Fundamental Physics in the Principle of Relativity

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Abstract

This paper investigates the physical logic of the relativity principle in particle dynamics. Through an analysis of causality in dynamics, it identifies the root cause of the problems regarding inertial forces and inertial frames in Newtonian mechanics, discovering that the formal system of Newton's second law neglects to consider the causal correspondence of reference objects. The dynamic characteristics of a reference frame should be attributed to the reference object itself. Consequently, reference objects and the objects under investigation should be placed on a completely equal footing. Therefore, this paper introduces a new equation for particle dynamics that is unaffected by inertial frames and can be directly applied in all translational reference frames. For rotating reference frames, on the one hand, the nature of inertial forces has been revealed previously—namely, that they are real forces acting on reference objects weighted by mass ratios. Therefore, the physical effects of gravity have been clearly established as not equivalent to the physical effects of inertial forces. On the other hand, according to the spirit of causal correspondence, extending the relativity of dynamics to rotating reference frames requires determining the physics of the rotating reference frame, which further necessitates including the dynamic properties of at least four non-coplanar reference objects that define the reference frame. Therefore, from a mathematical perspective, there is currently no way to construct a unified, concise formula. It is precisely based on these two fundamental physical considerations that this paper argues any current generalized principle of relativity lacks sufficient justification. The key to extending the relativity principle of dynamics lies in ensuring the causal correspondence of reference objects on both sides of the dynamic equation.

Full Text

Preamble

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Abstract

This article investigates the physical logic underlying the principle of relativity for particle dynamics. Through analysis of causal correspondence in dynamics, we uncover why the puzzle of inertial force and inertial reference frames persists in Newtonian mechanics. The conclusion is that the causal correspondence of the reference frame has been neglected in the formulation of particle dynamics. The dynamical properties of a reference frame should be attributed to its reference object, and simultaneously, the reference object and the object under investigation should be placed on a completely equal footing. Therefore, we introduce a new particle dynamics equation that is unaffected by inertial reference frames and remains invariant across all translational frames of reference.

Regarding rotating reference frames, on one hand, the nature of inertial forces is revealed as the mass-ratio weighted real force acting on the reference object. Consequently, the physical effect of gravitational force is not equivalent to that of inertial force. On the other hand, in the spirit of causal correspondence, the physics of rotating reference frames must incorporate the dynamical properties of four non-coplanar reference objects. Hence, it is difficult to reconstruct this into a concise formula. In this sense, this article also proposes that Einstein's principle of general relativity is not credible. The key to extending the dynamical principle of relativity lies in ensuring causal correspondence of reference object(s) on both sides of the dynamical equation.

Keywords: Particle dynamics; Inertial force; The principle of relativity; Reference object

1 Introduction

The dynamical principle of relativity represents a fundamental property of dynamics, defining the scope of applicability of dynamical equations. Within this applicable scope, the dynamical equation remains valid provided its mathematical form and physical definition remain unchanged.

In Newtonian mechanics, the principle of relativity for particle dynamics is the Galilean principle of relativity [**?**, **?**]. This principle states that the laws of classical mechanics are mathematically invariant in any inertial reference frame. In other words, all inertial frames of reference are equivalent (equal weight). Newton's second law can only be applied to inertial frames of reference (here the inertial reference frame is denoted by Σ, and the investigated moving object or particle is denoted by p):

$$F_{jp} = m_p a_{jp(\Sigma)}$$

The puzzle, however, is that Newton's second law is only applicable in inertial reference frames, yet the inertial reference frame is itself defined by Newton's first law. That is, if an object can always remain in a state of relative rest or uniform linear motion without interaction, then the reference frame is inertial. The condition for defining an inertial reference frame is substantively included in Newton's second law. Therefore, given that inertial reference frames cannot be found in practice, a logical circularity exists according to these definitions [**?**, **?**]. As shown in the second section of this article, such a logically circular definition is entirely avoidable.

