Does Physics need a second scientific revolution？

——Christianity encourages tackling foundational problem of Physics

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Abstract：This article identifies an inbuilt defect of modern Physics. It consists in not providing enough connection between the two bodies of knowledge that make up Physics：observations of and experiments with material things，on the one hand，and mathematical theories，on the other. More specifically，the defect consists in that mathematical structures are *applied* to experiences of the material world，as if they were *only* in the mind of the physicist. Nevertheless，the success of mathematical Physics suggests that these mathematical structures are somehow related to the material realities they are applied to. – Due to the inbuilt defect，mathematical theories in Physics have to undergo a procedure of approval or disapproval by experiments. However，even if approved，the hypothetical character of such a theory cannot be removed. A theory never becomes definitive. – The roots of the said defect lie in the scientific revolution during the 16th and 17th centuries. This article makes three of them explicit：（i）the dominant view that Nature and human cognitive capacities do not fit together，（ii）most present day ways of understanding Mathematics do not involve the material world，and（iii）the scientific revolution has essentially brought，for Physics，its mathematization. – It is proposed that Thomistic hylomorphism is a suitable tool to show how those mathematical structures that are used in Physics *have their root* in material things themselves. The "application" of mathematical structures to experiences of the material world thus has an objective foundation. The belonging of mathematical structures to material things is based on that the hylomorphic structure unites organically the singularity of a material thing and its belonging to a species. – Christianity does not endorse any particular solution of that problem. However，Christianity contributes to a solution insofar it supports strongly the genuine intelligibility of our world. The spirit of Christianity thus supports the view of science as a sort of realist knowledge.

Key words：Physics，Mathematization，Hylomorphism，Intelligibility，Christianity

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Ⅰ. Introduction

This article focuses on the problem which is commonly called the 'question of applicability of Mathematics in Physics'. As a result, a work programme is suggested for elaborating the view that certain mathematical structures *stem* somehow from material things. Therefore, these structures cannot be said to be 'applied' to material things, as if Mathematics were something alien to them.

We begin by exposing certain basic features of the so called scientific revolution of the 16th and 17th centuries, identify certain problems caused by that revolution and formulate the work programme accordingly. A Chinese reader might particularly notice that the work programme attempts to get the different parts of the problem into a harmonious relationship among each other.

It must be stressed that this problem is completely independent of any religious views. Nevertheless, it is Christianity that strongly encourages scientific and philosophical inquiry by affirming the deep intelligibility of this world. In other words, Christianity is intrinsically science-friendly. This will be briefly discussed in the last section of this article.

The root of modern Physics lies in the philosophy of nature as it has been shaped in antiquity by the Greeks. Their philosophical reflections always were based on observations and brought about the notions of 'substance', 'change' and 'cause'. Much later, approximately in the 14th century, another type of knowledge expressed in numbers, numerical proportions and other mathematical structures joined the existent philosophy of nature. About two centuries later, the interplay of these two branches of knowledge underwent a revolutionary change. The mathematical models of material reality had become sufficiently sophisticated that their predictions called for experiments as the tool for testing them. Eventually the tandem {experiment & theory} prevailed over mere observation.

Accordingly, mathematical theories in Physics became more and more dominant and tranformed Physics into something like a comet with a theoretical core and an experimental tail. At the same time, theory drifted away from experimental Physics. An example for how far this went is the characterization of the relationship between mathematical theory and material nature given by the physicist H. ? Hertz (1857-1894). According to Hertz, we *make ourselves* mathematical pictures or symbols of natural things in such a way that the mathematical consequences of the pictures also yield a picture of the natural development or behaviour of the corresponding natural things. This is the only feature that makes them symbols of material things. Therefore, it is possible that there are many suitable mathematical models or formulations of laws of nature①.

The thinness of the link between the experienced physical reality and its mathematical model goes hand in hand, surprisingly, with the breathtaking success of mathematical models in Physics. It is as if the physical science of the last three centuries has finally discovered mathematical

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① Hertz, H., *The Principles of Mechanics*, *Presented in a New Form*. London: Macmillan 1899; Introduction. Reprints New York: Dover Publications 1956; Mineola, N. Y.: Dover 2003.

structures as the intelligible core of nature. Then it almost became a necessity that the cognitive value of experience was estimated lower and lower, while the trust into the cognitive value of mathematical models was increasingly appreciated. The influence of contemporary philosophy fostered the conviction that nature does not release its secrets and that, therefore, the scientist has to furnish himself a picture of nature. Eventually, experience – observations and experiments – ceased to be considered as a *source* of theories. Instead, human genius became considered as inventor of theories, which made experience comprehensible.

Then, the conclusion can hardly be avoided that both experience and theories remain two bodies of knowledge independent of each other. Their juncture takes place, according to most physicists, *only* in the physicist's mind. In other words, it is excluded that mathematical theories in Physics are rooted in one or other way in the material things they refer to. Accordingly, they *are not extracted* somehow from the observer's or experimenter's experience. Application of mathematical structures is something exogene to material things, while extraction is something endogene.

In the former case, the success of physico – mathematical theories would be due to the internal organisation of the physicist's cognitive (and maybe other) capacities only. In the case of 'extraction', it would be due also to reality. Success as well as lack of success takes place in physical processes and is measured in terms of fitting predictions (and efficient technology). That means that success is not something purely theoretical, but requires some *practice*, experimental as well as adapting mathematical tools to an experimental situation. *Thought experiments* are not sufficient.

It is very significant that dealing jointly with experimental data and theoretical concepts is anything but a straightforward procedure. Rather, physicists make certain mathematical hypotheses motivated somehow by observational or experimental data, try to apply them to certain natural phenomena and then, based on that application, elaborate an approval or disapproval of the hypotheses in question. It seems that the hypothetical character of the application of mathematical theories to material things is considered to be unremovable. There is no evidence either that such a removal is considered necessary or beneficial for Physics. Physicists seem to be satisfied with a mere interlocking of both experience and theory, instead of an organic connection also rooted in physical reality than merely in the physicist's mind.

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The situation sketched above suggests we put the question of whether such mathematical structures *stem* from the material things they refer to and, therefore, can somehow be extracted from observational or experimental data about these very same things.

This article's contribution to answer that question develops in two steps: after having supplied some more details about the interlocking of experience and mathematical knowledge (section II.), we present as a first step three ideas that have been shaped during the scientific revolution and have been highly influential in bringing about present day Physics.

The first pivotal idea is that the view about the intelligibility of this world has been "pessimistic" for centuries (III.). The second, that the mainstream of modern Mathematics' selfunderstanding does not involve any reference to the material world (IV.). Third, the scientific revolution has brought, for Physics, essentially its mathematization (V.). And, due to the way of its historical performance, the mathematization has brought about several problems within Physics (VI.).

The second step offers some considerations about an agenda of overcoming these divisions (VII.). The main idea is to return to the unity of reality expressed by what could be called the metaphysical principle of no-contradiction. This in turn requires a thorough recourse to experience. This in turn requires positively taking into account every single material thing, and negatively to leave unused the known physico-mathematical theories. It is suggested to use, as an appropriate philosophical tool, the key notion of Thomistic philosophy of nature, namely hylomorphism. Among other things, hylomorphism gives a certain account of the singularity of each material thing.

