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Michael Petry Memorial Lecture:

„Hegel's Criticism of Newton's Physics: A Reconsideration“

by Thomas Posch (Vienna)

Let me open this lecture – since it is devoted to the memory of Michael John Petry – with the following quotation from the well-known conference volume *Hegel and Newtonianism*:

> „At first sight, what we seem to have here [i.e. in the relation between Hegel and Newton] is little more than the contrast between the tested accomplishments of the founding father of modern science, and the random remarks of a confused and somewhat disgruntled philosopher; and if we are persuaded to concede that it may perhaps be something more than this – between the work of a clearsighted mathematician and experimentalist, and the blind assertions of some sort of Kantian logician, blundering about among the facts of the real world.“[1]

These sentences have been written by Michael Petry twelve years ago, in 1992. They reflect a general attitude towards the relationship between Newton's and Hegel's work which Petry faced in the late 1960s; an attitude which he, however, tried to call into question in his own and in a joint international effort of research; an attitude which thereby became questionable among philosophers, but which still persists among scientists. Indeed, almost any scientist, more or less independent of his epistemological and philosophical concept, will still ask whether Hegel's objections to Newton's mechanics and optics – far from being justified – are the product of a post-scholastic approach at all. Even a physicist who has for some reason studied the original text of Newton's *Principia* and who has thus realized that there do exist inconsistencies in the Newtonian concept of force, will still strongly doubt whether Hegel's fundamental scepticism towards Newton's concept of dynamical laws is justified.

The persisting conception of Hegel's criticism of Newton's physics as an irrational or at least hopelessly exaggerated one partly has its roots mainly in Hegel's terminology and in his style. This does not mean that a mere translation of Hegel's arguments into any contemporary philosophical language be sufficient to immediately convince every Newtonian scientist. However, a non-Hegelian way of rephrasing the core of Hegel's anti-Newtonian philosophy of nature *can* help to understand to which extent the latter does satisfy any scientist's criteria for a rational and self-consistent theory. To de-

[1] M.J. Petry (ed.): Hegel and Newtonianism. Dordrecht & London 1993, Foreword, p. XI.

monstrate this is the central aim of my talk, which is structured as follows: In the *first part*, I'm trying to highlight basic features of Hegel's criticism of Newton's optics and celestial mechanics, eventually focussing on his concept of a "sense of nature". This part has the character of a review. Second – and that is supposed to be the „reconsideration" *part* of my paper – I'll try to highlight the *fundamental difference between Newton's and Hegel's ideas of natural laws and of the relation between mathematics and physics*. Third, the *metaphysical background* of this difference will be analyzed. It is by the analysis of this metaphysical background that I hope to render Hegel's criticism of Newton's scientific revolution more understandable.

I. Some basic features of Hegel's criticism of Newton's physics

There is a wide range of topics on which Hegel disagrees with Newton, while there is only one subject which Newton has, according to Hegel, treated adequately from a philosophical point of view – namely the foundations of analysis.[2]
It is well known that Newton's way of unifying terrestrial and celestial mechanics, his method of investigating the nature of light and, last but not least, his allegedly empiristic epistemology, have been critizised by Hegel in a very harsh way. Hegel's criticism can be traced back to his earlierst writings,[3] indicating that already the way in which Newtonian physics was tought in Tübingen in the 1790s gave Hegel the impression that Newton's fame as founding father of modern physics be doubtful at best. Had Hegel been educated in England or France, then his attitude towards this question would have probably been somewhat different, since he would have had to perceive Newtonianism as a widely accepted and solid basis of scientific research, a basis which it became in Germany only some decades after Hegel's death, when mathematical physics began to florish especially in Berlin. This does not imply, of course, that Hegel, if educated in England or in Germany around 1850, would not have critizised Newtonian physics at all. However, Hegel's ambition to be not only a *wiser philosopher*, but also a *smarter physicist* than Newton would not have risen under other circumstances like the above indicated.
In which respect did Hegel try to be a smarter physicist than Newton? For example, when he considers many of Newton's optical experiments as moot[4] or when he

[2] Cf. R. Wahsner, „Der Gedanke kann nicht richtiger bestimmt werden, als Newton ihn gegeben hat." Das mathematisch Unendliche und der Newtonsche Bewegungsbegriff im Lichte des begriffslogischen Zusammenhangs von Quantität und Qualität. In: A. Arndt (ed.): Hegels Seinslogik – Interpretation und Perspektiven. Berlin (Akademie-Verlag) 2000, p. 271-300.

[3] Cf. G.W.F. Hegel, Jenaer Systementwürfe II. Logik, Metaphysik, Naturphilosophie. Hrsg. von Rolf-Peter Horstmann. Hamburg 1982 p. 217: „aber diese Materie ist nicht die Materie an sich, sondern auf ein ihr Fremdes äußerlich bezogen; und dies Verhältnis auf die Materie überhaupt übertragen, oder diese Materie für die absolute Nehmen ist eine von den Verwirrungen, die eine untergeordnete Seite zur absoluten macht."