For actual reference frames, which are non-inertial (here denoted by O), no dynamical equation can be applied directly. Even through mathematical transformation of Newton's second law [**?**], we obtain:

$$F_{jp} = m_p a_{jp(\Sigma)} \Rightarrow F_{jp} = m_p[a_{jp(O)} + a_{O(\Sigma)}]$$

$$F_{jp} + (-m_p a_{O(\Sigma)}) = m_p a_{jp(O)}$$

In the kinematic portion of the above equation, acceleration is expressed relative to a non-inertial reference frame. However, such an expression is not a true dynamical formula, because the second term on the left-hand side $(-m_p a_{O(\Sigma)})$ is not a real force—it can neither be calculated theoretically like other common forces nor measured in practice, since the inertial reference frame Σ is still required as a premise. As a fictitious force, the definition of inertial force is introduced [**?**]:

$$f_{inertial} = -m_p a_{O(\Sigma)}$$

Thus, an equation that simulates Newton's second law for non-inertial reference frames is obtained:

$$F_{jp} + f_{inertial} = m_p a_{jp(O)}$$

It is worth noting that the calculation formula for inertial force still requires finding an inertial reference frame first. Therefore, the above formula does not overcome the dilemma that Newtonian mechanics' dynamical equations are always limited to the non-existent inertial reference frame [**?**]. In practical applications, kinematic quantities also cannot be measured by referring to an absolute background of the universe [**?**], so an approximated inertial reference frame must be directly selected for mechanical analysis. If the approximation is insufficient, the magnitude and direction of an inertial force must be further considered.

In special relativity, the dynamical principle of relativity is extended to the principle of special relativity. That is, all physical laws (mechanics, electromagnetism, and other interacting dynamical laws) are required to maintain mathematical form invariance in all inertial reference frames. In other words, the scope of equivalence between reference frames (equal weight) remains limited to inertial reference frames. Compared with Newtonian mechanics, the scope of application of dynamical laws is not significantly broadened [**?**].

In general relativity, Einstein's principle of general relativity is introduced as an axiom. The principle of general relativity is summarized as follows: all reference frames (including translational and rotating reference frames) are equal, meaning that an objective and realistic physical law should be established within all physical reference frames with unchanged mathematical forms. Compared with the originally inescapable inertial reference frame, the dynamical principle of relativity in Einstein's general theory of relativity is broadened to the greatest extent as a self-evident axiom [**?**, **?**]. As we all know, general covariance is a very important theoretical property of Einstein's general theory of relativity. The principle of general relativity is precisely the physical basis of general covariance [**?**] and therefore one of the theoretical cornerstones of Einstein's general theory of relativity. It was the "free-falling elevator" thought experiment that provided Einstein with the inspiration and ideas that led to Einstein's (non-weak) equivalence principle, which states that inertial force and gravitational force are physically equivalent. It is Einstein's (non-weak) equivalence principle that gives the principle of general relativity its "conceptual ladder" [**?**, **?**]. However, compared with the principle of Galilean relativity and the principle of special relativity, the principle of general relativity still lacks key theoretical proof and credible evidence.

This paper is devoted to exploring the physics and logic of the principle of relativity for particle dynamics. From the perspective of causal correspondence, we discuss the possibility of incorporating translational and rotating reference frames into the dynamical principle of relativity. The paper is organized as follows. The first part, as an introduction, expounds on the background and development of the principle of relativity. In the second part, we investigate the formal logic of Newton's second law. According to the most fundamental requirement of causal correspondence, we introduce a new particle dynamics equation applicable to any translational reference frame. The third part reflects on the above successful reformulation of Newton's second law, which fully demonstrates the importance and indispensable role of the reference object in establishing particle dynamics equations. The fourth part, combined with the fundamental requirement of causal correspondence for the reference frame, dwells on the mandatory requirements for extending the principle of relativity into rotating reference frames. The fundamental difficulty of such an extension is pointed out. Finally, this paper briefly explains that a moderately generalized principle of relativity can meet the basic requirements of physics.

