects of reality. In the case of physics, for example, its elementary basic concepts articulate the analogies of pre-physical aspects within the structure of the physical aspect, found in phrases such as *physical mass* (numerical analogy), *physical field* (spatial), and *energy-constancy* (the kinematic analogy).

(ii) On the basis of elementary (analogical) basic concepts, successively open for theoretical inspection and analysis, the compound (or complex) basic concepts of a scientific discipline are formed by simultaneously involving distinct analogical basic concepts.

Without exploring the methodology of compound basic concepts in any detail we may briefly state the result of such an analysis with respect to the nature of physical laws. The constitutive elements that ought to be incorporated in an account of natural (physical) laws cannot side-step the point of entry provided by the first four modal aspects and they are also dependent upon an awareness of the difference between *law for* and *lawfulness of* (i.e., the orderliness of) physical subjects.

Van Fraassen refers to Peirce who argues that *if* the 'uniformity' intended by Mill merely meant *regularity* without any real connection implied between events, then his argument will be destroyed (Van Fraassen 1991:22). The phrase used by Van Fraassen in this context, however, states that a law cannot be "the mere uniformity or regularity itself" for a "law must be conceived as the reason which accounts for the uniformity in nature" (Van Fraassen 1991:22). The use of the word 'reason' may be interpreted to suggest that laws result from the intellectual endeavors of human beings. Nonetheless he continues by claiming that a "law must be conceived as something real, some element or aspect of reality quite independent of our thinking or theorizing—not merely a principle in our preferred science or humanly imposed taxonomy" (Van Fraassen 1991:22–23). Within the above-mentioned context this implies that the word 'reason' rather means 'cause'—in the sense that a law is the (extra-mental) cause that accounts for the uniformity or regularity of nature. Of course a much easier account would be to state that the regularity of nature concerns its orderliness or law-conformity, entailing that whatever behaves in law-conformative ways is *subject* to a law as *order for*. For that reason perhaps the best translation of the German term *Gesetzmässigkeit* (Dutch and Afrikaans: *wetmatig*) is *subject to law* (as it was done in the translation of Wittgenstein's *Tractatus*).

When Van Fraassen discusses the views of Davidson he points out that although Davidson does not attempt to *define* laws it is nonetheless said "that laws are general statements which are confirmed by their instances" (Van Fraassen 1991:33). In this case the distinction between *ontic laws* and human statements intended to capture conceptually what such laws are all about collapses. The acceptance of ontic laws does need 'markers', i.e., terms helping us to articulate their ontic nature. The mere fact that we speak in the *plural* about such laws already reflects the constitutive role of the meaning of number (the *one* and the *many*) in our understanding of ontic laws. Furthermore, without the conditioning role of the spatial aspect it cannot be asserted that laws hold *everywhere*, i.e., that they apply *universally*. Although Van Fraassen does acknowledge *universality* as a "mark of lawhood" (Van Fraassen 1991:26) he does mention with reference to Armstrong and Lewis that the "criterion of universality" is "no longer paramount" in a "discussion of laws" (Van Fraassen 1991:28).[28]

Of fundamental importance is the distinction between *modal laws* and *type-laws* for it entails an account of the difference between *unspecified* and *specified* universality. A modal physical law holds for *all* kinds of physical entities without any specification, whereas a physical type-law only holds for a limited class of entities, namely those belonging to that type. Such a type-law, for example the law for being an atom, holds universally in the sense that it applies to all atoms, but this universality is *specified* since it holds for atoms only (and not for every kind of physical entity).

In the case of modal laws and type-laws the reverse side of universality is found in the *distinctness* of different laws, specified by using the idea of *delimitation* that is derived from the primitive meaning of space. Every law has its own *domain* of application, a specific and distinct *sphere* within which it obtains. But only when these two elements are combined with the *constancy* (or *uniformity*) of a law and with its *effect* (its *force*, its *validity*) is it possible to account for the constitutive elements of the compound basic concept of a natural (physical) law.

When Stegmüller discusses the law of causality he introduces multiple terms closely related to the conditioning role of the first four modal aspects and in fact approximates closely our idea of *compound basic concepts*.

> Still others might be added to the features we have already mentioned. But since with these the concept of a causal law has already reached such a high

[28] This may be the effect of not distinguishing between modal laws (with an unspecified universality) and type-laws (with a specified universality—see below).

