The Theory of Observational Relativity
Serial Report 2: Exploring the Objective and Real Mass of Photons

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Abstract: The theory of Observational Relativity (OR), as a new theory in human being's physics, has revealed the essence of the relativistic effects of Einstein relativity theory, and moreover, has generalized and unified Newton's classical mechanics and Einstein's relativity theory in the same theoretical system under the same axiom system. However, the original intention of OR research is not to establish the theory of OR, but to give photons some rest mass. According to the mass-speed relation of Einstein special relativity, an object of matter moving in inertial spacetime exhibit two distinct masses: the rest mass; the moving mass. However, as an object of matter reaches the speed of light, either its moving mass becomes infinitely large or its rest mass becomes infinitely small. Einstein chose to set the rest mass of photons to zero. It is puzzling that Einstein's moving mass depends on observation: the same material object has different moving masses relative to different observers. Therefore, people subconsciously believe that Einstein's moving mass is not objective and real, and that only the rest mass is the objectively real mass with real inertial effects and real gravitational effects. So, if photons had no rest mass then they would have no mass. According to the materialist view of nature, the natural world is a world of matter, and all matter or material particles, including photons, have the intrinsic and objectively real mass. Naturally, the objectively real mass must be independent of observation. OR serial report 1 has elucidate the theoretical validity and empirical basis of OR. Now, OR serial report 2 will report on the exploration for the objectively real mass of photons by the theory of OR. The theory of Inertial OR (IOR) proves that photons possess the rest mass; the theory of Gravitational OR (GOR) predicts that the theoretical value of the rest mass of a photon with the frequency f is $m_o=hf/c^2$. Thus, according to the theory of OR: all matter or material particles possess the objectively real rest mass; a material object, whether it is a massive star or a tiny photon, must possess the rest mass of its own if it exists objectively; otherwise, it does not exist.

Key Words: photon, mass-speed relation, classical mass, inertial mass, gravitational mass, relativistic mass, moving mass, observed mass, observational mass

1 Introduction

OR serial report 1 [1] has reported to readers a new theory in physics: **Observational Relativity** (OR) [2-5].

The theory of OR has discovered that human perception of the objective world not only relies on observation but also is restricted by observation. All spacetime models and theoretical systems in human physics must be branded with observation: the Galilean transformation and Newtonian mechanics are the products of idealized observation with the idealized agent OA_∞; the Lorentz transformation and Einstein theory of relativity, both the special and the general, are the products of optical observation with the optical agent OA(c).

Galileo and Newton represent the objective and real physical world; whereas Einstein presents to us only the optical image of the physical world.

The theory of OR, unexpectedly, has generalized and unified the two great theoretical systems of human physics, Newton's classical mechanics and Einstein's relativity theory, in the same theoretical system under the same axiom system. The theory of OR has had significant discoveries, revealing the root and essence of the relativistic effects of spacetime and matter motion: all relativistic effects are observational effects and apparent phenomena; the speed of light is not really invariant and spacetime is not really curved.

OR serial report 2 will continue to report on another important discovery of the theory of OR: the rest mass of photons is not really zero.

The theory of OR was not designed or manufactured; it was just an accident.

Revealing the essence of relativistic effects and unifying Newton's classical mechanics and Einstein's relativity theory was not the original intention of OR.

Initially, the theory of OR only attempted to give photons a little bit of rest mass.

The issue of photon mass is a major one in physics.

The author believes that a physicist should first and foremost be a materialist: the natural world is a world of matter, and mass characterizes the objective existence of matter; all matter or material particles, including photons, must possess the, objective and real intrinsic mass. The objective mass must be independent of observation; the real mass must exhibit both real inertial effects and real gravitational effects.

Human being's physics should embrace the dialectical materialist view of nature: everything in the natural world is the contradictory unity of matter, the two sides of the contradiction are both mutually independent and interdependent, and can be transformed into each other under certain conditions.

In a sense, Einstein's theory of relativity, both the special [6] and the general [7], provides an excellent interpretation for the Dialectics of Nature and the Dialectical Materialist View of Nature.

Matter is the contradictory unity of mass and energy. According to Mach [8] and Einstein [9,10], everything in the natural world is relative. In Einstein's theory of relativity, mass and energy are relative and can be transformed into each other: mass is energy; energy is mass.