[4] Vorlesung über Naturphilosophie Berlin 1821/22, Nachschrift von B.v.Uexküll, ed. G. Marmasse & Th. Posch, Frankfurt am Main 2002 (henceforth: Uexküll), p. 83: „Die Newtonschen Experimente sind zum Teil entsetzlich schlecht und ebenso schlecht die Schlüsse, welche daraus gezogen sind."

questions several aspects of Newton's way of calculating planetary motions, this seems a bit overexaggerated even to the reader who is willing to take into account the possibility of errors both in the *Principia* and in the *Opticks*. To this claim I should add that I agree with the following statement by M. J. Petry: "If the natural science of the day is questioned, this is usually because Hegel thinks that it is overlooking qualitative differences. He never quarrels with it simply in order to make striking observations or indicate novel connections."[5] True, Hegel does not question Newton's optical experiments or his calculations in celestial mechanics just "to make striking observations". True, there *is* a metaphysical background even of these Hegelian critical remarks which seem to concern mere empirical questions (and I shall try to elucidate this background later in this talk rather extensively). Notwithstanding, we have to recognize that Hegel does attack Newton the *physicist* at some points, not only Newton the *philosopher.* In his lectures on the philosophy of nature, Hegel misses no occasion to stress that Newton erroneously claimed the impossibility of constructing a fully colour-corrected refracting telescope;[6] that the Colour Wheel does in fact not look white when rotating;[7] that it is unnecessary to completely darken the room when studying the sun's spectrum using a prisma[8] etc. etc. In all these cases, I think that Hegel overshoots the mark, running the risk of getting lost in details which do not contribute substantially to the respective main points of interest (such as the nature of gravitiy or the nature of light).

It has to be admitted, though, that Hegel had a point here and there even when trying to be a smarter physicist than Newton. For example, Hegel found inconsistencies in Newton's use of the concept of centrifugal force[9] – inconsistencies which independently led post-Newtonian physicists to the clarification or even to the refutation of this concept.[10]

It must be taken into consideration furthermore that Hegel had a prominent example in his effort to outplay the physicist Newton: namely Goethe, who had done the same in his *Farbenlehre* and whom he repeatedly praises for his "great sense of nature".[11]

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[5] Hegel's Philosophy of Nature, ed. and trans. by M.J. Petry, 3 vols., London and New York (George Allen and Unwin) 1970, Introduction, vol. 1, p. 30.

[6] E.g. Vorlesung über Naturphilosophie, Berlin 1825/26, unpublished manuscript by H.W. Dove, p. 56: „So sagt Newton, es seien keine Achromate möglich. Das große Gerüste der Anwendungen ist daher [!] selbst morsch in sich."

[7] Ibid., Ms. p. 57: „Newtons Schwungrad ergiebt grau, indem die Farben sind ein Helles u[nd] auch ein Dunkles"

[8] E.g. Uexküll, Ms. p. 134 (ed. Marmasse/Posch p. 83): „Newton fängt von Prismen an (überflüssig, daß das Zimmer völlig verfinstert ist)."

[9] W. Neuser, Introduction to: G.W.F. Hegel, Dissertatio philosophica de orbitis planetarum, Weinheim (Acta Humaniora VCH), 1986; M. Nasti de Vincentis, Hegel's Worm in Newton's Apple, in: Hegel and the Philosophy of Nature, ed. by St. Houlgate, New York (SUNY) 1998, p. 227sqq.; M.J. Petry: Hegel on Newton, Coulomb and Bode: the background to The Orbits of the Planets. In: W.Ch. Zimmerli, K. Stein & M. Gerten (eds.): „Fessellos durch die Systeme". Frühromantisches Naturdenken im Umfeld von Arnim, Ritter und Schelling. Stuttgart-Bad Cannstatt 1987 (frommann-holzboog) 1997, p. 391-457.

[10] Cf. M. Jammer, Copcepts of force, New York 1957.

[11] E.g. Uexküll, Ms p. 137: „Die dem Begriffe gemäße Ansicht der Farbe verdanken wir bekanntlich dem uns als Dichter und in jeder anderen Rücksicht ebenso werten Mann, dem Herrn von Goethe.

"Sense of nature" is a central expression in Hegel's natural philosophy. Even though Hegel does certainly not reduce his method of natural philosophy to this "sense", he seems to be of the opinion that it is a necessary opponent of understanding (*Verstand*) and especially of the Newtonian understanding. So we should try to clarify what this "sense of nature" is.

It is supposed to be a method of contemplating nature which conserves natural phenomena as totalities instead of decomposing them into parts which are then made sort of atoms of the phenomena. This can be illustrated by the example of planetary motion as well as by the example of the spectrum of the sun. In the case of planetary motion, Hegel opposes its decomposition according to the parallelogram of forces, arguing that the concrete totality is thereby artificially dissected; it must be noted, though, that (as S. Alexander rightly observes) "Hegel does not deny the convenience of the distinction, but he accuses Newton of mistaking the directions into which the motion is resolved for real and actual forces, independent of each other."[12]

In the case of Newton's theory of colour, Hegel argues similarly; he states that considering colours as the components or elements of light reverses the real order of the things, which is, according to him, that light is the primordial phenomenon and colours only emerge if light interacts with matter.

Hence, sense of nature is conceived as a synthetic way of grasping the essence of phenomena; as a way of experience which does not introduce any distinctions of which it then forgets that they are extrinsic. It is debatable to which extent Hegel has worked out a *definition* of this method of experience and recognition. On any account, some stress must be laid upon the fact that the sense of nature which should grasp a phenomenon as a whole is not necessarily in opposition to mathematical recognition of nature; for we shall see later in the analysis of Hegel's concept of natural laws that he greatly appreciates what he calls "laws of the phenomena" (as opposed to laws of forces). These so-called laws of the phenomena are characterized by a consideration of natural phenomena in their totality, which does not exclude the derivation of mathematical relations between moments of these phenomena such as space and time.

II. Hegel's view of the relation between physics and mathematics

There is another motive in Hegel's criticism of Newton's physics which is even more fundamental than the epistemology of the "sense of nature": namely *the totally different way in which Newton and Hegel conceive the relationship between mathematics and physics*. This difference reflects two entirely different methods of conceiving the essence of nature and the method of science. (Let us briefly consider the Newtonian way first.)

Dieser hat nach seinem großen Sinn die Farbe und das Licht herangezogen. Besonders von Seiten der Malerei hat dieser Gegenstand sein Interesse erweckt. Sein reiner, einfacher Natursinn, die erste Bedingung eines Dichters, mußte notwendig der Newtonschen Ansicht widerstreben."

