The Epistemology of Contemporary Physics: Classical Mechanics II

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Abstract: In this paper of "The Epistemology of Contemporary Physics" series we investigate Newton's third law and discuss and analyze its epistemological significance from some aspects with special attention to its relation to the principle of conservation of linear and angular momentum. The main issue in this investigation is the potential violations of this law according to the claims made in the literature of mainstream physics. This issue may cast a shadow on the validity of classical mechanics, and its Newtonian formulation in particular, formally and epistemologically and could have important implications and consequences on contemporary physics in general. However, what is more important about this issue from our perspective is the lack of clarity, comprehensibility and coherence in the investigation and analysis of this issue and its implications marked by the absence of appropriate conceptual and epistemological frameworks to deal with this issue properly and systematically. As a result, what we find in the literature is a collection of contradicting views which are mostly based on personal choices and preferences and selective or biased theoretical analysis with the lack of proper experimental verification and substantiation.

Keywords: Epistemology of science, philosophy of science, contemporary physics, fundamental physics, modern physics, classical mechanics, Newtonian mechanics, Newton's third law, law of action-reaction, conservation of momentum.

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1 Introduction

Newton's third law is one of the pillars of classical mechanics in its Newtonian formulation (and possibly further). It may also be seen as the most important and physically significant law among Newton's laws of motion (as discussed already in [1]) due mainly to its link to the principle of conservation of linear and angular momentum (see for instance [2]) which is one of the main pillars of all physics. In fact, some scholars even consider this law as one of the most important laws of Nature (see for instance [3]).

Nonetheless, this law is one of the most troubling parts and problematic aspects of the Newtonian formulation of classical mechanics (and possibly classical mechanics in general and even beyond). This is not only because of its rather epistemological obscurity (see [1]) but also because of its (claimed) formal violations and exceptions which cast a shadow on its validity and hence on its status as a real physical law (as well as putting question marks on its epistemological significance and its relation to the conservation of momentum among other implications and consequences). However, it is important to note that the blame in these claimed violations and exceptions may be put (in some cases at least) on other physical theories and aspects (like Lorenz electrodynamics theory) rather than on Newton's third law itself.[1] Moreover, such violations are denied altogether by some scholars who justify their denial by certain conceptualizations or formulations (or even novel theories within or outside the mainstream physics).

The problematic nature of Newton's third law (or perhaps the problematic aspects surrounding this law which possibly relate to other physical theories and aspects as indicated already) was observed rather early in the history of contemporary physics. For example, Henri Poincare noticed that (see pages 194-195 of [4]):

The most satisfactory theory is that of Lorentz; it is unquestionably the theory that best explains the known facts, the one that throws into relief the greatest number of known relations, the one in which we find most traces of definitive construction. That it still possesses a serious fault I have shown above. It is in contradiction with Newton's law that action and reaction are equal and opposite - or rather, this principle according to Lorentz cannot be applicable to matter alone; if it be true, it must take into account the action of the ether on matter, and the reaction of the matter on the ether. Now, in the new order, it is very likely that things do not happen in this way. (End of quote)

In more recent times a number of problematic (or potentially problematic) aspects related to Newton's third law are similarly identified (or indicated or investigated) by a

[1] This issue should be investigated further in due course within this series.

number of scholars. Some of the common views in the literature about this issue are (noting that some of these views may originate from the same cause):

• Newton's third law is violated or has no place in relativistic mechanics (see for instance [2, 5]).

• Newton's third law is violated in electrodynamics (see for instance [6]).

• Newton's third law is violated by Lorentz force law (see for instance [3, 7]).

• Biot-Savart law does not obey Newton's third law (see for instance [8, 9]).

• Newton's third law is violated in the interaction (or rather relationship) between the (Newtonian) space and the material objects (see for instance [10]).

• Inertial forces do not obey Newton's third law (see for instance [11]).

• Non-equilibrium forces (in certain physical systems) violate Newton's third law (see for instance [12]).

Our intention in the present paper is to investigate in rather sufficient details the significance and limitations of Newton's third law and its (potential) violations where we focus in this respect on analyzing its relationship to the principle of conservation of linear and angular momentum. The main purpose of all this is to asses the effect of the (potential) violations of Newton's third law on the validity and applicability of the Newtonian formulation of classical mechanics, and hence the effect of this on the classical mechanics and contemporary physics in general (with special attention and consideration to the epistemological and interpretative aspects of these issues).

However, our investigation should also reveal and highlight the messy situation of the investigations of these issues and the lack of consistent and objective scientific methodology in most of the approaches that deal with these issues in the literature. The situation is generally surrounded with ambiguities, misconceptions, randomness, selectivity and lack of sufficient experimental substantiation and verification.

The structure of this paper is that we start with a preliminary section (where we investigate some introductory issues related to our main subject). We then investigate in the subsequent section some instances of violation (or rather claimed or tentative or potential violation) of Newton's third law which we find in the literature of mainstream physics (noting that there are other instances of claimed violations in the literature of the so-called "fringe science" which we do not consider in this paper). We then discuss briefly (in another section) some general remarks related to our main investigation before we outline in a "Conclusions" section the main results and conclusions that we obtained from our investigation in the present paper.

2 Preliminaries

We investigate in this preliminary section some important issues related to our main subject (as explained in the Introduction).

2.1 Relationship between Newton's Third Law and Conservation of Momentum

According to the literature of mainstream physics, the physical essence of Newton's third law is the conservation of momentum and this is shown, for instance, through the derivation of the principle of conservation of momentum from Newton's third law (which can be found in elementary physics textbooks and even in some secondary school curricula).[2]

However, despite this intimate relationship between Newton's third law and the conservation of momentum they are not equivalent,[3] neither formally nor epistemologically (and this seems obvious from analyzing their contents and implications). For example, the derivation of the conservation of (linear and angular) momentum from Newton's third law usually depends on the use of Newton's second law (in its linear and angular forms) which is not incorporated in the conservation of momentum or part of it (see for instance [2, 13]).[4] On the other hand, the conservation of momentum is more general in theory and application than Newton's third law (at least among the majority of mainstream physicists) since the conservation of momentum is valid and applicable in theories and branches other than classical mechanics and its Newtonian formulation and beyond their domain of validity (in fact there seems to be a general consensus among physicists that the conservation of momentum is valid and applicable in all physics and hence it is one of the most fundamental laws or principles of Nature). This can be concluded, for instance, from the fact that the conservation of momentum in modern physics is usually obtained from theoretical arguments based on the properties of space[5] and related symmetries (noting

[2] In fact, the conservation of both linear and angular momentum can be derived from Newton's third law noting that this law consists of three main facts about the action-reaction forces on the two interacting objects: (**a**) the equality of the two forces in magnitude, (**b**) being in opposite directions, and (**c**) being along the line joining the two objects. Further clarifications about this issue will follow.