However, the Hypothesis of the invariance of light speed, as the most basic logical premise of Einstein relativity theory, leads to two specious arguments:

(1) The speed of light is the ultimate speed in the universe and cannot be surpassed;

(2) Photons have no rest mass.

Subconsciously, people believe that the objective and real mass of matter or material particles is and can only be the rest mass. The absence of rest mass in photons is tantamount to asserting that photons have no mass. Then, with no mass, what could the energy of photons rely on for existence? The existence of matter with only energy and no mass is irreconcilable with the dialectical materialist view of nature.

So, giving photons a little rest mass became the original intention of OR research.

Driven by their inherent views on nature, great physicists such as Feynman [11], de Broglie [12,13], and Schrödinger [14,15] did not believe that photons have no rest mass, and ever spared no time and effort in attempting to determine the rest mass of photons by observations or experiments. Till this day, many experimental physicists still attempt to find the rest mass of photons through observations and experiments. They hope to find out the rest mass of photons outside of the moving mass of photons. Proca even prepared an amendment scheme for the Maxwell electromagnetic equations to account for the presence of massive photons [16]. However, all efforts to determine the rest mass of photons have been futile, leaving only a series of upper limits on the rest mass of photons that continuously approach zero [17-19]. In 2014, the Particle Data Group (PDG) recommended an upper limit of 1.5×10^{-54} kg for the rest mass of photons [20].

Unlike determining the rest mass of photons by observations or experiments, the author of OR attempt to theoretically assign a small rest mass to photons and establish a theoretical model of expected photon mass (EPM).

However, the theoretical model of EPM has unexpectedly evolved into the theory of OR.

The theory of OR goes beyond the EPM original intention and expectation, not only obtaining the rest mass of photons, but also establishing the whole theoretical system of OR [2-5], generalizing and unifying Newton's classical mechanics and Einstein's relativity theory [1]. Moreover, it establishes the basic theoretical framework for the theory of observational quantum (see Chapter 6 of the 1st volume IOR of OR Monograph [2-5]), generalizing Planck's quantum mechanics and de Broglie's matter-wave theory, and moving towards the unification of relativity theory and quantum theory [21].

The theory of OR [2-5] lists the problem of photon mass as one of the 15 big puzzles in modern physics, involving two fundamental questions:

(1) Does a photon have the rest mass of its own?

(2) If so, then how much does it weigh?

The 1st volume of OR monograph, **Inertial Observational Relativity** (IOR), theoretically proves that photons, like all material particles, possess the objective and real mass, that is, the so-called **rest mass** m_o; the 2nd volume of OR monograph, **Gravitational Observational Relativity** (GOR), theoretically proves that the theoretical value of the rest mass of a photon with frequency f is $m_o=hf/c^2$.

OR serial report 1 [1] has elucidated the logical and theoretical correctness of OR, as well as, the empirical basis and empirical evidences of OR.

OR serial report 2 will focus on interpreting BP-02: **The Problem of Photon Mass**, one of the 15 big puzzles in modern physics listed by the theory of OR.

2 Matter Mass and Photon Mass

Matter is the objective existence and physical reality of the natural world. **Mass** is the quantity of matter contained in a material object or a material system.

Excluding electromagnetic radiation, gravitational radiation, and other mass adsorption or mass dissipation, the mass of a matter system should be conserved.

According to the theory of OR, a material object or system, whether it is a massive star or a tiny photon, must possess the intrinsic mass of its own if it exists objectively; otherwise, it does not exist. This is in line with the dialectical materialist views of matter and nature.

So, what views on matter and mass did Newton and Einstein hold respectively?

2.1 Newton's View of Mass and Newton's Photon

The concept of mass originated from Newton.

In his book **The Mathematical Principles of Natural Philosophy**, Newton wrote [22]: "The quantity of matter is that measure of it which arises from its density and from its density and volume conjointly." This passage can be roughly understood as:

Mass (m) = Volume (V) × Density (d)

where m, V, and d represents the mass, volume, and density of a material object, respectively.

The mass of matter makes a material object present both inertial effects and gravitational effects.

In Newtonian mechanics, the inertial and gravitational effects of mass are clear and unambiguous. Newton's second law, $F=ma$, embodies the inertial effect of mass m; Newton's law of universal gravitation, $F=GMm/r^2$, embodies the gravitational effect of mass m.

The existence of gravitational interaction is objective.