> level of complexity, let us confine ourselves to them. For faced with the question 'what are causal laws?' we must, in accordance with them, give the following answer: *causal laws are quantitative, deterministic, nearby action, succession micro-laws formulated by means of continuous mathematical functions in relation to a homogeneous, isotropic spatio-temporal continuum governed by certain principles of conservation* (Stegmüller 1977:36).

Dooyeweerd did not apply his own transcendental-empirical method of analysis to the idea of 'law' in general, for he frequently simply (intuitively) states that a law *determines* and *delimits* whatever is subjected to it (see Dooyeweerd 1997-I:508).

If the distinct *scope* of laws delimit their unique areas of validity, then it is recommendable not to allow the concept of a natural law to degenerate into an amorphous collection of predicates, such as it is found in the recent proposal of the physicist Stafleu. He says that a law is sometimes hidden behind the name axiom, constant, proposition, rule, relation, thesis, symmetry, theorem, design, pattern, connection, prohibition, comparison, phenomenon or prescription (see Stafleu 2002:39). This list contains elements referring to the law-side and the factual side as well as a mixture of ontic phenomena and what is the product of human activity. For example, for the sake of convenience Stafleu calls a mathematical law-conformity ("wiskundige wetmatigheid") such as the theorem of Pyhtagoras a natural law (Stafleu 2002:39).

Inherent to a natural law is its meaning as an *order for*—and this mode of speech makes an appeal to the *unity in the multiplicity* of different laws, for without such a *unity* laws will clash and will not be able to constitute an *order of laws* (a law-order). The constitutive role of the numerical mode is evident in this concept of *order*. Furthermore, a law entails its *correlate*, namely that which is factually subjected to it—and this insight points at the inherent *universal scope* of a law—derived from the spatial awareness of *everywhere* (at all places). Without the spatial (dimensional) distinction between *above* and *below* the assumed correlation of *law* and *subject* does not make any sense. That the *validity* of a natural law is not something incidental is captured by saying that it holds *constantly*—demonstrating the constitutive role of the kinematic mode. The notion of *validity* (*being in force*) derives from the core meaning of the physical aspect and it has to be incorporated in the concept of a physical (natural) law, because otherwise the ability to say that a law *determines* what is subjected to it would collapse.

The compound or complex basic concept of a natural (physical) law may therefore be formulated as follows;

> As a unique, distinct, and universally valid order for what is factually correlated with and subjected to it, a natural law constantly holds (either in an unspecified way as in the case of modal laws or in a specified way as in the case of type laws) within its domain of validity.

However, what is particularly striking in reflections on the relation between *law* and *factuality* is the widely found confusion of *law* and *law-conformity*.

5 A Non-Reductionist Interpretation of Physics

Our analysis of the development of the theoretical understanding of physical reality made it is clear that regarding the nature of physical entities as centered in their arithmetical, spatial, or kinematic aspects, leads to antinomies. Although material entities without any doubt do function within these three (pre-physical) aspects, they are still always qualified by the *physical* aspect. Consider for a moment the many-sided existence of an atom.

As early as 1911, Rutherford proposed the hypothesis that atoms consist of a (electrically positive) nucleus and negatively charged particles moving around it (a view which was inspired by the nature of a planetary system). In the following year (1912), Niels Bohr set up a new theory which contained two important new ideas: (i) the electrons move only in a limited number of discrete orbits around the nucleus and (ii) when an electron moves from an orbit with a high energy content to one with a low energy content, electromagnetic radiation occurs. In 1925, Pauli formulated his exclusion principle (Pauli-exclusion).[29] According to the division of charges of electrons, corresponding electron-shells exist, and in each peel there is room for a 'maximum' number of electrons. This maximum number is given by the simple formula: $2n^2$. In the first peel (known as the K-peel) there is room for 2 electrons; in the following L-peel, there is room for 8; in the M-sheel for 18; in the N-sheel for 32; and so on. Within a sheel with a quantum number *n*, (where there is room for $2n^2$ electrons) sub-orbits are identified so that each sub-orbit with a quantum number *l* has room for $2(2\,l + 1)$ electrons.

Multiple elementary particles are integrated in the unified functioning of the atom as an individual *whole*. So when physicists talk of the nature of these particles, the original meaning of space (combined with numerical analogies within space), is prominent. In other words, the aspects of number and space are first explored in what we say about elementary particles.

The nucleus of the atom has a certain *size* and its diameter multiplied by 100,000 specifies the distance between the nucleus of an atom and its (circling) electrons.[30] Thus the matter of an atom is concentrated in a volume of less than *a*

0,0000000000000000001

part of the volume of the atom—which amounts to saying that atoms are for more than 99,9999999999999999999% empty (19 zeros after the comma—Kiontke 2006:27).