[3] Statements that assert the equivalence of Newton's third law and the conservation of momentum can be found in the literature. For example, we read in Taylor (see page 21 of [2]) "conservation of momentum and Newton's third law are equivalent to one another". However, the meaning of "equivalent" is rather different to what we mean here.

[4] In fact, the non-equivalence should be aggravated if we adopt the view that Newton's second law is a definition in some sense (see [1]).

[5] The conservation of linear momentum is supposed to be based on the homogeneity of space while the

that these arguments are more general than classical mechanics and hence they extend beyond its domain of validity; moreover they are not based on Newton's third law).

Nevertheless, if the derivation of the conservation of momentum (within classical mechanics or rather its Newtonian formulation) is based exclusively on Newton's third law then we can say that the conservation of momentum is violated within the framework of Newtonian formulation of classical mechanics, and hence if the conservation of momentum is a fundamental principle of all physics that cannot be violated (as suggested already) then this means that classical mechanics (in its Newtonian formulation at least) is incorrect from this aspect or at least it requires rectification and correction or amendment (such as by imposing certain extra conditions on its validity and applicability). On the other hand, if violation to the conservation of momentum is allowed (which seems to be a bizarre view) then we may be able to rectify this embarrassing situation in classical mechanics by putting some restrictions and conditions on Newton's third law (noting that our loss by accepting a violation to the conservation of momentum should be greater than any supposed gain by this rectification).

2.2 Importance of Newton's Third Law

The importance of Newton's third law was investigated in a previous paper of this series (see [1]) and also implied by the discussion of the previous subsection. What we need to add here is that the importance of Newton's third law should be demonstrated and reflected in two main aspects:

1. The importance of this law in itself within the framework of classical mechanics (and its Newtonian formulation in particular).
2. The importance of this law in physics in general mainly through its relation to the principle of conservation of (linear and angular) momentum (and possibly through other implications and consequences).

So, from the first aspect any potential violation to this law should affect classical mechanics but not necessarily other parts and disciplines of physics (and the conservation of momentum in particular), while from the second aspect any potential violation could have far reaching consequences on the entire physics. The second aspect should depend primarily on the relationship between Newton's third law and other laws and principles of physics (particularly the principle of conservation of momentum), where this relationship is essentially determined by the presumed position and role of Newton's third law within

conservation of angular momentum is supposed to be based on the isotropy of space.

the contemporary physics in general. In fact, there are conflicting views and opinions in this regard where some scholars grant this law a central position and role within the contemporary physics in general (due mostly to its supposedly strong relationship with the principle of conservation of momentum in general) while other scholars restrict its role (or main role) to classical mechanics (and the Newtonian formulation in particular).

Anyway, the first aspect may not represent a serious problem due to the already-imposed limitations on the validity and applicability of classical mechanics (which we discussed in [1]) and considering that classical mechanics is generally seen as an approximate theory or a limit to other fundamental theories, and hence any violation will not introduce a fundamental change on the status of classical mechanics (and its Newtonian formulation in particular) from this perspective. This is unlike the second aspect since it extends beyond classical mechanics to reach (at least potentially) other physical theories and disciplines and hence it could affect physics fundamentally and in general (noting in particular its potential effect on the conservation of momentum which is supposedly a fundamental principle of all physics).

We should also mention (with regard to the first aspect) that any violation of Newton's third law should affect the Newtonian formulation of classical mechanics but should not affect the other formulations of classical mechanics directly since Newton's third law is proprietary to the Newtonian formulation. However, due to the supposed equivalence of these formulations to the Newtonian formulation (as explained in [1]) these formulations could be affected indirectly through their implications and consequences which are related to this equivalence. Accordingly, violations to Newton's third law should affect (in this sense and capacity) classical mechanics in general.

2.3 Weak and Strong Forms of Newton's Third Law

According to the literature of physics, Newton's third law has two forms: weak and strong. In fact, Newton's third law consists of three main components or ingredients related to the attributes of the action and reaction forces which act on the two interacting objects and their relationship:

- These forces are equal in magnitude.
- These forces are opposite in direction.
- These forces are acting along the line joining the two interacting objects (or rather particles).

Accordingly, while the weak form of Newton's third law consists of the first two components only, the strong form consists of all these three components.

The following points are worth noting in this regard:

1. The violation of Newton's third law may occur (in theory and hypothetically) by violating both forms of Newton's third law (i.e. by violating at least one of the first two components and possibly the third component as well) or by violating the strong form only (i.e. by violating the third component only). In fact, the literature seems to contain claims of potential violations of both these forms in various physical situations and circumstances or scenarios where the violation of each form occurs independently, i.e. there are examples of potential violation of the strong form only and other examples of potential violation of both forms (noting that violation of the weak form implies, in some sense, violation of the strong form).
2. We should notice that while some scholars consider both forms as being valid and legitimate (in the sense that they represent a sort of "independent" physical laws, or rather independent representations of Newton's third law, that apply in different situations and circumstances), other scholars seem to consider only one of these forms as being valid and legitimate (and hence if the weak form is the actual and real representation of Newton's third law then there is no violation to Newton's third law by violating the third component,[6] while if the strong form is the actual and real representation of Newton's third law then violating any one of the three components is a violation to Newton's third law with no distinction between which component is the violated one). Anyway, it seems that most scholars (see for instance § 1.5 of [2]) adopt the view that Newton's third law is actually the weak form, and hence the strong form (or rather its content) is restricted to central forces. This may seem logical because the conservation of angular momentum (which is based on the third component) is restricted to central forces (see for instance pages 94-95 of [2]). This should also be inline with the common position in the literature about the nature of the relationship between the weak/strong form of Newton's third law and the conservation of linear/angular momentum (as indicated earlier), i.e. the weak form implies the conservation of linear momentum while the strong form implies the conservation of angular momentum.
3. Noting that the third component is usually used in the derivation of the conservation of angular momentum, the violation of the strong form (of Newton's third law) specifically and exclusively may be associated with the violation of the conservation of angular