Christianity has no stance with respect to any particular solution of this problem. Yet Christianity settles a general frame for more successfully attempting its solution. This is so because Christianity supports the conviction of the intelligibility of this world, and conversely that the human mind is capable of understanding this world (VIII.). This holds despite of limitations and the possibility of errors of the human mind.

Ⅱ. The progressive character of the mathematization of Physics

Listening to what physicists say about their own science provides deeper acquaintance with the intellectual climate in Physics. We confine ourselves here to quoting short statements about the relationship between Mathematics and material things of four representative physicists of the 20th century. They essentially agree irrespective of their different philosphical backgrounds.

First, Albert Einstein: The world of experience and the world of concepts are united in the same person, but experiences do not influence the shaping of concepts and vice versa. Therefore it is possible that "all concepts, even those which are closest to experience, are from the point of logic freely chosen conventions, just as is the case with the concept of causality."② And even more explicitly: "The theoretical attitude here advocated is distinct from that of Kant only by the fact that we do not conceive of the "categories" as unalterable …, but as … free conventions. They appear to be *a priori* only insofar as thinking without the positing of categories and of concepts in general would be as impossible as is breathing in a vacuum."③ Nevertheless, the hermetic separation of the

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② Einstein, A. "Autobiographical Notes", in Schilpp, P. A. (ed.) *Albert Einstein – Philosopher and Scientist*. La Salle (Illinois, USA): Open Court, 1949 (first edition), p. 13.

③ Einstein, A. "Remarks concerning the essays …." in Schilpp, P. A. (ed.) *Albert Einstein – Philosopher and Scientist*. La Salle (Illinois, USA): Open Court, 1949 (first edition), p. 674.

two worlds coexists with their (ununderstandable) correlation: "The very fact that the totality of our sense experiences is such that by means of thinking (…) it can be put in order, this fact is one which leaves us in awe, but which we never shall understand. … The fact that it is comprehensible is a miracle."④

The Einsteinian formula 'incomprehensibility of the comprehensibility' goes hand in hand with his view that the scientist's epistemological attitude is divided into strongly opposed parts: "The scientist … must appear to the systematic epistemologist as a type of unscrupulous opportunist: he appears as a *realist* insofar as he seeks to describe a world independent of the acts of perception; as *idealist* insofar as he looks upon the concepts and theories as the free inventions of the human spirit (not logically derivable from what is empirically given); as *positivist* insofar as he considers his concepts and theories justified *only* to the extent to which they furnish a logical representation of relations among sensory experiences. He may even appear as *Platonist* or *Pythagorean* insofar as he considers the viewpoint of logical simplicity as an indispensable and effective tool of his research."⑤

Second, Eugene P. Wigner: "The miracle of the appropriateness of the language of mathematics for the formulation of the laws of physics is a wonderful gift which we neither understand nor deserve."⑥

Third, Richard P. Feynman: "I think, it is safe to say, that no one understands quantum mechanics. Do not keep saying to yourself, if you possibly can avoid it," But how can it be like that? "because you will go" down the drain "into a blind alley from which nobody has yet escaped. Nobody can know how it can be like that".⑦

Fourth, Roger Penrose: "I should begin by expressing my general attitude to present day quantum theory, by which I mean standard, non-relativistic quantum mechanics. The theory has, indeed, two powerful bodies of fact in its favour, and only one thing against it. First, in its favour are all the marvellous agreements that the theory has had with every experimental result to date. Second, and to me almost as important, it is a theory of astonishing and profound mathematical beauty. The one thing that can be said against it is that it makes absolutely no sense!"⑧

These quotations might be interpreted as the opinion of some individuals who cannot claim to

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④ Einstein, "A. Physics and Reality". *Journal of The Franklin Institute*, Philadelphia, Pennsylvania, U.S.: 1936, 221,3, p.351.

⑤ Einstein, A. "Remarks concerning the essays …." in Schilpp, P. A. (ed.) *Albert Einstein – Philosopher and Scientist*. La Salle (Illinois, USA): Open Court, 1949 (first edition), p.684.

⑥ Wigner, E. P. "The Unreasonable Effectiveness of Mathematics in the Natural Sciences". *Communications in Pure and Applied Mathematics*, New York: John Wiley & Sons, Inc., 1960, vol. 13, No. 1, last paragraph. Also accessible on-line, for instance, at www.dartmouth.edu/~matc/MathDrama/reading/Wigner.html. Wigner is a major figure in the development of quantum theory during the 30's, 40's and 50's of the 20th century.

⑦ Feynman, R. P., *The Character of Physical Law*, Cambridge, MA: MIT Press, 1967, p. 129. Feynman is a major figure in the development of quantum theory during the 40's, 50's and 60's of the 20th century.

⑧ Penrose, R. Gravity and State Vector Reduction, in: R. Penrose and C. J. Isham (eds.), *Quantum Concepts in Space and Time*; Oxford: Clarendon Press, 1986, p. 129. Penrose is a major figure in the development of mathematical tools in quantum and relativity theory during the 70's and 80's of the 20th century.

represent the stance of the majority of physicists. But, as a matter of fact, none of these views has been convincingly contradicted.

The trend of applying Mathematics to many fields of human knowledge is ever increasing. Therefore, the use of axiomatics, hypothetical deduction and universal propositions occupies more and more space besides the rationality proper of that field before the advenience of mathematical tools. The case par excellence is Physics, where evidences and inductive reasoning, which allows for contingency and exceptions, are increasingly marginalized. Besides, the common use of the expression ？ applying Mathematics‘ and similar ones is even a sign for a process of *replacing* the original rationality of experience. The reason is that it implicitly denies that mathematical objects or structures *originate* in some way in the objects they are ？ applied to‘.

Applying Mathematics to physical problems is really an art of its own. But it has its limits, because there is always an element of trial and error in connection with a *particular* problem. This situation in turn suggests to distinguish between a purely theoretical and a practical knowledge of the link between mathematical objects and structures and material things. The theoretical knowledge answers to the question ？ why? “ and is missing, at least for the time being. The practical knowledge answers to the question ？ how to use? “ and is highly developed.

Even more: as the history of Physics since Newton‘s times shows, the solidity of theoretical Physics with its wealth of ideas furnished by the clear – cut mathematical rationality has led to the conviction that Mathematics is more than a useful tool in Physics. One testimony might be sufficient:

“Although Mathematics and Physics have grown apart in this century, Physics has continued to stimulate mathematical research. Partially because of this, the influence of Physics on Mathematics is well understood. However, the contributions of Mathematics to Physics are not as well understood. It is a common fallacy to suppose that Mathematics is important for Physics only because it is a useful tool for making computations. Actually, Mathematics plays a more subtle role which in the long run is more important. When a successful mathematical model is created for a physical phenomenon, that is, a model which can be used for accurate computations and predictions, the mathematical structure of the model itself provides a new way of thinking about the phenomenon. Put slightly differently, when a model is successful it is natural to think of the physical quantities in terms of the mathematical objects which represent them and to interpret similar or secondary phenomena in terms of the same model. Because of this, an investigation of the internal mathematical structure of the model can alter and enlarge our understanding of the physical phenomenon. Of course, the outstanding example of this is Newtonian mechanics which provided such a clear and coherent picture of celestial motions that it was used to interpret practically all physical phenomena. The model itself became central to an understanding of the physical world and it was difficult to give it up in the late nineteenth century, even in the face of contradictory evidence. A more modern example of this influence of Mathematics on Physics is the use of group theory to classify elementary particles."⑨

This conviction, in turn, has paved the way for making a decisive step. So far, the relationship between mathematical objects and material things has been something outside the focus of attention. Measurements and, more generally, experiments, have been considered as *bridges* between material things and mathematical theories. Bridges are not part of either side; but rather a sort of third entity that connects both sides. Nevertheless, until the advenience of quantum physics the bridges had been practically neglected.