[12] S. Alexander, Hegel's Conception of Nature, Mind, vol. XI (1886), no. 44, p. 495-523.

IIa. Newton

Newton made several paramount statements on his view of the relation between mathematics and physics (or „mechanics“ or „natural philosophy“) in quite prominent passages of his *Principia*. Already the first sentence of his Foreword refers to this problem. There can be no doubt that Hegel carefully studied this first sentence, and little – if any – doubt that it embarrassed him, given that it reads (I cite in Latin):

> „Cum veteres *mechanicam* [...] in rerum naturalium investigatione maximi fecerint; et recentiores, missis formis substantialibus et qualitatibus occultis, phaenomena naturae ad leges mathematicas revocare agressi sint: Visum est in hoc tractatu *mathesim* excolere, quatenus ea ad *philosophiam* spectat.“[13]

I would suggest to rephrase this as follows: “Now that (since *Bacon*) the *substantial forms* (of the *Aristotelians*) have been abandoned from natural philosophy, mathematics should replace them to the maximum possible extent.” Having in mind the development of physics in the second half of the 19th century, this might appear to us as a reasonable and well-defined programme; however, during Newton’s lifetime, it was not as well-defined, for it was still unclear: What means „mathematics“ in the context of science? Is it geometry, algebra, analysis, or the sum of all these disciplines? And – more importantly –: *Can the mathematical description of nature* – promising as it is – *replace the Aristotelian ontological framework without introducing a new (even though maybe implicit and unwanted) ontology into the history of human thought?* As for this question, Petry has rightly emphazised that Newton seems to have underestimated the „metaphysical“ content of his *Principia*.[14]
Before commenting on this issue still further, let me quote another interesting statement of Newton on the relation between mathematics and, as he puts it here, „philosophy“. In the beginning of the third book of his *Principia*, he writes (– this time I quote from Motte’s translation into English):

> „In the preceding books I have laid down the principles of philosophy; *principles not philosophical but mathematical*: such, namely, as we may build our reasonings upon in mathematical inquiries. These principles are the laws and conditions of certain motions, and powers or forces, which chiefly have respect to philosophy; but, lest they should have appeared of themselves as dry and barren, I have illustrated them here and there with some philosophical scholiums, giving an account of such things

[13] I. Newton, Philosophiae Naturalis Principia Mathematica, Praefatio ad Lectorem.

[14] It is true, though, that Petry did not explicitly trace back this metaphysical content to the application of mathematics. He writes: “Er [Newton] war [...] auch nicht bereit zuzugeben, daß seine eigenen Experimente, obwohl gründlich und streng durchdacht ausgeführt, nicht vollkommen ohne metaphysische Voraussetzungen auskommen können, und daß es für einen praktizierenden Naturwissenschaftler unmöglich ist, ohne Hypothesen zu arbeiten. [...] In dieser Hinsicht harmonieren ihre [Hegel’s and Goethe’s] Ideen viel besser mit modernen Auffassungen als das etwas positivistischere Ideal Newtons.” (M. J. Petry in: Hegel und die Naturwissenschaften, ed. M.J. Petry, Stuttgart-Bad Cannstatt 1987, p. 327).

> as are of more general nature, and which philosophy seems chiefly to be founded on; such as the density and the resistance of bodies, spaces void of all bodies, and the motion of light and sounds. It remains that, from the same principles, I now demonstrate the frame of the System of the World."[15]

This passage is quite astonishing for the modern reader, since it reflects a quasi-Cartesian understanding of mathematics which has been left behind at the latest in the 19th century. For Newton and his contemporaries, mathematics is by no means identical with what we call „pure" mathematics.[16] Newton considered equations describing the trajectories of particles in space as *mathematical equations*, not as elements of what we would call *theoretical physics*. It is evident that this is not only a terminological problem, since it is one of the basic features of the mechanistic wordview to be based upon an immediate (i.e. unreflected) application of mathematics to scientific inquiry.[17]
It seems to me that Newton's application of mathematics is indeed quite unreflected; that he finds it more or less self-evident that the phenomena described by the sciences have a mathematical structure.[18] Thereby he leaves aside the question *why* quantitative categories of thought can be applied to the descripition of nature at all and *which implications* this description has. At the same time, what Newton calls „philosophy" or „natural philosophy" is supposed to be *little more than applied mathematics* – in order not to involve any hypotheses, if possible. I will come back to this point later when examining Hegel's arguments in this regard.

IIb. Hegel

Hegel's view on the relation between mathematics and physics is in extreme opposition to Newton's. Hegel goes so far as to call the ambition to mathematically proove theorems of physics „ridiculous". „The physical" (Physisches) – says Hegel quite radically in his lecture on natural philosophy from 1823/24 – „cannot be proved

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[15] Sir Isaac Netwon's Mathematical Principles of Natural Philosophy and his System of the World, Translated into English by Andrew Motte in 1729. Rev. By F. Cajori. Vol. Two: The System of the World. University of California Press, Berkeley-LosAngeles-London 1934, p. [397]. – Italics mine.

[16] It was C.F. Gauss who, at the beginning of the 19th century, laid stress on the importance and the development of „pure mathematics".

[17] Cf. L. Fleischhacker, paper presented at the symposium „Zur Kritik des mechanistischen Weltbilds", Berlin, Aug. 2004; to be edited by R. Wahsner.

