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Fr. Rudolf Larenz[*]
Helsinki, Finland

SUBSTANCE AND DYNAMICS:
TWO ELEMENTS OF ARISTOTELIAN-THOMISTIC PHILOSOPHY OF NATURE IN THE FOUNDATION OF MATHEMATICS IN PHYSICS

The *background* of this article is the situation, in which Physics finds itself since the scientific revolution in the 16th and 17th centuries.[1] It gives rise to an *evaluation*, which in turn suggests to take *measures in order to improve the situation*, so much so that one could speak of an internal reform of Physics. The situation of Physics can be summarized as follows:

1. Physics has a *great advantage*: there are *two* bodies of knowledge, namely experience and mathematics. These two bodies of knowledge are *interlocked*, so that the one science called 'physics' has two branches: on the one hand, experimental, and on the other hand, theoretical physics.

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[*] The author holds a PhD in Theoretical Physics.

[1] Of the many accounts of the Scientific Revolution we mention here only a few of those that are of an immediate interest for the topic of this article: Bernard Cohen, *The Newtonian Revolution* (Cambridge: Cambridge University Press, 1983); Eduard Jan Dijksterhuis, *Die Mechanisierung des Weltbildes* (Berlin-Heidelberg-New York: Springer, 1956), Reprint 2002, Dutch original 1950; Karen Gloy, *Von der Weisheit zur Wissenschaft* (Freiburg i.Br.: Karl Alber Verlag, 2007); Hans Wußing, *Die Große Erneuerung: Zur Geschichte der wissenschaftlichen Revolution* (Springer Basel AG, 2002).

2. But, by this very differentiation into two branches, Physics has got a *severe problem*: *nobody knows, on a purely theoretical level, how and why these two branches belong together*.

3. Nevertheless, as is well known, they do bring about a highly efficient practical knowledge due to a sort of highly developed "practical management."

The core of this management consists in formulating *hypothetical* laws of nature in mathematical terms and confirm or disconfirm these laws by experiments. This is why the knowledge referred to in the preceding paragraph is *practical*. This management is highly successful, insofar it leads to predictions and, thus, to technology. However, these predictions are only relatively, never absolutely precise. True, there is no science in which predictions are absolutely precise. This fact helps to realize that what matters is success in terms of small margins of error or deviation. A prediction within a 0,015% margin of might be truly successful, but it cannot be true to a degree of 99,985%. In other words, success is considered more important than truth.

4. Another important pillar of that management consists in performing far-reaching *reductionisms* by means of abstractions and simplifications. Most of them have come to be inbuilt in the methodology of physics, others are bound to specific physical problems.

The *evaluation* of this situation can follow different paths, which would lead, accordingly, to different results. The starting point of one alternative would consist in attributing the highest value to the *efficiency* physics has shown to date and neglecting the inevitable lack of knowledge of full reality due to the inbuilt reductionisms. The starting point of the opposite alternative would consist in acknowledging that it might be appropriate to modify (by reductionisms) the picture of reality in order to obtain practically useful results. But it would be inappropriate to ascribe these results a fundamental value, because they contain a distortion of knowledge and, thus, deviate from truth.

It seems that following the second alternative would take away from physics its efficiency. But this has never been proven, and must be rather considered as an open question. It must be taken into account that while it is a *reduced picture of reality* that makes the design of highly efficient technological artifacts possible, the *manufactured real artifacts* are not affected by any reductionism. Therefore, one could claim that an undistorted and fuller knowledge of reality would yield even more efficient technological artifacts.

These two alternatives are the extremes of a whole spectrum of intermediate views. The latter qualifies for being part of a world view that is rooted in reality, which has proven to have invariable elements, while the former amounts to a higher form of engineering that might develop and even radically change in time. In choosing the latter perspective, one imposes upon oneself the challenge to effectively demonstrate, or at least make plausible, that there does exist a unity of both the mathematical and the experiential branch of knowledge in physics, which can be understood without experiments. On the contrary, it is experiments that should be understood in terms of that view based on experiment-independent knowledge of material reality. It requires no further explanation to show that this choice requires a lot of work, beginning with looking closely at the conceptual foundations of physics just as it has historically developed.

Having mentioned the *background* of this article and the *evaluation* of the situation of physics, we can proceed to articulate what we are aiming at. It is nothing less than laying the bases for solving the problem of the lack of unity of the mentioned two bodies of knowledge. It is likely that this cannot be done by demonstrating that such a unity exists without further details, but rather by *explicitly showing* why and how both bodies of knowledge are united. By so doing it will become obvious that the unity exists. As can already be deduced from the foregoing considerations, this is a major enterprise. Additionally, it is not clear beforehand the degree to which the problem can actually be solved. Therefore it is prudent at this point to speak about an *attempt* to solve it.

Irrespective of the overall strategy followed by such an attempt, it must start by avoiding the reductionisms to which I referred. In so doing, it gets rid, from the very outset, of an important part of the practical management dominating in physics. Then, taking into account that the reductionisms mentioned are recognized as such by experience, mainly by means of comparison to what is perceived to be the picture of nature without reductionisms, any attempt should keep within the domain of these experiences. This is a huge enterprise. Therefore, the following considerations are nothing but an overview of what has been done so far.

Given that physics has been ever since a science of experience, *natural realism* is the appropriate philosophical environment for the attempt to be undertaken. Aristotle is an outstanding philosopher of natural realism. But as he neither knew modern physics nor modern mathematics, we do not attempt to use Aristotelian texts in a literal way. Rather we take inspirations from Aristotle's metaphysics and philosophy of nature, in fact, decisive inspirations. This concerns, first of all, the conviction that the human mind is capable of conceiving a notion of reality according to what reality is and of achieving what is called truth. The most important inspirations come, on the one hand, from the hylomorphic notion of 'substance', as it is condensed in the seminal words "ἡ ἐσχάτη ὕλη καὶ ἡ μορφὴ ταὐτὸ καὶ ἕν, δυνάμει, τὸ δὲ ἐνεργείᾳ, . . . καὶ τὸ δυνάμει καὶ τὸ ἐνεργείᾳ ἕν πώς ἐστιν,"[2] and from the notion of 'efficient cause', on the other. As for the latter, most important is the view that the entire effect belongs to the cause as "stemming from it" and to the recipient as "being in it."[3]

[2] Aristoteles, *Metaphysica* VIII, 6, 1045 b 18–19.
[3] For the seminal original quotation and some more remarks, see the end of section "Returning to the Undeformed Situation."