We can use a balance to measure the weight of an apple on the surface of the earth, which is related to the gravitational force of the earth or the gravitational interaction between the earth and the apple, but not to whether the spacetime around the earth is curved.

However, Newton seemed unsure whether the mass that embodies the inertial effect and the mass that embodies the gravitational effect are the same. So, Newton proposed the concepts of inertial mass m_I and gravitational mass m_G.

With regard to the materiality of light, there have been two doctrines in history: the corpuscular theory of light and the wave theory of light. The corpuscular theory of light was proposed by Newton. As early as 1675, Newton put forward the hypothesis that light is composed of tiny particles of matter [23].

However, Newton was unable to determine the volume V and density d of a photon, and therefore, he was unable to calculate the mass m of a photon based on his own definition of mass.

According to the theory of OR, Newtonian mechanics is the theory of the idealized observation agent OA_∞. For ease of distinction, we agree to use the following symbols:

(1) $m_\infty=m(\infty)$: Newtonian mass or classical mass;

(2) $m_{I\infty}=m_I(\infty)$: Newtonian inertial mass;

(3) $m_{G\infty}=m_G(\infty)$: Newtonian gravitational mass.

2.2 Einstein's View of Mass and Einstein's Photon

Einstein's view on mass seems to differ from Newton's. In his theory of relativity, Einstein did not explicitly adopt the concepts of inertial mass m_I and gravitational mass m_G, but introduced two new mass concepts: the rest mass m_o; the moving mass m.

2.2.1 Einstein's Relativistic Mass

According to the mass-speed relation in Einstein theory of special relativity:

$$m=\frac{m_o}{\sqrt{1-v^2/c^2}}\qquad \left(\lim_{v\to c} m_o=0 \ \text{ or } \ \lim_{v\to c} m=\infty\right) \tag{1}$$

a material object P, as the observed object, possesses both its rest mass m_o and its moving mass m, in which $m=m(v)$ is relativistic, involving the speed v of the observed object P relative to the observer O.

So, which one, m_o or m, represents the objective and real mass of the observed material object P? Or, which one, m_o or m, has the objectively real inertial and gravitational effects? Actually, in Einstein's theory of relativity, the inertial and gravitational effects of mass are relativistic: ambiguous rather than clear.

People often thought that, in Einstein's theory of relativity, inertial mass and gravitational mass were the same. In fact, Einstein's relativistic mass also distinguishes between inertial mass and gravitational mass, involving the relativistic mass-speed relation, mass-energy formula, gravitational field equation and gravitational motion equation, and even Planck equation.

According to the theory OR, Einstein relativity theory is that of the optical observation agent $OA(c)$. For ease of distinction, we agree to use the following symbols:

(1) m_o: the rest mass (independent of observation);

(2) $m(c)=m_I(c)$: Einstein's moving mass or Einstein's inertial mass;

(3) $m_G(c)$: Einstein's gravitational mass.

Here $m(c)$ or $m_I(c)$ and $m_G(c)$ are all the relativistic masses of the optical observation agent $OA(c)$, which contain observational effects and apparent phenomena, and are not entirely objective and real.

2.2.2 Einstein's Photon Mass

According to Einstein relativity theory, a photon, as a material particle, should possess both the rest mass m_o and the moving mass m.

However, Einstein's photons seem quite peculiar: they only have moving mass but no rest mass.

The Rest Mass of Photons: $m_o=0$

According to Einstein's mass-speed relation (Eq. (1)), if the speed v of the observed object P reaches the speed of light c, either its rest mass m_o becomes infinitely small, or its moving mass m becomes infinitely large.

A physical quantity of infinity contradicts the principle of physical observability: no observation agent can observe it. Therefore, Einstein could only set the rest mass of photons to zero: $m_o=0$.

In fact, however, a physical quantity of infinitesimal also contradicts the principle of physical observability: n physical quantity of infinitesimal Q_P implies that the physical quantity $1/Q_P$ is infinitely large; either the observed object P does not exist, or the physical or material effects of P represented by Q_P do not exist.

The Moving Mass of Photons: $m=hf/c^2$

Einstein's theory of relativity alone cannot determine the moving mass m of a photon. Therefore, Einstein had to resort to Planck equation $E=hf$, although Planck equation was originally just a hypothesis and did not belong to the theoretical system of Einstein relativity theory.