[6] We note that violating the third component in this case may imply violation of some physical law or principle (other than Newton's third law), but this should be another issue not related to Newton's third law according to this representation of Newton's third law.

momentum. If so then violating the weak form implies violation of conservation of linear momentum, while violating the strong form (specifically) implies violation of conservation of angular momentum.[7]

2.4 Typical Example of Claimed Violation of Newton's Third Law

To clarify the situation further let have a simple example that demonstrates a typical and common instance of claimed violation of Newton's third law[8] (noting that there are many other examples in the literature about claimed violation of Newton's third law which are related to various subjects and fields as will be investigated in detail later on; see § 3).[9]

Let us have a system of two charged particles (where we label them as q_1 and q_2 for simplicity) which are initially at relative rest. When one of these particles (say q_1) moves it should feel the action force exerted by the field of q_2 immediately (because it is located in this field) but q_2 does not feel the reaction force exerted by the field of q_1 immediately (because the change in its field propagates at a finite speed according to the mainstream physics). So, while (at the instant of movement of q_1) there is a force acting on q_1 (which is supposedly an "action force"), there is no force acting on q_2 (which is supposedly a "reaction force") and this should represent a violation to Newton's third law.

In fact, this supposed violation is based on the following implicit assumptions (and possibly other assumptions noting that such assumptions generally depend on the specific examples and instances as well as the adopted theoretical frameworks):

1. The rejection of action at a distance (which is generally not acceptable in the mainstream physics)[10] and hence the interaction between the particles is taking place (supposedly) through fields the propagation of signals through them is subject to certain speed restrictions (which the mainstream physics impose through the adoption of special

[7] When we say "implies" it should mean "potentially implies" noting that we are not aware of physicists who accept such implications.

[8] In fact, this typical and common example of violation is related to electrodynamics and relativistic mechanics (see § 3.1 and § 3.2) which are the main fields in which claimed violations of Newton's third law are common.

[9] In fact, we are using simple (and rather non-technical) language in our explanation to this simple example to demonstrate some essential points and aspects that we need to examine in our subsequent discussions. It should be noted that other examples and instances of violations may have totally or partially different logic and rationale and hence some of the following discussion and analysis should not apply to them (i.e. this simple example does not typically represent all instances and examples of claimed violation).

[10] In fact, action at a distance gained some support in recent decades (due mainly to seemingly supportive evidence from quantum physics in general and quantum entanglement in particular) and hence it is more accepted now.

relativity).

2. The existence of a privileged frame. This is because when we assume q_1 moving (and q_2 at rest) it should be moving either relative to an absolute frame (which is a privileged frame) or relative to a frame in which q_2 is at rest (which is also a privileged frame even if it is not an absolute frame). It is worth noting that this assumption implies either the falsehood of special relativity (due to the existence of absolute frame) or the dependence of the violation of Newton's third law on the chosen frame since we can choose a frame in which the two charged particles move symmetrically towards each other and hence Newton's third law is not violated in this frame (although it should be violated in other frames).
3. The action-reaction pair is actually between the two particles and not between each particle and the field at its position. This is because if the action-reaction pair is between each particle and the field at its position then we have two separate action-reaction pairs where in each pair the action of one agent (whether this agent is the particle or the field at its position) is encountered by an instantaneous reaction by the other agent with no delay or retardation. However, as we will see this fix or proposal should not be accepted within the framework of classical mechanics (because classical mechanics is a theory for material particles not fields; moreover the paradigm of "force acting on a field" seems bizarre in classical mechanics and inconsistent with its conceptual framework even if we accept the paradigm of "field" in this mechanics).

The dependence of the claimed violations on certain assumptions (as highlighted and exemplified in these points which are related to this specific example) should highlight an important and general issue that is, the validity of the claimed violations generally depend on certain theoretical choices and preferences (most of which are related to the commonly accepted doctrines in mainstream modern physics). For example, if we accept action at a distance or reject special relativity or accept the paradigm of "force acting on a field" some of these claimed violations can vanish right away.

Anyway, according to the literature of mainstream physics (or at least this is the common view in the literature), although Newton's third law is (potentially) violated in situations like this, the principle of conservation of momentum is not because the electromagnetic field (or rather the "ambient field" to be more general) also carries momentum (as will be discussed later on), and hence the total momentum of the system (which consists of the two charges plus the electromagnetic fields in the above example) is conserved despite the "fact" that the total momentum of the system of the two charges alone (i.e.

without their fields) is not conserved due to the (potential) violation of Newton's third law. However, alternative views can also be found in the literature where (according to some of these views) neither the conservation of momentum nor Newton's third law are violated (see for instance [14, 15]).

An important remark (which may be captured partially from the previous discussion) is that these different (and possibly contradicting) views are generally based on theoretical analysis and not on experimental evidence (e.g. by direct measurement of action and reaction forces). In fact, even those views which are supposedly based on experimental evidence rely (mostly if not entirely) in their analysis and conclusions on selected theoretical assumptions and hypothetical frameworks and hence they are not actually (or at least purely) experimental. In short, they depend in their validity and rationale on certain choices and preferences ad hence they are not unconditionally experimental.

So, we can say (briefly and generally) that the alleged violations (as well as the different and contradicting views about them) are highly dependent on the adopted theoretical frameworks and hence in most cases the disputes about these violations cannot be settled down decisively and conclusively (e.g. by empirical evidence) noting as well that no sufficient experimental efforts have been dedicated to the investigation of these violations and disputes.

3 Instances of Claimed Violation of Newton's Third Law

There are many claims in the literature of physics about violations of Newton's third law in different physical systems and circumstances and for various reasons. In the following subsections we investigate common instances or cases of violation (or at least potential or tentative or claimed violations) of Newton's third law noting that these violations, or rather some of them, do not necessarily belong to different categories although we categorize them in separate subsections for the sake of clarity and organization.