The division of physics into two branches has brought it about that the terms 'substance' and 'dynamics' are used in physics differently. Experimental physicists work with experiments and real pieces of matter and thus rely strongly upon experience. That is why experimentalists give a common sense meaning to substance and dynamics. Instead, theoretical physicists are satisfied with a piece of paper and a pen. In their mind, they have stored and arranged all sort of mathematics, together with the modern self-understanding of mathematics as based on axioms, not on experience. Experience might have a role in selecting and shaping ideas that ultimately lead to axioms. But once being formulated, axioms pass on to be the only foundation of mathematics. The predominant formalist view of mathematics and its "new" axiomatic method as it is promoted, for instance, by Hilbert, strongly tend to exclude radically experience and to logically fix the meaning of concepts *only* by their mutual relationships. These relationships are defined in the axioms.

Physical concepts are inspired, by and large, by mathematical ones. That has led to a situation wherein theoretical physicists easily confuse substances with their properties, that is to say, independent realities with dependent realities. Additionally, they replace dynamics by mathematical formulas, which they call 'laws of nature'. On top of this, the communication between experimentalists and theoreticians has ended up producing, in one and the same person, a peculiar confusion of the two bodies of knowledge.

The confusion is rather unilateral and more often replaces natural things by mathematical objects, while giving them physical names. Thus, C. F. v. Weizsäcker writes: "The existence of particles follows immediately from the Special Theory of Relativity; they *are* irreducible representations of the Poincaré Group."[4] This sort of identifying material things with what is thought to be their mathematical representative is absolutely common.

[4] *Aufbau der Physik* (München: Hanser, 1985), 38. Italics are mine.

In view of this panorama, the problem of the lack of unity of the mentioned two bodies of knowledge can be viewed as a *problem of origin*: Where do mathematical laws of nature stem from—are they *invented* by the human mind and then *applied* to processes of material things, or do they *stem*, at least partly, *from* the material things they *refer* to? In this context, the word 'stem' means also that the physicist is essentially involved, because it is he who learns from observation and experiment and reflects on them. The mathematical laws of nature would be, then, something in the mind of the physicist. Consequently, the following considerations try to follow the path pinpointed by the words 'stem' and 'refer', which is the one of natural realism. In order to get a larger historical background that shows better the issue's relevance and provides ideas for later steps, we sketch the historical development of physics, inasmuch as mathematics is involved.

A Historical Sketch of Mathematics in Physics

For our purposes, it is hardly necessary to go into mathematical details. Three steps are sufficient:

1. *In antiquity*, insight into nature is obtained through sense experience, including observation, followed by philosophical reflection.

2. *In the late middle ages*, a certain mathematization of physics begins. It reaches a critical moment later in the Scientific Revolution during the 16^{th} and 17^{th} centuries and brings the systematic design and performance of experiments in order to corroborate already existing mathematical theories.

It is commonly held that the mathematization of physics has been the most important single feature of the Scientific Revolution. People like Francis Bacon, René Descartes, Galileo Galilei, Johannes Kepler and Isaac Newton have greatly contributed to the transformation of physics from a prevalently contemplative science into an experimental science.[5] Astronomy was mathematized since Antiquity, but will not be considered here, because it has almost no possibilities of experimentation and, thence, relies on observation only.

This transformation of physics is connected with the change of the *finality* of knowledge: Insight is no longer sought after for itself, but it has to serve the *dominium of nature*, as Descartes puts it.[6] According to Bacon, *achieving immortality* is the most important particular goal, which the dominium of nature should arrive at.[7] Together with the finality, also the type of knowledge has changed, roughly speaking, from a theoretical to a practical one, as has been mentioned above.

That change of type of knowledge can also be expressed by two other words: *substance thinking*, as a symbol for the theoretical knowledge of individual things as it is sought in classical philosophy of nature, and *function thinking*, as a symbol for the knowledge of mathematical laws of nature and their experimental confirmation.[8]

3. *Since the Scientific Revolution*, mathematics increasingly inspires the production of physical concepts. That is to say, *function thinking is* increasingly *dominating*. It is evident to everybody how overwhelmingly successful this methodical shift is: the western civili-

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[5] Cf., for instance, Alexandre Koyré, *From the Closed World to the Infinite Universe* (Baltimore: The Johns Hopkins Press, 1957), passim; Eduard Jan Dijksterhuis, *The Mechanization of the World Picture. Pythagoras to Newton* (Princeton University Press, 1986), passim.

[6] René Descartes, *Discours de la Méthode pour bien conduire sa raison et chercher la vérité dans les sciences*, VI, 2, English edition online, ed. Jonathan Bennett; available at: www.earlymoderntexts.com/assets/pdfs/descartes1637.pdf, accessed on: Feb 3, 2017.

[7] Francis Bacon, *The Works of Francis Bacon*, ed. Spedding, Ellis and Heath, Vol. III (London: Longmans and Co., 1858), 318.

[8] It seems that these words are not of general use. Yet, they are quite appropriate to describe the change in the intellectual sphere precipitated by the Scientific Revolution. Fernando Inciarte uses them as the main means of contrasting the scope of his book *Forma formarum. Strukturmomente der thomistischen Seinslehre im Rückgriff auf Aristoteles* (Freiburg/München: Karl Alber Verlag, 1970) against the current scientifically overinfluenced way of thinking. For the notion of 'substance', cf. especially *ibid*., 19–99.

zation is, by and large, now a technological one, and the corresponding world view is scientific.