[18] The concept of mass, even though introduced into physics by Newton is an interesting example in this regard. Newton seems to have missed the point that is was a nontrivial abstraction to define mass in the way he did (on the basis of an atomistic theory of matter). – Newton's „direct", unreflected application of mathematics in his physical investigations probably has its roots in Descartes; cf. e.g. E. Bloch, Das Materialismusproblem, seine Geschichte und Substanz, Frankfurt am Main (Suhrkamp Verlag) 1972, p.166: "[...] für Descartes fällt der physikalische Körper mit dem mathematischen zusammen."

mathematically".[19] Similarly, he writes in the *Logic of Measure* that the attempt to proove natural laws mathematically "in the strict sense of the word, i.e. neither empirically nor conceptually, is absurd".[20] And in the – hitherto unpublished – manuscript by H.W. Dove, recording Hegel's lecture from 1825/26, we find the phrase: „If nothing ought to be determined physically [as Newton pretends], then the term ‚force' should be totally omitted."[21] It is true that the terms „physics", „the physical" and „physically" are not exactly identical with their present-day counterparts. However, they do not refer to the second part of the natural philosophy either, since from a Hegelian standpoint it would be trivial to say that *philosophical* theorems cannot be proved mathematically. So we do have to assume that Hegel, when blaming Newton for pretending to have proved his physical theorems mathematically, has an archetype of modern physics in mind, which exists in parallel to natural philosophy (see Enc. § 246); and we do have to ask: Which conception of the relation between physics and mathematics do the above cited sentences reflect?

It is a conception which can be traced back to the time when Hegel lectured in Jena and published his *Dissertation on the Orbits of the Planets* and the *Phenomenology of Spirit*. In his *Dissertation* from 1801, Hegel stresses the difference between the domain of mathematics and the domain of physics. He writes: „De qua [i.e. Newton's] cum Mathesi Physices conjuctione praecipue monendum est, ut caveamus, ne rationes pure mathematicas cum rationibus physicis confundamus [...]."[22] In other words, Hegel warns us from assigning any ontological value to mathematical concepts like vector components of the motion of a body, as was mentioned above already. – In the Foreword to the *Phenomenology*, where Newton is not mentioned explicitly, Hegel argues again that it is impossible to construct mathematical proofs of theorems of statics and mechanics like the laws of the lever or the law of free fall. Such proofs, says Hegel in 1807, do not proove any more than the necessity of real proofs.[23] In other words, philosophy alone, provided that it makes use of the

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[19] G.W.F. Hegel, Vorlesung über Naturphilosophie Berlin 1823/24, Nachschrift von K.G.J v. Griesheim, Ed. G. Marmasse, Frankfurt a.M. et al. 2000, p. 144: „Man muß sich bei der ganzen Lehre nicht durch den Namen *Newton* bestechen lassen, in der Wissenschaft gilt kein Name, giebt es keine Autorität. Besonders lächerlich ist es wenn man sagt, er habe es mathematisch bewiesen. Phisisches kann nicht mathematisch bewiesen werden." This passage is within the discussion of Newton's theory of colour.

[20] G.W.F. Hegel, Wissenschaft der Logik I, in: Werke in 20 Bden., ed. E. Moldenhauer and K.M. Michel, Frankfurt am Main (Suhrkamp Verlag) 1970, vol. 5, p. 407: „[...] daß der Versuch, solche Beweise eigentlich mathematisch, d.h. *weder aus der Empirie noch aus dem Begriffe zu führen*, ein widersinniges Unternehmen ist." – Italics mine.

[21] G.W.F. Hegel, Vorlesung über Naturphilosophie Berlin 1825/26, Nachschrift von H.W. Dove, Ed. Th. Posch et al., in preparation; manuscript, p. 45: „Wenn nichts physikalisch bestimmt werden soll, so wäre der Ausdruck ‚Kraft' wegzulassen."; cf. Vorlesung über Naturphilosophie Berlin 1821/22, Nachschrift von B.v.Uexküll, ed. G. Marmasse & Th. Posch, Frankfurt am Main 2002, p. 58: „Newton braucht den Namen Kräfte, ungeachtet seiner öfteren Protestationen, daß hiemit nur mathematische Bestimmungen gemeint seien." – VGL. AUCH JSE II.

[22] G.W.F. Hegel, Dissertatio philosophica de orbitis planetarum, ed. W. Neuser, Weinheim 1986, p. 82.

[23] G.W.F. Hegel, Phänomenologie des Geistes, in: Werke in 20 Bänden, ed. E. Moldenhauer and K.M. Michel, Frankfurt am Main (Suhrkamp Verlag) 1970, vol. 3, p. 45: „Daß die sogenannten Beweise

dialectical method, can – in the strict sense of the word – proove the laws of the motion of natural bodies. The so-called proofs that applied mathematics – which Hegel rightly distinguishes from pure mathematics[24] – is able to deliver do not grasp the genuine relation between the moments of natural laws – e.g. space and time – which is the essential content of these laws. Like pure mathematics, applied mathematics is unable to seize the qualitative, immanent, selfdetermined motion (Selbstbewegung) of the concept[25] – a motion which includes non-quantitative *transitions* like that from the point to the line or the even more striking one from space to time.

But what should the scientist do with natural laws, if not try to proove them in some sense? He must feel quite uncomfortable with Hegel's distinction of "the empirical" (*das Empirische*) on the one hand and "the Notion", that is to say the philosophical way of reasoning on the other hand.[26] Given that the scientist is not a philosopher, should he pretend to derive natural laws merely from experimental research?

A part of the answer to this question can be found in a footnote to § 267 of Hegel's *Encyclopaedia* (3rd ed., 1830). In this footnote, Hegel comments on Lagrange's remark on the relation of the Taylor series to the motion of point masses. He praises Lagrange for *not pretending to proove* the law of free fall by the expansion of such a series. Lagrange – says Hegel – rightly refrains from any alleged proof of this kind but restricts himself to *adopting the acceleration term* (a t²) from *empirical research* and *comparing* the mathematical (i.e. analytical) theory with it.[27] A similar judgement can be found in Hegel's treatise on the calculus in the first volume of his *Science of*

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solcher Sätze, als der vom Gleichgewichte des Hebels, dem Verhältnisse des Raums und der Zeit in der Bewegung des Fallens usf., welche sie [die Mathematik] häufig gibt, für Beweise gegeben und angenommen werden, ist selbst nur ein Beweis, wie groß das Bedürfnis des Beweisens für das Erkennen ist, weil es, wo es nicht mehr hat, auch den leeren Schein desselben achtet und eine Zufriedenheit dadurch gewinnt."