According to Einstein's theory of special relativity, since a photon has no rest mass ($m_o=0$), it naturally has no rest energy: $E_o=m_oc^2=0$. Therefore, the kinetic energy of a photon is $K=E-E_o=E=mc^2$. The energy $E=hf$ in Planck's hypothesis of energy quanta is exactly the kinetic energy of photons. Thus, using Planck equation, Einstein had obtained the relativistic moving mass of photons: $m=hf/c^2$.

The moving mass of photons obtained in this way is not only used in the inertial-motion model of photons, but also in the gravitational-interaction model of photons.

2.2.3 Hawking Singularity

Our reason and logic dictate that the mass of a material object P at a specific moment should be deterministic and unique. However, according to Einstein's relativistic mass-speed relation (Eq. (1)), the mass of P not only can expand but also depends on observation.

As depicted in Fig. 1, for an apple resting on the surface of the earth, its mass observed by the relatively stationary observer O_o is the rest mass m_o of the apple; but its mass observed by the relatively moving observers O' and O'' are its moving masses, which are greater than the rest mass: $m(v'')>m(v')>m_o$ −− the higher the speed of the observer relative to the apple, the greater the moving mass of the apple will be. So, different observers, such as the stationary observer O_o, the train observer O' and the plane observer O'', have different masses of the apple.

This means that Einstein's relativistic mass relies on or depends on observation and observers, and is not entirely objective and real.

The theory of OR has clarified that the rest mass m_o is the objective and real mass of matter, possessing objectively real inertial and gravitational effects. Removing the rest mass m_o, then the remaining part $\Delta m = m - m_o$ of Einstein's relativistic moving mass m is purely an observational effect of the optical agent OA(c), rather than the objectively real physical existence, and naturally, has no objectively real inertial and gravitational effects.

Therefore, the null rest mass of photons would imply that photons have no objective and real mass. This would signify that photons would have no objectively real momentum and energy, and so that photons would no longer be the objectively physical existence.

The reason for the formation of such a paradox lies in Hawking Singularity.

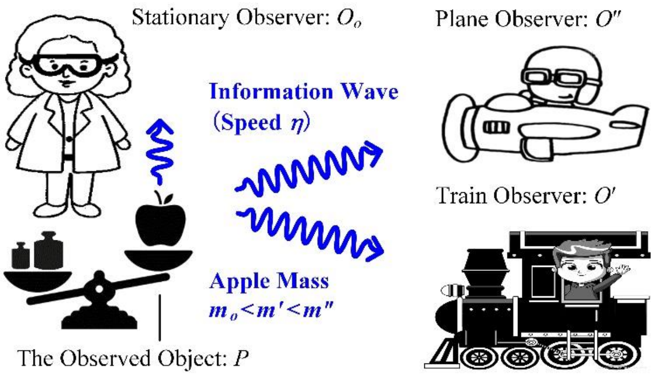

Figure 1 The Mass of an Apple: $m'' > m' > m_o$

Annotations: (1) Observed object P: an apple; (2) Stationary observer O_o: a balance or an observer stationary relative to P; (3) Observer O': a train driver; (4) Observer O'': a plane driver; (5) m_o: the rest mass of the apple; (6) m' and m'': the moving masses of the apple observed by O' and O'', respectively.

There is a singularity in the mass-speed relation of Einstein special relativity: Hawking Singularity. The theory of OR also has Hawking Singularity.

The theory of OR has discovered that light and photons play a special role in Einstein theory of relativity. Einstein theory of relativity, both the special and the general is a theory of optical observation armed with the optical agent OA(c). OA(c) adopts light as the observation medium, so the information wave of it is light and the informons of it are photons.

Therefore, in Einstein theory of relativity, the physical quantities of light and photons, including the speed of light and the mass of photons, are all located at the singularities of its theoretical model.

Based on the mass-speed relation of his special relativity, Einstein deduced that the rest mass m_o of photons is zero, and precisely, the speed of light $v=c$ falls at the singularity of the mass-speed relation $m=m_o/\sqrt{(1-v^2/c^2)}$.

In his book **A Brief History of Time**, Hawking wrote [24]: “Mathematics cannot really handle infinite numbers. At singularity, the theory itself breaks down or fails.”

It can be seen that the rest mass of a photon is not truly zero, which only means that Einstein's mass-speed relation fails at Hawking Singularity ($v=c$).

