The Epistemology of Contemporary Physics: Classical Mechanics I

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Abstract: In this paper of "The Epistemology of Contemporary Physics" series we investigate the epistemological significance and sensibility (and hence interpretability and interpretation) of classical mechanics in its Newtonian and non-Newtonian formulations. As we will see, none of these formulations provide a clear and consistent framework for understanding the physics which they represent and hence they all represent valid formalism without proper epistemology or sensible interpretation.

Keywords: Epistemology of science, philosophy of science, contemporary physics, fundamental physics, modern physics, classical mechanics, Newtonian mechanics, Lagrangian mechanics, Hamiltonian mechanics, analytical mechanics.

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1 Introduction

Classical mechanics is one of the most successful and useful scientific theories ever created despite its limitations due largely to its restricted domain of validity (i.e. classical macroscopic scale and inertial frames of reference).[1] It is tested successfully on countless terrestrial and celestial physical systems of different magnitudes and various specific features in observation, experimentation and application. In fact, it is the main mechanical theory used in scientific investigations and engineering applications at the classical macroscopic scale (noting the fact that it may be considered as a good approximation in some of its topics and aspects).

There are several formulations to classical mechanics such as Newtonian, Lagrangian and Hamiltonian (noting that the existence of more than one formulation of classical mechanics represents a demonstration of the principle of non-uniqueness of science and a simple instance of it; see § 5.3 of [1]). The dominant of these formulations is the Newtonian formulation which is represented mainly by Newton's three laws of motion, i.e. the law of inertia, the law of momentum or acceleration and the law of interaction (see for instance [2, 3]).

In this paper we briefly investigate the main epistemological characteristics of the Newtonian formulation of classical mechanics (and its interpretability and interpretation in particular). A similar (but much shorter) investigation will be conducted on the non-Newtonian formulations of classical mechanics (considering essentially the main two versions of these formulations; namely the Lagrangian and Hamiltonian mechanics).

However, before we start our investigation it is worth noting the following points:

1. "Classical mechanics" (which is in the title of this paper) has different meanings in the literature depending on the authors and contexts, e.g. it can be contrasted to quantum mechanics or to the relativity theories (or to other physical theories and branches). What we mean here by "classical mechanics" is the mechanics prior to the emergence of the new branches of mechanics of modern physics such as quantum mechanics and Lorentz mechanics.
2. The focus of the present paper is actually the "laws of motion" part of classical mechanics (noting that classical mechanics, as defined already, includes other topics and branches such as gravity).[2]

[1] In fact, there are other limitations and restrictions on the domain of validity (whether practically or conceptually) of classical mechanics or/and some of its formulations. For instance, the Newtonian formulation of classical mechanics is essentially about the mechanics of particles.

[2] "The laws of motion" should be understood as more general than Newton's laws of motion because

3. The focal point of the investigation of the present paper is the epistemological sensibility and interpretability (and interpretation) of classical mechanics (noting that other epistemological aspects and topics of classical mechanics should be investigated in upcoming papers).

The structure of this paper is that we investigate in the next two sections the Newtonian formulation and non-Newtonian formulations of classical mechanics. We then conclude our investigation with a "Conclusions" section in which we summarize the main facts and results that we discussed and obtained in this paper. Our plan is to investigate other epistemological aspects of classical mechanics (which are more specific or not related directly to interpretation and interpretability) in forthcoming papers of this series (as indicated already).

2 Newtonian Formulation of Classical Mechanics

The Newtonian formulation of classical mechanics is the most common and the most intuitive formulation of classical mechanics. Moreover, it historically precedes all other formulations of classical mechanics and hence it is the mother of all formulations of classical mechanics (noting that classical mechanics is the mother of all modern physics because virtually all the branches and theories of modern physics started from or based on classical mechanical deliberations and considerations).

In this section we investigate (following some preliminary reflections on Newton's laws of motion) the main features of this formulation and its main limitations and shortcomings from an epistemological perspective (or largely so) to reach a conclusion that this formulation has no sensible, consistent and complete epistemology and hence it has no valid interpretation although in principle it has the capability to be interpretable due to its rich, diverse and intuitive conceptual, philosophical and epistemological framework.

2.1 Preliminary Reflections on Newton's Laws of Motion

Before we go through our main investigation in this section (related to the features and limitations of the Newtonian formulation) it is useful to be aware of the following prelimi-

we are considering non-Newtonian formulations (as well as Newtonian formulation). So, it should be understood to mean something like "the mechanics of motion". For more clarity, the investigation of this paper is about the Newtonian mechanics (represented by Newton's three laws of motion) and the Lagrangian and Hamiltonian mechanics (representing the main formulations of non-Newtonian classical mechanics).

nary reflections on the Newtonian formulation as represented mainly by Newton's laws of motion. These reflections are outlined in the following subsections.

2.1.1 Relationship between Newton's First and Second Laws

It is common to consider Newton's first law as a special case of Newton's second law. Although this is not incorrect it is partially reflecting the actual relationship between Newton's first and second laws and hence it can be misleading. The reality is that Newton's first law is partially included in Newton's second law in the sense that Newton's first law contains more content and substance than what is implied by Newton's second law. To be more clear, Newton's first law has two ingredients:

1. The proposition that: absence of force results in absence of acceleration (or absence of temporal change of linear momentum). This ingredient is implied by Newton's second law[3] and hence from the perspective of this ingredient Newton's first law is a special case of Newton's second law since this ingredient of the first law is implied by the second law.
2. The proposition that: absence of force results in having an "inertial state of rest or uniform motion". This ingredient is not implied by Newton's second law because this particular "inertial state of rest or uniform motion" is more specific than the state of "absence of acceleration" or "absence of temporal change of linear momentum". For example, we can imagine that the absence of force results in a state of sudden and instant rest where the unaccelerated object (due to the cessation of force) comes to a state of standstill immediately and abruptly as soon as force ceases to exist. It should be obvious that this situation or scenario satisfies Newton's second law (since absence of force leads to absence of acceleration or absence of change of momentum) but does not satisfy Newton's first law (since absence of force does not lead to the aforementioned "inertial state of rest or uniform motion").