3.1 Violation in Electrodynamics

According to the literature of mainstream physics, Newton's third law is violated in electrodynamics (i.e. in some situations and circumstances). For example, we read in Griffiths (see § 8.2.1 of [6]) the following excerpt (noting that the *italicization* is from Griffiths):

In electro*statics* and magneto*statics* the third law holds, but in electro*dynamics* it does *not*. Well, that's an interesting curiosity, but then, how often does one actually use the third law, in practice? *Answer*: All the time! For the proof of conservation of momentum rests on the cancellation of internal forces, which follows from the third law. When you tamper with the third law, you are placing conservation of momentum in jeopardy, and there is hardly any principle in physics more sacred than that. Momentum conservation is rescued, in electrodynamics, by the realization that the *fields themselves carry momentum*. This is not so surprising when you consider that we have already attributed *energy* to the fields. Whatever momentum is lost to the particles is gained by the fields. Only when the field momentum is added to the mechanical momentum is momentum conservation restored. (End of quote)

So according to Griffiths (and actually many other scholars),[11] we saved the law of conservation of momentum but lost Newton's third law (noting that attributing part of the momentum to the field, which supposedly saves the law of conservation of momentum, does not save Newton's third law because the subject of this law is the forces on the two particles with no reference to the field noting that classical mechanics, and its Newtonian formulation in particular, is a mechanics of particles not of fields). This simply means (based on the claim and analysis of Griffiths):

1. Newton's third law is limited in validity and application, i.e. it is *sacred* but not as *sacred* as the law of conservation of momentum. This means a limitation on the validity of the formalism (and hence the epistemology) of classical mechanics even within its already-limited domain of validity (i.e. classical macroscopic scale and inertial frames of reference; see [1]).
2. If the law of conservation of momentum is derived from Newton's third law exclusively (at least in some fields and disciplines of physics)[12] then it is actually derived partly due

[11] For example, we read in Purcell and Morin (see page 679 of [16]) the following (noting that the *italicization* is from the authors): We see that Newton's third law, applied to the charges, does *not* hold. Equivalently (since $F = dp/dt$), the total momentum of the proton plus pion is not conserved. However, the sacred fact that is still true is that the total momentum of the *entire system* is conserved. And the system here consists of the two charges *plus* the electromagnetic field. We will learn in Chapter 9 that there is momentum *in the field*, and the field is changing here. The total momentum (proton plus pion plus field) is indeed conserved. This is not a two-body system! (End of quote)
However, we should take notice of the condition "applied to the charges" in this quote which may suggest that Newton's third law still holds (like the conservation of momentum) to the entire system (and this could be a difference with the view of Griffith). In fact, the phrasing of Purcell and Morin may indicate their intention to avoid taking a specific view about the violation of Newton's third law (and this should reflect and highlight the problematic nature of this issue).

[12] It should be noted that although the principle of conservation of momentum should acquire (generally and primarily) its legitimacy and validity from experiment and observation, such acquisition normally

to the partial validity of Newton's third law (as seen in the previous point). This could mean that the law of conservation of momentum (at least in classical mechanics) is not as general as it should be because it is subject to the same limitations of Newton's third law and hence it is limited to the instances in which Newton's third law is valid. This could put some restrictions on the validity and application of the law of conservation of momentum (theoretically and practically) in classical mechanics and its applications and extensions (and possibly even beyond classical mechanics). However, we are not aware of such restrictions in the literature of mainstream physics.

3. This violation of Newton's third law is not due to a restriction or condition on the law by imposing certain conceptual or theoretical restrictions on this law and its domain of validity and application (because being in electrodynamics is not such a conceptual or theoretical restriction) but because of the invalidity of this law in itself. This means that this violation (if held) could invalidate Newton's third law altogether and disqualify it as a law, and hence Newton's third law is not really a law, i.e. it is no more than a useful rule of thumb or a practical recipe for tackling and solving the problems in classical mechanics and related fields of physics (or something like these). This can have serious conceptual and theoretical consequences not only on Newton's third law in classical mechanics but possibly on the law of conservation of momentum as well (which is supposedly derived from Newton's third law in classical mechanics and possibly beyond; also see footnote [12]).
4. Referring to the previous point, we should draw the attention to a misconception about this issue among some scholars who talk about violation in classical mechanics and violation in electrodynamics as if these violations are physically distinct and different, and hence these scholars seem to allow violation to Newton's third law in electrodynamics but not in classical mechanics (or at least they put the onus and blame on electrodynamics specifically in these violations). In this regard, we should say that the physical situations in electrodynamics which are subject to the main limitations of classical me-

relies (at least partially) on theoretical considerations and formulations (such as Newton's third law) as well and hence it could be affected by such limitations (e.g. on the validity of Newton's third law). In fact, this should apply to experimental and observational evidence in general because no experiment or observation can be of substantial use without a proper theoretical framework that is required for its structuring and analysis.
We should also note that in the light of footnote [5] and the surrounding text, the derivation of the conservation of momentum from Newton's third law should still be needed (at least in some disciplines and circumstances) if such theoretical foundations are rejected or questioned or restricted for some reason (e.g. due to a fundamental position against such highly theoretical and mathematical methodologies or because of certain technicalities which may be found in the literature).

chanics (i.e. classical macroscopic scale and inertial frames of reference; see [1]) should be subject to the physics of classical mechanics from a purely mechanical perspective (i.e. from the perspective of the kinematic and dynamics of motion) even though their particular physics (especially their dynamical aspects such as forces and their origins) is based on another theory of physics (i.e. electrodynamics in this case). In fact, this is exactly what necessitated the use of other theories of physics to determine the force in Newton's *second* law which is considered (by some scholars) as a definition for this reason (at least in part; see [1]). In other words, the need for a physical theory (other than classical mechanics such as electrodynamics) to determine the specific dynamical agents and physical actors and how they operate within the given physical situation does not exclude the given physical situation from the validity domain of classical mechanics, and hence as long as the given physical situation is within the domain of validity of classical mechanics then it is a classical mechanical problem and thus it should be subject (from mechanical perspectives and considerations kinematically and dynamically) to the laws and principles of classical mechanics (i.e. no violation of Newton's third law or any other law can be tolerated as long as we accept classical mechanics as a valid physical theory in that situation).[13] This is unlike the situation where the other theory used in the modeling and formulation of the given physical situation is in contradiction with the classical mechanics from the beginning and hence it cannot be within the domain of validity of classical mechanics (as it is the case with relativistic mechanics; see § 3.2); in which case a violation of Newton's third law (or any other law of classical mechanics) can be tolerated since the given situation is not within the domain of validity of classical mechanics.