The singularities in all theoretical models of Einstein relativity theory root from Einstein's hypothesis of the invariance of light speed, and is characterized by the Lorentz factor in the Lorentz transformation: $\gamma=1/\sqrt{(1-v^2/c^2)}$, where the singularity $v=c$ can be referred to as the Lorentz singularity. Similarly, there is the general Lorentz transformation in the theory of OR, in which the general Lorentz factor is $\Gamma=1/\sqrt{(1-v^2/\eta^2)}$, and the singularity $v=\eta$ can be referred to as the general Lorentz singularity.

Both the Lorentz singularity and the general Lorentz singularity are referred to as Hawking Singularity in this article and even in the theory of OR.

3 From the EPM Original Intention to the Theory of OR

Originally, the author of OR believed in Einstein's theory of relativity, holding the belief that the universe possesses the invariant and unsurpassable speed. However, based on the dialectical materialist view of nature, the author of OR cannot accept Einstein's assertion that photons have no rest mass.

Therefore, the author attempted to establish a theoretical model of expected photon mass (EPM) that could confer the rest mass on photons.

Unexpectedly, however, the theoretical model of EPM has evolved to be the theory of OR.

3.1 The Ultimate Speed of the Universe and the EPM model

The so-called ultimate speed of the universe refers to the speed that cannot be surpassed.

In 1905, based on the Michelson-Morley experiment, Einstein proposed the principle of the invariance of light speed, theoretically derived the Lorentz transformation, and finally, established his theory of special relativity [6] and his theory of general relativity [7].

The hypothesis of the invariance of light speed is the fundamental and indispensable logical premise of Einstein relativity theory, including the special and the general.

The hypothesis of the invariance of light speed implies that the speed of light is the ultimate speed of the universe, which cannot be surpassed by any other form of matter motion in the universe.

The author of OR once even believed that the ultimate speed of the universe is not only unsurpassable, but also inaccessible or unattainable by all forms of matter motion in the universe, including light or photons.

Perhaps, the ultimate speed of the universe should be defined with Λ as follows.

Definition 3.1 The Ultimate Speed of the Universe: The speed $|v|\to\Lambda$ ($<+\infty$) at which the frequency f of the matter wave of a moving object P converges infinity is referred to as the ultimate speed of the universe.

To keep the feasibility of logical deduction, Definition 3.1 does not limit the speed of matter motion to reach Λ. However, although the frequency of light waves is very high, it is still finite. Therefore, the speed of light may be less than the ultimate speed Λ of the universe defined in Definition 3.1: $c<\Lambda$. In this case, the mass-speed relation

$m=m_o/\sqrt{(1-v^2/c^2)}$ in Einstein theory of special relativity might be rewritten as:

$$m=\frac{m_o}{\sqrt{1-v^2/\Lambda^2}}\quad (v\le c<\Lambda;\ m<\infty)\qquad (2)$$

This is the EPM model envisioned by the author.

If the moving mass m of photons and the ultimate speed Λ of the universe could be determined, the rest mass m_o of photons could theoretically be calculated:

$$m_o=m\sqrt{1-v^2/\Lambda^2}\ (>0);.$$

then the rest mass m_o of photons would no longer be zero.

Definition 3.1 has two direct logical consequences.

Corollary 3.1 (Observational Limit Speed Λ): The observed speed v of any moving object P cannot exceed the ultimate speed Λ of the universe, that is, $\forall v\ |v|\le\Lambda$.

Corollary 3.2 (Ultimate Speed Invariance): Relative to all inertial observers, the ultimate speed Λ of the universe is the same or invariant.

According to the theoretical model of EPM (Eq. (2)), the ultimate speed Λ of the universe should be greater than the speed of light c in vacuum; otherwise, photons would still be unable to acquire the rest mass.

So, what exactly is the ultimate speed Λ?

3.2 The Logical Deduction of EPM Model: $\Lambda=\eta$

The author of OR originally thought that the invariant speed, i.e., the ultimate speed of the universe, is the Λ defined by Def. 3.1 rather than the speed of light c. Based on this idea, the author embarked on establishing an axiom system, in the hope of being able to deduce a spacetime transformation relation for the theoretical model of EPM that confer the rest mass on photons.