But when the experimental process received its due attention, it could not be denied that the known physico – mathematical theories must be considered *incomplete*, because they do not describe the experimental process. But without any doubt, the experimental process is as natural as any other natural process, and this confronts physicists with the choice of (a) acknowledge this sort of incompleteness without reacting to it, for the time being, or trying to absorb the bridge into one of the two sides; either nature or theory. This latter alternative can be put as (b) trying to think the mathematical theory starting from material things with their own rationality, or (c) trying to think material things starting from a mathematical theory with its own rationality.

Option (b) has not received any attention, while option (c) has been given considerable attention in the field of the foundations of Physics, for the last 50 years. Option (a) continues being dominant in mainstream Physics. Option (iii) is suitably called ? the *theory* of measurement ". The following quotation is taken from the first monograph on the quantum theory of measurement.

"We shall hope to have established a systematic description of the quantum mechanical measurement process together with a concise formulation of the measurement problem. In our view the generalized mathematical and conceptual framework of quantum mechanics referred to above allows for the first time for a proper formulation of many aspects of the measurement problem *within* this theory, thereby opening up new options for its solution. Thus it has become evident that these questions, which were sometimes considered to belong to the realm of philosophical contemplation, have assumed the status of well – defined and tractable *physical* problems". ⑩

To the date, the results of this attempt have not been satisfactory. Besides mathematical difficulties that seem to be almost unsurmountable, the idea of a *theory* of measurement has split up

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⑨ Reed, M./Simon, B., *Methods of Modern Mathematical Physics*, vol. 1. New York, San Francisco, London: Academic Press, 1972, p. ix.

⑩ Busch, P., Lahti, P. J., Mittelstaedt, P. *The Quantum Theory of Measurement*. Berlin, Heidelberg, New York: Springer – Verlag, 21996, Preface, p. IX. Italics from the authors.

into different approaches that are quite different from each other⑪. But there are no signs yet that this option is going to be abandoned. This fact in turn might be interpreted as a sign that the spirit of mathematization has grown too strong. The same basic idea might be read off from some words of the influential mathematician D. Hilbert (1862 – 1943): "It is Mathematics which is the instrument that offers the connection between theory and practice, between thinking and observing. Mathematics is the connecting bridge and yields it stronger and stronger. This is why our present culture, insofar it concerns the intellectual comprehension and use of nature, has its basis in Mathematics."⑫

Concluding we might say that one can hardly avoid the impression that the rationality characteristic for Mathematics is marginalizing and trying to replace the rationality typical for the material world. But this easily can bring about the situation that, in practice, theoretical ignorance of the relationship to nature of mathematical laws of nature advances towards a systematic place in Physics.

The difficulties within option (c) suggest to have a closer look at option (b). Before doing so, it is appropriate to ask whether physical science must be necessarily the Physics we are witnessing today. In fact, there are some factors located in the scientific revolution, which have fostered the historical development of Physics into a certain direction. But precisely by doing so they have created other problems. To show this is the purpose of the following three sections.

Ⅲ. Three pivotal ideas Ⅰ: "Nature and human cognitive capacities do not fit together."

The purpose of this section is to make explicit the strong epistemological skepticism in philosophy since the times of the scientific revolution. It was inevitable that this had, on the long run, an equally strong impact on the emerging modern natural sciences. The quotations of renowned physicists at the beginning of the previous section can serve as a sample of that impact. We confine ourselves to a little anthology of quotations from influential philosophers from the beginning of the modern era until present time.

R. Descartes (1596 – 1650) wished to achieve above all *certainty* of his knowledge. To this end he introduced a methodological doubt onto everything, in order to accept only what escapes this

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⑪ There are several positions in competition without that comprehensive presentations or even reconciliations between them are at sight. The main positions can be characterized by the following key words: operationalism (theory of measurement), hidden variable theories, Copenhagen interpretation, many worlds, many minds, consistent histories, modal interpretations, quantum logic, Bohm – de Broglie interpretation, spontaneous collapse, decoherence. – An overview of the physical problematics can be found, for instance, in Busch, P. *The Quantum Theory of Measurement*. Berlin, Heidelberg, New York: Springer, 2002. A treatment of the philosophical problems of the quantum theory of measurement is offered in Mittelstaedt, P. *Physics and Philosophy. The Interpretation of Quantum Mechanics and the Measurement Process*. Cambridge: Cambridge University Press, 1998. Similarly Bub, J. *Interpreting the Quantum World. Cambridge*: Cambridge University Press, 1997.

⑫ Hilbert, D. *Naturerkennen und Logik*, Die Naturwissenschaften 18 (1930), S. 959 – 963. The translation is mine.

doubt and thus can serve as a starting point of a rational reconstruction of all other knowledge: "I had long before remarked that, in relation to practice, it is sometimes necessary to adopt, as if above doubt, opinions which we discern to be highly uncertain, as has been already said; but as I then desired to give my attention solely to the search after truth, *I thought that a procedure exactly the opposite was called for, and that I ought to reject as absolutely false all opinions in regard to which I could suppose the least ground for doubt, in order to ascertain whether after that there remained aught in my belief that was wholly indubitable.*"⑬

The methodical doubt includes also sense perceptions: "When I said that *the entire testimony of the senses should be regarded as uncertain and even as false*, I was entirely serious. This point is essential for a grasp of my Meditations—so much so that anyone who won't or can't accept it won't be able to come up with any objections that deserve a reply."⑭ The methodical doubt prevails truth and is not imposed by reality, but by the philosopher, who transforms himself voluntarily into a rationalist.

B. Spinoza (1632 – 1677) is one of those who seem to attach a sort of darkness to reality by saying that things are "mute"⑮, so that 'true' and 'false' can be referred to real things only in a metaphorical way. This is why he defends a rational reconstruction of a world view: "more geometrico demonstrata", that is to say, in a mathematical fashion⑯. Spinoza's fundamental idea is that the logical order of thoughts is the same as the order of the corresponding realities.

I. Kant (1724 – 1804) went beyond Descartes by introducing what he viewed as a Copernican turn. Knowledge depends only on the human observer, not on reality: "Although all our knowledge begins *with* experience, that doesn't mean that it all comes *from* experience."⑰ According to this view, the senses do not have any influence on shaping concepts by the mind. Rather, the mind creates spontaneously, while guided by its own a priori's, concepts and propositions.

The essentials of the kantian view continue being wide spread among physicists. To see this, it is sufficient to observe that theoretical physicists are giving, by and large, mathematical names to physical objects. This corresponds to what Kant expresses thus: "The order and regularity in appearances, which we call Nature, are put there by ourselves. We could never find them in

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⑬ Descartes, R., *Discourse on the method*; 4th chapter, beginning. http://www.earlymoderntexts.com/pdf/descdisc.pdf. ed. Jonathan Bennett. Accessed 2012 – 09 – 15. Italics are mine.