The attempts to save Newton's third law by certain conceptual and technical manipulations (e.g. by Sebens [15] who included the "mass of field" so that fields can be acted upon by forces in, seemingly, a classical sense)[14] do not seem consistent in spirit (if not

[13] To support our argument about "having a force law from electrodynamics is not sufficient in itself to make the physical situation an electrodynamics problem and not a classical mechanical problem" we can argue that in some examples of claimed violations in electrodynamics (and possibly other disciplines) such as the example given in § 2.4, the rationale of violation applies equivalently (i.e. equivalent to electrodynamics) to examples that belong exclusively to classical mechanics (in its extended sense that includes gravity). For example, if we replace the two charged particles in the example given in § 2.4 with two gravitating massive particles then the same logic of violation could apply in this case (which is a problem that belongs to classical mechanics exclusively).

[14] As indicated above, Sebens [15] ascribes mass to the field in his attempt to save Newton's third law (and hence forces can act on fields). However, this may be rejected (i.e. within this context and purpose even if it is accepted in other contexts and purposes) based on the fact that fields have no mass in a classical sense to which classical mechanics (and Newtonian formulation in particular) applies even if

in letter) with Newton's third law (and classical mechanics in general). The least that can be said in this regard is that (most if not all) these attempts are not intuitive or make much sense within the framework of classical mechanics and the Newtonian formulation in particular (and some may not make much sense even beyond the framework of classical mechanics). So, even if these attempts (or some of them) are accepted in general (based for instance on their presumed validity and merit from a formal perspective) they may save the principle of conservation of momentum (but not Newton's third law and within classical mechanics), and this could be limited to the formalism but not the epistemology (i.e. the epistemology could be affected anyway).

Also, the attempts to save the conservation of momentum by similar conceptual and technical manipulations are similarly problematic (although the conservation of momentum is more fundamental and entrenched in the fabric and structure of contemporary physics than Newton's third law and has more theoretical and experimental support independent of Newton's third law and hence it may be saved mainly for this reason). As indicated earlier, the inclusion of field (to save the principle of conservation of momentum) my be rejected (at least within the framework of classical mechanics and the Newtonian formulation in particular) because the Newtonian formulation of classical mechanics is a theory for material particles and not for fields and hence the inclusion of field (even if it is accepted in principle and within other theories and branches of physics) may save the conservation of momentum outside classical mechanics but not inside classical mechanics (and its Newtonian formulation in particular).

So in brief, if we accept the rationale of the claimed violation of Newton's third law in electrodynamics[15] (as outlined earlier) then we may lose the conservation of momentum (at least from this basis and foundation), as well as Newton's third law, within classical mechanics or at least within its Newtonian formulation (noting that the other formulations of classical mechanics do not include Newton's third law explicitly and directly although it may be obtained by derivation from their principles or by their presumed equivalence to the Newtonian formulation as indicated earlier; see [1]). Regarding outside classical mechanics (assuming that the validity of Newton's third law extends beyond classical

the concept of "mass of field" is accepted within the framework of other theories of modern physics. In fact, the concept of "field" (let alone the concept of "mass of field") does not exist within the framework of Newtonian mechanics which is essentially a mechanics of particles not fields. We should also refer the reader to [14] who seems to be the originator of this idea (i.e. inclusion of "mass of field" to save Newton's third law).

[15] In fact, the following argument may apply to similar instances of violation of Newton's third law which will be investigated in the next subsections, i.e. it is not restricted to electrodynamics.

mechanics, as some physicists believe), it seems that we will lose Newton's third law in its intuitive and "classical" sense at least (and hence we may lose it altogether as declared explicitly by several scholars some of whom are cited in this paper). We may also lose the conservation of momentum although this should depend on a number of factors (such as the embraced theoretical framework which usually depends on the branch of physics and the personal choices and preferences) and is usually excluded due to the fundamental role of the conservation of momentum in contemporary physics and its extra sources of support and validation (both theoretical and experimental) as indicated earlier.

Anyway, any loss (whether to Newton's third law or to the conservation of momentum and whether within or outside classical mechanics) should put big question marks on Newton's third law epistemologically (and possibly formally) as a law in itself and on its relation to the conservation of momentum. Some of these question marks may also extend to the conservation of momentum (although this does not seem very likely noting that the conservation of momentum is more central and essential than Newton's third law in contemporary physics as reflected by the common view among the mainstream physicists which accepts the violation of Newton's third law but not the violation of the conservation of momentum).

3.2 Violation in Relativistic Mechanics

According to the literature of mainstream physics, Newton's third law does not hold in relativistic mechanics (i.e. in some situations and circumstances). For example, we read in Taylor (see page 21 of [2]) the following excerpt (noting that the *italicization* is from Taylor):

Within the domain of classical physics, the third law, like the second, is valid with such accuracy that it can be taken to be exact. As speeds approach the speed of light, it is easy to see that the third law cannot hold: The point is that the law asserts that the action and reaction forces, $\mathbf{F}_{12}(t)$ and $\mathbf{F}_{21}(t)$, *measured at the same time* t, are equal and opposite. As you certainly know, once relativity becomes important the concept of a single universal time has to be abandoned — two events that are seen as simultaneous by one observer are, in general, *not* simultaneous as seen by a second observer. Thus, even if the equality $\mathbf{F}_{12}(t) = -\mathbf{F}_{21}(t)$ (with both times the same) were true for one observer, it would generally be false for another. Therefore, the third law cannot be valid once relativity becomes important. (End of quote)

Similarly, we read in Griffiths (see § 12.2.4 of [6]) the following excerpt (noting that the *italicization* is from Griffiths):

Unlike the first two, Newton's *third* law does not, in general, extend to the relativistic domain. Indeed, if the two objects in question are separated in space, the third law is incompatible with the relativity of simultaneity. For suppose the force of A on B at some instant t is $\mathbf{F}(t)$, and the force of B on A at the same instant is $-\mathbf{F}(t)$; then the third law applies *in this reference frame*. But a moving observer will report that these equal and opposite forces occurred at *different times*; in his system, therefore, the third law is violated. Only in the case of contact interactions, where the two forces are applied at the same physical point (and in the trivial case where the forces are constant) can the third law be retained. (End of quote)

Similar views and stands can be found in the literature of mainstream physics. In fact some of these views sound even stronger than these (for example, according to French [5]: "one of Newton's basic assertions about forces between bodies - the equality of action and reaction - has almost no place in relativistic mechanics"). Moreover, these views generally vary in the cause of violation of Newton's third law in relativistic mechanics, e.g. whether it is because of the relativity of simultaneity or because of the denial of action at a distance and the speed limit in communication (noting that these causes are generally interrelated) although this should depend in part on the specific example of violation as well as on the personal choices and opinions which the analysis depends on.

