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The Law of Inertia: How Understanding its History can Improve Physics Teaching

RICARDO LOPES COELHO
Faculty of Science, University of Lisbon, Campo Grande c5, P-1749-016, Lisbon, Portugal
E-mail: rlc@fc.ul.pt

Abstract The law of inertia is a problem in teaching due to the impossibility of showing the proposition experimentally. As we cannot do an experiment to verify the law, we cannot know if it is correct. On the other hand, we know that the science based upon it is successful. A study in the history of mechanics has shown that there are different foundations for the law but also that the law plays the same role in the science since Newton. To avoid a statement of which we cannot be sure, the present paper proposes to understand the law through its function in the theory. In this case, we do not have to say how a free body moves, but rather that the rectilinear and uniform motion is the motion of reference in Newtonian mechanics.

Key words: Law of inertia, force, mechanics, Newton, Hertz

1. Introduction

"The teacher is not playing fair" says Eddington, remembering his introduction to mechanics: "He is determined to have his uniform motion in a straight line, and if we point to him bodies which do not follow his rule he blandly invents a new force to account for the deviation" (pp. 123–124).

In fact, teachers today have the same difficulty. Speaking in a general way, they teach that a free body stays at rest or moves along a straight line. However, they cannot show it. We are speaking of teaching but the problem concerns the theory of mechanics itself: as it is impossible to do an experiment in compliance with the wording of the law, we cannot even know, strictly speaking, if the law is correct.

The history of mechanics has recently shown that there are different theses concerning the foundation of the law but convergence concerning the role or function of the proposition in the science. Hence, it will be proposed in the present article to consider the law through its function. In understanding the law in this way, we are only verbalizing what physicists have done. What really changes, is the metaphysical component of the theory: the attributing of movements or properties to bodies, which cannot be proved experimentally.

2. Teaching

Most of the physicists who wrote textbooks on Mechanics during the twentieth century pointed out that it is impossible to do an experiment to prove the law of inertia. Let us have a look at some of them.

Voigt, in *Mechanics*, 1901, formulates the law of inertia and says on it: "It is hypothetical, because one cannot completely manage to liberate a body from *all* action"[1].

Planck, 1916, equally refers to the impossibility of the experimental translation of the law: "The first question that we want to answer is the following: how does a material point move [...] when it is completely isolated, at an infinite distance from all other bodies, in empty space? Evidently, this experiment cannot be carried out [...] It can even be doubted, if the question asked above has some meaning"[2].

Nielsen, in *Lectures on Mechanics*, 1935, pointed out the problem: "As there is no means of withdrawing a material point from all interaction with other bodies, the law of inertia, taken by itself, is not open to any experimental control"[3].

Becker, in his book *Introduction to Theoretical Mechanics*, 1954, writes: "It is impossible to outline an experiment in which no forces are acting, since, to do so, an isolated body would be required" (p. 24).

French, in *Newtonian Mechanics*, 1971, writes: "It must be recognized that we cannot "prove" the principle of inertia by an experimental test, because we can never be sure that the object under test is truly free of all external interactions, such as those due to extremely massive objects at very large distances" (p. 164).

Budò, in *Theoretical Mechanics*, 1974, points out that the law of inertia "cannot be object of a direct experimental trial, since a body cannot be completely withdrawn from the actions of other bodies"[4].

The tenth edition of Bergmann and Schaefer's *Experimental Physics*, 1990, draws attention to the difficulty: "In what circumstances does a body [...] maintain the initial speed [...] For this, as Galileo has already recognised, the absence of all external action is necessary [...] *Such a limit case can never be realised experimentally*"[5].

Alonso and Finn's formulation of the law of inertia, 1992, speaks of a free particle[6]. They add, however: "Strictly speaking, there is no such thing, because each particle is subject to interaction with the rest of the universe in the world" (p. 95).

We can find an analogous situation in Nolting's *Mechanics*, 2005. He expresses the LI through a free body, which is defined as "a body, which is withdrawn from all external actions"[7]. He adds: "In this definition there is hidden a bold extrapolation, although also plausible from experiments. A body, which is completely isolated, does not exist"[8].

Strictly speaking, one could say, if the body referred to does not exist, nobody can know how it moves.

2.1. PROPERTY OF BODIES

Some physicists say that bodies have a property or natural tendency called inertia. Let us collect some statements on this issue.

Cutnell and Johnson, in *Physics*, 1997, say: "Inertia is the natural tendency of an object to remain at rest or in motion at a constant speed along a straight line" (p. 87).

Wilson and Buffo say, in *Physics*, 1997: "Inertia is the natural tendency of an object to maintain a state of rest or to remain in uniform motion in a straight line (constant velocity)" (p. 100).

Nevertheless, in Schaefer's *Introduction to Theoretical Physics*, vol. I, 1962, inertia as a property of bodies is considered a consequence of our causal thinking: as we need a cause to state that bodies remain at rest or in uniform and rectilinear motion, we have attributed to them the property of inertia[9].

Interpreting inertia as a consequence of a conceptual requirement, Schaefer does not consider it a property of bodies.

According to Sommerfeld the LI postulates the capacity of bodies, which is called inertia[10].

If the bodies have a property or natural tendency, which is called inertia, we understand why bodies remain at rest or in uniform and rectilinear motion. However, if it is true that it is impossible to design an experiment to prove that a body remains by itself in those states, we have no reason to speak of that property of bodies because we can never verify the consequence of the property. This means we have no experimental reason to attribute the property of inertia to bodies.

2.2. A SPECIAL CASE

Sometimes, the LI is presented as a special case of Newton's second law: if the resultant of the forces acting on bodies is equal to zero the bodies remain at rest or in uniform and rectilinear motion.

In *Sears and Zemansky's University Physics*, 2004, one reads: "A body acted on by no net force moves with constant velocity (which may be zero) and zero acceleration" (p. 124).

Serway, 1997, formulates Newton's first law as follows: "An object at rest remains at rest and an object in motion will continue in motion with constant velocity (that is, constant speed in a straight line) unless it experiences a net external force" (p. 109).

Halliday, Resnick and Walker, 1997, write: "Newton's first law: Consider a body on which no net force acts. If the body is at rest, it will remain at rest. If the body is moving with a constant velocity, it will continue to do so" (p. 80).