⑭ Descartes, R., *Objections to the Meditations on First Philosophy and Replies*. Fifth set of objections (Gassendi), reply to an objection to the second meditation. http://www.earlymoderntexts.com/pdfbits/desco5.pdf. ed. Jonathan Bennett. Accessed 2012 – 09 – 15. Italics are mine.

⑮ Spinoza, B. *Cogitata metaphysica*. Benedicti de Spinoza opera quotquot reperta sunt, Vol. IV, I.6. Den Haag: M. Nijhoff, 1914, p.198ff; the expression "res mutae" is on p.200.

⑯ Two of Spinoza's princial works are "Renati Des Cartes Principiorum Philosophiae pars I et II more geometrico demonstrata. Accesserunt eiusdem Cogitata Metaphysica" (Amsterdam, 1663)., and "Ethica ordine geometrico demonstrata" (1675).

⑰ Kant, I. *Critique of pure Reason* (second edition, 1787), p.1. www.earlymoderntexts.com/pdf/kantcpr1.pdf (ed. Jonathan Bennett). Accessed 2012 – 09 – 15.

appearances if it weren't that we, or the nature of our mind, had first put them there."⑱ Even though it might seem counterintuitive, the understanding isn't a mere power of formulating rules through comparison of appearances; it is itself the lawgiver of Nature. It's only through the understanding that Nature exists at all! …. Nature is the synthetic unity of the manifold of appearances according to rules. And appearances can't exist outside us—they exist only in our sensibility. Thus, Nature … is possible only in the unity of self - awareness."⑲ Using a contemporary expression, our experience is considered as *theory - laden*.

As well as in the views of Descartes and Spinoza, also in Kant's Copernican turn the communication between different humjan subjects becomes dependent on reconstruction. Thence the probem of 'private languages' arises: is it possible to give an account of private languages of different humans in the private language of one of them? In Physics, this problem can be apparently circumvented by advocating the universality of Mathematics.

B. Russell (1872 - 1970) offered another variety of arguing for the need of a rational reconstruction by discarding what he calls 'na? ve realism': "We all start from 'na? ve realism', i. e. the doctrine that things are what they seem. We think that grass is green, that stones are hard, and that snow is cold. But physics assures us that the greenness of grass, the hardness of stones, and the coldness of snow, are not the greenness, hardness, and coldness that we know in our own experience, but something very different. The observer, when he seems to himself to be observing a stone, is really, if physics is to be believed, observing the effects of the stone upon himself. Thus science seems to be at war with itself: when it most means to be objective, it finds itself plunged into subjectivity against its will. Na? ve realism leads to physics, and physics, if true, shows that na? ve realism is false. Therefore na? ve realism, if true, is false; therefore it is false. And therefore the behaviourist, when he thinks he is recording observations about the outer world, is really recording observations about what is happening in him."⑳

K. Popper (1902 - 1994) is considered as the most influential author in 20th century - philosphy of science. His writings bear clearly a Kantian influence. This can be seen in that Popper defines in the final section of his first and most important book "The Logic of Scientific Discovery" (1935) the thesis of the experimenting scientist's relationship to reality as *theory laden* experience:

"Even the careful and sober testing of our ideas by experience is in its turn inspired by ideas: experiment is planned action in which every step is guided by theory. We do not stumble upon our experiences, nor do we let them flow over us like a stream. Rather, we have to be active: we have to 'make' our experiences. It is we who always formulate the questions to be put to nature; it is we who try again and again to put these questions so as to elicit a clear - cut 'yes' or 'no' (for nature

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⑱ Kant, I. *Critique of pure Reason* (first edition, 1781), p. 125. www. earlymoderntexts. com/pdf/kantcpr1. pdf (ed. Jonathan Bennett). Accessed 2012 - 09 - 15.

⑲ *ibid.*, p. 127. Accessed 2012 - 09 - 15.

⑳ Russell, B. *An Inquiry into Meaning and Truth*. Harmondsworth: Penguin Books, 1966 (seventh edition), p. 13.

does not give an answer unless pressed for it). And in the end, it is again we who give the answer, it is we ourselves who, after severe scrutiny, decide upon the answer to the question we put to nature. "㉑

W. Stegmüller (1923 – 1991) is one of the many who echoes Popper: "Even though people are nowadays quite ready to acknowledge that we are lacking a thorough understanding of the phenomena of *science* and *scientific progress*, they mostly take it for granted that such a progress is a fact. But this too has no support at all. A? priori, it cannot be expected at all that we achieve acceptable theories about the world. To A. ? Einstein is attributed the statement that it belongs to the most ununderstandable things of this world that the world is, for us, understandable. And we could add that this being understandable is a very limited and eternally problematic issue. 'Our lack of knowledge is without limits and capable of making us understand what we are. Alas, it is precisely the overwhelming progress of the natural sciences?..., which opens our eyes again and again towards our lack of knowledge'. "㉒

In conclusion: In philosophy there is a broad, dominant and long tradition of the view that nature and human cognitive capacities do not fit together. However, this intellectual climate has not led to renouncing of investigation and communication. Instead, there have been offered a huge variety of attempts to substitute the supposed lack of intelligibility connected with the luminous and unifying source of *experience* by some other individualistic *rationality*.

Ⅳ. Three pivotal ideas Ⅱ: "Most Present day ways of understanding Mathematics are unrelated to the material world."

The selfunderstanding of Mathematics is dealt with by mathematicians as well as by philosophers, even though with different points of emphasis. While mathematicians focus, by and large, more on foundational issues of Mathematics, philosophers deal preferably with metaphysical and epistemological questions related to mathematical objects and mathematical knowledge, respectively. Nevertheless, both approaches overlap largely㉓.

The view of Mathematics *prima facie* most attractive is the platonistic one. That is to say, that mathematicians refer to abstract entities which exist independently from the mathematician's mind. These entities just have to be *discovered*, *not invented*, notwithstanding any axiomatization of Mathematics. G. Frege (1848 – 1925) and K. G? del (1906 – 1978) had views of this kind.

㉑ Popper, Karl R. *The Logic of Scientific Discovery*. London: Hutchinson & Co., 1959 (first edition); London: Routledge (Routledge Classics), 2002 (third edition). The English version of that part is unaltered with respect to the German version of 1935.

㉒ Stegmüller, W. *Probleme und Resultate der Wissenschaftstheorie und analytischen Philosophie*, Bd. Ⅱ, 1 Theorie und Erfahrung. Berlin, Heidelberg, New York: Springer – Verlag, 1974, S. 472. The inner quotation is from: Popper, K. R., "Die Logik der Sozialwissenschaften", in: H. Maus und F. Fürstenberg (ed.), Soziologische Texte, Bd. 58, Neuwied/Berlin, 1969, S. 103) The translation is mine.

㉓ For this whole section has been consulted, above all, the entry "Philosophy of Mathematics" (version 2. 5. 2012) of the Stanford Encyclopedia of Philosophy (abbreviated: SEP, http://plato. stanford. edu/) and related entries.