[24] Pure mathematics, according to Hegel, does not use the concept of time. It deals exclusively with space (geometry) and with numbers (arithmetics, algebra): „Der *Stoff*, über den die Mathematik den erfreulichen Schatz von Wahrheiten gewährt, ist der *Raum* und das *Eins*." (Phänomenologie des Geistes, l.c., p. 44).

[25] Cf. ibid., p. 45: Mathematics does not get „zum Übergange des Entgegengesetzten in das Entgegengesetzte, nicht zur qualitativen, immanenten, nicht zur Selbstbewegung [of the concept]." – See also the Logic of measure, l.c., p. 407: „Es muß aber noch ein höheres Beweisen dieser Gesetze gefordert werden, nämlich nichts anderes, als daß ihre Quantitätsbestimmungen aus den Qualitäten oder bestimmten Begriffen, die bezogen sind (wie Zeit und Raum), erkannt werden."

[26] See above, note 20: Hegel finds it absurd to proove a law „neither empirically nor conceptually" („*weder aus der Empirie noch aus dem Begriffe*").

[27] G.W.F. Hegel, Enzyklopädie der philosophischen Wissenschaften im Grundrisse (1830), in: Gesammelte Werke, in Verbindung mit der Deutschen Forschungsgemeinschaft hg. von der Rheinisch-Westfälischen Akademie der Wissenschaften, vol. 20, Hamburg 1992, p. 263f: „Hier ist mit Recht keine Rede davon[,] einen *Beweis* von s = bt² aufstellen zu wollen, sondern diß Verhältniß wird als in der Natur *sich findend* aufgenommen." Hegel then speaks of Lagrange's essentially „richtigen Gang, der diese Bestimmungen [i.e. the expansion of a Taylor series] nicht für einen *Beweis des Gesetzes* gebrauchen will, sondern dieses, wie hier gehörig, aus der Erfahrung aufnimmt und dann die mathematische Behandlung darauf anwendet."

Logic, even though this judgement is more focussed on the danger of assigning a physical meaning to the terms of the Taylor series.[28]
From this praise for Lagrange, it can be concluded that Hegel, far from opposing the application of mathematics – more specifically: of analysis – to mechanics, did have a certain idea of this application. This idea can be characterized as follows: experimental physics should examine the motions (and other changes of state) of bodies under certain idealized conditions. Incidentally, Hegel does not stress the aspect of idealization very much, he rather stresses the necessity of making experiments without doing too much violence to nature (this is emphazised in the discussion of Newton's theory of colour – see above). Now the motions thus examined by experimental physics should *not be explained* by any comprehensive theory; least of all should *forces* be introduced into the scientific description as explanatory principles, such that different phenomena would be derived from one basic set of concepts (e.g. space – time – mass – force or e.g. space – time – mass – energy). The latter task should be reserved to philosophy, since there is – according to Hegel – nothing between "the empirical" on the one hand and "philosophical theory" on the other hand. If it is not reserved to philosophy, and more specifically to a dialectical system of philosophy, some sort of a mechanistic worldview will inevitably result.
To properly understand this position and its motivation, it is necessary to go into the architecture of the encyclopaedic system a little more deeply.

III. The metaphysical background of Hegel's view of the relation between mathematics and physics

It is difficult enough to understand what Hegel means when repeatedly claiming that theorems of physics cannot be proved mathematically. However, it is much more difficult to say what *motivated* this claim. At first glance, the assumption seems quite natural that Hegel simply perceived Newton's use of mathematics as an epistemologically naïve one. Even though I admit that this methodological criticism *is* a part of Hegel's fundamental disapproval with Newton, I think that another point deserves our attention which is connected to the relation between physics and mathematics. This point is what I have elsewhere called *Hegel's anti-reductionism*.[29]

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[28] G.W.F. Hegel, Wissenschaft der Logik, in: Gesammelte Werke, l.c., vol. 21, p. 263: „Aber diese Gleichung [$x = at + bt^2$] hat selbst nur diese Gestalt, durch die Voraussetzung der *Erklärung*, die den *durch analytische Entwicklung* entstehenden Gliedern *gegeben* wird, erhalten; diese Voraussetzung ist, daß die gleichförmig beschleunigte Bewegung *zusammengesetzt* sey, aus einer formell-gleichförmigen [...] und einem Zuwachse, (dem a in $s = at^2$ d.i. dem empirischen Coeffizienten), welcher der Kraft der Schwere zugeschrieben wird, – einem Unterschiede, der keineswegs in der Natur der Sache irgend eine Existenz oder Grund hat, sondern nur der *fälschlich physikalisch gemachte Ausdruck* [italics mine] dessen ist, was bey einer angenommenen analytischen Behandlung herauskommt."
[29] Cf. Th. Posch, Hegel's Anti-Reductionism: Remarks on What is Living of his Philosophy of Nature, to be published in: *Angelaki. Journal of the Theoretical Humanities. 2005.*