There is a difference between the law of inertia and the special case of Newton's second law, when the resultant of the forces is equal to zero. In this latter case, there exist forces, whose consequence is that the velocity of the body acted upon is constant. The law of inertia tells us, however, what happens when there are no forces at all. From an experimental point of view the distinction is very clear: then it is easy to find situations where the resultant of the forces exerted upon a body is equal to zero and it is impossible to design an experiment with a body which is not acted on by any force.

If we admit that the LI is a special case of Newton's second law, we have to be consistent and say that we do not need three laws of motion any more, but only two. In such a case, a reorganization of Newtonian mechanics would be required.

2.3. THE CONNECTION WITH MASS

Sometimes, inertia appears connected with mass, although not always in the same way. Becker, 1954, writes, "*Inertia* is the property of a body by means of which the body resists a change in its motion [...] The quantitative measure of inertia is *mass*" (p. 24). According to Blatt, 1989, "Mass is the property that lends a body its inertia, its reluctance to change its state of motion. To cause a change of motion we must exert a force, and that must be greater the greater the mass. [...] *Mass is an inherent property of a particular body*" (p. 55).

The inertia here referred to means resistance of a body to a change of its motion, when it is acted upon by other bodies. The property of inertia, which was dealt with in § 2.1., justifies the perseverance of a body in its state of motion, when it is not influenced by any other bodies. Whereas the inertia referred to by Becker and Blatt is measured by the mass of a body, the inertia related with the law of inertia is independent of mass.

To connect the inertia referred to with that of the LI, it must be supposed that the 'resistance to a change' arises from the property of a body to persevere in its state of resting or of moving uniformly and rectilinearly. To be sure, however, that a body has this property, an experiment should be carried out. This condition leads to the difficulty already considered in § 2.1.

2.4. AN IDEAL CONDITION?

In discussions on the LI, it is sometimes proposed to consider the ‘motion of a free body’ as an ideal condition. The argument can be presented as follows. We cannot confirm the LI experimentally because we cannot outline the situation in which a body is completely free from external causes. Scientific knowledge is, however, not free of ideal conditions. Hence, ‘no forces acting on a body’ can be considered an ideal condition. In other words, as the argument is sometimes also presented, Newton’s first law cannot be empirically verified but we can think the law as a “thought experiment”.

The reason that the LI cannot be confirmed experimentally is not only because we cannot carry out such a situation but because the experimental configuration is theoretically unacceptable. The law says how a free body moves. Thus, to elaborate a ‘thought experiment’ a free body is required. However, to think of an experiment, an observer is needed. If there is an observing device there is no free body any more. An experiment with a material point that exists alone is therefore not thinkable.

Riemann (1826–1866) had already recognized this problem when he wrote: “The law of inertia is a hypothesis: if a material point exists alone in the universe and if it moves with a certain velocity, it will always maintain the same velocity”[11].

We can understand Planck in the same way when he asks if the question, ‘how does a free material point move’, has any sense at all. We can also understand Scobel, Lindström and Langkau, 2002, who say, ‘a free particle is fiction’[12]. Hanson, 1963, used a metaphor to express the same, “Making claims about such non-existent objects, for example, that they either remain at rest or move with uniform rectilinearity *ad infinitum*, seems somewhat like making claims about centaurus or mermaids” (p. 118).

3. History

In Newton’s *Principia* there are two kinds of force: *vis insita*, which is inherent to bodies[13]; and *vis impressa*, which is exerted upon a body[14]. From the first kind, there is only one force: the force of inertia[15]. Centrifugal force, pressure, impact are examples of impressed forces[16]. The maintaining of the state of rest or of uniform and rectilinear motion is connected to the first kind of force, the force of inertia; accelerations are connected with the second one.

Inherent forces to bodies will be rejected by d'Alembert as 'metaphysical entities', in 1743[17]. Euler, in 1750, criticised 'force of inertia' as a contradictory expression, which, consequently, should be eliminated from mechanics[18].

In Euler's *Mechanics*, 1736, the maintaining of rest, uniformity and rectilinearity of motion of a body, if not influenced by external causes, is expressed in three statements (two theorems and a corollary), whose demonstrations are based upon the principle of sufficient reason[19]. Euler imagines a body in an infinite and empty space and concludes that there is not sufficient reason for an alteration of rest, uniformity or rectilinearity because they would imply differences in space and these do not exist[20].

In d'Alembert's *Traité de Dynamique*, 1743, the maintaining of the states of rest or of uniform and rectilinear motion of a body, if external causes do not act upon it, is likewise expressed in three statements: two laws and a corollary. The first law, which concerns the maintaining of rest, is justified in the following way: a body at rest will remain so because there is no reason why a body moves more to one side than to the other[21]. From this proposition, the corollary is drawn as follows. Since there is no reason for a body to move more in whatever direction, the moving body will not move more in the direction of the movement than in the opposite one. Therefore, its velocity will be constant[22]. The second law concerns the rectilinearity of motion. The argument is analogous to the previous one: since there is no reason for the deviation of the moving body to the right or left of the direction of its motion, it will continue in the original direction[23].

D'Alembert pointed out that the maintaining of rest and of rectilinearity of motion are observable; the uniformity is not, but can be deduced. So, it can be concluded that he called 'law', what is observable, and 'corollary', what can only be deduced.

According to Laplace, *Traité de Mécanique Céleste*, 1799, the proof of the law of inertia can be summarised in the following way: there is no reason for a body to move by itself. In fact, the maintaining of rest, rectilinearity and uniformity of motion are justified in this way: there is no reason for a body to move in one particular direction. Laplace adds that the uniformity is not so evident as the rectilinearity[24].

In 1803, Lazare Carnot publishes the *Principes fondamentaux de l'équilibre et du mouvement*. Due to problems with the concept of force, he develops a new theory of mechanics, in which he does not start from axioms but from hypotheses. The first of his seven hypotheses corresponds to the law of inertia[25]. The statement is justified "by experiments" and "by reasoning". From experiments, Carnot picked up a particular case and generalised it for all bodies: a ball at rest on a flat table will remain so and if in motion will continue; the same goes for all other bodies in similar circumstances[26]. The argument "by reasoning" can be formulated in this way: there is no reason for a body to move by itself, in whatever direction[27].

According to Poisson, one understands by inertia of matter the impossibility of a body to move by itself[28].

Coriolis equally speaks of inertia as property of bodies[29].

The arguments of physicists are based upon everyday experience with bodies: they cannot move by themselves. In this context, it is understandable that the uniformity provides some difficulty because it could not be verified by any experiment. Nevertheless, the law is admitted and inertia is considered a property of bodies. Necessary conditions to verify the inertia led to criticism on the law.