Compared to Newtonian mechanics and Einstein relativity theory, the model of EPM or theory of OR has more basis logical premises and axiom system [1-5]:

(I) The Principle of Physical Observability

(II) The Conditions of Wave-Particle Duality

- (1) The Principle of Frequency-Speed Relation
- (2) The Definition of the Ultimate Speed
- (3) The Principle of OR Speed Addition

(III) The Definition of Time

(IV) The Principle of GOR Equivalence

(V) The Principle of GOR Covariance

As stated by the theory of OR [1-5], in the axiom system of OR, only the definition of OR time serves as an indispensable logical premise for the theory of OR, including IOR and GOR.

Time is the most basis physical quantity in physics: in a sense, the definition of OR time can be regarded as the first principle or the most basic logical premise.

In the axiom system of OR, the principle of physical observability and the conditions of wave-particle duality only serve as auxiliary logical premises for the theory of IOR. To deduce the theory of GOR based on IOR, there are two additional auxiliary logical premises in the axiom system of OR: the principle of GOR equivalence and the principle of GOR covariance.

The logical deduction of the model of EPM and the spacetime transformation of OR requires a physical quantity, whose physical significance is very clear [1]: the speed of the spacetime information of the observed object P relative to the observer O, denoted as η.

Theoretical derivation has led to an intriguing logical consequence [2-5]: $\Lambda=\eta$!

3.3 Physics and Observation

$\Lambda=\eta$ suggests that the so-called ultimate speed of the universe is actually only the speed η at which the information on the observed object P is transmitted, depending on the observation medium that is employed in observation by the observer O.

Thus, the theory of OR has discovered that all theoretical systems in human being's physics are linked to specific observation media or specific observation systems and must be branded with observation. Human being's perception of the objective world relies on observation and is also restricted by observation. This has led to the formation of the concepts of **Observation Agent** and **Observational Locality** in the theory of OR.

This implies that the relativistic physical quantities of the observed object P, including the relativistic moving mass of P, are physical quantities observed by a specific observation agent OA(η) ($\eta<\infty$), restricted by the observational locality of OA(η) ($\eta<\infty$), and not completely objective and real.

3.3.1 Observation Agent: OA(η)

Theoretically, all forms of matter motion or matter waves can serve as observation media to transmit the information on the observed object P for the observer O.

The theory of OR establishes an important concept: Observational Agent.

Observation Agent: The observation agent OA(η) or observation system $(P, M(\eta), O)$ employs the observation medium $M(\eta)$ to transmit the information about the observed object P for the observer O at a speed η; the matter wave $M(\eta)$ transmits information is referred to as the **information wave** of OA(η), and the matter particles constituting the information wave of OA(η) are referred to as the **informons** of OA(η).

The concept of **Informon** originates from Železnikar, referring to the material particles that can load and transmit information [25].

Theoretically, the information wave of the general observation agent OA(η) ($0<\eta<\infty$; $\eta\to\infty$) can be any form of matter motion and the informons of OA(η) can be any material particles, even a rock. Naturally, the information-wave speed η of OA(η) can theoretically be any value.

In particular, OA_∞ ($\eta\to\infty$) represents the idealized observation agent of Galileo and Newton; OA(c) ($\eta\to c$) represents the optical observation agent of Einstein.

The theory of OR is the theory of the general observational agent OA(η) ($0<\eta<\infty$; $\eta\to\infty$), which is the complete theory in Hawking's sense, so that Newton's classical mechanics and Einstein's relativity theory are in Hawking's sense merely two partial theories of OR [1].

3.3.2 Observational Locality: ∀OA(η) η<∞

In modern physics, the principle of locality plays an important role [26,27]. The principle of observational locality can be expressed as a corollary of locality principle.

The Principle of Observational Locality (POL) [2-5]: According to the principle of locality, the information-wave speed η of a realistic observation agent OA(η) must be finite or limited ($\eta<\infty$); it takes time for the information wave of OA(η) to cross space.

All observation agents with which human beings perceive the objective world, such as the human eye and ear, have the observational locality.

The theory of OR has discovered that all relativistic effects or phenomena, including time dilation and length contraction, the relativity of simultaneity, the null rest mass of photons, spacetime curvature, and even the invariance of light speed, are observational effects and apparent phenomena rather than the objective and real physical realities, the root and essence of which lie in the observational locality of human observation agents.

3.4 The Invariance of Information-Wave Speeds and the Theory of OR

Theoretically, all forms of matter motion or matter waves, not just light or electromagnetic interaction, can serve as observation media or information waves to transmit the information about observed objects for observers; the information-wave speed (the transmission speed of observed information) η of the observation agent OA(η) can be any speed, not just the speed of light c.