By the benefit of a deeper insight we can claim that the essence of all this is the paradigm of inertia which is the actual essence and substance of Newton's first law and this essence is what makes Newton's first law more informative than Newton's second law from this

[3] Actually, from a purely formal and logical perspective what is implied by Newton's second law is less than this because the causality of the absence of force to the absence of acceleration (which is implied by the statement "absence of force results in absence of acceleration") is not incorporated within Newton's second law (as will be investigated partly later on). So, what is actually incorporated is the association of force and acceleration in the sense that the presence/absence of one implies the presence/absence of the other.

perspective (and hence makes Newton's first law distinct from Newton's second law despite being partially included in Newton's second law).

In fact, the paradigm of inertia is pivotal and central to the Newtonian formulation of classical mechanics (and possibly to classical mechanics in general) and it has very important implications and consequences (both formally and epistemologically). For instance, the aforementioned scenario (of abrupt cessation of motion at the instant of cessation of force) implies violation of the principles of conservation of energy and momentum and hence we can claim that the conservation of energy and momentum are the result of the paradigm of inertia (although being so should be partially since the conservation of energy and momentum require more than the paradigm of inertia).

This should make Newton's first law (with its pivotal essence of "inertia") as important as[4] Newton's second and third laws (noting that Newton's first law is usually trivialized in the literature by depicting it as being just a special case of Newton's second law and totally embedded in it and hence it is no more than an important special case or a clarifying statement or attachment to Newton's second law and the Newtonian formulation of classical mechanics).

However, this trivialization of Newton's first law may be justified (partially) by noting that the literature of Newton's laws of motion (and classical mechanics in general) is usually and largely about the formalism of these subjects; and the paradigm of inertia does not demonstrate its real power and strength in the formalism (because it is implicitly and intrinsically embedded within the formalism). This is unlike the epistemology of these subjects where the paradigm of inertia is pivotal and central and hence we may say (laxly) that although Newtons first law is no more than a special case of Newton's second law from the perspective of formalism, it is more than a special case of Newton's second law from the perspective of epistemology (due to the special importance of "inertia" in the epistemology but not in the formalism).

Anyway, any potential disputes about these issues should not be of substantial value or importance to our current investigation and discussion and hence we do not pursue this debate further in this paper (although we may come back to some of these issues in forthcoming papers).

[4] And actually "as independent as" despite being partially included in Newton's second law.

2.1.2 "Hidden" Ingredients of Newton's Second Law

Newton's second law as commonly stated and formulated (i.e. force equals[5] mass times acceleration or force equals time derivative of linear momentum, that is $\mathbf{F} = m\mathbf{a}$ or $\mathbf{F} = d\mathbf{p}/dt$) misses an important ingredient of this law (especially from an epistemological perspective) which is the "implicit" fact that force is the cause of acceleration or change of linear momentum. In fact, this causality relationship between force and acceleration (or change of momentum) is usually not given sufficient attention (if given any attention at all) in the literature of physics and textbooks. Again, the reason seems to be its philosophical and epistemological nature which the literature of physics and textbooks have no much interest in since they are generally about the formalism of physics rather than its philosophy and epistemology.

Now, according to the common understanding among physicists (which may also be seen as being intuitive and commonsense), force is the cause of acceleration (as stated already). However, there seems to be an opposite view that considers acceleration as the cause of force where this view is mainly based on and justified by the Machian proposal (i.e. inertia is caused by the overall matter distribution in the Universe) in the sense that acceleration relative to the rest of the Universe induces inertial forces in the accelerated massive object. But whether (according to this view or according to its rationale) the induced force is the action or reaction force requires further analysis and clarification.

Anyway, any claim that independently-generated acceleration (i.e. without motivating force) causes force seems to be nonsensical and completely in conflict with our intuition which is based on and derived from our daily life experiences where we (by our free will and conscious determination) generate forces to produce accelerations (not the other way around), and hence for the aforementioned view to be logical (or at least not contradicting our intuition) the force that is supposedly caused by acceleration should be the reaction (and dependent) force, i.e. not the action (and independent) force. These issues (as well as other similar issues) should be the subject of further investigation and analysis in the future.

It is also useful and appropriate to mention here that there are other "hidden" or "implicit" facts which are usually not indicated or noticed in the common statements of Newton's second law and hence they should be highlighted and remembered. For example, "force" in the statement of Newton's second law is the resultant (or net) force. The obvious implication of this is that force is a necessary but not sufficient condition for generating

[5] We use "equals" for simplicity and brevity. To be more precise we should use "is proportional to".

acceleration (or change of momentum), and hence what is necessary and sufficient (within this context) for generating acceleration is "unopposed force" or "unbalanced force".

We should also note that the statement of Newton's second law as "force equals mass times acceleration" (i.e. $\mathbf{F} = m\mathbf{a}$) is restricted to the cases where mass is constant, and hence the more rigorous and general statement of Newton's second law is "force equals time derivative of linear momentum" (i.e. $\mathbf{F} = d\mathbf{p}/dt$).

Simple and (rather) delicate details like these should always be noticed and remembered when analyzing Newton's second law and extracting its implications and consequences to avoid confusion and blunders. In fact, this should apply to all other laws and facts.

2.1.3 Nature of Newton's Second Law

Whether Newton's second law is essentially a definition or a physical law (or physical fact) is an issue that is usually discussed in the literature.[6] Our view is that Newton's second law (like any other law) is a physical law that is based on definition (or rather definitions), and this is actually the essence of all human knowledge, i.e. human knowledge is actually an elaborate linguistic system that is built and based on a collection of definitions and conventions and hence it is creative and inventive in part and reflective and suggestive in another part.[7] So, in this regard Newton's second law is not different from any other physical law or factual statement or any other piece of human knowledge.

Yes, there is a specific reason that makes Newton's second law more eligible for this type of investigation and questioning, which is what we will discuss later on (see § 2.3.1) about the lack of technical definition to basic concepts in the Newtonian formulation (including the concept of force). So, from this perspective the consideration of Newton's second law as a definition (or rather technical definition) seems to be motivated by the desire to regard this law as a convention or definition so that the problem of lack of technical definition is supposedly addressed. However, as we will see (refer to § 2.2.3) this way of technically defining basic and elementary concepts (such as defining force by Newton's second law) is rather circular and hence this problem is not addressed properly by this attempt.