In 1869, Neumann defends the thesis that the law of inertia cannot make up a scientific foundation since it is 'completely incomprehensible'[30]. The law says, he argues, that a free body covers equal spaces in equal times along a straight line, but without indication neither of a frame of reference nor how the times are to be measured. In fact, he further argues, the direction of a moving point is indefinite without a frame of reference and celestial time does not give us sufficient guarantee[31].

Neumann proposed then a solution for the problem: three principles and two definitions. The first principle expresses the admission of an unknown body, called "*alpha*", absolutely rigid and existing in an equally unknown place in the universe[32]. This body functions as the universal frame of reference. The first definition is that of motion, which, consequently, is a change of place in relation to the body *alpha*[33]. The rectilinearity of the motion of a body left on its own, which equally acquires meaning by reference to the body *alpha*, constitutes the second principle[34]. The uniformity of motion is equally postulated. This is the third principle[35]. The last of Neumann's sentences is the definition of equal intervals of time: those in which a point left to itself covers equal distances[36].

In 1872, Mach said that he had already been faced with the same problems but could not corroborate Neumann's solution. The main reason for disagreement was the absolute motion, which would continue to be supposed in admitting the body *alpha*, whereas Mach defended the relative motion[37]. The subject is taken up again in *Mechanics*, 1883, in which he asserts: absolute space and absolute motion are mere beings of thought; the determination of the motion of a body requires other bodies[38]. On the bodies of the frame of reference, however, falls the requirement, to be a great distance from the observing body[39].

Neumann's work also stimulated Streintz's research, 1883, which deals with the question: in relation to what bodies or system of coordinates the law of inertia is valid[40]. The law holds in relation to the "*fundamental* *body*", is the answer, which is characterized by two features: it has no rotation and is independent of the surrounding bodies[41]. As a foot-note to the characterisation, however, can be read: "it is evident that the requirement attached to the fundamental body, that it must not make a rotation and must not be subject to foreign actions, constitutes an ideal case that in practice cannot be reached"[42].

In the 1880s, Lange published some papers on the subject. His research was also stimulated by Neumann's work referred to. As seen above, Neumann used the motion of a point left to itself to define equal intervals of time. Lange used the same procedure for the construction of the frame of reference[43]. He imagines three points sent from the same point of space in three, no coplanar directions and left to themselves. These three points, whose motion is admitted to be rectilinear, are thought of as linked to a fourth point of space. The three straight lines of this construction, being thought of as rigid, constitutes the frame of reference[44].

Lange's formulation of the law of inertia thus shows a clear parallel between the spatial and the temporal component. Each of them consists of two assertions: a definition and a theorem. The theorems express the rectilinearity and the uniformity of the motion of a body left on its own. The definitions establish the frame of reference and the measurement of time, which are, respectively, called "*inertial system*" and "*inertial scale of time*"[45].

With his construction of the inertial system, Lange intended to avoid astronomical bodies, like the body *alpha*. Hence, he used 'dynamic concepts', i.e., the movement of points left to themselves. However, Lange is explicitly aware of his construction. He speaks of 'convention' because it is necessary to admit the rectilinear motion of three points to verify it for a fourth one[46]. He adds, the law of inertia is not an experimental proposition but rather a hypothesis[47].

3.1. ON THE STRUCTURE OF THE FORMULATION

Even though there was a lot of criticism on the law of inertia and it became well known during the twentieth century that the statement is out of control, the law of inertia plays a role in classical mechanics. Let us have a look at some formulations to consider the function of the law. Newton writes: " [1] Every body perseveres in its state of resting or of moving uniformly in a straight line, [2] as far as it is not compelled to change that state by impressed forces"[48].

The first part of the statement (1) determines the mechanical state at which a body remains; in the second one (2), it is pointed out, a body does not move as indicated, only if it is disturbed by an impressed force. By 'impressed force' is understood an action exerted upon a body. This action arises also from the exterior of the body. Therefore, Newton's first law says that there is a natural state of a body, whose change can only arise from other bodies. As the natural state is the rest or the uniform and rectilinear motion, the accelerated motion has its origin in an external cause to bodies. As motions are accelerated or not, the law of inertia divides the set of motions into two subsets: the motion that a body does by itself; and the other motions, which are due to external causes.

We can verify that Newton's structure of the law has been conserved till now. Euler[49], d'Alembert[50], Carnot[51] but also Planck (1916)[52], Erikson (1936)[53], Sommerfeld (1947)[54], Hänsel and Neumann (1993)[55], Leisi (1996)[56], Daniel (1997)[57], Benenson, Stocker, Harris and Lutz (2001)[58], Hering, Martin and Stohler (2002)[59], Demtröder (2003)[60], Gehrtsen (2004)[61], among many others, have formulated the law with the same structure.

3.2. ON THE FUNCTION

In joining the present consideration on the structure of the formulation of the law with that on the foundation of the principle, we can conclude that there are different points of view on the foundation but there is convergence concerning the formulation. The analysis of the formulation shows that the LI indicates the natural motion of a body, which can only be disturbed by external causes.

The mathematician Jacobi was the first, to my knowledge, who considered the structure of the formulation. In his *Lectures on Analytical Mechanics*, Berlin, 1847–1848, he said: "From a mathematical point of view it is circular to say: the rectilinear motion is the natural one, consequently, an external cause is necessary for whatever motion, because one could with the same right put forward another motion as law of inertia of bodies, if one adds, if a body does not move in that way, an external action is charged with it"[62].

Jacobi's approach can be easily understandable in the present context. The law of inertia implies a disjunction in the set of motions: between the natural motion, which is attributed to bodies, and the other motions, for which external causes are supposed. Such a disjunction could be made likewise through the attribution of another motion to bodies since the remainder are delivered to external causes.

In 1852, Reech publishes a book on mechanics, *Cours de Mécanique d'après la nature généralement flexible et élastique des corps*, which was written against the reform of the Polytechnic School concerning the concept of force. Here, he criticises as well the traditional theory of mechanics due to the law of inertia: the rectilinear and uniform motion is not the natural motion, he argues. He uses it in his own theory, where it has the same function as in the traditional one, but only because it is the simplest motion that can be used for that. According to Reech, the law of inertia is a mere convention[63].