What do I mean with anti-reductionism and how does it influence the conception of the relation between mathematics and physics? Evidently, it is necessary to define reductionism before defining anti-reductionism. As Hegel sees it, reductionism is a tendency of human understanding „to put everything on the same level"[30] – such as on the level of mechanics or chemistry. It must be kept in mind that Hegel does not deny the possibility of applying mechanical models – or, in his terminology, the category of mechanism – even to subject matters of psychology.[31] The conception of the *Encyclopaedia* even *demands* mechanism to realize itself in a logical, natural and spiritual (psychological) form. Hence, it would be a serious misunderstanding to conceive of Hegel's anti-reductionism as a tendency to „forbid" the application of thought-categories to realms of reality which are apparently alien to these categories. On the contrary, it is the encyclopaedic system which makes it understandable why thought-categories designed to comprehend apparently „primitive" realms of reality can re-gain significance *as moments* – but just as moments! – of „higher" realms of reality. „Mechanical memory", as Hegel put it, is a good example thereof. However, the encyclopaedic system still conserves an important feature of the concept of the „chain of beings": It conserves the contention that philosophy should comprehend reality as having a hierarchical structure; that thought should not nivellate it, in spite of recognizing the usefullness of analogies and mechanical models. *Anti-reductionism*, in this sense, can be defined as *sticking to ontological hierarchies in a way that is compatible with Kant's critique of traditional metaphysics.*[32]

It is beyond my scope to enter into a general discussion of how and to which degree post-Kantian philosophy can stick to ontological hierarchies. This would require a seperate study. I'd rather like to connect the so defined anti-reductionism to the relation between physics and mathematics. At first sight, there is little interrelation between both topics. Why should a given concept of applying mathematics in science result in a reductionist or anti-reductionist worldview? Indeed, there is no *necessary* connection between one and the other. However, coming back to the idea that any unreflected use of mathematics in science is likely to favour the mechanistic worldview – and having in mind that the latter is certainly a kind of reductionism – we

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[30] Cf. Hegel's Philosophy of Nature, ed. by M.J. Petry, 3 vols., London & New York (George Allen and Unwin) 1970, vol. 2, p. 43 (§ 286, Add.): „The attempt is made to put everything on the same level. Everything can of course be treated from a chemical point of view, but everything can also be treated from a mechanical point of view [...]. When bodies are treated at one stage, these does not exhaust the nature of other bodies however, as for example when vegetable or animal bodies are treated chemically."

[31] See e.g. G.W.F. Hegel, Wissenschaft der Logik, Zweiter Band: Die subjektive Logik oder die Lehre vom Begriff, in: Gesammelte Werke, l. c., vol. 12, p. 133: „Wie der *materielle* Mechanismus, so besteht auch der *geistige* darin, daß die im Geiste bezogenen sich einander und ihm selbst äusserlich bleiben. Eine *mechanische Vorstellungsweise*, ein *mechanisches Gedächtnis*, die *Gewohnheit*, eine *mechanische Handlungsweise* bedeuten, daß die eigenthümliche Durchdringung und Gegenwart des Geistes bey demjenigen fehlt, was er auffaßt oder thut."

[32] However, I would not call Kant himself an anti-reductionist. His thought is – so to speak – too much concentrated on his justified critique of ancient, naive ontology, that he is by and large unable to highlight the merits of ontological hierarchies like the concept of the chain of being.

may now ask *to which extent Hegel's opposition to Newton is ultimately motivated by the impression that the author of the* Principia *does unintentionally favour reductionism by his very understanding of „*mathesim *excolere, quatenus ea ad* philosophiam *spectat".*

Newton's way of „*mathesim* excolere" depends on a new type of law that he introduced to science, even though he did not formalize it in the way in which it has been formalized and vastly generalized in the 18th and 19th centuries: the *dynamical law* which has the structure of a differential equation. The law of universal gravitation is an example of such a law. To state it briefly (and explain it afterwards): *Hegel's idea of Newton's being a reductionist is intimately connected to this new type of dynamical law.*

The dynamical law takes the place of the type of laws established by Kepler and Galileo – a type which is known to have been thoroughly analyzed by Hegel. I will henceforth call the laws of the Kepler-Galileo-type „phenomenological laws", following Hegel's crucial observation that Newton "set the laws of forces in the place of the laws of phenomena".[33]

The phenomenological laws are not entitled to be universal natural laws; rather, they refer to particular *classes* of phenomena which occur under certain circumstances, say, under terrestrial gravitation in vacuum, or under interplanetary conditions; furthermore in ideal gases etc. The dynamical laws, due to their formal structure, can describe motions or changes of state only after the specification of *boundary conditions* and after analytical or numerical integration. Phenomenological laws, too, can in many cases be derived from dynamical laws by the process of specifying boundary conditions and performing an integration. Galileo's law, e.g., can be derived from Newton's law of universal gravitation in such a way. Hence, even though not directly describing motions or changes of state, dynamical laws are in general considered as more fundamental than phenomenological laws. In this perspective, many phenomenological laws are considered as *no more than rules for particular classes* of motions governed by an underlying fundamental dynamical law.

As mentioned above, Newton did not yet use the terms „dynamical laws", „boundary conditions" etc. These *terms* as such are the result of a later formalization of Newton's predominantly geometrical understanding of forces. However, the basic *concept* of dynamical laws, and of the *dynameis* (forces) governing them – and being the very scope of scientific research – *can* be found in Newton's work.[34] Therefore, my claim

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[33] G.W.F. Hegel, Lectures on the History of Philosophy. Translated from the German by E.S. Haldane and F.H. Simson, London (Kegan Paul, Trench, Trübner & Co.) 1895, vol. 3, p. 323. Cf. also B. Falkenburg, *How to Save the Phenomena: Meaning and Reference in Hegel's Philosophy of Nature*, in: *Hegel and the Philosophy of Nature*, ed. by St. Houlgate, New York (SUNY) 1998, p. 97sqq.