Nevertheless, the three presently relevant views of Mathematics originated in the beginning of the 20th century and are anti – platonistic: the *logicistic* approach attempts a foundation of Mathematics by *reducing* it to logics. It is linked to Frege and B. Russell (1872 – 1970) and is practically abandoned. The *intuitionist* approach is linked to L. E. J. Brouwer (1881 – 1966). He considers the whole of Mathematics as a mental construction in the strictest sense of the word: mathematical objects are only those that have been effectively constructed: Brower rejects mathematical objects whose existence is only assured by a proof of the absurdity of its nonexistence. Such non – constructive proofs of existence have the form: "if there were not an x satisfying P, then we would arrive to a contradiction, hence there is an x satisfying P". He observes that such undesired proofs rest on the logical Boolean axiom that *the negation of a negation of a true proposition is true* which, in turn, is linked to the principle of excluded middle [for any proposition: either p is true or non – p is true]. The intuitionist approach is not used in current mathematics.

The presently dominant view among mathematicians is the *formalistic* approach, which is linked to D. Hilbert (1862 – 1943). It tries to understand Mathematics as a web of formal systems, without reference to any abstract entities. Nevertheless, the natural numbers, whose name suggests some proximity to the physical world, are thought to play a basic role within Mathematics. All anti – platonistic views rest decisively upon axiomatics.

As the views mentioned in the previous paragraph present themselves as rather independent from the physical world, the undeniable success of Mathematics in natural sciences, above all Physics, remains ununderstood. There are, however, also attempts to account for that fact. In this case, not all of Mathematics appears to be linked to the material world. Therefore, accounts of such a link are not necessarily a foundation of Mathematics as a whole. Nevertheless, the multiple internal connections within Mathematics make it difficult to draw a distinction between parts of Mathematics relevant for Physics and others that are irrelevant (at present).

One attempt to understand the link between Mathematics and the physical world goes back to Aristotle. He opposes the platonic view of two separated worlds – the hierachically ordered ideas, from which the individuals of the material world participate in one or other way. According to Aristotle, each material individual has – so to speak – *incoporated* its own idea or 'substantial form', as he calls it.

The account of Aristotle of the status of mathematical objects is centered on five concepts: 'abstraction' or 'taking away' or 'removal' or 'subtraction' (*aphairesis*), 'precision' (*akribeia*), 'as separated' (*hôs kekhôrismenon*), 'qua' or 'in the respect that' (*hêi*), and 'intelligible matter' (*noêtikê hylê*)㉔. The first five concepts indicate that the status of mathematical objects is something secondary, derived or otherwise dependent or incomplete. However, the concept 'intelligible matter' is less obvious. And, importantly, all concepts indicate

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㉔ Principal sources are the *Posterior Analytics*, *De Anima iii*. 6 – 8, Metaphysics iii. 2, vi. 1, vii. 10 – 11, ix. 9, x. 1 – 2, xi. 2 – 3, 7, xiii. 1 – 3, *Physics* ii. 2. (cf. SEP, entry "Aristotle and Mathematics" (version 26. 3. 2004), 7.

that mathematical objects do not exist outside the mathematician's mind.

Another attempt of understanding the link between Mathematics and the physical world has been proposed by W. V. O. Quine (1908 – 2000) and H. Putnam (1926 –) and has become known as (methodological) *naturalism*[㉕]. It consists in renouncing of traditional metaphysical and epistemological thinking and instead consider as basic the currently best *scientific theories*, that is to say, the currently most successful ones. They express what exists, what we know and the way how we know it. To this naturalistic view has to be added Quine's thesis of *confirmational holism*: scientific experience globally confirms a theory as a whole, together with its methedological ingredients. As physical theories are formulated in mathematical terms, through which entire mathematical theories are linked to it, these latter are also confirmed by experience.

Quine goes beyond this. "It seems that mathematics is indispensable to our best scientific theories; it is not at all obvious how we *could* express them without using mathematical vocabulary. Hence the naturalist stance commands us to accept mathematical entities as part of our philosophical ontology. This line of argumentation is called an *indispensability argument*?"㉖.

Still another attempt to understand Mathematics is called *Fictionalism*. It is not only opposed to mathematical Platonism, but also to Aristotle's view of mathematical objects as derived and thus dependent from real beings. "Fictionalism holds that mathematical theories are like fiction stories such as fairy tales and novels. Mathematical theories describe fictional entities, in the same way that literary fiction describes fictional characters."㉗ Or in more concise terms: "Fictionalism … is the view that (A) our mathematical sentences and theories do purport to be about abstract mathematical objects, as platonism suggests, but (B) there are no such things as abstract objects, and so (C) our mathematical theories are not true."㉘

With respect to a link of mathematical entities to the physical world, provided they are considered as fictional, it must be concluded that ? scientific theories, in particular physical theories, should be derived, at least in principle, without using Mathematics at all?. Otherwise mathematical theories considered as fictional would appear to be indispensable for Physics. This in turn is at odds with their supposed fictional character. Comparing this with Einstein's stance as mentioned in section II, it remains open whether Einstein would consider Mathematics as indispensable for Physics.

In conclusion: Fictionalism and the current anti – platonistic accounts of Mathematics have no roots in the physical world, except (perhaps) Arithmetics. On the other hand, the aristotelian view of mathematical objects is based on the perceptional knowledge of the physical world. Both the aristotelian and the fictionalist view are opposed to mathematical Platonism insofar mathematical objects exist only in the scientist's mind. The naturalistic view proposed by Quine is foremost

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㉕ cf. SEP, entry "Naturalism in the Philosophy of Mathematics" (version 1. 11. 2008), 2.

㉖ SEP, entry "Philosophy of Mathematics" (version 2. 5. 2012), 3. 2 Naturalism and Indispensability

㉗ SEP, entry "Philosophy of Mathematics" (version 2. 5. 2012), 4. 5 Fictionalism

㉘ SEP, entry "Fictionalism in the Philosophy of Mathematics" (version 16. 9. 2011), 1. 1.

characterized by putting *scientific* theories and not philosophical ones as a foundation of our knowledge. Additional principles, namely that of confirmational holism and the indispensability argument, are needed in order to give Mathematics an overall link to the physical world.

The situation is unsatisfactory, because even the aristotelian and the naturalistic view offer only an utmost generic account of the link between Mathematics and the material world. Given the overwhelming success of mathematical theories in Physics, the most satisfactory rationale would be to have a view that certain mathematical objects and structures are something endogene from precisely those material things the behaviour of which they refer to. This would radically eliminate the problem of 'why mathematics is applicable to nature', as if mathematics were something exogene to nature.

Ⅴ. Three pivotal ideas Ⅲ: "The mathematization of Physics is an essential part of the scientific revolution."

The term 'scientific revolution' is nowadays commonly used to characterize the historical period in which the medieval philosophy of nature has undergone a *metamorphosis* to yield natural sciences as we know them today. This period's beginning is commonly marked by the publication of Nicolaus Copernicus' (1473 – 1543) *opus magnum* called "De revolutionibus orbium coelestium" in 1543, where he proposes heliocentrism instead of geocentrism. But there are more major changes, which involve also basic philosophical ideas such as 'cause' and 'order'. A certain completion was reached with I. Newton (1642 – 1727), whose *opus magnum* carries the title "Philosophiae Naturalis Mathematica Principia". Later major changes within natural sciences such as the transition from classical Physics to Relativity and Quantum Physics or the birth of modern Microbiology are sometimes also called 'revolutionary', but they are by far not so deep as the *metamorphosis* that took place during the roughly 200 years from Copernicus to Newton.