Anyway, the violations of Newton's third law in relativistic mechanics may be challenged by various arguments which are normally based on different theoretical grounds and they usually depend on one's own convictions. For example, the challenges may be based on the rejection of special relativity or some of its postulates or principles or implications (such as the denial of action at a distance and the speed limit in communication), or based on the introduction of certain modifications and interpretations on the relativistic mechanics which lead to the negation of such violations.

However, all these claimed violations and their challenges are based on their own theoretical frameworks which depend primarily on personal choices and preferences, and hence it is virtually useless to try to prove or disprove any one of these claims or their challenges in an absolute sense and meaningful manner (refer to § 2.2 of [17] for more details). Nonetheless, we can say (in a more general and useful argument away from the specific and detailed technicalities which are required to deal with these violations and challenges specifically and individually) that Newton's laws are supposedly limited by the "scale" factor (related to speed) to the classical domain (see [1]) and hence any supposed failure of Newton's third law in relativistic mechanics should not be a problem (at least in itself) because the domain of validity of relativistic mechanics is not included in the domain of validity of classical mechanics.[16] Yes, such supposed violations should be addressed by those physicists who believe that the validity of Newton's third law extends beyond classical mechanics (assuming that these physicists believe in relativistic mechanics).

Anyway, if this violation of Newton's third law implies a violation of the law of conservation of momentum (which Newton's third law supposedly implies even in relativistic mechanics, assuming the validity of Newton's third law beyond classical mechanics and hence it extends in principle to relativistic mechanics) then we could have a more serious problem because momentum is supposedly conserved in relativistic systems (although this should require some modification to the definition of momentum and possibly other related modifications in conceptualization and formulation). However, these issues and details belong to the relativistic mechanics (which is not the subject of investigation of the present paper) but we should remember what we said earlier that is the conservation of momentum in contemporary physics has extra sources of support and validation (both theoretical and experimental) which are independent of Newton's third law and hence the conservation of momentum should be saved eventually even if Newton's third law is violated or lost altogether.

3.3 Violation in Non-Inertial Frames

Newton's third law is violated (according to some scholars) by the inertial (or fictitious or pseudo) forces which appear in non-inertial frames. We may quote in this regard the following passage (see page 60 of [11]):

Inertial forces are caused not by the interaction of bodies, but by the properties of non-inertial reference frames themselves. Therefore inertial forces do not obey Newton's third law. (End of quote)

We discuss and assess this issue in the following remarks:

1. If these forces are really fictitious (in the sense of being imaginary and illusory) then there should be no violation of any law because they are fictitious and hence it is nonsensical to attribute any real physical effect (such as violating Newton's third law) to them. So, anyone who accepts this claim of violation should accept in advance the physical reality of fictitious forces; otherwise he should be contradicting himself (at least

[16] However, we should remark that (at least) some examples of claimed violations in relativistic mechanics are based on faulty arguments or questionable rationale, and hence they should be rejected regardless of the acceptability (in principle) of such violations due to the imposed limitation on the domain of validity of classical mechanics and Newton's laws of motion.

implicitly).

2. Newton's laws of motion are restricted in validity to inertial frames of reference. Now, fictitious forces (whether we consider them real or not) appear only in non-inertial frames of reference and hence any supposed violation of Newton's third law by these forces should not be a problem to Newton's third law or to the Newtonian mechanics in general because these forces are not supposed to be subject to the Newtonian laws or mechanics because they are not within its domain of validity. Yes, if we consider Newton's third law (or rather its essence) as a fundamental law of Nature that should (in principle) apply in all frames of reference (as some physicists believe) then this could be a sensible claim of violation (regardless of its merit and correctness from this aspect or other aspects and regardless of its relation to classical mechanics).
3. It may be argued that if these fictitious (or rather inertial) forces are real then what is the problem in having an interaction (thanks to the inertia) between the material objects and the *physical* space where one of them acts while the other reacts (even though this may not be consistent with the Newtonian view and possibly other views). In fact, we may even conceptualize this interaction and label it specifically as "inertial interaction".

   However, this can be challenged by the fact that we indicated earlier, i.e. Newtonian mechanics is essentially a theory for the mechanics of particles and hence any supposed interaction that is to be subject to Newton's third law must be between massive particles, and the space is obviously not a particle (in fact this seems to be indicated in the above quoted passage of [11] by "interaction of *bodies*").[17]

   We should note that this reason may also be used as an excuse or pretext for justifying the "non-violation" by claiming that since the supposed interaction involves a non-particle entity (i.e. space) then it should be outside the domain of validity (or rather outside the formulation) of Newtonian mechanics and Newton's third law in particular[18] (but we should notice as well that this sort of argument may be applied even to the real forces in the supposed interactions between particles and physical fields, such as the electromagnetic field, which we discussed earlier).

[17] In fact, this challenge may be enforced by claiming that no "tangible effect" on space can be observed in such presumed interaction and hence this presumed interaction cannot be real.

[18] In fact, this may also be used as a reason for "violation" because it is outside the "domain of validity" of Newtonian mechanics.

3.4 Violation in Interaction between Space and Material Objects

This alleged violation of Newton's third law is based on a philosophical interpretation to the "Newtonian epistemology" about the nature of the relationship between the Newtonian space and the material objects that it "contains" (which, i.e. the relationship, supposedly provides an explanation to the inertial effects that originate from the Newtonian space). This alleged violation is supposedly expressed in the following quote from the Foreword of [10] which reads:

The concept of space was enriched and complicated by Galileo and Newton, in that space must be introduced as the independent cause of the inertial behaviour of bodies if one wishes to give the classical principle of inertia (and therewith the classical law of motion) an exact meaning. To have realized this fully and clearly is in my opinion one of Newton's greatest achievements. In contrast to Leibniz and Huygens, it was clear to Newton that the space concept (a) was not sufficient to serve as the foundation for the inertia principle and the law of motion. He came to this decision even though he actively shared the uneasiness which was the cause of the opposition of the other two: space is not only introduced as an independent thing apart from material objects, but is also assigned an absolute role in the whole causal structure of the theory. This role is absolute in the sense that space (as an inertial system) acts on all material objects, while these do not in turn exert any reaction on space. (End of quote)

We may also quote in this regard the following excerpt from [18]: In Newton's mind this change of condition was acceleration of the body relative to absolute space. It is puzzling that Newton never mentioned the fact that the force of inertia, which opposes acceleration, violates his Third Law of Motion, for absolute space cannot sustain the required reaction force. (End of quote)

In fact, this may be seen as a bizarre view and twisted interpretation to the essence of the relationship between space and material objects in classical mechanics if it is supposed to be about Newton's third law (as the second quote states explicitly). However, regardless of this the essence of this view does not seem to be connected to Newton's third law in the technical sense of this law because this is a view taken from a purely philosophical perspective (i.e. it is not physical or technical) and hence this alleged violation (regardless of its soundness) is irrelevant to our subject and objective of the present paper. Moreover, this sort of interaction may be considered as being cosmological in scale and hence it is outside the domain of validity of classical mechanics and its Newtonian formulation (see [1]) because the Newtonian space is a cosmological entity and not a physical entity in the classical macroscopic sense and at this level.