2 Successful Reformulation of Newton's Second Law

The vitality of physical laws lies in their predictability. According to predictability, cause and effect can generally be separated. Therefore, the causal correspondence between cause and effect can be regarded as the most fundamental requirement for physical laws [?].

Before analyzing causal correspondence in the formalism of particle dynamics, there is a cognitive problem about reference objects and reference frames that must be clarified first. Are reference objects and reference frames mathematical or physical? As a useful reference frame in physics, at least its reference origin must be established on a real reference object [?, ?]. This is particularly obvious in the selection of non-inertial frames of reference. Only when the reference object is selected does the non-inertial reference frame become exactly clear. Even for the center-of-mass reference frame, the solid reference object selected by the center-of-mass reference frame is equivalent to all the particles in the entire particle system, but the spatial position of the center-of-mass is redefined and processed mathematically.

Therefore, when studying the motion of the center-of-mass relative to the external environment, we must consider the total external forces acting on all particles in the entire particle system. If the center-of-mass reference frame is not boiled down to solid reference objects, there would be no sense of force for the center-of-mass.

Because a physical reference frame must be found in the real universe, there is a problem with whether it can be found [?]. A mathematical reference frame is a category of definition. When using the ground (or laboratory) reference frame, in fact, any stationary object in the ground (or laboratory) can be selected as the reference object. Acceleration is measured with respect to any point at rest on the ground (or in the laboratory), equivalently, with respect to any object at rest at that point. In this case, the reference object is the object at rest at that point. In principle, the range of the reference object can be arbitrarily determined as long as it can be regarded as a particle. Because when the ground (or laboratory) reference frame is approximated as an inertial reference frame, properties such as the mass of the reference object do not matter in the calculation. But a real object must exist at that point; otherwise, physical measurements such as acceleration cannot be truly validated and executed. It is precisely the materialist view that the physics of the reference frame must be attributed to the reference object, and the reference object must be real. Upon this foundation, a universal particle dynamics equation can be rigorously derived, as has been shown before according to a fundamental requirement of causal correspondence [?]. But here we are going to demonstrate a more coherent and deeper logic that reflects the irreplaceable physics in the extension of the dynamical principle of relativity.

First, in Newtonian mechanics, the law of causality, which is summarized directly from a large number of classical mechanics experiments and used as the basis for determining the calculation formula of common forces, is not Newton's second law [?], because the exact inertial reference frame has never been found and the total net force required by Newton's second law has never really been fully counted. On the premise that the reference frame is fixed, we usually describe the dynamics of a moving object compared with its previous mechanical state. The newly imposed force and the resulting relative acceleration constitute a causal difference equation between the previous and subsequent states. In this sense, the law of causality relied upon is an empirical law just described by a difference equation:

$$\Delta F \propto m\Delta a$$

Here ΔF represents the newly imposed force compared with the previous state, and Δa represents the resulting acceleration increment compared with the previous state. Historically, such a difference equation (the differential causality may be expressed as $dF \propto m\,da$) has been the basis in the study of calculation formulas for common forces, including gravitational force, friction, and elasticity. Once the calculation formula for forces has been summarized from particular experiments, the dynamics equation can be tested in other general cases. Therefore, particle dynamics is essentially a causal law about force and acceleration—force should be the cause, and acceleration is the effect [?].

Second, there is a necessary procedure: the difference equation ($\Delta F = m\Delta a$) as an empirical law must be elevated to a theoretical formula, where the force term must count all forces acting on the particle. Because if we don't, every time we apply the formula in a new situation, we won't know which force should be taken into account and which should not.

Third, when Newton's second law is desired to be applicable in a practical reference frame (O), its theoretical formula should be written as $F_{jp} = m_p a_{jp(O)}$. Since force is the cause and acceleration is the effect, the cause (F_{jp}) depends only on the object under investigation p, while the effect ($a_{jp(O)}$) depends both on p and on the reference frame O (in fact, equivalently dependent on the reference object o, which is defined as the origin of the reference frame). Now, from a different perspective, skipping the details of force and acceleration and looking only at the above equation formally (with the specific selection of particle as the variable), it is equivalent to saying that there is only one formal variable of cause (F_{jp}): p, while there are two formal variables of effect ($a_{jp(O)}$): p and o. However, the measured relative acceleration is determined to vary with o. Therefore, judging from this formal logic, it is obvious that the cause and effect contained in the above Newton's second law do not satisfy one-to-one correspondence (the formal variables are different). This is called causal asymmetry in this article.