Within Physics, outstanding changes during that revolutionary period include first the replacement of *impetus* (inbuilt momentum) by *inertia* (resistence to exterior forces), and second the overcoming of the world's division into a terrestrial and a celestial region in virtue of universal gravitation, which in turn is linked to the overcoming of the division into light and heavy bodies according to their natural motion. These changes refer to Mechanics and Astronomy. Major changes occurred also in Optics, Chemistry and Medicine.

With respect to properly scientific issues, the scientific revolution is a huge web of many discoveries and developments. They are accompanied, even made possible, by only a few, but deep philosophical changes. One of them is the replacement of causes by laws of nature. The classical view was that of a bundle of four interconnected causes, introduced by Aristotle. Two of them were intrinsic (or constitutive) causes of a material thing, namely form and matter, and two of them were extrinsic causes, namely efficient and final cause. In the course of the scientific revolution, the final cause was dropped altogether, the efficient cause became the most important, and the material and formal cause were replaced by something more or less unified and gave rise to an atomistic view of material things.

Again, the prominence of efficient causes favoured the importance of experiments. Among these, measurements became particularly important, because they gave way to abstract laws of nature. In Physics and Astronomy, laws of nature could most conveniently be formulated in mathematical terms, such that Galilei (1564 – 1642) could say that the book of nature "is written in mathematical letters"㉙. Mathematical laws of nature, in turn, allow for calculability, predicitons and hence technology.

As a consequence of the profound changes in philosophy of nature and scientific knowledge, there was a profound change of how the human person as a whole related to the nature he or she was living in. The historian of science A. Koyré is one of the first in using deliberately the word 'revolution', when he says, for instance: "… this 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." ㉚ In other words, such an increasing dominium of nature caused a transition from a sort of contemplative life (*vita contemplativa*) to an active life (*vita activa*)㉛.

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 conderations based on value, perfection, harmony, meaning, and aim, because these concepts, from now on *merely subjective*, cannot have a place in the new ontology." ㉜

Thus there are good reasons to think that the mathematization of Physics has been the most important single factor in bringing about the scientific revolution㉝. On the one hand, the "silence"

㉙ Galileo Galilei, *Il Saggiatore* (The Assayer, 1623), translated by Stillman Drake (1957) as *Discoveries and Opinions of Galileo*, pp. 237 – 238.

㉚ Koyré, A. *Newtonian Studies*, p. 3ff., Cambridge, Mass.: Harvard University Press, 1965, p. 5. Cf. also Koyré, A. "Galileo and the Scientific Revolution of the Seventeenth Century", *Philosophical Review* 52 (1943), 333 – 346.

㉛ cf. Koyré, A. *Newtonian Studies*, Cambridge, Mass.: Harvard University Press, 1965, p. 5.

㉜ *ibid.*, p. 6 – 7

㉝ Cf. the monumental oeuvre of E. J. Dijksterhuis, *The Mechanization of the World Picture* (London: Oxford University Press, 1961 [Reprint: *The Mechanization of the World Picture. The Scientific Revolution: A Historiographical Inquiry*. Chicago: University of Chicago Press, 1994], which gives to understand that above many continuities and discontinuities the only real break brought about by the scientific revolution was the work of the Archimedean Galileo and by Kepler, the Platonist and Pythagorean-*the first two scientists truly to mathematize nature*.

of nature most certainly has influenced the view that Mathematics is by itself unrelated to nature. On the other hand, the experimental findings have contributed to giving the mathematization of nature its role as a source of rationality and of consequences in practice (technology) and in mindset (dominium of nature). But the mathematization has also raised philosophical questions concerning the relationship between nature and the mathematical laws of nature, as has been sketched in section I. These are questions of a theoretical understanding, part of which will be addressed in the following section.

Ⅵ. Four problems in Physics raised by the scientific revolution

One question at the very root of the mathematization of our view of nature concerns the experiment called 'measurement': Everybody has learned to perform simple measurements of length, weight and time. Perhaps this very fact has made him or her forget to wonder about *why* it is possible that two different things can be compared at all. *Why* is it that different measuring devices applied to the same object yield approximately *equal* results? On the other hand, why are the results of different performances of measuring the *same* object only *approximately* equal?

At this point, it must be noted that the formulations in the preceding paragraph depend on the fact thatthe human obser ver/experimenter fits into his measurement as a macroscopic body. Therefore, descriptions like 'long', 'short', heavy', light', fast', 'slow' and the like are made in relation to macroscopic units. But there is a qualitative difference between the macroscopic and the microscopic realm. For instance, while the diameter of a macroscopic sphere can be measured by other macroscopic devices, nobody has ever verified that an elementary particle, e. g. an electron, has a geometrical shape, let alone has measured it. Only by hypothetical assumptions and extrapolations from the macroscopic world a physicist might give an electron such geometrical properties.

In other words, the practice of Physics contradicts its theoretical view: on the one hand, the generally accepted theoretical view is that elementary particles and atoms are more fundamental than solid bodies in the sense that solid bodies "consist" somehow of elementary particles. This means that the properties of *macroscopic* things should be traced back to the properties of their microscopic constituents. In fact, the task of solid state Physics is, above all, to link properties of macroscopic bodies to properties of microscopic ones.

But on the other hand, it is a fact that the experimenter is a macroscopic entity and must use macroscopic instruments. This has led to the situation that the properties of a microscopic body are defined in terms of properties of macroscopic instruments. But as these macroscopic instruments themselves consist of microscopic things, their properties should be defined by the properties of their microscopic constituents. If this would be done by using the same procedure, i. e. taking the properties of the microscopic constituents of an instrument as defined by properties of other macroscopic bodies, the result would be a regress ad *infinitum*. Thus there is a need of defining the properties of a microscopic body by means of properties of other *microscopic* bodies which, in turn, are defined by means of properties of other microscopic bodies. This has not been done so far. Indeed, consistently carrying through this idea would amount to a major internal reform of Physics. One might well object that this enterprise is almost impossible, and that it is not clear how much benefit Physics would gain from it. But such objections "a priori" can hardly be proved.

A second problem arises from the fact that in mathematical laws of nature, the description of behaviour is dissociated from the reference to the individuals, the behaviour of which they describe. Rather, the connection of a law with "its" individuals is exclusively a performance within the experimental physicist.

Truly, predictability and its consequences, above all technology, have been achieved by mathematical laws of nature. But this has been achieved by at the expenses of intrinsic reference of a law to "its" individuals. Obviously, this is a characteristic of the imperfect interlocking of mathematics and nature referred to in section I. And it makes it more easy to understand that the mathematical laws of nature are not obtained by a sort of derivation starting from observational or experimental data. Rather they are hypthetically conceived and then in a procedure of trial and error "applied" to material things.