We should also note (mainly in connection to the second quote) that if the inertial forces are considered as reaction forces generated by the Newtonian *physical* space in response to the action forces that generate the acceleration (see [1]) then it may be claimed that there should be no violation to Newton's third law. However, this may be challenged by the fact that both forces (according to this conceptualization) act on the same object and hence this is not a subject for Newton's third law whose (action and reaction) forces act on separate objects. So, if "no violation" should be accepted then it should be in this negative sense.

We should finally note that the issue in this subsection is intimately related to the issue of the previous subsection (see § 3.3). However, we prefer to consider these two issues as separate and independent of each other. This is based on our distinction between the "resistance of inertia" (or the "force of inertia" as stated in the previous quote) which is a property of material objects that demonstrates itself in all types of frame (whether inertial or non-inertial), and the "inertial forces" (or fictitious or pseudo forces) which are a property of non-inertial frames of reference since these forces demonstrate themselves only in non-inertial frames.

3.5 Violation in Biology

There are claims in the recent literature of physics (mostly within the category of science popularization) that Newton's third law is violated in some biological systems and phenomena such as in the movement of sperms. However, we think these claims should not be taken seriously at this stage for various reasons such as:

1. There are many ambiguities surrounding these claims and this should question their credibility. It is likely that these claims are made by biologists who have poor understanding of physics and its main role which is the rigorous determination of the fundamental laws of Nature and hence it is not about phenomenological analogies and similarities that can be found in popular science and everyday chats and activities. In fact, this claim of violation may be similar to the use of Newton's third law in daily conversations and political debates (where some people try to give themselves the image of being smart, sophisticated and well-educated by quoting Newton's third law foolishly and nonsensically).
2. This issue is related to the issue of biology (and life ultimately) and if it is part of physics or not, i.e. whether biological phenomena and life obey the physical laws (possibly in a

very complex form) and hence they belong to physics or not (in which case they should be subject to a different type of laws and hence they are beyond the reach of physics at least in its current state of development). This issue, as well as its consequences and implications, is not clear cut and could be a matter of choice and convention. Therefore, this issue may not have a definite answer since it depends on personal choice and preference.

However, it should be obvious that everything that we observe in this world belongs to the physical world including the biological systems and phenomena (to which these cases of alleged violation of Newton's third law belong) and hence they are physical in this sense and should be subject ultimately to the fundamental laws of physics. Nevertheless, it should also be obvious that not everything that is physical (i.e. belonging to the physical world and subject ultimately to the fundamental laws of physics) belongs to the science of physics. In fact, contemporary physics should be restricted by definition and convention to phenomena that do not involve things like life and human behavior which are too complex to be tackled by our current (and rather limited) knowledge and understanding of the physical world. Hence, biological and social sciences for instance (as well as many other branches of science and knowledge) should not be seen as branches of physics (at least in its current state) despite being physical in the aforementioned sense and subject ultimately to the fundamental laws of physical world.

Yes, if physics becomes so powerful and broad to the limit that it can formulate laws and principles capable of describing and predicting the behavior of biological and sociological systems and their phenomena (as well as similar complex systems and phenomena) then these branches of science could be included as branches of physics in its extended sense. However, this seems to be a non-achievable (and possibly impossible) goal at least for the foreseeable future. If our current physics (which is based on many simplifications and deals mostly with very simple physical systems) cannot find (exact) solutions even to some of the simplest systems (like the helium atom) then there is no hope (at least for the foreseeable future) to extend physics to this ambitious extent and dimension. In fact, physics in its current state (despite its complexity and elaboration) is a very simple and primitive science (in comparison to the complexities of the physical world that it is supposed to depict) that effectively deals only with the very simple systems using very simple models, patterns, techniques, methodologies ... etc. most of which are no more than imitations and approximations. So, we should not be very ambitious at this stage of scientific development to expect that we can develop physical theories about life or biological systems or society or economy for instance.

To conclude, the investigation and analysis of biological systems and phenomena by contemporary physics and within its current frameworks and tools is entirely inappropriate. Contemporary physics is too simple to deal with such complex systems and phenomena even though these systems and phenomena are physical in the above sense and they belong to the physical world and hence they should be subject ultimately to the fundamental laws of "physics" although this must be in a very complex and sophisticated way due to their complexity and sophistication. So, any claim of violation of Newton's third law (or any other physical law) in biological systems and phenomena should be treated at this stage with caution and skepticism.

3.6 Other Violations

There are a number of other claims (mostly in the recent literature of physics) of violations of Newton's third law in various physical systems and disciplines. In fact, some of these systems and disciplines do not seem to belong to classical mechanics and may not fall within its domain of validity. Moreover, some of these claimed violations may not be really violations to the fundamental physics of Newton's third law (i.e. they can be similar in nature to the claimed violations in biology which we discussed in § 3.5). These claims include, for instance, violations in colloidal systems, fluid dynamical systems, and statistical mechanical systems (see for example [12, 19–21] noting that there is some overlapping in this categorization).

However, such violations may be explained and justified by the commonly held view of keeping the (very sacred) principle of conservation of momentum while sacrificing the (less sacred) Newton's third law (if this sacrification is required). They may also be explained and justified by claiming, for instance, that Newton's third law holds true for the complete "particles-plus-environment" systems (similar to the previous justifications with regard to the conservation of momentum) even though it does not hold for the particles (or matter) involved in these violations (see for example [21]). In fact, claims like this are generally based on a desire to keep Newton's third law safe, i.e. they are not based on solid experimental evidence or theoretical foundation independent of this desire (which is generally based on a conviction that Newton's third law is a fundamental law due, mostly, to its intimate link to the conservation of momentum which is seen unanimously as a fundamental law of Nature).