We should also note that considering Newton's second law as a definition may also be justified by the claim that without a definite physical force law[8] (that identifies the force

[6] In fact, this discussion may extend occasionally to Newton's laws of motion in general (e.g. whether the first law is a definition for inertia or inertial frame).

[7] These issues are discussed in detail in chapter 2 of [4].

[8] In fact, we may need more than one definite physical force law to identify all the forces in the given physical situation (as discussed extensively in the textbooks of classical mechanics).

in Newton's second law) the second law is physically useless and without any real physical content or substance. However, although the need for a definite physical force law may partially legitimize and justify this consideration, the aforementioned claim is not free of exaggeration since Newton's second law as it is (i.e. without a definite physical force law) still has real physical content and significance (especially at the epistemological level) although it may not be very useful formally and practically in investigating and analyzing specific physical situations and circumstances (which are represented typically in solving specific problems in classical mechanics).

Anyway, if we ignore all these technicalities (and possibly other similar technicalities) then we can consider Newton's second law as being both a definition and a physical law at the same time (especially if we adopt the aforementioned view about human knowledge). In fact, any specific consideration should depend, in part, on how we build and construct our conceptual and axiomatic framework for the Newtonian formulation (e.g. with which collection of primary concepts we start and how we define or hypothesize them and so on) and the second law in particular. It should also depend on our adopted philosophical and epistemological views and opinions (or our doctrine in these regards). In brief, there is no single correct view (i.e. it is not a black-and-white issue) since there are many considerations that can determine and justify (or falsify) the chosen stand about this issue. In fact, there are many aspects about this issue that deserve to be investigated and inspected closely; however our investigation so far is enough for what we need in the immediate future (noting that we will pursue this investigation further when we need).

2.1.4 Importance of Newton's Third Law

The association of Newton's third law with the principles of conservation of linear and angular momentum is well known, and hence this law enjoys (from this perspective) an exceptional importance among Newton's laws of motion noting that the conservation of momentum (which Newton's third law represents within classical mechanics) is one of the most fundamental principles in all physics not only in classical mechanics (and noting as well that Newton's first and second laws do not enjoy such a distinction by having a similar association with or representation of a fundamental principle of physics like the conservation of momentum).[9]

In fact, it may be claimed (from another perspective) that Newton's third law is the most important law among Newton's three laws of motion *from a real physical perspective*

[9] We should also note that Newton's first and second laws may be regarded as definitions.

and content because the first law is included in the second law while the second law is essentially a definition without physical content (i.e. it is like an empty shell without substance inside) because without a definite physical force law (that identifies the force in Newton's second law) the second law is physically useless and without any real physical content or substance; and this (according to this claim) is not the case with Newton's third law because of its implication of the conservation of momentum (which is one of the most fundamental and verified principles of Nature).

However, this claim (apart from being questionable from some of its bases and foundations such as the claim that the first law is included in the second law and the claim that the second law is essentially a definition without physical content which were discussed and questioned in the previous subsections; see § 2.1.1 and § 2.1.3) is not free of exaggeration because every one of these laws has its role and importance within the Newtonian formulation and classical mechanics. We should also mention in this context the potential violations of Newton's third law (see § 2.3.5) which should cast a shadow on this claim (and possibly even on the aforementioned exceptional importance of Newton's third law). Anyway, these issues should be investigated in detail in the forthcoming papers of this series.

2.2 Features of Newtonian Formulation of Classical Mechanics

The main epistemological features (which are largely related to interpretability and interpretation) of the Newtonian formulation of classical mechanics are investigated briefly in the following subsections (noting that some of these features are related to the formalism of the Newtonian formulation as well although this is of no interest to us in this investigation whose focus is epistemology). More specific and detailed investigations to some epistemological features and aspects of this formulation should be pursued in upcoming papers of this series.

2.2.1 Rich and Intuitive Conceptual Framework

The Newtonian formulation of classical mechanics is associated with and based on a rich (and almost complete) conceptual, philosophical and epistemological framework. A close inspection to the Newtonian formulation should reveal that this formulation includes (explicitly or implicitly) almost all the conceptual elements required for the description of motion (which is the essence of mechanics as defined to be the science of motion and its causes) kinematically and dynamically in a clear and deterministic way (e.g. absolute space, absolute time, matter in its characteristic and quantitative qualification as mass, causes or agents of motion which are commonly labeled as "forces", etc.).

Furthermore, almost all the basic concepts and elements in the Newtonian formulation (i.e. mass, force, velocity, acceleration, space, time, etc.) are intuitive (or virtually intuitive),[10] and this should justify the general feeling (or impression) that the Newtonian formulation is the mechanics of commonsense, especially when noting this in its proper historical context and perspective where this mechanics was conceived and born in the traditional philosophical environment of Renaissance (or just post Renaissance) which was still under the strong influence of the ancient or classic "Aristotelian" philosophy which is the "philosophy of commonsense" (at least within its "Natural Philosophy" part).

Hence, this formulation possesses a proper conceptual framework to be *interpretable in principle* and even *actually-interpreted* (although this does not mean that it actually has a proper interpretation). This is in contrast to (at least some of the) other formulations of classical mechanics (i.e. the non-Newtonian formulations which will be investigated in § 3) which lack a proper conceptual framework and hence they are not interpretable as we will see later on.

It is worth noting the following points about the Newtonian formulation and its conceptual, philosophical and epistemological framework (noting that some of these points apply to classical mechanics in general):

1. We can identify two main parts of the conceptual framework of the Newtonian formulation: an intrinsic part which is presumed within (or based on or implied by or ... etc.) the formalism of this formulation and an extrinsic (or appended) part which is attached historically to this formulation and it is consistent and compliant with the formalism and its spirit although it is not necessarily required by (or based on or implied by or ... etc.) the formalism. In general, we do not distinguish between these two parts although the intrinsic part is the most significant epistemologically (and hence the most important to us).
2. We can say that the Newtonian formulation (within its conceptual framework) is characterized by being *absolute* and *deterministic* in the sense that all the physical quantities and relationships in this formulation are defined and quantified in an absolute sense

[10] We should admit that our intuition about these concepts (or at least some of them) should be partly attributed to the formal education (at elementary and higher levels). However, this does not change the fact that we have such intuition about these concepts. We should also note that even the non-intuitive (or less intuitive) concepts in the Newtonian formulation are generally defined by using intuitive (or more intuitive) concepts (such as defining the non-intuitive concept of momentum as the product of mass times velocity which are intuitive concepts in general).

and hence all the physical quantities can *in principle* be determined quantitatively with an infinite precision while all the outcomes of the events and occurrences can be completely determined *in principle* according to the given conditions and circumstances (and regardless of any observer or frame of reference). So, any ambiguity or uncertainty about the quantities and outcomes should be caused by casual ignorance of the observer and not by intrinsic indetermination of the factors involved in the presumed physical situation. In fact, this represents a strong form of realism where the observer and the observed are totally independent of each other and where the observed has complete and definite reality (irrespective of the observer or frame of reference).