One might well object that the universality of a law of nature cannot be achieved otherwise than by a loss of intrinsic reference to individuals. Even more: that a law of nature refers intrinsically to a particular individual can hardly mean anything else than that this law of nature is completely confined to that particular individual. It seems that we find ourselves before the choice {lack of reference & universality} versus {incorporated reference & no universality}. But again, this is not proved. Rather one could argue that true laws of nature should be more comprehensive by incorporating individuality as well as universality. Mathematical structures are only part of such a comprehensive law of nature.

A third problem is related to the twosidedness of every measuring process referred to in the beginning of this section. Measurements are based upon the action of the measuring object on the measuring device. But the device - though being an artifact of natural things - is not less a thing of nature than the measuring object. In rigor, then, we have to speak of an interaction of both sides of an experiment. But then, what have we to make with the following words of W. Heisenberg (1901 - 1976):

"Truly, our accustomed description of nature and in particular the idea that processes in nature follow strict laws are based upon the assumption that it is possible to observe phenomena *without exercising an notable influence on them*. To attribute a certain cause to a certain effect makes sense only if we can observe effect and cause without intervening at the same time in the process perturbing it."㉞ But: "By means of the intervention necessary for the experiment we destroy certain

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㉞ Heisenberg, W. *Physikalische Prinzipien der Quantentheorie* (written 1929/30), Bibliographisches Institut, Mannheim, 1958, IV. 3. (Translation and italics are mine.)

connections that are characteristic for the microscopic world."㉟

Another prominent text of Einstein – Podolsky – Rosen highlights the same idea: "Any serious consideration of a physical theory must take into account the distinction between the objective reality, which is independent of any theory, and the physical concepts with which the theory operates. ... *Every element of the physical reality must have a counterpart in the physical theory.* .... *If, without in any way disturbing a system, we can predict with certainty (i. e., with probability equal to unity) the value of a physical quantity, then there exists an element of physical reality corresponding to this physical quantity.*" (Italics by the authors.)㊱

Even though these formulations have been made many decades ago, they do influence the present day view of most physicists: experiments are unilateral in the sense that experimental devices are expected to yield information about the experimental object, but not vice versa. But physicists learned in the context of quantum physics that they both do interact. Thus the question arises of what hinders to draw the consequence and treat both side equally?

A fourth problem comes from the temporal limitations imposed on experiments. In practice, all experiments are cut out from their environment by boundaries in time. This seems very reasonable, because the experimenter wishes to obtain results in finite time. But does a temporal limitation correspond, in rigor, to something in nature? Is it not plausible that limitations of that kind, which are considered to yield simplifications and practicability, on the long run rather import problems? A similar question could be formulated with respect to spatial limitations.

Summing up we can say that the scientific revolution has brought great achievements in Physics. But it has also introduced new problems into Physics. The most serious ones are, to my mind, the four aforementioned: (1) To the date, the macroscopic realm is *not fully* characterized by means of the microscopic one. Current solid state Physics relies on the idea that macroscopic bodies are built up by bodies of the microscopic realm. But as has been said, the properties of *microscopic* bodies are characterized by the properties of macroscopic instruments. But as these instruments, too, are build up by microscopic constituents, their properties need a characterization by microscopic things *without* the mediation of macroscopic bodies. Otherwise, a regress *ad infinitum* is unavoidable. This exceeds the possibilities of experimentation and, therefore, is a task for a sort of Philosophy intimately connected with Physics. (2) Mathematical laws of nature, being universal, do not contain the unrepeatable features of the individual material things the behaviour of which they are supposed to describe. Problem (3) concerns the profound conflict between two antagonistic features of every experiment: on the one hand, it is a means for gaining information, but on the other hand, it disturbs that information. Perhaps here must be found an appropriate understanding of the activity and passivity of material things. The dynamics in turn is linked to

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㉟ Heisenberg, W. *Wandlangen in den Grundlagen der Naturwissenschaften.* Stuttgart; S. ? Hirzel – Verlag, 1959 (nineth edition), S. 103. (Translation and italics are mine.)

㊱ Einstein, A., Podolsky, B., Rosen, N., "Can quantum – mechanical description of physical reality be considered complete?" *Physical Review*, 47 (1935), p. 777f.

problem (4) which concerns the division of the world into limited space – time regions, to which experiments are considered to be confined.

Ⅶ. Conclusion

Thus it turns out that the four problems sketched in the previous section are connected with each other. In some sense, they form a chain, wherefore a renouncing of the spatio – temporal limits of experiments (problem (4)) obliges to deal with problems (1) – (3), too. At this point, one has to choose between two alternatives. Either one declares the success of unreformed Physics as satisfactory. Then Physics continues as until now with the inbuilt risk that the mentioned four problems exercise an uncontrolled influence. Or one tackles the internal reform of mathematical Physics in favour of its transparency and internal consistency. This requires extremely much work, but it might yield, on the long run, an even deeper success. In this latter case, the very success of mathematical theories in Physics strongly suggests to combine the task of solving the four aforementioned problems with the inquiry of why and how *specific* mathematical structures somehow have their roots in material things. These two aims determine the following basics of a work programme:

(α) Renounce of the spatial and temporal limitations of experiments and allow for unlimited interaction of material things.

(β) Give equal weight to *both* sides of interactions, e. g. in an experiment.

(γ) Renounce of using any physico – mathematical theory *at the beginning of the internal reform*.

(δ) Base your considerations exclusively on experience that is not theory – laden.

(ε) Try to specify what could be called qualitatively the "reflective loop" referred to in the previous section as problem (1).

(ζ) Try to extract mathematical structures inductively from all these experiences.

The view expressed here is innovative because this work programme pretends to achieve more than presenting *just a parallel philosophical view of nature* which does not really interfere with how physicists are exercising their profession. It also pretends more than to *provide methodological standards for physical investigation*. If it succeeds, it could be called in all propriety an internal reform of Physics.

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Despite of its innovative character, the above work programme does not look promising. Things might change to the better, when we go searching for philosophical forerunners. Such a philosophical forerunner would have to meet two conditions. First, it must be experience – *based*. In other words, experience is understood as a genuin *source* of knowledge. What is more, the gap between particular perceptions and a universal theory requires an intelligible link, namely *induction*. Additionally, such a forerunner should offer an account of the activity and passivity of material things. This condition dissuades from relying on rationalist philosophies.

The second condition concerns the singularity of material things. In order to account for the interaction of individual material things, their singularity must necessarily be taken into account. But it cannot be adequately expressed by using exclusively concepts or linguistic terms: Neither universal concepts (for instance, the platonic διάιρεσις) nor even demonstrative pronouns would do it. The only linguistic means to refer precisely to *this individual* is by proper names. But while it is possible to give proper names to macroscopic things, for instance volcanos, rivers or trees, it is impossible to link proper names to single atoms or elementary particles. Therefore, the second condition dissuades from relying on the analytic way of doing philosophy⑦. Beyond the limits of language alone, one can refer to a material thing by pointing a finger at it. This requires sense perception, sight in particular. But this procedure is simply impossible in the case of elementary particles.

Does that mean that the proposed work programme aims at something impossible? As a matter of fact, the hylomorphism proposed by Aristotle and, in a different framework, by Thomas Aquinas, has a certain account of the singularity of material things. So the work programme can, perhaps, make use of an already developed philosophical conceptuality. However, it is impossible to give an appropriate account of this particular feature of hylomorphism in a few paragraphs.