In 1894, Hertz's posthumous work, *The Principles of Mechanics Presented in a New Form*, is published. Hertz became famous due to the discovery of electromagnetic waves at the end of the 1880s and dedicated himself from around 1890 to the foundations of physics, which in that time meant mechanics. His mechanical theory starts from three primitive notions and one axiom. The notions are time, space and mass; the axiom, called *fundamental law*, has the form of the law of inertia but for systems. It runs: "Every free system persists in its state of rest or of uniform motion in the straightest path"[64].

If a system does not move like this, i.e. not uniformly or not along the path with the smallest curvature, then, according to Hertz's mechanics, there is a force. This can now be understood in the following way: as this theory starts from the uniform motion along the path with minimal curvature, it is right to speak of force only if the body does not move uniformly or not along the path referred to. From the point of view of the Newtonian mechanics, one could say, as a system consists of material points, whose distance among them remains unchangeable, there are already forces in Hertz's free system[65]. Hertz saw the possible objection and answered it in advance: "Your assertion is correct for the mode of thought of ordinary mechanics but it is not correct independently of this mode of thought"[66].

The answer can now be understood in the following way. As classical mechanics starts from the uniform and rectilinear motion, there is a force, if the path of the motion is not a straight line. As Hertz's theory starts from another motion, there is reason to consider forces only if the indicated motion is not carried out. So, it is understandable that Hertz speaks on the "mode of thought of ordinary mechanics": This is linked with the motion which the theory starts from.

To make the steps covered explicit, let us consider briefly the mathematical expressions involved. In Newtonian mechanics there is force if

$$m_\nu \ddot{x}_\nu \neq 0$$

where m_ν represents the mass of the particle ν and $\ddot{x}_\nu$ the acceleration along the coordinate x_ν. Hertz defends, however, that there is no force if (§ 368)

$$m_\nu \ddot{x}_\nu = -\sum_{\iota=1}^{i} x_{\iota\nu} \mathrm{X}_\iota$$

where the right-hand side of the equation has its origin in the constraints of a free system. According to Hertz, there is force only if (§ 482)

$$m_\nu \ddot{x}_\nu + \sum_{\iota=1}^{i} x_{\iota\nu} \mathrm{X}_\iota = \mathrm{X}_\nu$$

where X_ν is the component of the force along the coordinate x_ν.

The comparison of Newtonian with Hertzian mechanics shows that forces depend on the starting motion of the theories. Hertz introduces forces, if the motion of a system is not the motion indicated in his axiom. Newton introduces force, if the motion is not the motion indicated in his first axiom. Thus, Newton's first law and Hertz's fundamental law have the same role in the respective theories. The function of the LI in Newtonian theory is therefore this: it indicates the motion of reference of the theory.

4. Conclusion

In teaching, we say that a free body remains at rest or moves uniformly along a straight line. This, however, can neither be corroborated nor falsified by any experiment, as has been said since the beginning of the twentieth century. If we cannot do any experiment concerning the law, we cannot know if it is correct.

The history of mechanics shows us that the law has a function in the classical theory and that this function, the indicating of the motion of reference, must not necessarily be played by the uniform movement along a straight line. Jacobi had seen that the motion of reference could be different; Reech introduced the uniform and rectilinear motion into his theory as a convention; Hertz carried out a mechanical theory based upon a motion of reference, which is not the Newtonian one.

Joining these data, it seems to be reasonable to understand the law on account of its function: the law of inertia establishes the motion of reference in the Newtonian theory. In doing so, the difficulty concerning the law disappears, since we do not need to prove any more, what we cannot do. Beyond that, in doing so, no real change is introduced into the theory of mechanics: we are only expressing in words what physicists, who have developed classical mechanics, have done.

Looking back, we can even appreciate Newton's foundation of mechanics. The first law establishes the motion of reference; Newton's second law indicates the process of measurement of the deviation from that motion. From a formal point of view, one can say that with the first law a unity for the science of motion is indicated and with the second one a process to estimate the deviation from the unity. The criticism on Newton's theory arises from its "metaphysical component": from the attributing of the motion of reference to the body by itself and the force to the neighbourhood of it. From this latter consideration arises the problem of the concept of force, which motivated the criticism of d'Alembert, Carnot, Kirchhoff, Mach, Hertz, Poincaré, among others (Coelho 2001). In understanding the law through its function, it will be simple to overcome the alternative conceptions of force. This is, however, a subject for another time.

Notes

[1] "er ist hypothetisch, weil man keinen Körper in voller Strenge von *jeder* Einwirkung zu befreien vermag" (p. 31).

[2] "Die erste Frage, die wir beantworten wollen, ist nun die: Wie bewegt sich ein materieller Punkt, ohne Rücksicht auf seine Vorgeschichte, wenn alle etwa früher wirksamen Ursachen seiner Bewegung beseitigt sind, wenn er sich also vollkommen isoliert, in unendlicher Entfernung von allen anderen Körpern, im leeren Raume befindet? Selbstverständlich läßt sich dies Experiment nicht rein anstellen [...] Ja, man darf zweifeln, ob die gestellte Frage überhaupt einen Sinn hat" (p. 8).

[3] "Da man keine Mittel hat, einen Massenpunkt jeder Wechselwirkung mit anderen Körpern zu entziehen, ist das Trägheitsgesetz für sich allein genommen keiner direkten experimentellen Kontrolle zugänglich" (p. 194).

[4] "Das Axiom [...] kann nicht Gegenstand einer unmittelbaren experimentellen Überprüfung sein, da ein Körper nicht vollständig jeder Einwirkung anderer Körper entzogen werden kann" (p. 32).

[5] "unter welchen Umständen ein Körper eine ihm erteilte Anfangsgeschwindigkeit nach Größe und Richtung beibehält [...] Nötig ist dazu, wie schon Galilei erkannte, das Fehlen jeglicher äußeren Einwirkung. [...] *Experimentell verwirklichen läßt sich dieser Grenzfall natürlich niemals*" (p. 54).

[6] The law of inertia says: "*a free particle always moves with constant velocity, or (which amounts to the same thing) without acceleration*" (p. 95).

[7] "*ein Körper, der* **jeder** *äußeren Einwirkung entzogen ist*" (p. 109).

[8] "In dieser Definition steckt eine recht gewagte, wenn auch plausible Extrapolation unserer Erfahrung. Den restlos isolierten Körper gibt es nicht" (p. 109).