It should be obvious that being *absolute* and *deterministic* should provide the Newtonian formulation with complete clarity, sensibility and intuitivity both in formalism as well as in epistemology, and hence these characteristics should be seen as an advantage in this formulation (and in its epistemology in particular) although this does not mean that these characteristics are free of problems, question marks and criticisms.

3. We can say that the Newtonian formulation (within its conceptual framework) is consistent in general with all the (relevant)[11] epistemological principles of science (see § 5 of [1]). The principles of reality and truth as well as the principle of causality are obviously satisfied within the conceptual framework of this formulation (at least by not having contradictions between these principles and this formulation). This should also be the case with regard to the principle of intuitivity (as declared earlier that this conceptual framework is generally intuitive). The principle of economy (noting that it is not a necessity or obligation) may also be satisfied by comparing this formulation to other formulations of classical mechanics (and even to other types of mechanics); moreover intuitivity should imply economy in some sense (see § 2.4.5 of [5]). Anyway, this formulation is at least not in conflict with the principle of economy (noting that the Newtonian formulation is not unnecessarily excessive or elaborate in its formalism and epistemology) and this should be enough for meeting the criterion of being *consistent* with the principle of economy (as well as the other relevant epistemological principles of science).

   It should be obvious that being consistent with the epistemological principles of science should provide the Newtonian formulation with complete "epistemological legitimacy" from this perspective, and hence this characteristic should be seen as another advantage in this formulation.

[11] We note that even the principle of non-uniqueness of science is realized within the classical mechanics which the Newtonian formulation represents one of its variants (as indicated earlier).

2.2.2 Existence of Absolute Frame of Reference

This is an obvious epistemological feature that characterizes the Newtonian formulation of classical mechanics (noting that the main non-Newtonian formulations of classical mechanics lack a proper conceptual, philosophical and epistemological framework and hence they do not seem to care about the existence or non-existence of an absolute frame of reference and this should be endorsed by their technical and local nature; see § 3).[12]

In fact, the mere existence of the paradigms of inertial and non-inertial frames in the Newtonian formulation is based on (and cannot be justified without) an implicit assumption of the existence of a cosmological (or global) absolute frame of reference. This is because any local frame of reference should be ultimately referred to a global reference frame at cosmological scale (i.e. by envisaging a hierarchical sequence of reference frames which are ultimately referred to a single frame at cosmological level). Accordingly, the existence of an absolute frame of reference is not only a prior philosophical assumption (as it is the case historically) but it is also a logical and epistemological requirement for the Newtonian formulation of classical mechanics. In other words, the presumption of the existence of an absolute frame of reference is intrinsic to the formalism of Newtonian formulation (see point 1 of § 2.2.1) and not only a philosophical attachment that have been added to this formulation for historical reasons.

In this regard we should draw the attention to the following remarks:

1. We use "absolute frame" as a term more general than the Newtonian absolute space (as well as time) and the "Machian frame" which is based on the overall distribution of matter in the Universe (according to Mach's proposal about the origin of inertia). In fact, "absolute frame" is more general than these two proposed absolute frames and than any other potential or proposed absolute frames such as the Cosmic Microwave Background Radiation (CMBR) or the luminiferous ether, i.e. any one of these four potential or proposed frames of reference, as well as any frame other than these four, can be accepted as realization to the concept of "absolute frame" as long as it can produce sensible and consistent epistemology (which should also be compliant with a

[12] It is useful to note that the existence of a cosmological (or global) absolute frame of reference does not necessarily mean the existence (or non-existence) of a state of absolute rest and uniform rectilinear motion. In fact, this should depend on the nature of this absolute frame and its actual realization. For example, if the absolute frame is realized through an infinite Newtonian-type frame (i.e. infinite absolute space-time) then a state (of absolute rest and uniform rectilinear motion) may not be possible to define sensibly. On the other hand if the absolute frame is realized through a Machian-type frame then such an absolute state may be defined sensibly. In fact, some of the confusion and absurdity in special relativity may originate from the lack of proper distinction between the existence of absolute frame of reference and the existence of a state of absolute rest and uniform rectilinear motion.

correct formalism that is based on this realization of "absolute frame"). Furthermore, we may accept more than one of these absolute frames simultaneously as long as this condition is satisfied, i.e. they can produce sensible and consistent epistemology which is in compliance with a formalism based on these multiple realizations.[13]

2. We should note that "absolute frame" includes (absolute) time as well as (absolute) space and hence it is more general than the aforementioned Newtonian absolute space (which is specifically about space only) and "Machian frame" (which is apparently about space only).

So in brief, "absolute frame" is more general from these two perspectives, i.e. the perspective of various realizations (i.e. the aforementioned four or more realizations) and the perspective of inclusion of absolute time.

2.2.3 Centrality of "Force" Concept

Here we discuss the fact that the central concept in the Newtonian formulation of classical mechanics is the concept of force. This should be obvious because this concept is common to all the three laws of the Newtonian formulation and it is the subject of proposition in Newton's second and third laws (as well as being implicitly so in Newton's first law). It should be obvious that the concept of force as a "pull or push" (or something like these) is intuitive although its technical meaning may not be so (as we will highlight some of its potential technical and epistemological ambiguities).

In fact, it may be claimed that there is an "intrinsic ambiguity" in the concept of force because there is no technical definition of this concept (within the Newtonian formulation) independent of Newton's laws (noting that these laws are based on this central concept and hence using them as a basis for a technical definition may be seen as a kind of circularity). However, this concern may be dismissed by considering "force" as a basic term whose concept is defined generically and elementarily by its intuitive meaning (and hence we can be content with this type of "definition" since it is sufficient for most or all theoretical and practical purposes formally and epistemologically).