Obviously, the metamorphosis of philosophy of (inanimate) nature into modern physics is anything but a homogeneous development in which later stages simply enrich the previous ones. The historian of science A. Koyré is one of the first in using deliberately the word 'revolution', when he says, for instance: "[T]his revolution, one of the deepest, if not the deepest, mutations and transformations accomplished—or suffered—by the human mind since the invention of the cosmos by the Greeks, two thousand years before."[9] In other words, such an increasing dominion over nature caused a transition from a sort of contemplative life (*vita contemplativa*) to an active life (*vita activa*).[10]

Koyré pinpoints the significance of the Scientific Revolution for the mindset of mankind by giving two characteristics:

> (a) the destruction of the cosmos, and therefore the disappearance from science . . . of all considerations based on this concept, and (b) the geometrization of space . . . nearly equivalent to the mathematization (geometrization) of nature and therefore the mathematization (geometrization) of science. The disappearance—or destruction—of the cosmos means that the world of science, the real world, is no more seen, or conceived, as a finite and hierarchically ordered, therefore qualitatively and ontologically differentiated, whole, but as an open, indefinite, and even infinite universe, united not by its immanent structure but only by the identity of its fundamental contents and laws . . . This in turn, implies the disappearance—or the violent expulsion—from scientific thought of all considerations based on value, perfection, harmony, meaning, and aim, because these concepts, from

[9] Alexandre Koyré, *Newtonian Studies* (Cambridge, Mass.: Harvard University Press, 1965), 5. Cf. also idem, "Galileo and the Scientific Revolution of the Seventeenth Century," *Philosophical Review* 52 (1943): 333–346.

[10] Cf. Koyré, *Newtonian Studies*, 5.

now on *merely subjective*, cannot have a place in the new ontology.[11]

Paradoxically, one comes across with the word 'cosmos' in ordinary speech every day, mostly in the composite form 'cosmology'. Meaning as it does 'order' resp. 'knowledge of order', it also refers to notions like stability, equilibrium, transparence and even beauty. One cannot fail to see how far mathematized physics with its hypothetical character and changing paradigms has drifted away from the intellectual climate that has generated the notion of cosmos.

It is true that the life conditions produced by modern natural sciences over centuries have paved the way for getting used to a way of thinking highly influenced by science. Therefore, the contrast presented by Koyré is *subjectively* felt less strongly as he formulates it. Nevertheless, the *objective* differences remain unchanged, and among them is also the reductionist mathematization of physics, which has led to the lack of unity of the two bodies of knowledge in physics. That is to say, it is unknown *whether*, *why* and *how* mathematical concepts and material things are connected. In other words, it is unknown whether, why and how substance thinking and function thinking are connected—not only by the fact that they refer to the same reality, but by an *interior rationale* that makes them an organically structured unity.

That problem is well known, although not always expressed in the terms used here. Solutions are not in sight, although the vast literature dealing with the problem is ever increasing. Even though physics continues being a science decisively depending on experiments and experience, it is an important topic for analytic philosophers. This is surprising insofar the analytic tradition seems to be centered around the equivalence of thinking with language.[12] This defocuses from experi-

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[11] *Ibid.*, 6–7.

[12] "The basic tenet of analytical philosophy, common to such disparate philosophers as Schlick, early and late Wittgenstein, Carnap, Ryle, Ayer, Austin, Quine and Davidson, may be expressed as being that the philosophy of thought is to be equated with the

ence and therewith from dynamics, which are essential for experimental sciences like physics.

This historical sketch corroborates the conclusion we have already arrived at, namely that it is a philosophically challenging problem trying to elucidate the relationship between substance thinking and function thinking, that is, between individual material things and abstract mathematical objects via the experimenter-theoretician's experience of material things. However, the fundamental contrasts mentioned in the Introduction and the revolutionary historical change from an experience-based science with some mathematical appendices to a mathematics-based science with some experiential appendices call for a carefully planned strategy.

Strategy

The problem is difficult and, as has already been said, its solution is a major enterprise. Therefore, we shall attempt to give only the beginning of an answer. That is to say, we try to find a connection between individual material things and some abstract mathematical object or objects. This, of course, is motivated by the hope that this way can be continued in the future and, eventually, leads to an understanding of why present day physico-mathematical theories are successful. That is not equivalent with saying that these successful present day theories could be straightforwardly *deduced* in some sense from logically previous experiential knowledge. The reason is that these theories, while successful, correspond to a *deformed* picture of nature. It is not reasonable to expect that from the experienced picture of nature could be deduced what corresponds to a deformed picture of nature.

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philosophy of language; more exactly: (i) an account of language does not presuppose an account of thought, (ii) an account of language yields an account of thought, and (iii) there is no other adequate means by which an account of thought may be given." Michael Dummett, *The Interpretation of Frege's Philosophy* (Cambridge, Mass.: Harvard University Press, 1981), 39.

But it is reasonable to expect that these theories could be embedded into a larger framework, which is faithfully based on our previous experiential knowledge of the material things to which these theories are applied. Such a framework would also contain mathematical elements. The beginning of an answer will be given in three steps.

1. *The first step* consists in specifying certain elements common to every experiment. The reason is that it is precisely experiments which connect real material processes and mathematical theories. It turns out that all of these elements are far reaching reductionisms or cut-offs from reality (section “Reductionisms”).

2. *The second step* begins with inquiring what happens if one does *not* allow for these cut offs. After all, a philosophical approach within natural realism requires, before anything else, to *not omit any reality recognized as such. Thus, in our case, the philosophical method does not involve abstractions.* Accordingly, we have to take into account *all* available experience (section “Returning to the Undeformed Situation”).

3. *The third step* consists in reflecting on these experiences and making inferences. This resembles somehow what is called in logics a deduction, even though it is rather an organic stepwise exploration of reality. It turns out that there is a dynamical order, which indeed exhibits mathematical features (section “From Self-Referentiality to Automorphisms”).

This is still far away from a philosophical *foundation* and also from an embedding of whole physico-mathematical theories. One sign of it is that theories always involve mathematical expressions called ‘equations’. But such a result allows already for the conclusion that natural realism in general, and the two important Aristotelian notions of ‘substance’ and ‘dynamics’ in particular, offer insights that have not been achieved elsewhere.

Reductionisms

The first step mentioned in the foregoing section consists in specifying a list of the elements common to every experiment. Experiments are the "bridge" between material things and physico-mathematical theories, with the important feature that the bridge has still to be built. That is to say that, by means of natural processes and in a carefully planned way, the experimenter *intervenes* in those other natural processes in which he is interested. As a general rule, the experimenter intervenes in four interconnected ways:

1. *The experimenter puts spatial limits on experiments*.

2. In an experiment designed and to be carried out by him, *the experimenter determines* which of the two sides serves as the object and which as the apparatus.

3. *The experimenter stops* his intervention by his own initiative, *i.e*. he puts a temporal limit. Only this makes possible a result at all. Generally, experiments comprise a final *result* and a *way* towards that result. (Excepted from this are instantaneous processes (particle decays and reactions)). But, as a rule, *only the result* enters the physico-mathematical theory.