[9] "Um dieses Verhalten der Körper, eine einmal vorhandene gleichförmige geradlinige Bewegung beizubehalten, unserem Kausalbedürfnis näher zu bringen, hat man ihnen die Eigenschaft der "*Trägheit*" oder des "*Beharrungsvermögens*" zugeschrieben, und daher nennt man den oben ausgesprochenen Satz auch das *Trägheitsgesetz*" (p. 77).
("To render the behaviour of bodies, which maintain the rectilinear and uniform motion, nearer to our causal need, one has attributed to them the property of "*inertia*" or "*capacity of perseverance*", and hence one also calls the proposition referred to *law of inertia*").

[10] "Das Gesetz postuliert ein *Beharrungsvermögen* der Körper in diesem natürlichen Zustande. Dieses Beharrungsvermögen nennen wir auch die *Trägheit des Körpers*" (p. 2).
("The law postulates a *capacity of perseverance* of bodies in this natural state. This capacity of perseverance we also call *inertia of a body*").

[11] "Das Trägheitsgesetz ist die Hypothese: wenn ein materieller Punkt allein in der Welt vorhanden wäre in sich im Raum mit einer bestimmten Geschwindigkeit bewegte, so würde er diese Geschwindigkeit beständig behalten" (p. 493).

[12] "Ein freies Teilchen ist eine Fiktion" (p. 30).

[13] "'*Materiae vis insita est potentia resistendi, qua corpus unumquodque, quantum in se est, perseverat in statu suo vel quiescendi vel movendi uniformiter in directum*" (p. 2)
("Inherent force of matter is the power of resisting by which every body, so far as it is able, perseveres in its state either of resting or of moving uniformly straight forward" (1999, p. 404)).

[14] "*Vis impressa est actio in corpus exercita, ad mutandum ejus statum vel quiescendi vel movendi uniformiter in directum*" (p. 2).

("Impressed force is the action exerted on a body to change its state either of resting or of moving uniformly straight forward" (1999, p. 405)).

[15] "By inherent force I mean only the force of inertia" (1999, p. 796).

[16] "Moreover, there are various sources of impressed force, such as percussion, pressure, or centripetal force" (1999, p. 405).

[17] "ainsi on ne sera point surpris qu'en conséquence de cette réflexion [...] j'aie entiérement proscrit les forces inhérentes au Corps en Mouvement, êtres obscurs & Métaphysiques, qui ne sont capables que de répandre les ténèbres sur une Science claire par elle-même" (pp. xvi–xvii). ("so one will not be at all surprised that because of this reflection [...] I might have entirely banned the inherent forces of the Body in Motion, obscure and Metaphysical beings, which are only capable of spreading darkness on a clear Science by itself").

[18] "A l'occasion de cette définition du terme de force, je remarque, que c'est très mal à propos, que quelques-uns nomment l'inertie la force d'inertie. Car, puisque l'effet de l'inertie consiste dans la conservation du même état, et que celui des forces tend à changer l'état des corps, il est évident que ces deux effets sont directement contraires entr'eux, et que l'inertie marque plutôt une chose tout à fait opposée à l'idée des forces " ((1750) 1752, *Recherches sur* ..., OO, p. 112, § 9).
("On the occasion of this definition of the term force, I notice, by the way, that it is very bad that some name inertia the force of inertia. For, since the effect of inertia consists of maintaining the same state and that of forces tends to change the state of bodies, it is evident that these two effects are directly contrary to each other, and that inertia represents something entirely opposed to the idea of forces").

[19] "Quanquam enim permansionem in quiete motusque uniformem continuationem in directum ex principio sufficientis rationis demonstravimus" (Vol. I, § 75).
("We demonstrated the perseverance at rest and the continuity of uniform motion in a straight line from the principle of sufficient reason").

[20] "Concipiamus corpus hoc existere in spatio infinito atque vacuo, perspicuum est nullam esse rationem, quare potius in hanc vel illam plagam moveatur [...]" (Vol. I, § 56).
("If we conceive a body existing in an infinite and empty space, there is clearly no reason for it to move more to one part of space than to the other [...]"). The justification of the uniformity and of the rectilinearity of the motion of a body is analogous (Vol. I, § 63, § 65).

[21] "Un Corps en repos y persistera, à moins qu'une cause étrangere ne l'en tire. Car un Corps ne peut se déterminer de lui-même au mouvement, puisqu'il n'y a pas de raison pour qu'il se meuve d'un côté plutôt que d'un autre" (§ 3).
("A body at rest remains so, unless a foreign cause makes it leave that state. For a body cannot decide to move by itself, since there is no reason why it should move to one side rather than to another").

[22] "Delà il s'ensuit, que si un Corps reçoit du mouvement par quelque cause que ce puisse être, il ne pourra de lui-même accélérer ni retarder ce mouvement" (§ 4).
("From that it follows, that if a Body receives movement through whatever cause that it might be, it could neither accelerate nor delay this movement by itself").

[23] "il n'y a pas de raison pour que le Corps s'écarte à droite plutôt qu'à gauche" (§ 6).
("there is no reason for the Body to go to the right rather than to the left").

[24] "Un point en repos ne peut se donner aucun mouvement, puisqu'il ne renferme pas en lui-même de raison pour se mouvoir dans un sens plutôt que dans un autre" (p. 14);
"La direction du mouvement en ligne droite, suit évidemment de ce qu'il n'y a aucune raison pour que le point s'écarte plutôt à droite qu'à gauche de sa direction primitive [...] l'uniformité de son mouvement n'est pas de la même évidence. [...] A la vérité, un corps étant incapable de se donner aucun mouvement à lui-même, il paroît également incapable d'altérer celui qu'il a reçu" (p. 14).
("A point at rest cannot give itself any movement, since it does not embody in itself reason for moving in one direction rather than in another";
"The direction of the movement in a straight line comes evidently from the fact that there is no reason for the point to go to the right rather than the left from its original direction [...] the uniformity of its movement is not from the same evidence [...] In truth, a body being incapable of giving any movement to itself, it seems equally incapable of altering that which it has received").