The causal asymmetry exists on both sides of Newton's second law formula.

That is why Newton's second law only applies to the inertial reference frame, which exists only in theory rather than in practice. In other words, if the traditional theoretical formula of Newton's second law is desired to be directly applicable in any practical reference frame, it is not adequate to consider only the forces acting on the object under study; the forces acting on the reference object should also be considered, since any practical reference frame is defined according to a real reference object. It is worth emphasizing that the requirement of causal correspondence is so fundamental that it is not limited to the specific form of particle dynamics; whether classical mechanics or relativistic mechanics, the requirement of causal correspondence should be implemented in general. The actual reference frames are ever-changing in practice, and the actual accelerations relative to the reference frames are also ever-changing. As long as force corresponds to the cause and acceleration corresponds to the effect, why do we only need to consider the force acting on the investigated object but not consider the force acting on the reference object?

Finally, how can we establish the correct theoretical formula based on the causality given by the difference equation ($\Delta F \propto m\Delta a$)? The key is to ensure that the force and acceleration of the reference object satisfy causal symmetry on both sides of the new particle dynamics formula. The only new physics that should be included may be that, for the first time, the dynamics of the reference frame is properly attributed to the reference object, to which Newton's second law is naturally applied. The complete derivation is presented as follows.

At any given moment, the total force acting on a particle under study should be objective and not change with the observer. Therefore, the corresponding result must also be objective—that is, independent of the choice of reference frames. A complete objective acceleration of the particle under study can only be expressed as the acceleration in the background of cosmic space:

$$F_{jp} = m_p \frac{d^2}{dt^2} \Omega_{jp}$$

The background of cosmic space here refers to the void left in the universe after the removal of all evolvable things. The objectivity of the position here simply means that it has nothing to do with any artificial choice made by the human mind. Therefore, the particle's position in the background of cosmic space is inherently objective since the frame of reference has not been artificially introduced. Here the letter Ω is specially used to indicate the objective position of the particle in the background of cosmic space. This point is exactly analogous to the concept of "event" in special relativity [**?**]. The objective position of any particle at any moment actually constitutes an event.

Similarly, in special relativity, any event itself is assumed to have an objective position in the background of space-time so that the coordinate values of the same event can be related in different inertial reference frames. To say the least, at any moment, any particle with an objective position in the background of cosmic space is also a necessary but not sufficient component of Newton's absolute space-time view.

Digging deeper, the fact that a particle or event has an objective position in the background of cosmic space might mean that the background of cosmic space is absolute. In order to be compatible with the experiments of relativistic physics, it is necessary to minimize the extent to which the absolute concept exists. The concept of space-time may be further divided into the background of space-time and the scale of space-time. The scale of space-time is actually the length of the basic units of space-time, which is defined by the observer according to the physics phenomena inherent in the natural material world, so it should be affected by some kinds of interactions and could be relative. But the background of space-time reflecting the length of the scale of space-time must be absolute. Because the background of space-time itself is not a specific matter, there is no interaction acting on it. Therefore, the simplest basis of deduction here may indicate that only the background of cosmic space is absolute.