[34] Cf. I. Newton, Principia, Foreword: „Alle Schwierigkeit der Philosophie besteht wohl darin, daß wir aus den Bewegungserscheinungen die Kräfte der Natur erschließen und alsdann von diesen Kräften ausgehend die übrigen Erscheinungen genau bestimmen. [...] Ich habe nämlich viele Gründe dafür jedenfalls zu vermuten, daß alles von bestimmten Kräften abhängen könnte, durch die die Teilchen der Körper aus noch nicht bekannten Ursachen entweder wechselseitig gegeneinander stoßen und in

that *it is the introduction of dynamical laws which Hegel refuses to accept* as a progress of science is by no means absurd. Quite the reverse, it can be shown that Hegel's words on Newton's alleged intermingling of mathematics and physics as well as his general anti-reductionism are related to what we might call *apology of the phenomenological against the dynamical law*.

Hegel's well-known praise for Kepler as well as his praise for Lagrange implies that the author of the *Encyclopaedia* essentially would want the scientists to discover and deal with *phenomenological laws* of motions (and of changes of state), while he would not want them to construct whole *theories* deriving several classes of motions from *unified dynamical laws*. Hegel is convinced that only phenomenological laws like Kepler's laws, Galileo's law of free fall or Snell's law of refraction can be integrated into a philosophical theory of natural phenomena that does really deserve this name. Unified dynamical laws, by contrast – like Newton's law of universal gravitation (together with his axioms of mechanical motion) – appear to Hegel as a sort of a *semi-philosophy* which on the one hand has to use *de facto* metaphysical categories and on the other hand cannot justify the use of these categories nor construct a hierarchical system of them.[35]

Hegel's apology of the phenomenological law is furthermore related to his famous distinction between physics and natural philosophy as "thinking" and "comprehending consideration of nature" ("denkende" and "begreifende Naturbetrachtung").[36] This distinction is progressive compared to any sensualistic approach to physics which would deny even the status of "thinking consideration of nature", insisting, e.g. on the idea that physics is just a method of economically dealing with perceptions.[37] At the same time, Hegel's distinction is problematic in reserving the status of "comprehending consideration of nature" to philosophy. Ultimately, this implies an unwillingness to concede the status of a *theory* (with its own epistemological status) to physics.

In any case, stating that physics – and science in general – is not "comprehending consideration of nature" encourages Hegel to insist on the scientist's task being the discovery and mathematical formulation of phenomenological laws. These laws *are indeed not sufficient for the foundation of a theory of nature*, for they do not relate different classes of motions, or, more generally speaking, different classes of phenomena, to each other: e.g. they do not relate magnetism to electricity or acoustical to mechanical phenomena, while dynamical laws aim precisely at that (e.g. Maxwell's equations or the equations of wave mechanics). But now comes the point: The *way* in which dynamical laws relate apparently different realms of (phenomenal) reality to each other appears to Hegel as a dangereous mechanistic way. True, dynamical laws – suspects Hegel – would probably make it possible for physics to

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regelmäßigen Strukturen zusammenhängen, oder sich wechselseitig fliehen und voneinander zurückweichen."

[35] Cf. G.W.F. Hegel, Enc. 1830, § 18.

[36] G.W.F. Hegel, Enc. 1830, § 246; according Petry's translation, physics and philosophy are related to each other in the same way as „thinking consideration of nature" and „comprehending consideration of nature".

[37] Cf. Ernst Mach's concept of science.

become a *theory* of nature on its own, but a reductionistic theory which does harm to the ambitions of philosophy. Phenomenological laws are not likely to do harm to a dialectical concept of nature, because they can be integrated into it as moments, thereby gaining their place in the hierarchy of an increasingly concrete "system of the real". This is, in my reading, Hegel's view of science as "cooperating with philosophy".[38]

It is possible to give a still preciser description of the kind of natural laws Hegel approves from a philosophical point of view and the kind of laws he disapproves. Hegel greatly appreciates *power laws* relating to each other what he would consider as *phenomenological quantities* (such as orbital periods and distances from the sun etc.). He is convinced that – at least in many important cases – it is possible to develop sort of an a priori deduction of such power laws from the concepts of the respective related entities, even though he admits that this is a most difficult task.[39]

What Hegel disapproves of, on the other hand, are non-phenomenological natural laws, especially if they are supposed to establish a link between different branches of physics and if they accomplish this by highly abstract concepts such as force, energy, entropy, probability etc. True, most of these concepts have been introduced to science only after Hegel's death; but Hegel's resistance to this type of concepts is evident enough from the way in which he treats atomism and Newton's concept of force.

An interesting example to illustrate this point is the *principle of conservation of energy*. It seems to be misleading in the present context insofar as it is neither a principle established by Newton nor a dynamical law in the strict sense of the word, since it is not formulated as a differential equation and does not refer to forces, but to energies. However, it must be noted that the energetic approach is equivalent to the Newtonian approach of founding mechanics upon the concept of force[40]; the energetic approach is, technically speaking, an integrated version of the dynamical approach.

Now there is little doubt that Hegel would have critizised the principle of conservation of energy in a very similar way as he critizised Newton's law of gravitation. Like the latter, the energy conservation principle represents a *partial unification of hitherto distinct theories* like mechanics and thermodynamics. Insofar as it is formulated in sentences like "heat *is* a kind of mechanical energy"[41], this principle threatens to nivellate the difference between mechanical motions and phenomena related to heat.[42] I do not claim that any way to state – and any effort to interpret – the energy

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[38] Cf. Hegel's Philosophy of Nature, ed. and trans. by M. J. Petry, loc. cit., vol. 1, p. 201: „Physics must [...] work together with philosophy ao that the universalized understanding which it provides may be translated into the Notion."

[39] W 5, 407 (already cited).

[40] Cf. H. Hertz, Hertz *Die Prinzipien der Mechanik in neuem Zusammenhange dargestellt*, Leipzig 1894.

[41] This was the version of the energy conservation principle which Robert Mayer had in 1842.