4. *The experimenter dismisses* the apparatus after having used it by *not* attributing the result equally to both sides, *but to the object only*. This holds in classical physics (including Relativity) as well as in quantum physics. This fourth intervention is the most incisive one, for it makes appear the relational properties of material things as absolute ones.

None of these four interventions corresponds to anything in nature: neither the experimenter's putting spatio-temporal limits to the experiment, nor his preferential choice of an object nor his abstracting from the process that yields the result itself, which in turn is made possible by his stopping the intervention (except in the case of instantaneous processes), nor his almost complete dismissal of the apparatus which is a natural material thing just as the object. *Our present day physical knowledge does not refer to the real nature but to its deformed picture*.

The deformation is partly due to the preconceived and rigid character of the above four interventions. They have little to do with the approximations, generalizations, analogies and partial views that occur in every day life and the use of which is quite flexible. The latter allow for a huge variety of ways of acting, etc., and are mostly connected with *practical* aims. The former (i.e. the interventions) resemble rather a Procrustean bed and are intended for obtaining knowledge, even though that knowledge is used later for practical aims.

Eventually, the fifth point:

5. *The experimenter-theoretician links* the individual measurement values (and/or other experimental data) to certain abstract objects of the physico-mathematical theory. Here two heterogeneous things are put together—something individual and something abstract—without anything intermediate. A good example for demonstrating the difficulties that arise from such a practice is the so called paradox of Schrödinger's cat.

Schrödinger's thought experiment puts together two things: on the one hand, a living cat in a box, where is also arranged a suitable device, the operation of which is initiated by the decay of a single atom. In the (unforeseeable) moment of the atom's decay, the device would act upon another machine that kills the cat. All these things are individual and located here and now in space and time. On the other hand, there is the abstract mathematical quantum theory which offers two simultaneously possible states of any cat: dead or alife. The theory consists of universal concepts that are not located here and now in space and time. It does not *specifically* refer to an individual atom.

Summing up: Present day physics offers a deformed picture of nature due to the cut-offs introduced by the experimenter in order to obtain a connection between experienced natural processes and mathematics. This has made physics a sort of highly efficient scientific engineering, but it *eo ipso* disqualifies physics for a *direct* relationship to any branch of realist philosophy, *e.g*. a realist philosophy of nature, metaphysics, or a realist natural theology. Additionally, there is an unbridged gap between individual material things and abstract mathematical objects.

Returning to the Undeformed Situation

The second step consists in looking more closely at what has been referred to as '*not* allowing for the cut offs' just mentioned in the previous section. That is to say, we have to *omit* the aforementioned deformations of one's picture of nature. Only then it is possible to begin with the original situation, which has been left behind in order to make a certain connection to mathematical objects. For the sake of clearness, we first compile a list of these omissions. Thereafter we present a list of experiences that give a fairly good account of what is meant by 'original situation'. Finally, some very brief remarks about Aristotle's philosophical elaboration of the notions of 'substance' and 'dynamics'.

Here is the list of the omissions required for the return to the original situation:

1. One has to omit the spatial limits of every experiment.

2. One has to abstain from considering one side of the experiment as the object under investigation and the other side as the apparatus which is just a means of investigation. Therefore, the experimenter must *equally* consider *both* sides. What is more, he must consider them without limits. That is to say, he must take into account the whole world.

3. The experimenter has to renounce putting an end to the experiment. There is not coming about any result, not even in the end of the world. Consequently, the whole experimental enterprise has turned pointless.

4. Accordingly, the fourth cut off, the dismissal of the apparatus, does not take place either. Nor does the attribution of the result to the object alone.

5. And eventually, neither takes place the connection of individual measurement values (or other experimental data) with any abstract mathematical variable.

When confronted with these ideas, a physicist would probably comment that they would simply kill physics as an experimental science. This, in turn, would kill technological progress. Those willing to take part in such an enterprise would appear as opposed to our technological civilization. One could counter this comment by pointing out that it misses the point, because the real question at stake is whether a deformed picture of reality would do better than a *non* deformed picture of reality. Or in other words, whether and how success and truth are linked to each other.

Such a physicist could well corroborate his defense of physics as it is practiced to date by adding the following hint: Precisely the second cut off and, in a minor degree, also the others, makes it possible to see the qualitative gain of knowledge experiments can offer. This gain is based on an understanding of the idea that every experiment involves *two* sides. Even though the experimenter is mainly interested in the *object* and not in the apparatus, nature does not depend on particular interests. Therefore, *both sides* are equally important. In other words, the apparatus causes a certain behavior of the object under investigation, and conversely, the object causes a certain behavior of the apparatus. So both contribute to disclose something of nature. Neither Aristotle nor any other philosopher until the late middle ages knew of this *particular capacity of nature to disclose itself*. It does not replace mere observation, but it adds something important to it.

In turn, an imaginary discussion partner of that physicist could reply by two remarks. First he could invite the physicist to take his own argument seriously that nature has no particular interests. Then, the physicist should take into equal account both the object and the apparatus. And second that Physics has been transformed from an experiential science into a sector of Mathematics, where the mathematical objects have been given physical names. Specifically, he could refer to the fourth cut off, the dismissal of the apparatus after having performed the experiment. As a consequence, the result of the experiment has to be attributed *to the object alone*.

Additionally, if the result is a measured value, one might claim that this is the key to the total mathematization of physics, so that the mathematical theory could also describe the experiments which have previously confirmed that same theory. Exaggerating a little bit, the claim maintains that a theory could, in principle, describe its own discovery and experimental confirmation. This idea has been pursued in the last 30 years or so, and the results are rather discouraging.[13] We stand here in front of a sort of claimed self-referentiality of the *theory*. Later, we will find a real self-referentiality *of reality*, which is quite a different thing.

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In the following we present a list of experiences, which are important parts of the original situation, *i.e. without* interventions of an experimenter. There are the classical experiences which preserve their importance. But there are also specific modern experiences. In this context it should be stressed that the word 'experience' means more than sense perception. In the self understanding of natural realism in general, and in Aristotle's view in particular, there exists a sort of continuity between sense perception and abstract concepts formed by the mind. Therefore, rather than *ordering sense data*, experiences are the *source of conceptual insights*.