[29] It applies to fermions, i.e. elementary particles with a semi-integral spin (1/2, 3/2, 5/2, etc.) for which the statistical laws of Fermi–Dirac are formulated.

[30] The current physical view is that quarks are the ultimate "building blocks" of these elementary particles. A distinction is drawn between an *up quark* (with a charge of +2/3) and a *down quark* (with a charge of −1/3)—but apparently there are not any *free* quarks. The proton, for example, consists of two up quarks and one down quark. The *size* of electrons and quarks is smaller than 10^{-18}—they are so *small* that they are described as *point-like* (see Kiontke 2006:27). *Hydrons* include those *fermions* and those *bosons* designated as *mesons*. Furthermore, hadrons are constituted by *quarks*. Those known as *baryons* in turn include nucleons (neutrons and protons) and *hyperons*. Whereas the hadrons are "heavy" the *leptons* are *small*, including the electron and particles such as the *muon*, *tauton* and their corresponding *neutrinos*. More information on this micro-dimension is found in Penrose (2005:645 ff).

Some facts about the way in which atoms function within the kinematic aspect are equally astonishing. According to wave mechanics we find quantified wave movements around the atom and the electron of a hydrogen atom (in its lowest orbit), move around the nucleus at a speed of about 6.8 million km per hour (Kiontke 2006:27).

From these facts it is evident that the *distinct number* of elementary particles within the internal atomic structure are joined into a typical *spatial* and *kinematic* order of electronic orbits that configure the atom as an individual *physical–chemical micro-totality*. The special spatial configuration which is manifest within the internal arrangement of the parts of an atom reflects the typical *foundational function* of atoms. Biochemistry discovered many *isomeric* forms, that is, they have identified *chemical configurations* that are constituted by the *same* atoms, viewed from a purely numerical perspective, but that nonetheless, owing to different *spatial* arrangements, differ *chemically*. The formula C_3H_6O may yield the following (chemically distinct) configurations: CH_3CH_2CHO or CH_3COCH_3. Another example is $C_4H_4O_4$. That the chemical difference between maleic acid and fumaric acid has its foundation in alternative spatial arrangements is self-evident—just as clear as it is that the number of atoms as such cannot account for this chemical difference. In other words, it is intuitively clear that molecules such as these have a spatial foundational function and not a numerical foundational function. On the other hand, the point-like nature of small particles may suggest that in their case the *numerical* function is decisive. One may be tempted to argue that such particles have their foundational function in the numerical aspect, but the problem is that in the case of electrons and quarks their actual size is unknown (Kiontke 2006:27). Nonetheless, as Stafleu remarks, the electron is characterized by exactly determinable values for its charge, rest mass, the magnetic moment and the lepton number (Stafleu 1989:91).[31]

The problem of the interweaving of different kinds of entities first of all challenges the limitations of the whole-parts relation—a relation that appears in its original modal meaning within the spatial aspect.[32] Suppose we ask whether or not Sodium and Chlorine are genuine *parts* of table salt. Surely every division of table salt must continue to display the NaCl structure. But what happens when the process of division reaches a single salt molecule? If such a molecule is divided one ends up with a Sodium atom and a Chlorine atom—and it is evident that real parts of salt will still possess the same chemical structure of salt, namely NaCl. The critical

[31] A detailed explanation of primary and secondary foundational relations is found in Stafleu, where, for example, *energy*, *force* and *current* respectively are related to *quantitative*, *spatial* and *kinematic* concepts (Stafleu 2002:26–28, 128–171). His analysis explores the possibility to discern the first three modal aspects as the foundational function of different kinds of physical entities—and in doing that demonstrates how fruitful philosophical distinctions are for a special science such as physics. Quantum electro-dynamics has to take into account the interaction of the electron with its own quantified surrounding field—charge and field are inseparably connected (see Rollwagen 1962:10). Stafleu holds that elementary particles have a arithmetical foundational function.

[32] Note the difference between mathematical space (that is continuous and infinitely divisible) and physical space (that is discontinuous and therefore not infinitely divisible). Both kinds of space are *extended*—the similarity between them; but within the moment of similarity the difference between them manifests itself, thus demonstrating the nature of a (modal) analogy.

question is whether Sodium and Chlorine each has a salt structure, i.e., are Sodium and Chlorine true parts of salt? The answer is self-evident because neither one on its own has a NaCl structure!