[42] NB: In his *Jenaer Systementwürfe*, Hegel uses himself terms which he borrows from mechanics (like lever, throw etc.) for the description of phenomena related to heat.

conservation principle will necessarily reduce the essence of heat to the essence of mechanical motion; such a claim would be a as naïve as certain uncritical attempts to understand the concept of energy as the basis of physics par excellence. What I claim is that we can better understand *Hegel's* view of natural laws by hypothetically constructing his assessment of the law of energy conservation. So, once again, a Hegelian assessment of the energy conservation principle would – very much like the Hegelian assessment of Newton's law of gravitation – not involve the statement that the concept of energy is totally useless in physics. To the contrary, Hegel would find it highly significant, for example, that the radiation energy emitted by a star can be related by a power law to its surface temperature (if the star is considered as representing the case of a blackbody). He would try to find a reason immanent in the very concept of temperature which makes this law (the Stefan-Boltzmann law) understandable from a philosophical point of view, especially with respect to the occurence of the *fourth power*, which is, by the way, rather rare in natural laws. At the same time, Hegel would say that it is problematic to set up equations relating different *kinds of energy to each other*, following the principle of understanding, which is looking for quantitative identity ("das Verstandesdenken, welches an der Linie der Gleichheit fortgeht"). In this perceptive, the energy conservation principle, too, entails the danger of overlooking essential differences between the kinds of energy which it equates numerically.

The general rule behind this hypothetical assessment of energy conservation is the following. Not only Newton is of the opinion that physics should beware from metaphysics, but Hegel is of this opinion as well; just that his he defines the use of metaphysics in physics quite differently. While in Newton's view, the introduction of the concept of force helps physics to surmount the status of a scholastic doctrine, Hegel holds that forces, energies and other highly abstract concepts of physics, if used for a unification of natural laws without the guidance of philosophy, accidentally render science a new variety of metaphysics.

IV. Conclusions

Does the reconstruction of the metaphysical background of Hegel's criticism of Newton's method render the former, in its basic structure, fully justified? I would say: Yes and no. Let me begin with the "yes"-part of this answer.

Hegel's criticism of the type of natural laws introduced by Newton has several merits. First of all, by praising Kepler and chastizing Newton, Hegel proposes to make a fundamental difference between what he considers as phenomenological laws on the one hand and dynamical laws on the other hand. Second, he rightly points out that the establishment of dynamical laws is more than a self-evident application of mathematical equations to physics. In this sense, he shows that Newton has maybe a somewhat naïve concept of the relation between mathematics and physics. Third, Hegel reminds us of the fact – or rather, he foresees – that scientific theories, based upon the unification of dynamical laws, may abet the mechanistic worldview if

uncritically understood as “theories of everything”.[43] In other words, Hegel’s criticism of Newton’s aiming at unified dynamical laws is fully justified if re-interpreted as a criticism of the harm which the mechanistic worldview can do to philosophy.[44]

This point, however, leads me to the shortcomings of Hegel’s anti-Newtonian attitude. It can be considered as a widely accepted result of the research on Newton and Hegel that Newtonianism and the mechanistic worldview are not exactly one and the same thing.[45] If this is true, then Hegel, by identifying both, has partly failed to correctly assess Newton’s achievements; and insofar as the latter laid the foundation of modern physics, Hegel has also failed to correctly situate physics from an epistemological point of view. In this regard, I would say that it might have been an option 200 years ago to restrict physics to the quest for phenomenological laws and to state that natural philosophy alone will be able to construct a comprehensive theory of nature based on the selfdetermination of the Notion (as Hegels puts it); however, the development of physics in the 19th century forces us to conceive the relation between physics and philosophy in a different way. The starting point of this way should be the recognition of physics (as well as chemistry etc.) as a seperate *theory* of nature; in other words, the recognition that science does not need to wait for a philosophical interpretation in order to become something more complex and more consistent than what Hegel calls “the empirical”.

This does not mean, however, that a philosophical interpretation of scientific theories be superfluous; it rather means that it has to be an interpretation of *scientific theories* in the strict sense of the word, not an interpretation of isolated laws and phenomena. Today as well as at Hegel’s time, it does make sense to give a philosophical answer to the question for the difference between the chemical and the mechanical object; while it probably makes less sense to “proove” laws of mechanical motion (or chemical interaction) in a philosophical manner. It does make sense to ask how the status of objectivity has changed with the transition from classical to quantum mechanics, while it would be short-sighted to aim at an a priori deduction of Heisenberg’s uncertainity principle. Hegel’s philosophy of nature – even though avoiding isolated, allegedly philosophical considerations of natural phenomena in its best parts – is not free of the temptation of philosophizing about individual scientific theorems and equations. It is true that Hegel makes plenty of astonishing and elucidating observations when philosophizing about Galileo’s and Kepler’s laws; however, it is doubtful whether he thereby gives a good example to his followers from a methodological point of view.

All these ideas can probably be summarized in the following sentence: *Hegel’s justified insistence on qualitative differences within the realm of nature is not – contrary to his own conviction – necessarily coupled to the refutation of the Newtonian quest for unified dynamical laws*, even though the latter seem to automatically endanger the former at first sight.

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[43] More details on this point can be found in Th. Posch, Hegel’s Anti-Reductionism: Remarks on What is Living of his Philosophy of Nature, loc. cit.

[44] Cf. Wahsner, The Phil. Background to Hegel’s Criticism of Newton’s Mechanics, in Petry 1993.

[45] Cf. Wahsner / v. Borzeszkowski, Newton und Voltaire.

It is certainly true, however, that unified dynamical laws are much more difficult to integrate into a philosophy of nature of the Hegelian type. The reason for this is that the philosopher, in contemplating these laws, can by no means rely on his “sense of nature”, but has to analyze the epistemological status of the scientific disciplines that have worked out the respective laws, the formal structure of them, and their phenomenal content, until eventually arriving at a refined concept of nature as a “system of stages” – stages, about which the scientist may say in the end: “Isn’t it all the same anyway?”