Anyway, we should point out to the following potential ambiguities (or similar dif-

[13] Accepting more than one absolute frame simultaneously may be collectively and in combination (where each frame can provide a reference for certain part of the formalism or/and epistemology of physics) or individually and independently (where each frame can provide a reference for certain formalism or/and epistemology for the entire physics). In fact, the role of simultaneous multiple absolute frames can be envisaged in many different ways, situations and scenarios (and this should be inline with the principle of non-uniqueness of science and an instance of it; see § 5.3 of [1]). These issues should be investigated in the future papers of this series.

ficulties) in or around the concept of force within technical contexts especially from an epistemological viewpoint:

1. Ambiguity arising from the distinction (within the Newtonian formulation) between fictitious and non-fictitious forces (see § 2.3.4).
2. Ambiguity arising from the distinction (within the Newtonian formulation) between action and reaction forces (see § 2.3.6).[14]
3. Ambiguity of the concept of "inertia" (which is a pivotal concept in the Newtonian formulation) from a technical perspective noting that the definition of this concept is usually based on (or associated with) the concepts of force (which contains the aforementioned ambiguities) and inertial forces.

These issues (and similar issues) should be investigated directly or indirectly (or touched on) in the future.

2.2.4 Additivity Principles

A physical quantity (such as mass) is "additive" if this quantity for a composite system is the sum of this quantity for its individual components. For example, the mass of a two-particle system is the sum of the masses of these two particles (unlike the temperature of this system, for instance, which is not additive in this sense since it cannot be obtained by summing the temperatures of the two particles).

The Newtonian formulation (and classical mechanics in general) contains a number of additivity principles regarding certain additive physical quantities (noting that most of these additivity principles are implicit). These additivity principles (or rules) have theoretical justifications (some of which are discussed in the literature of classical mechanics) as well as experimental and observational verifications. In fact, although these additivity principles rarely "appear in public", they underlie most physical arguments and theoretical models in the Newtonian formulation (and some even in the non-Newtonian formulations) of classical mechanics and hence they play (implicit or unseen) fundamental roles in the Newtonian formulation of classical mechanics (both formally and epistemologically).

It is worth noting the following points about the additivity principles in the Newtonian formulation:

1. "Additivity" here should include the additivity of scalar quantities (such as the additivity of mass) and the additivity of vector quantities (such as the additivity of force which

[14] What we actually mean is the required and necessary distinction between independent and dependent forces (which the Newtonian formulation fails to do apart from a trivial labeling of "action" and "reaction"). This ambiguity should be clarified by reading § 2.3.6.

represents superposition of force vectors).

2. Some additivity principles may be linked to some conservation laws (e.g. mass additivity and mass conservation); see § 2.2.5.
3. "Composite system" in the above definition of additivity can be extended and generalized to include frames of reference in the sense that a given physical quantity for a given object in a given frame of reference (say frame A) is the sum of the value of that quantity in another frame (say frame B) plus the value of that quantity that characterizes the relationship between these frames. For example, according to the Newtonian mechanics the velocity of a particle (in a given direction) in frame A is the velocity of the particle in frame B plus the velocity of frame B relative to frame A. Hence, the velocity in the Newtonian mechanics is additive in this sense (which is not the case in the relativistic mechanics for instance).

2.2.5 Conservation Laws

The Newtonian formulation of classical mechanics embeds a number of conservation laws (or principles) which are:

1. The conservation of mass which is a postulated fundamental principle.
2. The conservation of mechanical energy (within certain conditions) which can be derived from Newton's laws of motion (usually with the requirement of some extra considerations and constraints and depending on the given assumptions).
3. The conservation of (linear and angular) momentum (within certain conditions) which can be derived from Newton's laws of motion (usually with the requirement of some extra considerations and constraints and depending on the given assumptions).

It is useful to note that these conservation laws (especially those of energy and momentum) are not restricted to the Newtonian formulation of classical mechanics (see § 3). Moreover, as indicated already the conservation laws of energy and momentum are derivable (within certain conditions and assumptions) from Newton's laws and hence they are not central to the formalism of the Newtonian formulation although they (with the conservation of mass) are epistemologically significant and can be central to the epistemology and interpretation of classical mechanics in its Newtonian formulation. In fact, (at least) some of these conservation laws are physically more fundamental than some of Newton's laws (and hence when we say "they are not central" it does not mean that their physical content is marginal or less significant but it means that they are derivable from Newton's laws which represent the main and primary body of the Newtonian formulation).

We should also note that the views and methods used in the literature to present and establish the above conservation laws vary in general, and hence the above statements about these laws (e.g. whether they are postulated or derived and how and why) represent our views (or rather certain views) which may contradict other views in the literature. However, these details are marginally significant to our current investigation and purposes and hence we ignore these details (referring the interested readers to the literature of classical mechanics).

2.3 Limitations of Newtonian Formulation of Classical Mechanics

The main epistemological limitations and shortcomings (which are largely related to interpretability and interpretation) of the Newtonian formulation of classical mechanics are investigated briefly in the following subsections (noting that some of these limitations and shortcomings are related to the formalism of the Newtonian formulation as well although this is of no interest to us in this investigation whose focus is epistemology). More specific and detailed investigations to some epistemological limitations and shortcomings of this formulation should be pursued in forthcoming papers of this series.

2.3.1 Lack of Technical Definition to Basic Concepts

The Newtonian formulation of classical mechanics may be criticized by the absence of rigorous technical definitions to some of its basic and fundamental concepts. For example, "mass" is usually defined as the "quantity of matter" but this is not a rigorous technical definition. Other proposed definitions of mass (which are supposedly technical definitions) are also problematic such as being circular (like its definition as the product of volume times density, i.e. "*mass* density") or being dependent on Newton's laws (as it is the case with the definition based on the reciprocal proportionality to the magnitude of accelerations which is essentially no more than a "rumination" to Newton's second law or a sort of tautology noting that Newton's second law itself requires the definition of its basic concepts and ingredients in advance to be completely and technically determined and hence it cannot be used in this way as a basis for a technical definition to some of its concepts or ingredients).