Although a particle has an objective position in the background of cosmic space, the objective position itself cannot be measured directly. What we can really measure is the difference between two objective positions. Introducing the actual reference object, it naturally constitutes a mathematical vector:

$$\mathbf{r}_{jp(o)} = \Omega_{jp} - \Omega_{jo}$$

Thus, we can construct a particle dynamics equation that can be used directly by observers. Any object in the universe should be equivalent in the most basic laws of dynamics. So for the actual reference object o, its dynamics also satisfies:

$$F_{jo} = m_o \frac{d^2}{dt^2} \Omega_{jo}$$

Here the reference object o is defined as the reference origin of a non-rotating reference frame O. Thus, a reference frame without rotation relative to the background of cosmic space can be established. The nature of choosing a reference frame is to make a relative measurement of acceleration, and as a causal correspondence, forces should also be relatively counted [**?**]:

$$\frac{F_{jp}}{m_p} - \frac{F_{jo}}{m_o} = \frac{d^2}{dt^2}[\Omega_{jp} - \Omega_{jo}] = \frac{d^2 \mathbf{r}_{jp(o)}}{dt^2} = \mathbf{a}_{jp(o)} = \mathbf{a}_{jp(O)}$$

The acceleration relative to the reference object o is equal to the acceleration relative to the reference frame O. F_{jp} and F_{jo} respectively represent the total force acting on the object under study p and the total force acting on the reference object o from the whole universe (but not including forces that have not been transmitted). Obviously, Eq.(9) is applicable to any non-rotating reference frame O (note: here the applicable reference frame must be non-rotating since

$\mathbf{a}_{jp(o)} = \mathbf{a}_{jp(O)}$). Newton's second law is just a special case of the new particle dynamics equation (9) when the total net force acting on the reference object is zero ($F_{jo} \approx 0$). Therefore, strictly speaking, the new particle dynamics equation and Newton's second law are not equivalent [?]. But the new particle dynamics equation complements an independent term omitted by Newton's second law in the "definite integral" process of their common differential causality ($dF \propto m\, da$).

In special relativity, the theoretical dynamics equation is $f = dp/dt$, but our reformulation starts from $F_{jp} = m_p a_{jp(O)}$. Why is this reasonable? In fact, the former formula is only more applicable to the case of variable mass than the latter. The essence of the variable mass problem in the classical low-speed case (such as the rocket launching problem) can be attributed to the separation and relative motion between particles in a particle system [?], rather than being an issue of dynamics of a single particle. Thus, the fundamental equation for particle dynamics in Newtonian mechanics is still $F_{jp} = m_p a_{jp(O)}$, and $f_{jp} = dp_{jp(O)}/dt$ can be regarded as an effective form introduced when single-particle dynamics is extended to particle systems. As for special relativity, the relativistic form of particle dynamics $f_{jp} = dp_{jp(O)}/dt$ is favored because the mass of a particle can change, and its physical origin can be attributed to the principle of constant speed of light. But in fact, even in relativistic mechanics [?], the real basic starting point is $F^{\mu} = m_0 d^{2x^{\mu}}/d\tau^2$. Only in a specific reference frame is the relativistic form $f_{jp} = dp_{jp(O)}/dt$ derived from this starting point.

3 Application Example of the Generalized Dynamics Equation

We take a three-body system including the Sun (S), the Earth (E), and the Moon (M) as an example to illustrate the practical advantage of the generalized dynamics equation (9). The dynamics of the Moon with respect to the Earth is addressed. Since the geocentric reference frame is not exactly inertial, the dynamical equation is given by Newtonian mechanics:

$$F_{M \leftarrow E} + \mathbf{f}_{inertial} = m_M \mathbf{a}_{M \leftarrow E}$$

However, to solve the dynamics of the Moon in the geocentric reference frame, an inertial frame of reference must be introduced first. Because the investigated system is an ideal system only including the Sun, Earth, and Moon, there is no substantial object that can be approximated to establish an inertial frame of reference to a high degree. In principle, direct application of equation (10) is difficult. However, to show the influence on calculation accuracy brought by the approximation of the inertial reference frame, it is assumed that the heliocentric reference frame can be approximated as the inertial reference frame. Therefore, in the heliocentric reference frame, the inertial force is approximated as:

$$\mathbf{f}_{inertial} \approx -m_M \mathbf{a}_{E\leftarrow S}$$

The degree of approximation of the selected heliocentric reference frame will directly determine the accuracy in solving dynamics equation (10) in practice. The higher the actual reference frame approximates the inertial reference frame, the higher the calculation precision will be. Then, to calculate $\mathbf{a}_{E\leftarrow S}$ accurately, we need to measure the acceleration of the Earth relative to the Sun. If we expect to do this mathematically by reversing the process to theoretically solve $\mathbf{a}_{E\leftarrow S}$, we will get stuck in the same cycle as when we started to calculate $\mathbf{a}_{M\leftarrow E}$.