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[13] The idea is called 'the theory of measurement'. In practice, it is only of interest for quantum theory. The first monography appeared in 1991: Paul Busch, Pekka J. Lahti, Peter Mittelstaedt, *The Quantum Theory of Measurement* (Berlin-Heidelberg-New York: Springer).

The *first experience* is what can be called ‘perspective of solid bodies’. It is classical, but already in ancient times it has disclosed the astronomic world of things beyond reach, and in modern times the microscopic part of our world. The environment we are living in consists of solid bodies like tables, houses, bookshelves, and also living bodies, humans and animals. It shapes our immediate experience and concepts. Using solid-body-like instruments we discover and explore little by little a macroscopic, astronomical world and a microscopic, atomic world. And we ourselves are located in what could be called the ‘mesoscopic’ world. In short, everything material is thought of and handled with/by our experiences and concepts learned from the perspective of solid bodies.

This perspective deserves our attention, above all, because of the very fact that solid bodies are ‘solid’, stable, and often even rigid. This has fostered the idea that one can attribute physical properties such as volume, diameter, temperature, etc., to each solid body alone, *without* taking into account that these properties are perceived from a certain perspective and often have been determined by means of *other* solid bodies. *There is no rational justification for abstracting from those other solid bodies and from the perspective of solid bodies in general*. In short, the relational way of being of solid bodies has been replaced by a picture where they are attributed an absolute way of being. And this view has been applied to all material things, from the whole universe to single elementary particles. Examples can be found in most manuals of physics. There appear expressions like ‘diameter of the universe’ or ‘diameter of an electron’ in the sense of absolute values.

The *second experience* is that of the *multiplicity*, *diversity* and *individuality*, *identity* and *temporal continuity* of material things. Referring to a single material thing, ordinary experience distinguishes between the individual as a *whole* and its *properties*, such as a tree, on the one hand, and its height, weight, color(s), mechanical properties, etc., on the other. All these concepts refer to classical experiences, so that nothing more need to be said here.

The *third experience* is also classical and consists in the stability, periodicity and equilibrium of processes. Translations of solid bodies give an idea of stability, and the astronomical year, circular movements and rotations of solid bodies give an idea of periodicity. Finally, equilibrium or balance is a general condition of dynamical order. The Newtonian axiom *actio* = *reactio* draws on this experience.

The *fourth experience* concerns what commonly is called *space*. In this point the modern experiences depart clearly from Aristotle's ideas. Einstein proposed a classification of notions of space as follows: Space is either conceived as a *positional quality* of each and every material thing or as a *container* of all material things together. In the first case, there is no space without things, and in the second case, there are no things without container, and the container-space exists also without things. Obviously, Newton's concept of absolute space belongs to Einstein's category of container space, while Aristotle's concept of place is closer to, but not identical with, the idea of a positional quality.

As a container-space has never been observed, we stick to the 'space as positional quality of every single material thing', even though this alternative has never been seriously taken into account. The reasons are easy to find: First of all, one must determine, what a single material thing is. Are elementary particles such single material things, or macroscopic solid bodies? Second, a space made up of the positional qualities of material things seems to become more and more complicated together with the increasing number of material things. In practice, it looks like an impossibility to deal with billions of billions of billions of positional qualities of elementary particles, and the conceptual elegance of such an idea seems to be null.

Nevertheless, let us continue with that alternative. Positional qualities of material things are *mutual or reciprocal*. That is to say, material things adopt their positions exclusively with respect to other material things and vice versa. Together with the observed “flexibility” of all these relational arrangements—on the astronomical level as well as on the level of elementary particles, everything is uninterruptedly moving—one is led to the necessary conclusion that they are *dynamic*. That the dynamic positioning of material things is really uninterrupted is confirmed by the following observation: when looking at whatever place of the universe, we observe that solid bodies have uninterruptedly clear positions, which vary in a clear way. This means that material things interact continuously with each other, performing their mutual positioning. It can be shown that this argument extends to microscopic things as well, picturing the *whole universe as a thoroughly dynamic entity*.

The observation that material things act one upon the other leads us straightforward to the complementary *fifth experience*: material things act one upon the other. This is a classical experience, which has led Aristotle to develop his view of certain accidents, i.e. dependent realities, named action and passion, in the context of efficient causality. We shall return to this topic at the very end of this section.

The *sixth experience* is modern and refers to the characteristics of so called interference experiments. Such interference experiments have been done historically first in *optics*. Early in the period of the Scientific Revolution, there were two competing theories about what light is: one theory said that light consists of particles, and the other said that light is made out of waves. Interference experiments have been taken to support the view that light is made out of waves. Quantum physics says that all material things whatsoever have properties of particles *and* of waves. Thence the term ‘particle-wave dualism’. There are good reasons to think that *this view is mainly due to the fourth cut-off mentioned above*. But instead of going into details of those reasons, we specify directly the sixth experience: one finds another dualism, namely the dualism of individual—non-individual. One can easily perceive a similarity between “particle—individual” and also between “wave—non-individual.” But also the difference is huge.

This sixth experience is closely connected with the *seventh experience*, which is equally modern. It finds the dualism ‘individual—non-individual’ just mentioned also in experiments of reactions and decays of elementary particles. Moreover, these experiments yield some more details about the relationship between the individual and non-individual part. They show that elementary particles are such that they exhibit an *invariable combination of invariable properties* like spin, mass, electric charge and others. These invariable combinations are found only in individual things. And most importantly, they are realized without any differences in different individual things. That is to say that such invariable combinations themselves do not refer to anything individual, but are realized only in individual things. In short: the observations suggest that elementary particles are a dualistic structure. An equivalent formulation is that they are individuals of invariable species.

Note that a necessary condition for speaking about the dualistic structure of an elementary particle is that space is *not* a container (5^{th} experience), but when space is made up by the things themselves via their positional qualities. Otherwise the observations and experiments referred to would tell something about things *in the container*, and their interactions *in the container*. If a container space is claimed to exist, one cannot, in rigor, speak only about the things contained in the container without referring to the container.