[25] "Cette hypothèse est le principe connu sous le nom de *loi d'inertie*" (p. 53).
("This hypothesis is the principle known as the *law of inertia*").
[26] "L'expérience prouve, que si sur une table horizontale parfaitement unie, on place une boule sans lui imprimer aucun mouvement, cette boule restera en repos jusqu'à ce qu'on vienne l'en tirer. [...] ce qui a lieu pour un globe placé sur une table horizontale, doit s'étendre à tous les corps possibles, dans toutes les positions possibles, pourvu qu'ils soient dégagés de toute influence étrangère" (pp. 51–52).
("Experiments prove that, if on a perfectly uniform, horizontal table, a ball is placed without imposing upon it any movement, this ball will remain at rest until something takes it out of that state [...] that which takes place for a globe placed on a horizontal table, must extend to all possible bodies, in all possible positions, provided that they are free of all foreign influence").
[27] "à ne considérer la chose que sous le rapport du seul raisonnement, ou [on] ne voit pas pourquoi ce corps prendroit de lui-même un mouvement plutôt d'un côté que de l'autre" (p. 51).
("considering the thing from the point of view of reasoning alone, one cannot see why this body would make a movement by itself to one side rather than to the other").
[28] "L'impossibilité où sont tous les points matériels de se mettre en mouvement ou de changer le mouvement qui leur a été communiqué, sans le secours d'une force, est ce qu'on entend par l'*inertie* de la matière. [...] chaque point matériel trouve [...] jamais en lui-même, le principe de son mouvement" (pp. 208–209).
("The impossibility where all material points are starting movement or changing the movement that has been communicated to them, without help of a force, is what is understood by *inertia* of matter [...] each material point finds [...] never in itself, the principle of its movement").
[29] "Cette propriété de la matière de ne pouvoir modifier d'elle même son état de mouvement ou de repos, est ce qu'on nomme l'*inertie*" (p. 5).
("This property of matter not being able to modify by itself its state of movement or of rest, is what one calls *inertia*").
[30] "Ein in Bewegung gesetzter materieller Punkt läuft, falls keine fremde Ursache auf ihn einwirkt, falls er vollständig sich selber überlassen ist, in *gerader Linie* fort, und legt in gleichen Zeiten *gleiche Wegabschnitte* zurück. - So lautet das von *Galilei* ausgesprochene Trägheitsgesetz.
In dieser Fassung kann der Satz als *Grundstein* eines wissenschaftlichen Gebäudes [...] Denn er ist vollständig *unverständlich*" (1870, p. 14).
("A material point placed in motion, follows a *straight line* and covers *equal distances* in the same time, if it is not acted on by an external cause, if it is completely left on its own. Thus, runs the law of inertia stated by *Galilei*.
In this form, the proposition cannot be the *foundation stone* of a scientific construction [...] Then it is completely *incomprehensible*").
[31] "Wir wissen ja nicht, was unter einer Bewegung *in gerader Linie* zu verstehen ist; oder wir wissen vielmehr, dass diese Worte in sehr verschiedenartiger Weise interpretiert werden können, unendlich vieler Bedeutungen fähig sind" (1870, p. 14).
("We do not know what to understand by movement *in a straight line*, or more than that, we know that these words can be interpreted in many different ways, they are capable of infinite meanings").
[32] "Als *erstes Princip* der *Galilei-Newton*'schen Theorie würde daher der Satz hinzustellen sein, dass an irgend einer unbekannten Stelle des Weltraumes ein unbekannter Körper vorhanden ist, und zwar ein *absolut starrer* Körper, ein Körper, dessen Figur und Dimensionen für alle Zeiten unveränderlich sind. Es mag mir gestattet sein, diesen Körper kurzweg zu bezeichnen als den Körper *Alpha*" (1870, p. 15).
("As *first principle* of the *Galilei*an-*Newton*ian theory, would therefore be to put forward the proposition: in an unknown place in the universe there exists an unknown body, *absolutely rigid*, a body whose shape and dimensions are unalterable for all times. Permit me to call this body by the name body *alpha*").
[33] "Hinzuzufügen würde sodann sein, dass unter der *Bewegung* eines Punktes nicht etwa seine Ortsveränderung in Bezug auf Erde oder Sonne, sondern seine Ortsveränderung in Bezug auf jenen Körper Alpha zu verstehen ist" (1870, pp. 15–16).
("It would be then to add that by the *motion* of a body the change of place in relation to the Earth or to the Sun is not to be understood, but rather the change of place in relation to the body *alpha*").

[34] "*zweites Princip* [...] dass ein sich selbst überlassener materieller Punkt in gerader Linie fortschreitet, also in einer Bahn dahingeht, die geradlinig ist in Bezug auf jenen Körper Alpha" (1870, p. 16).
("*the second principle* [...] a material point left on its own follows a straight line, therefore a trajectory, which is rectilinear in relation to the body *alpha*").
[35] "*Zwei* materielle Punkte, von denen jeder sich selbst überlassen ist, bewegen sich in solcher Weise fort, dass gleiche Wegabschnitte des einen immer mit gleichen Wegabschnitten des andern correspondiren.
In dieser Form und Beschränkung repräsentirt der Satz ein *drittes Princip* der Galilei-Newton'schen Theorie" (1870, p. 18).
("*Two* material points, each one of which left by itself, move in such a way that equal portions of the path of one always correspond to equal portions of the path of the other.
In this form, the proposition represents a *third principle* in the Galileian–Newtonian theory").
[36] "[...] können wir nämlich jetzt *gleiche Zeitintervalle* als diejenigen definiren, innerhalb welcher ein sich selbst überlassener Punkt gleiche Wegabschnitte zurücklegt" (1870, p. 18).
("[...] we can now define *equal intervals of time*, those in which a point left by itself covers equal portions of the path").
[37] "Nun muss ich noch hinzufügen, dass wenn auch die Schwierigkeiten, die ich in dem Trägheitsgesetze gefunden [habe], ganz mit jenen *Neumann*'s übereinstimmen, doch meine Auflösung derselben eine andere ist. *Neumann* meint die Schwierigkeiten dadurch zu heben, dass er alle Bewegung als eine absolute betrachtete, bestimmt durch einen hypothetischen Körper α. Allein damit bliebe alles beim Alten" (1872, p. 48).
("I have to add, however, that although the difficulties which I detected in the law of inertia agree with those of *Neumann*, my solution for them is different. *Neumann* thought he had overcome the difficulties in considering all the movement as an absolute motion, determined through a hypothetical body α. With this alone, everything remains as before").
[38] "Über den absoluten Raum und die absolute Bewegung kann niemand etwas aussagen, sie sind bloße Gedankendinge" (1933, pp. 222–223).
("On absolute space and absolute motion nothing can be said, they are mere beings of thought").
[39] "Voneinander sehr ferne Körper, welche in bezug auf andere ferne festliegende Körper sich mit konstanter Richtung und Geschwindigkeit bewegen, ändern ihre gegenseitige Entfernung der Zeit proportional" (1933, p. 228).
("Bodies that are very remote from one another, which in relation to other fixed, distant bodies move with a constant direction and velocity, change their relative distance in a manner proportional in time").
[40] "*Mit Bezug auf welchen Körper oder welches Coordinatensystem gilt das Trägheitsprincip, oder gelten die Differentialgleichungen der Bewegung eines materiellen Systemes?*" (p. III)
("*In relation to what bodies or system of coordinates is the principle of inertia valid or are the differential equations of movement of a material point valid?*")
[41] "*Zur Vereinfachung der Ausdrucksweise werde ich künftig einen Körper, der keine Rotation ausführt und der als vollkommen unabhängig von allen umgebenden Körpern betrachtet werden kann, als Fundamental-Körper (FK) bezeichnen*" (pp. 24–25).
("*To simplify the manner of expression, I will designate for Fundamental Body (FB) a body which does not have rotation and might be considered as completely independent from all surrounding bodies*").
[42] "Es ist selbstverständlich, dass die für den Fundamentalkörper gestellte Forderung, er solle keine Rotation ausführen und keiner fremden Einwirkung unterworfen sein, nur den Idealfall bildet, der in der Praxis nicht wird erreicht werden können" (p. 25).
[43] "Genau ebenso nun, wie die *eindimensionale* Inertialzeitscala definirt werden konnte an Hand *eines einzelnen* sich selbst überlassenen Punktes, so lässt sich das *dreidimensionale* Inertialsystem definiren an Hand *dreier* sich selbst überlassener Punkte" (1885b, pp. 336–337).
("Exactly as an inertial, *one-dimensional* scale of time can be defined thanks to *a unique* material point left by itself, also an inertial, *three-dimensional* system can be defined thanks to *three* points left by themselves").