Here, the heliocentric reference frame can be approximated again as an inertial reference frame. So the acceleration of the Earth relative to the Sun numerically satisfies Newton's second law as an approximation:

$$\mathbf{a}_{E\leftarrow S} \approx \frac{F_{E\leftarrow S}}{m_E}$$

So far, in the application of Equation (10) under the traditional approach, it has been superimposed with two approximations at the theoretical stage, rather than at the actual measurement or statistical stage.

In contrast, when the generalized dynamics equation (9) is directly applied:

$$\frac{F_{M\leftarrow E}}{m_M} - \frac{F_{E\leftarrow S}}{m_E} = \mathbf{a}_{M\leftarrow E}$$

Because the discussion is limited to the ideal three-body system, the forces acting on the Moon and the Earth can be calculated respectively according to the law of gravity:

$$F_{M\leftarrow E} = G\frac{m_M m_E}{r_{M\leftarrow E}^2} + G\frac{m_M m_S}{r_{M\leftarrow S}^2}$$

$$F_{E\leftarrow S} = G\frac{m_E m_S}{r_{E\leftarrow S}^2} + G\frac{m_E m_M}{r_{E\leftarrow M}^2}$$

Substituting back the above theoretical expression of the force, equation (13) can be directly solved. It's not hard to verify that the inertial force in (10) is exactly expressed as:

$$\mathbf{f}_{inertial} = -m_M \frac{F_{E\leftarrow S}}{m_E}$$

By comparing (16) with (11), it can be found that no approximation is used in the application of the generalized dynamics equation (9). The expression

(16) for the inertial force is accurate here. While in the traditional approach of formula (10), the real calculation of inertial force inevitably requires approximation. The application of the generalized dynamics equation (9) eliminates the approximation and avoids the resulting error in precision.

Interestingly enough, in the traditional approach, the obtained expression for inertial force will return to the exact expression (16) if and only if the inertial reference frames are approximated twice to the same extent (see (12) substituted back into (11))! In fact, the twice approximations of inertial reference frames of the same degree perfectly offset the error caused by the approximation itself. And this exact cancellation is actually independent of the degree of approximation. That is to say, it is independent of what kind of actual reference frame is chosen to approximate the inertial reference frame. This shows that under the standard framework of Newtonian mechanics, if the approach in the non-inertial reference frame is still dependent on the concept of the inertial reference frame, it is essentially running in circles. However, the application of the generalized dynamics equation (9) has captured the essence of physics.

In a word, our reformulation of the particle dynamics equation is successful, and the idea of extending the principle of relativity from inertial reference frames to translational reference frames is correct.

4 Causal Correspondence and the Indispensable Reference Object

In fact, in Newton's second law for the reference frame, only its state of motion is considered, but the force acting on the reference object has been ignored [**?**]. This causes Newton's second law to hold in theory only in inertial frames of reference, though no strict inertial reference frame can be found in practice.

Perhaps someone looking back at the application of traditional Newton's second law might think the reference object doesn't seem necessary to the reference frame itself. Actually, this is not the truth. As long as it is a real physical application, the reference object must be used; otherwise, it is impossible to define the origin point of the reference frame. This is particularly obvious in the selection of non-inertial frames of reference. Only when the reference object is selected does the non-inertial reference frame become exactly clear. However, in the selection of the ground and laboratory reference frame, this point is very hidden and seems to never be related to the specific reference object. A fundamental reason is that here the ground or laboratory reference frame has been approximated as an inertial reference frame, so the force acting on the reference object, which corresponds to the inertial force, is ignored from the generalized dynamics equation. But in practice, even if the force acting on the reference object is ignored, the acceleration of the object under study must still be measured relative to the actual reference frame. Otherwise, there would be no problem with finding an inertial reference frame.