This also applies to "force" which is usually defined as a "push or pull" (which is not technical) or by Newton's second law (which, as before, requires the definition of its basic concepts and ingredients in advance to be completely and technically determined and hence it cannot be used in this way as a basis for a technical definition to some of its concepts or ingredients).

However, the lack of technical definitions may not be seen as a serious problem from an epistemological perspective (which is our focus in this investigation) noting the intuitivity of most of the elements and ingredients of the conceptual framework of the Newtonian formulation (as indicated in § 2.2.1). Nevertheless, regardless of accepting or rejecting this defence the lack of rigorous technical definitions to some basic concepts and ingredients (independently of the formulation itself) should be considered as a shortcoming in the sense that it is better (at the least) to have rigorous technical definitions to all the basic concepts and ingredients of this formulation so that the formulation be completely technical and rigorous (and this is particularly important to the epistemology and interpretation of this formulation).

We should also remember in this context the ambiguities surrounding the concept of force (as discussed in § 2.2.3) noting that some of these ambiguities are not related (at least directly and primarily) to the definition of the concept of force. These ambiguities (and potentially other ambiguities) should cast a shadow on the clarity and integrity of any epistemology and interpretation of the Newtonian formulation (and some even on classical mechanics in general).

2.3.2 Restricted Validity to Inertial Frames

One of the main limitations of the Newtonian formulation of classical mechanics is that the validity of this formulation is restricted to inertial frames. This restriction on the validity of the formalism of this formulation should impose a parallel restriction on the validity and extension of its epistemology and interpretation. Yes, the validity of this formulation may be extended (in some sense) to non-inertial frames by the introduction of the concept of "fictitious force" which supposedly compensates for the failure of this formulation in non-inertial frames. However, the concept of "fictitious force" is not free of problems (at least from an epistemological perspective; see § 2.3.4), and hence this remedy does not seem to address the original problem entirely and satisfactorily.

We should also note that the concept of "inertial frame" may be seen as problematic theoretically[15] (and even practically), and this should add another source of epistemological (and even formal) difficulties to this formulation from this perspective. However, we think the acceptance of the paradigm of "absolute frame" (which is one of the main features of the Newtonian formulation; see § 2.2.2) regardless of the physical realization

[15] For instance, it may be claimed that "inertial frame" cannot be defined and identified by the validity of Newton's laws (as it is commonly done in the literature) due to circularity (or potential circularity).

and origin of this frame (whether by Newton's absolute space and time or by Machian-type frame or by the CMBR or by the ether or by something else) should address this issue satisfactorily (at least theoretically and epistemologically).

2.3.3 Restricted Validity to Classical Macroscopic Scale

We should remind the reader first that "scale" is more general than "size" (see § 7.2 of [1]). The following are two obvious and famous examples of the restrictions on the validity of the Newtonian formulation of classical mechanics due to limitations imposed by the "scale" factor:

1. From the perspective of the "size" scale, the Newtonian formulation is invalid (at least in its basic form) at quantum and sub-quantum scales. In our view, it should also be invalid at cosmological scale. Its validity at astronomical scale is at least tentative (noting that there seems to be indications of its invalidity at this scale). So in brief, the validity of the Newtonian formulation is certainly restricted (epistemologically as well as formally) to certain size scale(s).
2. From the perspective of the "speed" scale, the Newtonian formulation is similarly invalid (at least in its basic form) at high speeds (i.e. comparable to the speed of light) and this is what necessitates the introduction of Lorentz transformations and mechanics (as well as other proposed physical theories that deal with this problem regardless of accepting or rejecting Lorentz transformations and these proposed theories). So, the validity of the Newtonian formulation is restricted (epistemologically as well as formally) to certain speed scale(s).

In fact, other potential limitations on the Newtonian formulation due to scale restrictions (from perspectives other than size and speed) are also possible. Anyway, regardless of these (and other related) details the validity of the Newtonian formulation of classical mechanics is certainly restricted (formally and epistemologically) to certain *scales* and hence it cannot provide a full epistemological theory or interpretation even if we ignore or address other limitations and shortcomings of this formulation.

It is worth noting that it is not enough to address this problem (as well as the previous problem; see § 2.3.2) by considering or labeling the Newtonian formulation (or even the entire classical mechanics) as an approximation to a more fundamental theory. In other words, this is not a solution to this limitation (in fact this "solution" is essentially an admission of this limitation as well as other similar limitations).

2.3.4 Ambiguity of Origin of Fictitious Force

The concept of "fictitious force" in the Newtonian formulation of classical mechanics was invented to account for the failure of Newton's laws in non-inertial frames of reference. To put it in more friendly terms, this concept was introduced to the Newtonian formulation to "extend the validity" of Newton's laws from inertial frames of reference to non-inertial frames of reference. Accordingly, "fictitious force" may be defined as a hypothetical force that should be assumed to exist in a non-inertial frame of reference to make Newton's laws of motion applicable in that frame.

Anyway, we should note that fictitious forces are real forces because they have observable physical effects (such as the effects of Coriolis force on the global winds and ocean currents) and they can be directly felt by our bare senses (such as the feeling of pressure on our muscles and organs when traveling in an accelerated vehicle or boarding a taking-off plane). So, "fictitious" is actually a technical term to indicate that these forces are restricted to non-inertial frames (i.e. they do not exist in inertial frames) and hence "fictitious" should not be understood to mean something like "imaginary" or "illusory".[16]

What distinguishes fictitious forces from "real" forces is that they do not have a directly observable origin.[17] For example, the centripetal force is "real" because it is exerted by directly observable things like a string (connected to a rotating ball) or magnetic attractive field or gravitating massive body, but the centrifugal force is "fictitious" because there is no directly observable thing to which it can be attributed although in reality there should be some origin to it such as being an intrinsic property of space[18] or being the result of overall gravity of the matter in the Universe (as may be explained by Mach's proposal for

[16] In fact, they are "imaginary" and "illusory" from a Newtonian viewpoint and in a certain sense because (as we will see) they have no known physical origin or observable genesis within the conceptual framework of the Newtonian formulation. We may also rationalize the "fictitious" nature of these forces by saying that an observer in a non-inertial frame cannot identify a physical origin or tangible source to them and hence in his view they are imaginary and illusory (or "fictitious").