[44] "Die *ideale Construction* des Inertialsystemes würde also etwa folgendermaßen auszuführen sein. Drei materielle Punkte P_1, P_2, P_3 werden gleichzeitig vom selben Raumpunkte ausgeschleudert und dann sich selbst überlassen. Sobald man sich vergewissert hat, dass sie nicht in einer geraden Linie gelegen sind, verbindet man sie einzeln mit einem *ganz beliebigen* vierten Raumpunkte Q. Die Verbindungslinien, welche bez. G_1, G_2, G_3 heißen mögen, bilden zusammen eine dreiseitige Ecke. Lässt man nun diese Ecke *in unveränderlicher Starrheit ihre Gestalt bewahren* [...] so ist ein Coordinatensystem, worin die Ecke ihre Lage beibehält, ein Inertialsystem" (1885c, p. 543).
("The *ideal construction* of the inertial system will, therefore, be carried out in the following way. Three material points P_1, P_2, P_3 are thrust forward simultaneously from the same point in space and left by themselves. We must be sure that they are not placed on the same straight line and we link each one of them with whatever fourth point Q in space. The linking lines, which shall, respectively, be called G_1, G_2, G_3 constitute together a figure of three sides. The figure is left *to maintain its shape completely rigid* [...] a system of coordinates, where the figure maintains the position, is an inertial system").

[45] "*Definition* I: 'Inertialsystem' heißt ein jedes Coordinatensystem von der Beschaffenheit: dass mit Bezug darauf die in einem Punkte zusammenlaufenden stetig beschriebenen Bahnen *dreier* gleichzeitig von demselben Raumpunkte projicirter und dann sich selbst überlassener Punkte (die aber nicht in einer Geraden liegen sollen) sämmtlich *geradlinig* sind.
Theorem I: In Bezug auf ein Inertialsystem ist auch die Bahn eines *jeden vierten* sich selbst überlassenen Punktes *geradlinig*.
Definition II. "Inertialzeitscala" heißt eine jede Zeitscala, in Bezug auf welche irgend *ein* sich selbst überlassener Punkt in seiner Inertialbahn *gleichförmig* bewegt ist.
Theorem II. Rücksichtlich einer Inertialzeitscala ist auch *jeder andere* sich selbst überlassene Punkt in seiner Inertialbahn gleichförmig bewegt" (Ib. pp. 544–545).
("*Definition* I: We call, 'inertial system' a system of coordinates obtained in such a way that the trajectories which cross on a point and are drawn continuously by *three* points, which are projected simultaneously from the same point in space and afterwards left by themselves, are all *rectilinear*.
Theorem I: In relation to an inertial system, the trajectory of *whatever fourth* point left by itself, is *rectilinear*.
Definition II: We call, 'inertial scale of time' a scale of time in relation to which whatever other point left by itself in its inertial trajectory moves *uniformly*.
Theorem II: In relation to an inertial scale of time *whatever other* point left by itself in its inertial trajectory also moves uniformly").

[46] "*Für drei oder weniger als drei Punkte ist die geradlinige Bewegung in Bezug auf ein Coordinatensystem Sache einer bloßen Convention; erst für mehr als drei Punkte ist sie mehr als Convention, ist sie Forschungsergebniss*" (Ib. p. 542).
("*For three points or less, the rectilinear movement in relation to a system of coordinates is a mere convention. Only for more than three points is it more than a convention, is it a result of research*")

[47] "Betrachten wir nun die Stellung des Gesetzes zu dem durch Beobachtung unmittelbar oder mittelbar gewonnenen empirischen Material, so erscheint es nicht correct, ihm den Charakter eines eigentlichen *Erfahrungssatzes* zuzusprechen. Vielmehr ist und bleibt das Trägheitsgesetz eine physikalische *Hypothese*" (1885a, p. 270).
("If we consider the position of the law in relation to the empirical elements that are obtained by direct and indirect observation, it does not seem correct to attribute to the law the character of an *experimental proposition*. Instead of this, the law of inertia is and remains a physical *hypothesis*").

[48] "[1] Corpus omne perseverare in statu suo quiescendi vel movendi uniformiter in directum, [2] nisi quatenus illud a viribus impressis cogitur statum suum mutare" (1726, p. 13).
Thomson and Tait write: "The last clause, "*nisi quatenus*," etc., admirably prepares for the introduction of the second law, by conveying the idea that *it is force alone which can produce a change of motion*" (p. 242) (See Galili and Tesitlin 2003).