In fact, if the generalized dynamics equation (9) takes the special case:

$$F_{jo} = 0$$

which just means that the total force acting on the reference object equals zero, the formula (9) reduces back to Newton's second law. Therefore, Newton's second law can definitely be derived from the generalized dynamics equation (9), but not vice versa, because in the derivation of the generalized dynamics equation, new physics has actually been added. The dynamics of the practical reference frame is completely attributed to the reference object, and the reference object is also completely placed on an equal status with the object under study.

Compared with the Newtonian era, people at that time were easily bound by ideas such as "geocentric theory" or "heliocentric theory," and even Einstein had the idea of a steady-state universe at the beginning. On one hand, this led to people depending on the idea of an absolute inertial reference frame for a long time without reconstructing the dynamics equation directly from the non-inertial reference frame. On the other hand, it is precisely because of the preconceived concept of an inertial reference frame that people tend to only consider the kinematical properties of the actual reference frame relative to the inertial reference frame and do not further consider the force acting on its reference object.

The reference object is indispensable for describing particle dynamics. In the spirit of causal correspondence, no matter what the specific form of particle dynamics is, whether relativistic or non-relativistic, as long as the force acting on the reference object does not appear in the formula of particle dynamics, the dynamics equation cannot be truly generalized into actual reference frames.

5 Mandatory Requirements from Rotating Reference Frames

First, from a physical point of view, we investigate the basis of the principle of general relativity. Compared with Newton's second law (1), the second term of equation (9) is explicitly added, which just explains the extra term introduced by the transformation of reference frames for Newton's second law—inertial force. By comparing equation (9) with equation (4), the physical nature of the inertial force originating from the form of Newton's second law is expressed as [**?**]:

$$\mathbf{f}_{inertial} = -m_p \frac{F_{jo}}{m_o}$$

It can be seen that the nature of inertial force is the mass-ratio weighted real force acting on the reference object, which can be gravity or other common forces. More importantly, this force is not applied to the object under study but to the reference object. Because the concept of inertial force [?, ?] is rooted in the form of Newton's second law, to fundamentally solve the problem of inertial force, the best and most thorough way is to find the exact equivalent correspondence or physical substitution under the exact same framework. Given the above explicit explanation, the nature of inertial forces is proved to be not physically equivalent to gravitational force. Therefore, Einstein's principle of general relativity, which is just based on the equivalence principle [?, ?, ?], is now provided with solid evidence to the contrary.

Second, from a mathematical point of view, whether particle dynamics can remain invariant under rotational transformation between reference frames can be analyzed qualitatively according to the fundamental requirement of causal correspondence. It is well known that for a physical reference frame attached to a rotating rigid body, at least four non-coplanar reference particles fixed on this rigid body are needed to determine all kinematic properties for the rotating rigid reference frame. Therefore, when constructing the formula of dynamics, if a physical rotating reference frame is selected, the formula of dynamics must theoretically include at least four non-coplanar reference particles' kinematical information and exerted forces simultaneously to maintain causal symmetry on both sides of the dynamics formula. This is very difficult and needs further study, but at least it has not been achieved under the current framework of mathematical physics. Moreover, to investigate one moving particle in a rotating reference frame, the dynamics formula must therefore introduce four non-coplanar reference particles simultaneously, which is also extremely uneconomical in metaphysics.

Finally, it is suggested that the principle of physical relativity for particle dynamics should be generalized to all translational reference frames. For the rotational part, the rotating reference frame can be used in principle, but it should first make a coordinate transformation into the adjoint translational reference frame, and then the new generalized dynamics equation is applicable.

Based on the above analysis in terms of physics and mathematics, we propose that Einstein's principle of general relativity is not credible.