[17] For instance, we read in French (see page 509 of [6]): The observer explains the extension of the spring by saying that it is counteracting the outward centrifugal force on m which is present in the rotating frame. Furthermore, if the spring breaks, then the net force on the mass is just the centrifugal force and the object will at that instant have an outward acceleration of $\omega^2 r$ in response to this so-called "fictitious" force. Once again the inertial force is "there" by every criterion we can apply (except our inability to find another physical system as its source). (End of quote)

[18] We may distinguish between *geometric space* which is an abstract mathematical entity and *physical space* which (supposedly) is a real physical entity with certain properties and attributes such as having electric permittivity and magnetic permeability (which determine the speed of light in *vacuum* for instance) or exerting certain gravitational and inertial influences and effects (and so on). In fact, the paradigm of physical space in this sense is acceptable formally and epistemologically as long as it serves a legitimate role and a justified purpose in a consistent physical theory.

instance).

From our viewpoint, the concept of "fictitious force" should be seen as an epistemological defect or gap in the Newtonian formulation of classical mechanics because since it is a real force[19] it should have a physical origin and authentic genesis (according to the principle of causality; see § 5.2 of [1]) and hence the absence of this origin in the theory creates a gap (at least epistemologically) in this theory. It is worth noting that the concept of "fictitious force" does not exist in the other two main formulations of classical mechanics (namely the Lagrangian and Hamiltonian mechanics) because they, unlike the Newtonian formulation, are not based or centered on the concept of "force" (see § 3).

2.3.5 Violations of Newton's Third Law

There are discussions and investigations in the literature of mechanics and electromagnetism about violations of Newton's third law in some physical phenomena (or theories or branches of physics). More specifically, we refer to the claimed violations of Newton's third law (i.e. from a formal perspective) in electrodynamics and relativistic mechanics (as well as other potential violations) which are discussed in the literature.

Accordingly, any potential or proposed epistemology of the Newtonian formulation to classical mechanics should address this *defect in the formalism* of this formulation which should obviously have an impact on its epistemology and interpretability or interpretation. In fact, this is a big issue and hence we postpone the discussion and investigation about it to the future papers of this series.

2.3.6 Missing Asymmetry in Newton's Third Law

It is obvious that from a purely technical and formal perspective there is an implicit symmetry in Newton's third law (i.e. the two forces in this law are represented symmetrically without any technical or formal distinction between them noting that the sign is arbitrary). This symmetry is misleading or not describing the actual physical situation completely and clearly (noting that the physical situation is actually asymmetric at least in some cases). In other words, the implicitly-presumed "formal" symmetry of forces in Newton's third law is not sufficient or able to explain the physical situation epistemologically (at the least) in these circumstances because (assuming an interaction between agent

[19] As indicated earlier, fictitious forces are real forces in commonsense and according to our direct sensual experiences although they are not real in a technical meaning according to the Newtonian formulation of classical mechanics.

A and agent B) we can easily distinguish between the situation when A pushes B and the situation when B pushes A although from a purely formal perspective of Newton's third law the two situations are identical. In fact, we can see this distinction from a causality perspective where in one situation A is the cause of interaction while in the other situation B is the cause of interaction.

The mere labeling of one force as action and the other force as reaction (as it is usually done in the statement of Newton's third law) is not enough to make a clear and realistic physical and epistemological distinction between the two situations (noting as well that this seeming distinction by labeling is external and is not included or embedded technically within the formalism or epistemology of the physical situation). In other words, we must have a hidden (real and physical) element or ingredient in these physical situations that distinguishes the two cases, and this element is not incorporated within the theory in its formal and technical aspect (and hence it is essentially missing in its epistemological aspect noting as well that there is no such distinction within the conceptual framework extrinsically). The failure to include this element makes the theory ambiguous epistemologically (as well as possibly being formally incomplete).

To represent the physical situation (in the above example and its alike) completely and clearly, the law (or an extension or attachment to the law) should distinguish realistically, technically and intrinsically between two types of force: independent force (which is usually labeled as "action") and dependent force (which is usually labeled as "reaction"). It should be obvious that there is a real physical difference between these types of forces (noting that the emergence of the dependent force is caused by the existence of the independent force but not the other way around or symmetrically) and this difference is neither incorporated within Newton's third law formally and technically nor identified or clarified epistemologically (i.e. what is the physical element or ingredient that qualifies a force to be an independent action force while another force as a dependent reaction force?). So in our view, if this missing asymmetry is not a gap in the Newtonian formulation from the perspective of formalism, it should be at least a gap in this formulation from the perspective of epistemology.

We should finally note that in some physical circumstances and instances the physical situation is seemingly symmetric, e.g. agent A and agent B push each other equally and symmetrically. However, this should not affect the fact that the action (or independent) force and the reaction (or dependent) force in these circumstances are still asymmetric because what is symmetric in these circumstances is the two action forces of the two agents (as well as the two reaction forces) and hence the action force of each agent and its corresponding reaction force are still asymmetric.[20]

2.4 Interpretability and Interpretation of Newtonian Formulation

Based on our investigation in the previous three subsections we can conclude that although the Newtonian formulation of classical mechanics possesses a rather elaborate conceptual, philosophical and epistemological framework which qualifies this formulation to be interpretable *in principle*, this framework lacks sufficient epistemological consistency and integrity to be a proper basis for consistent and complete interpretation as it stands.

This means, in short, that the Newtonian formulation is interpretable in principle but does not actually have an interpretation. Yes, if certain shortcomings and defects in this formulation are addressed and corrected it may become eligible for having a proper interpretation (i.e. within its limited domain of validity or even within larger domain of validity depending on the proposed modifications, remedies and rectifications).

So in brief, although the recipe of the Newtonian formulation represents a good and successful formalism at the practical level (within its domain of validity and the required conditions and assumptions) it does not have a sensible and complete epistemology or a valid and consistent interpretation due to these problematic issues.