In this case the internal sphere of operation of the atoms remained intact although, through the chemical bond, they were taken up in the table salt molecule. Dooyeweerd to develop a theoretical approach in order to account for the retention of the internal nature of entities that are interlaced (cf. Dooyeweerd 1997-lll:627 ff., 694 ff). When the internal sphere of operation of a interwoven entities is retained, the term *enkapsis* is employed. When one kind of entity is foundational for another kind of entity, the situation is captured by speaking of a *one-sided enkaptic foundational relationship*—which is what we found in NaCl. One may also designate the idea of enkapsis by using the term *encapsulating*.

Within the realm of physically qualified entities we encounter different geno-types. Atoms are, for instance, geno-types within the radical type (realm) of material things. Within different bonds the same atom displays a number of *variability types*. When an atom engages in chemical bonding, a characteristic enkaptic totality emerges: (i) besides the internal sphere of operation of an entity there is (ii) an external enkaptic sphere of operation in which the enkaptically-bound entity serves the encompassing enkaptic totality.

The factual configuration of a water molecule thus exists on the foundation of the geno-type of the chemical bond between the oxygen and hydrogen atoms. Without these atoms a water molecule cannot exist. They therefore serve as foundational for water. Does this imply that the atoms totally become part of the chemical bond that exists within the molecule? Not at all, because the bond applies only to the binding electrons and not to the whole atom. Besides, the atom nucleus is not just a specific characteristic of the atom, but precisely that nuclear part of an atom that determines its physical–chemical geno-type (compare the atomic number = the number of protons of the nucleus), as well as the atom's place within the periodic table.

The fact that the atom nucleus remains structurally unchanged in the chemical bonding secures the internal sphere of operation of the atom. Because the electrons cannot be disengaged from the nucleus of the atom these atoms function as a whole in the water molecule. Note that it cannot be said that the atoms function in the chemical bond for the bonding does not encompass the atomic nuclei. Nonetheless the atoms (with their nuclei, electron shells and bonding electrons) are present *as a whole* in the water molecule which embraces them. The interweaving of the atoms within the molecule does not make them intrinsical parts of the molecule, since this would abrogate the internal sphere of action of the atoms.

The external enkaptic function of the oxygen and hydrogen atoms in the water molecule indicates the functioning of the atoms within the molecule as a totality via the intermediate role of the chemical bond. This presents us with a three-fold distinction:

(i) First of all, we must identify the internal sphere of action of the atom.
(ii) Secondly, we find the chemical bond that leaves the atom nucleus unchanged because it only affects the outer electron shells, so that the atom nuclei can in no way be part of the chemical bonding.

(iii) Thirdly, we find the enkaptic structural whole of the water molecule that enkaptically embraces the atomic nuclei and bonds and ascribes to each of them their typical place within the enkaptic whole.

This view side-steps the one-sidedness of an atomistic understanding of a molecule (over-emphasizing the continued existence of atoms within the chemical bond at the cost of the totality character of the resulting whole) and of a holistic view (that over-emphasizes the totality-character of the molecule in such a way that the foundational atoms are seen as *integral parts* of the whole).[33] Van Melsen highlights these two extremes: "In modern theories atomic and molecular structures are characterized as associations of many interacting entities that *lose* their own identity. The resulting aggregate originates from the converging contributions of all is components. Yet, it forms a new entity, which in its turn controls the behaviour of its components" (Van Melsen 1975:349).[34]

6 The Wave-Particle Duality

6.1 Complementarity—Limits to Experimentation

There are also remarkable limits to physics in the sense of experimental exactitude and determination. By introducing his principle of uncertainty Heisenberg showed that it is impossible simultaneously to measure the impulse and position of an electron. The Copenhagen interpretation of quantum physics employs the notion of complementarity in order to account for the impossibility of establishing both at once—thus allowing for two irreducible (and complementary) modes of description, in terms of "place" and "impulse," respectively.

[33] The classical starting-point for a universalistic or holistic over-estimation of the whole-parts relation is found in Aristotle's appreciation of the city-state as the encompassing whole of society: "Therefore the state, according to its nature, is prior to the family and the individual, since the whole must precede the part."

καὶ πρότερον δὲ τῇ φύσει πόλις ἢ οἰκία καὶ ἕκαστος·ἡμῶν ἐστίν. τὸ γὰρ ὅλον πρότερον ἀναγκαῖον εἶ ναι τοῦ μὲρους

—Aristotle, Politica, 1253a, 19–20.