This makes the way free to identify the *eighth experience*. As we have seen, the positional qualities govern the mutual relationship of material things which, as has been said in the context of the fourth experience (space as result of positional qualities of material things), is dynamic. Therefore, the positional qualities are characteristics of that dynamic. The *eighth experience* presupposes two experiences: a) the forth experience, i.e. the view of space as a positional quality of every material thing, to which also belongs the inductive inference of the uninterrupted (pairwise) interaction of things, b) solid bodies *consist* of a huge number of elementary particles. The *eighth experience* is, strictly speaking, a conclusion from these two and consists in that elementary particles exhibit themselves to the experimenter as such by interacting with experimental devices. In other words, *elementary particles are such that they collectively disclose each other in the confrontation of single particles with huge agglomerations of them*. This formulation is quite qualitative, but it has a clear observational ground.

Even though this experience might be called *vague*, it makes a point against the fiction that elementary particles are discovered by realities entirely foreign to them. In an equally vague way, it constitutes the opposite to the tentative claim mentioned in the first part of this step II that there exists a mathematical *theory* of what has been taken to date as an independent element of a theory's experimental confirmation, that is to say, a *theory* of measurement. Such a theory would be, in principle, an account of its own experimental discovery. This eighth experience suggests that our *material* world consisting of elementary particles somehow discloses itself. One could also say that it is a condition for an epistemologically "bright" climate.

All these experiences are highly inductive knowledge. Think, for instance, of the invariable combination of invariable properties, typical for species of elementary particles. They lack any sort of fragmentation. The classical notion of induction consists essentially in that the observer becomes aware of something universal in the perceived particular situations. That is to say, induction is necessarily linked to sense perception and experience. Now, contrasting those invariable combinations affirmed by an experimenter with the multiple fragmentations imposed by the experiments followed by the fragmentation of their perception, it requires a lot of trust in induction as a natural capacity of the observer in order to be convinced of the existence of elementary particles. And precisely that is what happens among physicists, despite the equally generalized skeptical attitude against induction fostered by many philosophers of science.

A remark might be in place in order to indicate that neither this eighth experience nor any other of the aforementioned experiences do presuppose or involve physicalism, *i.e*. the stance that all constituents of the cosmos, including living organisms, are nothing more than huge and complex compositions of elementary particles, without any more unity. This problem probably can be fully assessed only in a conceptual framework in which the act of being is different from and metaphysically previous to the substantial form. According to the arguments advanced in favor of the unity of the substantial form of things which have come into being by some sort of composition of less perfect components, there is a certain hierarchy of perfection, and the corresponding higher substantial forms assume what corresponds to the forms of the previous components that have ceased to exist as independent beings.[14]

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The considerations about the Aristotelian notions of 'substance' and 'dynamics' can be brief, because these notions are widely and well known. Additionally, the purpose of this paper is not to perform a detailed exegesis of Aristotle's texts but rather to show that it is fruitful to assess experiences in Physics in a way inspired by Aristotelian thought. In fact, for the notion of 'substance', it is sufficient to count with what is above indicated within the 'second experience' as 'property'. 'Property' is a word extensively used by physicists, and its meaning carries implicitly the question 'of what'? The 'what' is the substance. This latter word is hardly used by physicists, but they refer instead to the

[14] Cf., for instance, John Goyette, "St. Thomas on the Unity of Substantial Form," *Nova et Vetera* 7:4 (2009): 781–790 [https://www.thomasaquinas.edu/sites/default/files/goyette1.pdf]; and John F. Wippel, "Thomas Aquinas and the Unity of Substantial Form," in *Philosophy and Theology in the Long Middle Ages. A Tribute to Stephen F. Brown*, ed. Kent Emery Jr., Russell L. Friedman and Andreas Speer (Leiden and Boston: Brill, 2011), 117–154.

names of material things, such as ‘a property of *an electron*’, where ‘electron’ is the individualized name of a species of elementary particles. However, there is also the widespread misunderstanding of treating properties (dependent) as if they were substances, *i.e*. independent realities.[15]

Aristotle deals with substances and their dualistic structure at length in books Z, H and Θ of his *Metaphysics*: an individual material thing is a whole, where all parts fit harmoniously together and thus form the aspects of a unique design, in which the substantial form can be distinguished from the prime matter. It carries the more specific name of hylomorphic structure. While it is true that Aristotle has performed his analysis of the individual material thing only having before him macroscopic ones, it is also true that the two main features of hylomorphism, the dualism of ‘individual–non-individual’ and the mutual implication of both matter and form can also be discovered in the realm of elementary particles.

Rather different is the case of the notion of ‘dynamics’. As is well known, Aristotle takes it as obvious that material things act one upon the other so that one can speak of the impact *of* a certain material thing *on* others.[16] According to Aristotle, this view is linked to the perspective of solid bodies, which can be seen from the fact that he uses repeatedly, in these same passages, words like “touching” in order to indicate a condition of the efficient causality to be effective: there must be an immediate “contact.” Therefore, the agent itself needs to be

[15] Examples are, in classical physics, the division of a bigger body’s mass (a property, i.e. a dependent reality) into smaller independent units in order to calculate its gravitational force of the whole body in terms of these units. The same holds for the calculation of the so-called self energy of an electrically charged body: the property ‘charge’ is divided into independent parts. In present day physics, an eloquent example is the so called Higgs boson (a particle and thus an independent reality), which is considered to bring about what has been attributed, until the date, to the mass of particles, i.e. a dependent reality).

[16] This view is presented mainly in book III of Aristotle’s *Physics*, available online at: http://classics.mit.edu/Aristotle/physics.html.

moved—receive an influence—in order to act upon another material thing.

Accordingly, here are two topics to consider: on the one hand, the transitive character of efficient causality ("one thing (agent) acts upon *another* (patient)") and, on the other hand, the condition for that transitive causality to take place: 'local contact of agent and patient'. There is no 'action at a distance'. However, 'contact' as well as 'distance' are notions formed within the perspective of solid bodies referred to above as the first experience. This suggests the assessment that the transitive character of efficient causality is a real metaphysical topic, i.e. a statement on the level of principles. On the other hand, the condition of local contact depends on the view that macroscopic bodies are the "fundamental entities" in the material world. This latter view has proved wrong. According to present day experiential knowledge, it is elementary particles that are the "fundamental entities." Almost all physicists apply the notions 'whole' and 'part' by saying that macroscopic things *consist* of elementary particles. Very few physicists, if any, apply those notions the other way round by saying that an elementary particles is a suitable *part* of macroscopic things. As to philosophers, the situation might be different.