It must be admitted that Aristotelian as well as Thomistic philosophy of nature are considered outdated. One reason for that is that they have not made any pronouncements about what is an experiment. Even less about the question what is a measurement. But both experiment and measurement are essentials of modern Physics. My claim is that the metaphysical core of Aristotelian – thomistic philosophy of nature is useful for answering these questions. For the present problem, the first relevant metaphysical notion is 'hylomorphism'. It refers to the constitution of material things as members of species or agglomerations of such members. The second relevant piece is the general principle called 'agere sequitur esse'. It expresses a sort of proportionality between the dynamics of something and what it is. Thus, this principle can be claimed to offer a *rationale* for how laws of nature do stem from the very things they refer to⑧.

Ⅷ. Is there any specific contribution of Christianity to solving the problem?

Let us anticipate the answer: Indeed, there is a specific contribution of Christianity to solve that problem. But Christianity does not do so by making assertions that belong to the competence of

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⑦ This does not exclude that the analytic approach can offer interesting views, for instance Lowe, E. J. *The Four – Category Ontology. A Metaphysical Foundation for Natural Science*. Oxford, London, New York: Oxford University Press, 2006.

⑧ A detailed account of the problems mentioned in section VII. together with the first steps of this work program can be found in Larenz, R. "What can Thomistic Philosophy of Nature Contribute to Physics?", in: *Societal Studies*, Vilnius (Lithuania): Mykolas Romeris University, 2013(2), online www. mruni. eu/en/mokslo_darbai/sms/paskutinis_numeris/. Alternative access via www. ceeol. com.

professionals in Natural Sciences or Mathematics. Christianity contributes exclusively to a philosophical issue by stating a *positive* view of the intelligibility of this world. Obviously, this view is opposed to what has been said in section III. about the view of most modern philosophers.

The New Testament as well as the Old Testament make far reaching statements about the intelligibility of this world. In particular, the Catholic Church is most explicit in linking both objective intelligibility and subjective capacity of understanding together. She does so by stating that it is possible that somebody reaches, *without* having any knowledge about Christianity, the insight that the things of this world are what the Bible calls 'created' and that they, therefore, have a Creator㉙.

Nothing is said, in this context, about the intellectual path to be followed, not even whether such an intellectual path has been, or will be, realized in history or the future. The statement is confined to saying that the things of this world "give an account" on their being created, and that human mind is capable of understanding this language of reality. From the Catholic point of view, Christian revelation is epistemologically "optimistic". It follows that experience has a positive cognitive value.

As the status 'created' of a thing comprehends whatever belongs to it, no information about this thing can be separated from the insight into its being created. In our context, the emphasis lies on the following conclusion: given the premises (1) the *behaviour* of material things stems precisely from those same things, (2) the *knowledge* of this behaviour, expressed in laws of nature, is connected with the insight into the being created of those things, it follows that *the search for laws of nature profits from the intelligibility of the world and the cognitive capacity of the human mind*, at least insofar as the laws of nature contribute to the knowledge of things as being created.

Therefore, a scientist who happens to be a Christian is, by his faith, enabled to an "epistemological optimism". And exactly by this, a scientist who happens to be a Christian is almost forbidden by his faith to base the particular propositions of his scientific discourse in any way on this very same faith. He is exclusively relegated to his natural capacity of insight and reasoning.

For the sake of clarity, it should be added that the assertions of the Bible about single historical facts such as the age of the universe, of the earth and of mankind or the extension and dating of the flood are *particular* assertions. They should be evaluated in the light of the Bible's universal affirmations about the intelligibility of this world and, perhaps, in the light of further exegetical criteria. In this context, creationists easily give too much credit to present day natural sciences, if they do not examine whether the epistemological climate in these sciences is compatible with the epistemological climate generated and witnessed by Christian revelation.

True, Christian faith tells also, that sinfulness *darkens* the human mind and makes its activity laborious, but it does not make it impossible. Therefore, scientific reasoning continues depending exclusively on every scientist's own intellectual capacity and his or her professional training. A

㉙ cf. Vatican Council I, Dogmatic Constitution *Dei Filius* (24. 4. 1870), Chapter 2, first paragraph. Online at www.disf.org/en/documentation/11 - VaticanCouncilI.asp. Accessed 2012 - 09 - 15.

scientist who happens to be a Christian possesses by his faith a guarantee that the thesis of the intelligibility of the world and the cognitive capacity of the human mind *is true*. He or she has *more intellectual steadfastness* in the laborious activity of investigating this world. Likewise, God's grace and a Christian's striving to follow Christ contribute to that same goal. But this interior strength does not provide *arguments* which would be less accessible to non – believers, or not accessible at all.

In conclusion, the statement "there is no specifically Christian way of doing science" is ambiguous. A scientist who happens to be a Christian, should not draw on the Christian revelation, or on the Bible in particular, when making scientific propositions or proving them. Rather he should exclusively focus on the object in question and use his human capacities of inquiry and rational discourse. In that sense, the statement cited is true. But if it comes to the existence of truth at all, which touches the very notion of science, or to the fundamental discernment between an "epistemological optimistic (bright) or pessimistic (obscure) climate", this statement is false. The Christian way of doing science is embedded in an epistemologically bright or optimistic climate.

Ⅸ. Final Remark

The claim that the mathematization of Physics performed in the course of the scientific revolution during the 16th and 17th centuries should be corrected is based on good reasons. It would be a thorough internal reform, almost a second scientific revolution. This is why it should not only be judged by its success in showing why and how mathematical structures are rooted in material things. It must also explain why the present mathematical Physics has been so successful, despite the problems sketched in section Ⅵ.

中文题目：

物理学需要第二次科学革命吗？
——基督教促进物理学基础问题的解决

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摘要：本文指出了当代物理学的内在缺陷。这一缺陷在于当代物理学无法充分勾连构成物理学主体的两种知识：一方面是对以物质世界为对象的科学实验的观察，另一方面则是数学理论。具体来说，这一缺陷可表述为：虽然数学模型被应用于以物质世界为对象的实验，却如同它仅仅在物理学家脑海中运算一样。不论如何，数理物理学的成功，说明这些数学模型在某种意义上是与其所适用的物质实在相关联的。由于其内在缺陷，物理学中的数学理论必须经历实验的证实或证伪。然而，即使被证实，这一理论依然是假设的。一种理论永远无法具有完全的确定性。上述物理学的内在缺陷根源于 16、17 世纪的科学革命。本文试从三方面对此进行阐释：一、自然与人类认知能力并不统一成为主流观念；二、大多数对数学的理解方式并不涉及物质世界；三、科学革命从根本上导致了物理学的数学化。有人提出圣托马斯 · 阿奎那的形质说可以作为适合的工具，以阐释为何那些物理学中的数学模型其本身也是根植于物质世界的，从而为数学模型在以物质实在为客体的实验中的应用提供了客观基础。数学模型之属于物质世界，乃建基于形质结构能够将物质实体的个体性和它必然从属于某一种类的属性有机结合。基督教并未认可针对这一问题的任何解决方案。然而，只要基督教还在坚持我们所处世界的可认知性，他就对解决这一问题做出了贡献。从而，基督教精神坚持科学作为一种实在的知识。

关键词：物理学、数学化、形质说、清晰度、基督宗教