[34] It should be noted that also in this context there is an ambiguity in Dooyeweerd's terminology, because he talks of the interlacement of *individuality-structures* (i.e. of *laws*)—instead of clearly stating that the issue concerns the interwovenness of *entities* subject to their type laws (individuality-structures). The intention is not to say that *laws* are enkaptically intertwined, but simply to account for the factual interlacements found between different kinds (types) of entities in their subjection to type laws. Stafleu also speaks of the mutual interlacement of *laws* ("character's" in his terminology, as clusters of laws) (see Stafleu 2002:150).

6.2 The Typical Totality Structure of an Entity (Wave and Particle)

After Einstein reverted to a particle theory regarding the nature of light, it has been shown on the basis of interference phenomena that, that it is always possible to ascribe a wave-character to elementary particles. Conversely, the Compton-effect—regarding the interaction of a photon and an electron—supplied evidence to support the idea of distinct particles. De Broglie broadened the perspective by showing that with each and every moving particle (atoms, molecules and even macro-structures) one can associate a wave (cf. Eisberg 1961: 81, 151).

Although it turned out to be impossible to establish experimentally at the same time both the particle and the wave nature, Bohr claims that these two perspectives are complementary (cf. Bohr 1968:41 ff.).

In the light of the generalization provided by De Broglie one may ask: if it is possible to describe or explain entities qualified by energy in terms of two mutually exclusive experimental perspectives, namely as particles and as waves, is it then still meaningful to speak about their unitary structure? This question puts the finger exactly on that point where the special scientific description reaches its limits and needs to fall back upon a perspective transcending the confines of special scientific inquiry. What is here required is a philosophical account transcending the mere combination of one or more (modally delimited) special scientific points of view. The idea of the unity and identity of an entity could never be provided to us by theoretically explicating various modal functions, simply because this underlying unity is presupposed in all theoretical explanations. In a strict and technical sense this idea of an entity in its totality—preceding the analysis of its modal aspects—refers to an individual whole embedded in the inter-modal and inter-structural coherence of reality, to an entity emerged in the depth-layer of an all-embracing unity transcending genuine concept-formation and only to be approximated in a concept-transcending limiting idea.

It is important since number, space and movement remain irreducible aspects regardless of the nature and type of entities functioning within them (their modal universality), it is also from this perspective understandable why the functionally distinct concepts particle and wave cannot be reduced to each other—a state of affairs supported by experimental data. Irreducible modal perspectives may also serve as modes of scientific explanation. Consequently, the terms ‘particle’ and ‘wave’ reflect analogical connections within the kinematic aspect of entities to the numerical and spatial aspects. The connection to number we call a particle; the connection to space we call a wave.

Born, Pymont, and Biem agree with this point, and reject any dualism on the issue. They hold that it increasingly becomes clear that “nature could neither be described by particles alone, nor solely through waves,” because a proper understanding cannot toggle between a “particle image [Teilchenbild]” and a “wave image [Wellenbild].” This leads to a unitary view of physical systems. What we have called modes of explanation these authors designate as “Darstellungen” (representations)—and they specifically mention three distinct (but present at once) modes of explanation: an “Ortsdarstellung” (spatial position), a “Wellendarstellung” (impulses or velocities—kinematic explanation) and an "Energiedarstellung" (the physical mode of explanation) (Born, Pyrmont, Biem, 1967/68:416–417).

7 Concluding Remark

The preceding analyses are directed by the biblical teaching that all creation depends on God. They therefore reject all forms of reductionism inspired by taking anything in creation to be what all else in creation depends on. The implications of the non-reductionist ontology explored in our exposition were directed at the uniqueness and mutual coherence of the various aspects of reality, in particular the first four modal aspects: number, space, the kinematic and the physical.

Such an approach is critical of "theories of everything." Breuer holds that the idea of *reductionism* provided the most important stimulus for engaging in "theories about everything"—but his own view approximates the idea of a non-reductionist approach. He holds that if one does not if one does not assume reductionism it is "possible to advance a universally valid physical theory, another universally valid biological theory and in addition a universally valid economic theory" (Breuer 1997:3).

Physics, though widely regarded as one of the 'most exact' sciences, cannot avoid broader philosophical issues. These broader issues leave a physicist with only two options: (i) explore the implications of a non-reductionist ontology for physics or (ii) succumb to reductionist thought-patterns with their antinomous consequences.

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