According to the fifth experience, we take the transitive character of efficient causality for granted, with the specific condition that this is true for elementary particles exclusively. Solid bodies are composed of elementary particles and can be considered as acting one upon the other in virtue of the transitive actions of their components on each other. In this way we agree to Aristotle's affirmation "ἀλλ' ἔστιν ἐνεργητικὸν τοῦ κινητοῦ, ὥστε ὁμοίως μία ἡ ἀμφοῖν ἐνέργεια" (The active thing is another thing than the moved one, but nevertheless the action belongs to both (own translation)).[17]

[17] Aristotle, *Physics*, III 3, 202a 15. This topic is dealt with at length in the rest of the chapter after the sentence just quoted. The two joint statements have been taken without alteration by the Aristotelian tradition, which might be seen, as an example, from the

Furthermore, from the fourth experience that space is built up by the positional qualities of every single material thing, one can conclude that there is an efficient causality intrinsic to material things which, therefore, need not receive an influence in order to act upon others. Aristotle's view is bound to a perspective of solid bodies and is left behind.

In modern physics, the assessment of the same experiences is quite different, insofar as the transitive character of efficient causality has been *separated*, since Newton, from material things, so that the latter are considered *inert*. But as interaction of material things is at the root of physics as an experimental science, the existence of intermediate or 'exchange' particles must be assumed, which substitute (transitive) actions by giving an account of the observed changes. But if one assumes that the exchange particles are real and not only fictitious entities, the question arises how an exchange particle exercises an impact on the "destinee" particle that changes, because the local *vicinity* of two things as such does not provide an explanation of an *impact*. In other words, it is unclear how the idea of exchange particles could *substitute* the transitivity of an efficient cause's action.

The modern physical notion of inertia, in virtue of which a material thing moves (locally) *without* external cause, is derived from the perspective of solid bodies ('principle of inertia'). The very formulation of that principle presupposes a concept of space or location. From the perspective of elementary particles, which relate to each other by their positional qualities, *i.e*. in a dynamic way, the principle of inertia *needs* the uninterrupted transitive causality of elementary particles. A contradiction between that principle and uninterrupted dynamical relationship of elementary particles arises only when one unreasonably tries to apply experiences of macroscopic things uncritically to microscopic things.

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comments of Thomas Aquinas on this passage: Thomas Aquinas, *In III Phys.*, lect. 4, n. 10 and lect. 5, n. 10.

Summing up: In addition to the classical experiential knowledge of material things and their properties, modern physics has brought substantially new experiential knowledge. Particular emphasis deserves the eighth experience which can be expected to have a considerable impact on the epistemological climate of present day physics by shifting it from a rather "dark" epistemological climate into a "bright" one. The Aristotelian notions of 'substance' and 'dynamics' are sketched in order to sharpen the pertinent second and fifth experiences. In the light of these experiences, the Aristotelian view is dismissed inasmuch as it depends *exclusively* on the perspective of macroscopic bodies.

From Self-Referentiality to Automorphisms

The third step consists in reflecting on the eight experiences presented in the previous section in order to stepwise make explicit features of reality contained in these experiences. They invite us to first eliminate the reductionisms by omitting them and then to try to show how some mathematical elements of present day physical theories are *rooted* in the very same material things to which the theories refer. This would be opposite to conceiving such theories as pure inventions and *applying* them to those material things. This would be a way, perhaps the only one, to achieve an explanation of the success (though limited) of such theories. However, it is impossible to present the details of such an argument in just a few pages. In this final section, we intend to give the basic statements of how this argument goes and the results achieved so far.

1. The argument itself develops in a rather *deductive* way, quite opposite to the experiences listed in the previous section, which yield an *inductive* knowledge. Here, the word 'deductive' does not refer to a syllogistic procedure. It rather means a mental process of elaboration *without* adding further insights from experience. It is, so to speak, a way of exploring reality from *inside*. I will mostly use the Aristotelian terms 'hylomorphic structure' or 'hylomorphism', 'substantial form'

and 'prime matter'. This definitely does mean that metaphysical structures cause a certain dynamical order. It definitely does *not* mean that every law of nature could be deduced from metaphysical principles. There is a huge margin for observation and experiments, which will have to show the properties material things actually have.

2. The starting point for the deductive process mentioned are *elementary particles and not solid bodies*. The reason is that only elementary particles are a hylomorphic structure and, *in virtue of their substantial form, would allow for universal laws of nature*. Only the dynamics of elementary particles can be described by their hylomorphic constitution. Solid bodies, in turn, are composed of elementary particles.

3. Space is a positional quality of single elementary particles. Space is not a container (cf. the fourth experience above). The positional qualities are dynamical. The positional qualities of solid bodies are a result of the joint positional qualities in the strict sense of their elementary components. *This is a most important shift*, namely from considering single material things with "absolute" properties to considering always a collective of material things (in rigor: the whole universe) with "relative" properties.

4. The relationship between substance and its dynamics is located on the level of elementary particles. It is based on the hylomorphic structure as such, allowing for, but not taking into account specific differences. Then it says that such substances are active due to their being a substantial form, and passive due to that they are prime matter. This is an application of the principle 'agere sequitur esse' (action follows being), which has rather to do with Thomas Aquinas's metaphysics of being. This principle is crucial for the whole argument.

5. Every particle gives, by its hylomorphic structure, to its proper action as well as to its proper passion an *accompanying* determination as follows: the particle is active in virtue of its form, and the action is *conditioned* by its being this and not that particle. This is the accompa-

nying efficacy of the particle as prime matter. In analogy, the particle is passive in virtue of its prime matter, and the passivity is *conditioned* by the invariability of the particle inasmuch it is the substantial form. This is the accompanying efficacy of the particle as substantial form. So we have *proper dynamics* and its *accompanying determinations*, both in virtue of the same hylomorphic structure.

6. The two basic characteristics of the global dynamical order derived from the hylomorphic structure of elementary particles are:

a) An elementary particle does *not interact with itself*. It exclusively acts upon other particles. This seems to be contrary to our experience in the realm of macroscopic solid bodies. For instance, a human can put his arm up by means of the other arm, a dog can scratch behind its ear, and a cat can lick its paw, just to mention a few examples. However, there is no contradiction, because there are no cases of a part of a solid body moving itself. Always another part is needed.

b) Elementary particles act *only directly* upon other elementary particles. There is no intermediation of third particles. This, too, is contrary to our experience in the realm of macroscopic solid bodies. Nevertheless, neither here is a contradiction, because of the difference between the perspectives of elementary particles and solid bodies. Yet, the question remains open, where this contrast stems from.