[49] "[1] *Corpus absolute quiescens perpetuo in quiete perseverare debet*, [2] *nisi a causa externa ad motum sollicitetur*" (Vol. I, § 56);
"[1] *Corpus absolutum habens motum aequabiliter perpetuo movebitur* [...] [2] *nisi causa externa in id agat aut egerit*" (Vol. I, § 63);

"[1] *Motus directio* [...] *est linea recta, in qua corpus* [...], [2] *nisi a causis externis impediatur*" (Vol. I, § 72).
("[1] *A body at rest will persevere at rest*, [2] *unless it is set into motion by an external cause*";
"[1] *A moving body always moves with constant velocity* [...] [2] *unless an external cause acts on it or has acted on it*";
"[1] *The direction of motion* [...] *is the straight line, in which a body* [...], [2] *unless it is obstructed by an external cause*").
[50] "[1] Un Corps en repos y persistera, [2] à moins qu'une cause étrangere ne l'en tire" (§ 3);
("[1] A body at rest remains at rest, [2] unless a foreign cause takes it out of this").
[51] "[1] tout corps persévère dans son état de repos ou de mouvement uniforme et rectiligne, [2] jusqu'à ce qu'il reçoive l'action d'une puissance étrangère" (p. 53).
("[1]Every body perseveres in its state of resting or of moving uniformly and rectilinearly, [2] until receiving an action from a foreign force").
[52] "daß [2] *ein allen Bewegungsursachen entzogener materieller Punkt* [1] *sich gleichförmig und geradlinig [...] bewegt*" (p. 9).
("*a material point*, [2] *that is taken away from all causes of motion*, [1] *moves uniformly and rectilinearly* [...]").
[53] "[1] *Every material body persists in a state of rest or uniform motion* [2] *unless it is compelled by a force to change that state*" (p. 80).
[54] "**Lex prima**: [1] *Jeder Körper beharrt in seinem Zustand der Ruhe oder gleichförmigen geradlinigen Bewegung*, [2] *wenn er nicht durch einwirkende Kräfte gezwungen wird, seinen Zustand zu ändern*" (p. 3).
("**Lex prima**: [1] *Every body perseveres in its state of resting or of moving uniformly and rectilinearly*, [2] *if it is not compelled by acting forces to change its state*").
[55] "[1] *Ein Massenpunkt verharrt im Zustand der Ruhe oder der gleichförmig geradlinigen Bewegung*, [2] *solange keine Kräfte auf ihn einwirken*" (p. 54).
("[1] *A material point perseveres in its state of resting or of moving uniformly and rectilinearly*, [2] *as long as no force acts on it*").
[56] "[1] *Jeder Körper beharrt im Zustand der Ruhe oder der gleichförmigen, geradlinigen Bewegung*, [2] *wenn er nicht durch einwirkende Kräfte gezwungen wird, seine Bewegung zu ändern*" (p. 8).
("[1] *Every body perseveres in its state of resting or of moving uniformly and rectilinearly*, [2] *if it is not compelled by acting forces to change its motion*").
[57] "Das erste Newtonsche Axiom lautet in Newtons Originalformulierung:
LEX I.
Corpus omne [...]
Das können wir ins Deutsche etwa folgendermaßen übertragen [...]" (p. 51–52).
("Newton's first axiom in its original formulation is as follows:
LEX I. Corpus omne [...]
We can translate this into German as follows [...]).
[58] "[2] A body that is not under external forces [1] does not change its momentum" (p. 40).
[59] "[1] Jeder Körper behält seine Geschwindigkeit [...] bei, [2] wie er nicht durch äußere Kräfte gezwungen wird, seinen Bewegungszustand zu ändern" (p. 30). ("[1] A body maintains its velocity, [2] since it is not compelled to change its state of motion by means of external forces").
[60] "[1] *Jeder Körper verharrt im Zustand der Ruhe oder der gleichförmigen geradlinigen Bewegung*, [2] *solange keine Kraft auf ihn wirkt*" (p. 51).
("[1] *Every body perseveres in its state of resting or of moving uniformly and rectilinearly*, [2] *as long as no force acts on it*").
[61] "[2] Ein sich selbst überlassener Körper [1] bewegt sich geradlinig gleichförmig (*Galileisches* **Trägheitsprinzip**)" (p. 12).
("[2] A body by itself [1] moves rectilinearly and uniformly (*Galilei*'s **Principle of inertia**").
[62] "Es ist vom rein mathematischen Standpunkt aus ein Cirkel, zu sagen, die geradlinige Bewegung ist die eigene, folglich ist zu jeder andern eine äußere Hinzuwirkung erforderlich: denn man könnte mit demselben Rechte jede andere Bewegung als Gesetz der Trägheit eines Körpers setzen, wenn man nur hinzufügt, wenn er sich nicht so bewegt, ist eine Außenwirkung daran Schuld" (pp. 3–4).

[63] “Mais alors, il y aura une convention à faire. Il s’agira de savoir quelle sorte de mouvement, rectiligne ou curviligne, uniforme ou varié, nous devrons admettre, comme étant celui d’un point matériel entièrement libre en apparence, et parce que nous aurons une entière latitude à cet égard [...] avec le seul avantage ou inconvénient d’en voir résulter de plus ou moins grandes simplifications dans les relations mécaniques des systèmes, nous serons conduits naturellement à faire servir à un tel usage l’état de mouvement rectiligne uniforme, et à rencontrer cette fameuse *loi d’inertie* de la matière, qui ne sera plus un principe ni un fait d’expérience, mais une pure convention, la plus simple de toutes celles parmi lesquelles nous nous trouverons obligés de choisir” (p. 49).
(“But then, there will be a convention to make. It will be a matter of knowing what sort of movement, rectilinear or curvilinear, uniform or varied, we should admit, as being that of a material point, entirely free in appearance, and because we will have an entire latitude in this respect [...] with the only advantage or disadvantage of seeing it result in more or less great simplifications in the relation of mechanical systems, we will be naturally led to make use of the state of rectilinear and uniform movement, and to find this famous *law of inertia* of matter, which will no longer be a principle nor a fact of experience, but a pure convention, the simplest of all those among which we find ourselves obliged to choose”).

[64] ”Jedes freie System beharrt in seinem Zustande der Ruhe oder der gleichförmigen Bewegung in einer geradesten Bahn” (§ 309).

[65] “Ein materielles System, welches keinen anderen als inneren und gesetzmäßigen Zusammenhängen unterworfen ist, nennen wir ein freies System” (§ 122). (“A material system which is subject to no other than internal and regular connections is called a free system”)

[66] “Euere Behauptung ist allerdings richtig für die Denkweise der gewöhnlichen Mechanik, aber sie ist nicht richtig unabhängig von dieser Denkweise” (p. 40).

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