6 Conclusions

This paper is devoted to the practical applicability of particle dynamics. Therefore, hypothetical reference frames in mathematics are not included in our discussion. Because in principle, the dynamics in this kind of imaginary reference frame can be obtained by making a mathematical transformation based on the realistic dynamics in an actual reference frame. Therefore, it is the invariance in the physical reference frame, rather than the mathematical reference frame, that is most urgently needed to be addressed and must be addressed.

Regarding the relation between the reference object and the reference frame, if the reference object is first assigned in a specific problem, the reference frame can be established naturally with the reference object as the reference origin. If the reference frame is assigned first, then in principle any actual object fixed in the reference frame can be regarded as a reference object. The most conventional ground reference frame, for example, actually selects any object fixed to the ground as a reference object.

Practically speaking, any reference object we can find for an actual reference frame is in perpetual motion in the universe, but we can never be sure of the exact position or velocity of this reference object (including the observer's Earth) in the universe. Although any object can use very distant galaxies to determine its rotation relative to the universe, for dynamics, the ideal solution is that as long as the reference objects are selected, people can completely determine the movement of any object relative to the reference object according to the forces acting on the object, without having to change the mathematical formula for dynamics. This is the basic spirit of the dynamical principle of relativity [?, ?, ?].

According to the discussion in this article, the new generalized dynamics equation (9) keeps the formula invariant under arbitrary transformation between translational reference frames. Compared with the Galilean mechanical principle of relativity based on inertial reference frames and the principle of general relativity based on arbitrary reference frames [?, ?, ?], the invariance for arbitrary translational reference frames lies between them and has been proved in the logical derivation of the new generalized dynamics equation [?]. Therefore, the form invariance based on translational reference frames shown in the new generalized dynamics equation (9) can be called a principle of moderate relativity.

As the first demonstration of the nature of inertial force by the new generalized dynamics equation, equation (18) clearly does not support Einstein's principle of general relativity. According to the basic spirit of causal symmetry for particle dynamics, no matter what the specific form of particle dynamics is, whether relativistic or non-relativistic, as long as the force acting on the reference object does not appear in the form of the dynamics equation, the dynamics equation cannot be generalized to actual reference frames. Moreover, if the dynamical principle of relativity is to be further generalized into rotating reference frames, it is necessary to include at least four reference particles' kinematics and forces simultaneously on both sides of the dynamics equation. This has not been explicitly achieved in existing mathematical physics and needs further exploration. Therefore, any generalization of the principle of relativity to rotating reference frames for particle dynamics needs to be carefully treated and verified. To say the least, Einstein's principle of general relativity is not credible.

In fact, the principle of moderate relativity can meet the basic needs of practical observation and application. On one hand, we can never be sure of the exact position or velocity of the observer's Earth in the background of the universe. As for the acceleration of the reference frame with respect to the background of the universe, it can be distinguished in principle but is difficult to determine. In other words, the translation of the reference frame with respect to the background of the universe should not be categorically distinguished. On the other hand, due to the eternity and invariability of the background of the universe, we can always determine the rotation of any reference frame with respect to the background of the universe by means of sufficiently distant galaxies. In practice, since the background of the universe is objective, the direction in the background is also objective, and we can define the direction in the background with the help of galaxies far enough away. Therefore, for any reference object, we can define the orientation of coordinate axes according to the direction in the background of the universe and on this basis establish a reference frame without rotation. In other words, the rotational motion of the reference frame can be distinguished in principle. Thus the dynamics law that is really necessary for observers is to keep the form invariant in any non-rotating reference frame. Furthermore, for particle dynamics, any translational phenomena can always be attributed to the motion of a single particle, and any single particle has no concept of rotation. Any reference object, as long as it can be treated as a particle, has no issue with rotation. Therefore, the issue of rotation for reference frames can in essence be technically attributed to a mathematical problem, which can be separated from the physics of dynamical relativity in principle. The simplest and most useful principle of relativity should be keeping dynamics laws invariant with respect to any translational reference frame.

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Note: Figure translations are in progress. See original paper for figures.