3 Non-Newtonian Formulations of Classical Mechanics

The non-Newtonian formulations of classical mechanics generally come under the title of "analytical mechanics". The most common of these formulations are the Lagrangian and Hamiltonian mechanics. It is worth noting the following points about the non-Newtonian

[20] In fact, a closer look should reveal that we actually have (at least) three distinct cases:
1. A person pushes a wall: the situation in this case is obviously asymmetric because the independent action belongs to the person while the dependent reaction belongs to the wall.
2. Two gravitating objects (e.g. Sun and Earth) or two attracting/repelling electric charges: in this case it seems we have a symmetric situation since the force exerted by each object or charge can be regarded as action or reaction (although we may assume that we have two action forces and two reaction forces, but this seems to complicate the situation unnecessarily).
3. Two persons push each other equally and symmetrically: in this case we should assume (to be logical) that we have two action forces and two reaction forces (and this case is what we indicated in the main text above).
So, each one of these situations requires investigation and distinction at the epistemological level to identify what physical factor distinguishes the situation in each one of these cases. Anyway, the mere existence of these three distinct cases should support our proposal that Newton's third law does not depict the physical situation completely (at least from epistemological perspective and in some cases) and this can be seen as a gap in the epistemology of the Newtonian formulation.

formulations of classical mechanics:[21]

1. These formulations have very mathematical and technical nature and hence they should be classified more appropriately as branches of mathematical physics rather than physics. In other words, these formulations are essentially mathematical methods for classical mechanics rather than independent paradigms (with independent and specific conceptual, philosophical and epistemological frameworks) of classical mechanics, and hence from this perspective they do not contrast the Newtonian formulation of classical mechanics (which has elaborate, independent and specific conceptual, philosophical and epistemological framework). Accordingly, the central focus of these formulations is formalism not epistemology and interpretation since they are not associated with proper conceptual, philosophical and epistemological frameworks. So, in this regard they may be likened to quantum mechanics which (in our view) is a formalism without a sensible epistemology or a valid interpretation, i.e. it is not interpretable (see § 8.6 of [5]).
2. The fact that the Newtonian formulation is vector-based while the non-Newtonian formulations are scalar-based may grant these formulations more "coordinate-flexibility", and this may be seen as a sign or indication of the specific characteristic of the Newtonian space (which is supposedly Euclidean) in contrast to the space that these formulations can represent and apply to (i.e. they, unlike the Newtonian formulation, have "space-flexibility" corresponding to their "coordinate-flexibility" in the sense that they can in principle work in Euclidean and non-Euclidean spaces if such flexibility is required). This may be seen as an advantage to these non-Newtonian formulations that can have not only formal benefits but also epistemological benefits.
3. These formulations (or at least some of them) have limitations in validity and application, e.g. they may not work in certain physical systems like non-conservative systems.[22] Hence, even if we assume that they have epistemology and interpretation they are limited in these aspects following their limitation in validity and application.
4. These formulations (like the Newtonian formulation; see § 2.3.3) are scale-limited since their validity is generally restricted (at least tentatively) to the classical macroscopic scale (although some of these formulations have adaptations and variations used in other scales, e.g. in dealing with quantum or cosmological systems).

[21] In fact, these points are supposed to provide a brief investigation to the non-Newtonian formulations of classical mechanics in general where we assess their epistemological merit and their potential interpretation(s) or even their interpretability. More detailed and specific investigations about these formulations and related issues may be pursued in the future.

[22] We are referring in this point to limitations that are usually not found in other formulations of classical mechanics (particularly the Newtonian formulation), and hence they represent extra limitations.

5. (At least) some of these formulations are based on (or formulated in) non-intuitive abstract concepts and principles (like the concept of "action" and "the principle of least action") and this should make any *potential* epistemology and interpretation to these formulations more abstract and difficult (or rather "more impossible" considering other factors).[23]
6. It is shown in the literature that these non-Newtonian formulations are equivalent to the Newtonian formulation in (at least some) formal aspects (e.g. Newton's laws can be derived from the Lagrangian and Hamiltonian formulations) and this may be seen as a basis for these non-Newtonian formulations to have (in principle) proper epistemology and interpretation due to this equivalence to the Newtonian formulation.[24] However, this formal equivalence should not make these non-Newtonian formulations epistemologically equivalent to the Newtonian formulation (because formal equivalence does not imply epistemological equivalence). Nevertheless, even if an epistemology of these non-Newtonian formulations is obtained (presumably) through their equivalence to the Newtonian formulation, the obtained epistemology is actually the epistemology of the Newtonian formulation and hence it should not be credited to these non-Newtonian formulations (regardless of the obtained epistemology being similar or dissimilar to the Newtonian epistemology).

So in brief, while the Newtonian formulation of classical mechanics has a rather clear and elaborate conceptual, philosophical and epistemological framework, the non-Newtonian formulations (like the Lagrangian and Hamiltonian mechanics) do not possess such a framework. Hence, the Newtonian formulation is interpretable in principle (even though it may not have a proper, complete and consistent interpretation due to its epistemological shortcomings, defects and gaps as outlined earlier) while the non-Newtonian formulations are not interpretable due to the aforementioned lack of proper conceptual frameworks.

[23] In fact, even the concept of "energy" (which is the basis of some non-Newtonian formulations and which is less abstract than the concept of "action") is more abstract (and hence less intuitive) than the concept of force (which is the central concept in the Newtonian formulation) and this should make any interpretation more difficult (noting that interpretation is essentially based on intuition).

[24] In fact, there are many aspects (and potential interpretations) to this supposed equivalence which require extensive investigation and inspection. We may discuss some of these aspects in the future.

4 Conclusions

We outline in the following points the main facts and results that we discussed and obtained in this paper:

• While the Newtonian formulation of classical mechanics possesses a rather elaborate and intuitive conceptual, philosophical and epistemological framework which qualifies it (in principle) to be interpretable and have a proper interpretation, the non-Newtonian formulations of classical mechanics do not possess such a framework.

• Although the Newtonian formulation of classical mechanics is interpretable in principle (thanks to its aforementioned framework) it does not have a proper epistemology or consistent and complete interpretation due to epistemological defects and gaps. On the other hand, the non-Newtonian formulations of classical mechanics are not interpretable due to the lack of conceptual, philosophical and epistemological frameworks that are required for any interpretation, and hence these formulations can be regarded as formalism without an epistemology that qualifies them to have an interpretation in principle (i.e. they are like quantum mechanics in this regard).

• To conclude, the Newtonian formulation has no sensible interpretation, while the non-Newtonian formulations are not interpretable. Hence, none of the formulations of classical mechanics have a proper epistemology or sensible interpretation.

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