4 General Remarks

Before we reach the end of this paper by summarizing our conclusions it is useful to take notice of some general remarks as outlined in the following subsections.

4.1 Dependence of Claimed Violations on Adopted Theoretical Frameworks

The views and stands on both sides of the debate about the claimed violations of Newton's third law (as well as their potential impacts and implications related, for instance, to their effects on the integrity and generality of the principle of conservation of momentum) are highly dependent on the adopted theoretical frameworks and individual choices as well as disputable theories and paradigms (such as special relativity and action at a distance). In fact, in most cases the judgments made and the conclusions reached about these alleged violations and their potential consequences strongly depend on individual views and opinions (which mostly represent personal tastes and preferences) about certain physical theories and issues (e.g. whether we believe in special relativity or not and whether we employ Lorentz force law in our theoretical framework and analysis or not).

We should also note that certain conceptualization elements which are closely related to epistemology (rather than formalism) are employed sometimes in analyzing the instances of claimed violation and drawing the conclusions from them. For example, in some instances of alleged violation of Newton's third law the authenticity of violation depends (in part) on the conceptualization of the reaction force which (i.e. this conceptualization) depends on the missing asymmetry in Newton's third law (which we discussed in § 2.3.6 of [1]), i.e. whether we have a symmetric situation (since the force exerted by both objects can be conceptualized as only action or only reaction) or we have an asymmetric situation[19] (since we can conceptualize the situation as having two action forces and two reaction forces which is like the situation of two persons pushing each other equally and symmetrically); see points 2 and 3 of footnote 20 of [1].

4.2 Insufficiency of Experimental Evidence in this Debate

Most views and opinions about the claimed violations of Newton's third law (on both sides of the debate) are not based on hard experimental evidence, i.e. they are based

[19] Or rather a double or reciprocal asymmetric situation.

either on purely theoretical analysis (which usually rests on commonly accepted theories and paradigms of modern physics) or on experimental evidence analyzed by tentative or questionable theoretical frameworks (see § 4.1). This should cast a shadow on the credibility of many of these instances of violation and the adopted views and stands (on both sides of this debate).

In fact, some of these claims can be verified conclusively and decisively by conducting laboratory experiments to measure the (magnitude, direction and alignment of) action and reaction forces directly and independently of the adopted theoretical frameworks or theories (such as electrodynamics and special relativity) which are used in the analysis of the alleged violations and in the drawing of the reported results and conclusions.

4.3 Seriousness of Claimed Violations

In our view, the claimed violations (assuming their authenticity, i.e. the evidence and arguments forwarded in their support are correct and acceptable in general) fall into three main categories:

1. Very serious violations which are (mostly) those that threaten the principle of conservation of momentum (whether linear or angular) or its generality from some aspects or in some fields. We should also include in this category those which are threatening some fundamental theories (such as special relativity) for those scholars who embrace these theories.
2. Serious violations which are those that threaten Newton's third law but not the principle of conservation of momentum (or other fundamental principle or law or theory of physics).
3. Minor or trivial violations which are those that can be tackled and fixed by some minor modifications and mild compromises and amendments to the adopted frameworks and personal choices and preferences, and hence any supposed breach or violation of Newton's third law (or other principles or laws or theories of physics) can be avoided.

In fact, all these categories seem to exist within the existing instances of claimed violations. It should be obvious that the (degree of) seriousness of these claimed violations and breaches should (similarly and equally) impact the epistemology of the affected laws and theories (and actually the contemporary physics in general) as well as the affected formalism.

5 Conclusions

We outline in the following points the main conclusions that we can obtain from the investigation of the present paper:

• The violation of Newton's third law is mostly (but not unanimously) accepted in contemporary physics. In fact, we can identify three main groups of physicists with regard to this issue: those who definitely accept this violation, those who definitely reject this violation (and hence they propose certain remedies and fixes to keep the third law intact), and those who do not take any specific position and hence they avoid expressing their view, if they have any view, about this issue (i.e. they do not seem to care about Newton's third law as long as the conservation of momentum is preserved). This is unlike the principle of conservation of linear and angular momentum which (unanimously) survives in these supposed violations (i.e. we are not aware of physicists who regard these supposed violations of Newton's third law as violations to the conservation of momentum).

• The violation of Newton's third law should cast a shadow on the status of this law as a real physical law within and outside classical mechanics (noting that what is significant, or more significant, of such violations is the violation within classical mechanics due to the limited validity of Newton's laws to the validity domain of classical mechanics, i.e. classical macroscopic scale and inertial frames of reference).[20] This should have serious epistemological (and possibly formal) implications and consequences on classical physics (and possibly beyond).

• The violation of Newton's third law requires further investigation to its actual relationship with the principle of conservation of momentum and if this principle could be affected or violated by the violation of Newton's third law (at least within the framework of classical mechanics). This is because the aforementioned unanimity about the integrity of the principle of conservation of momentum in these instances of violation seems to be based (at least in part) on a general conviction among contemporary physicists of the sacredness of this principle which mostly originates from general theoretical and mathematical arguments (such as the supposed properties of space and related symmetries) rather than independent and specific analysis and investigation to these instances of violation individually and specifically.

• The violation of Newton's third law may require imposing further limitations on the

[20] We should note that "limited validity of Newton's laws" should mean "in principle and primarily" noting that (at least) some of these laws may be extended in validity (according to the view of some physicists) beyond classical mechanics and its domain of validity (as explained earlier).

domain of validity of classical mechanics (and its Newtonian formulation in particular) in addition to those already-imposed limitations (i.e. classical macroscopic scale and inertial frames of reference; see [1]).

• The contradicting views about the violation of Newton's third law add more ambiguities (in addition to what we discussed in [1]) to this alleged law especially from the epistemological and interpretative perspectives.

• Most (if not all) views about the violation of Newton's third law (on both sides of the debate) are not based on hard experimental evidence, i.e. they are based either on purely theoretical analysis or on experimental evidence analyzed by tentative or questionable or debatable theoretical frameworks. Moreover, the judgments about such violations usually depend on views and opinions (as well as personal choices and preferences) about certain physical theories and issues (e.g. whether or not we believe in special relativity or employ Lorentz electrodynamics in our framework and analysis). These factors and complications (as well as the other mentioned factors in this regard) should increase the ambiguity and uncertainty about this problematic issue.

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