7. The two aforementioned characteristics generate a global dynamical order: It is a global involution that specifies conceptually what has been called a ‘collective self-referentiality’ (cf. section “Returning to the Undeformed Situation,” end). *This means that our approach appears to be self-consistent, i.e. it reproduces, on a more explicit conceptual level, what has been part of the experiential starting point* (*eighth experience*, in the same section, middle part).

At this point, we might ask how much we have approached the aim stated in the introduction, namely the attempt of laying the bases for solving the problem of the lack of unity between the two bodies of knowledge present in physics. In other words, the question is whether a *rationale* or part of it has been found, which unites observations (including experimental experience) and certain mathematical entities. So far, no such mathematical entity has been presented. It is true, that present day physico-mathematical theories cannot be literally re-derived from metaphysical principles, becauses these theories underlie the reductionisms pointed out above. Nevertheless, there can be expected a certain mathematical embedding of physical theories depending on metaphysical principles. Such a dependence can well be in keeping with the difference between metaphysics and philosophy of nature, on the one hand, and mathematics, on the other.

To begin with, the concept of perturbation can be eliminated. In experimental settings, a perturbation is understood as an influence of the apparatus on the object's action on the apparatus. While it is obviously true that the object is influenced by the apparatus, it is *not* true that, because of that influence, the object's influence on the apparatus changes. The absence of perturbation can be shown to be a consequence of the hylomorphic constitution of elementary particles. Interestingly enough, Newton's third axiom *actio* = *reactio*, which is one of the pillars of classical physics and has been taken over into modern physics, does not rule out the concept of perturbation.

Second, it is the hylomorphic structure of elementary particles which generates their dynamical order. This can be understood in the light of the principle *agere sequitur esse*. The dynamical order has a global feature, which strongly resemble the dynamical features of every single particle. The global feature can be characterized, within the limits of these short expressions, as a threefold convolution. The features of individual particles resemble what is called 'spin' in quantum physics. This global-individual dynamical order is somehow self-referential and thus exhibits a degree of intelligibility completely foreign to the mindset of modern physics.

Third, the relationship of this dynamical order with its global and individual aspects have not yet been shown to yield specific mathematical elements. Nevertheless, the author hopes to be able to publish such more specific results in the near future. What *is* clear that in the forefront are mathematical entities which reflect the mentioned self referentiality. These entities are so called mathematical automorphisms. As a matter of fact, automorphisms already occur in physics in the form of so called groups: on the one hand, in connection with space-time, the so called Galilei and Poincaré Groups, in classical physics and Special Relativity, respectively. On the other hand, something similar happens in General Relativity and in connection with the classification of elementary particles.

Finally, it may be said that the approach of this article to mathematics in physics differs from the historical Aristotelian approach to mathematics. While the Aristotelian one involves, from the very outset, an *abstraction from the nonquantitative properties of material things* and yields numbers and geometrical objects, the approach presented here is based on the hylomorphic structure of elementary particles, *which generates a dynamical behaviour* that is somehow "proportional" to their hylomorphic structure. Abstractions do not occur.

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Altogether, these statements sketch (together with the whole argument that leads to them), in the particular case of the connection of experience and mathematics in physics, the role which philosophy can occupy in science. In this case, philosophy takes up the task to fill a gap produced by physics itself: the gap between *models* of reality expressed in mathematical terms, and *reality* itself, which is taken for (more or less) unknowable. Yet, a realist philosophy finds enough to know of reality itself that it can offer, even though to date just on an embryonic level, an understanding of the connection between both experience and mathematical objects and, in doing so, serve the unity of human knowledge.

This leads, surprisingly perhaps, to the conclusion that filling a gap by philosophical means is not only an increase of sapiential knowledge proper to philosophy, *scire propter scire*. Such a knowledge might be left aside by scientists insofar as they are merely seeking *applications* of scientific knowledge, *scire propter uti*. However, the deepening of physical knowledge by philosophical categories is likely to improve the science as such and, thus, make possible more, or better, applications. This should also motivate *scientists* to seek a philosophical understanding of their science.[18]

SUBSTANCE AND DYNAMICS:
TWO ELEMENTS OF ARISTOTELIAN-THOMISTIC PHILOSOPHY OF NATURE IN THE FOUNDATION OF MATHEMATICS IN PHYSICS

SUMMARY

The article aims at proposing a way of solution to the problem why mathematics is efficient in physics. Its strategy consists in, first, identifying servere reductionisms performed on physical processes in order to have them correspond to mathematics. As this makes it impossible to understand the *real* relationship between matter and mathematics, a necessary step on the way to an understanding is to abandon the reductionisms from the very outset. Consequently, one is faced with the need of searching for mathematical elements in nature, as if there never had been any successful mathematics in physics. And for this search, one has to rely on experience alone. To this end, the article takes its inspiration from two pillars of Aristotelian philosophy of nature, the notions of 'substance' and 'dynamics', together with a careful examination of the treasure of accumulated experience in physics. Upon this basis, the hylomorphic structure of elementary particles, which are considered to be at the basis of all material substances, is the source for the most common features of the dynamical order of material things in general. This dynamical order, in turn, is quite likely to be reflected in mathematical terms.
This is a novel approach because, at present, the most common framework for dealing with the question of mathematics in physics is *Scientific Realism*. It addresses the question why *the existent physico-mathematical theories* are successful. In order to find an

[18] In that sense, the proposal of this article might be considered as a specification in a particular case of what has been proposed in general by P. Gondek, "The Place of Philosophy in the Contemporary Paradigm for the Practice of Science," *Studia Gilsoniana* 3 (2014): 85–96. The article proposes arguments "for the cultivation of philosophy as sapiential or wisdom-oriented knowledge whereby human knowledge is realized more fully" (*ibid*., 85). This would have a considerable impact on the mindset of many people.

answer, it starts from these theories and some methodological considerations, but does not address the question of *where these theories stem from*. In particular, it does not consider the possibility that these theories might, at least in part, stem from the material things they are referring to. The latter approach is what is suggested here. It is that of *Natural Realism*, of which Aristotle is an eminent representative.

KEYWORDS

Aristotle, dynamics, elementary particles, experience, hylomorphism, mathematics, natural realism, physics, scientific realism, substance.

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