$\Lambda=\eta$ leads to an important theorem:

The Invariance of Information-Wave Speeds -- $\forall u\in(-\eta,\eta)$ $\eta\oplus u=\eta$ [1-5].

The theorem of the invariance of information-wave speeds tells us that if observers employ an specific observation agent OA(η) to perceive or observe the objective world, due to the observational locality ($\eta<\infty$) of OA(η), the information-wave speed η of OA(η) becomes the ultimate speed Λ of the observers. Therefore, from the perspective of the observers, the information-wave speed η of OA(η) is invariant relative to the observers or OA(η) and cannot be surpassed by the speeds of observed objects.

This implies that the universe does not truly possess an ultimate or unsurpassable speed. The speed of light is not really invariant. The invariance of light speed is merely a special case of the invariance of information-wave speeds, and it is valid only if observers observe the physical world through light or electromagnetic interaction.

Einstein's theory of relativity, both the special and the general, has been in existence for over 100 years. So far, people still do not understand why the speed of light is invariant. However, readers must understand the invariance of information-wave speeds.

As stated in OR serial report 1 [1], the invariance of information-wave speeds is not only a product of logic and theory, but also has empirical basis and empirical evidences, supported by observations and experiments. In the Michelson-Morley experiment, the invariance of light speed is only a phenomenon, whereas the invariance of information-wave speeds is the essence. As an empirical evidence, the Michelson-Morley experiment is not a support for Einstein's invariance of light speed, but a support for the invariance of information-wave speeds.

OR serial report 1 [1] has elucidated how to deduce the theory of OR based on the invariance of information-wave speeds, including IOR and GOR.

Based on the axiom system of OR, starting from the definition of time, to the invariance of time-frequency ratio, to $\Lambda=\eta$, to the invariance of information-wave speeds, ultimately, the author's original intention of EPM has evolved into the theory of OR.

3.5 OR Goes beyond EPM Original Intention

The theory of OR has achieved and surpassed the original intention of EPM.

The theory of OR has revealed the root and essence of the relativistic effects in Einstein's theory of relativity: all relativistic effects or relativistic phenomena, including the inertial and the gravitational, are observational effects and apparent phenomena caused by the observational locality ($c<\infty$) of Einstein's optical agent OA(c).

Einstein's assertion that photons have no rest mass is limited to the perspective of optical observation, and its root also lies in the observation locality ($c<\infty$) of the optical observation agent OA(c).

OR serial report 2 only discusses photon-mass issue.

The theory of OR suggests that the rest mass of photons is not really zero.

As the author of OR wishes, the theory of IOR theoretically proves that photons, like all other materal particles, have the rest mass of their own: $m_o>0$; the theory of GOR predicts that the rest mass of a photon with frequency f is $m_o=hf/c^2$.

4 IOR Proves: Photons have the Rest Mass

Photon-mass problem 1:

Does a photon have the rest mass of its own?

The answer of the theory of IOR is affirmative.

The theory of Inertial Observational Relativity (IOR) has generalized and unified Newton's inertial mechanics and Einstein's special relativity [1].

According to the theory of OR: the rest mass is exactly the objectively real mass of matter; all material particles, including photons, have the rest mass of their own (see Chapter 5 of the 1st volume IOR of OR monograph [2-5]).

4.1 IOR Mass-Speed Relation

The theory of IOR is a theory of inertial motion for the general observation agent OA(η) ($0<\eta<\infty$; $\eta\to\infty$), in which the IOR factor $\Gamma(\eta,v)=1/\sqrt{(1-v^2/\eta^2)}$ is the characteristic physical quantity of IOR, characterizing the relativistic effects of the inertial spacetime and inertial motion of the object P observed by OA(η).

If $v<\eta$, the IOR relativistic factor $\Gamma(\eta,v)$ can be decomposed into the Galilean factor Γ_∞ and the observational-effect factor $\Delta\Gamma(\eta,v)$ in term of the Taylor series:

$$\Gamma(\eta,v)=\frac{1}{\sqrt{1-v^2/\eta^2}}=\Gamma_\infty+\Delta\Gamma(\eta,v)$$
$$\begin{cases}\Gamma_\infty=\lim\limits_{\eta\to\infty}\Gamma(\eta,v)\equiv 1\\ \Delta\Gamma(\eta,v)=\frac{1}{2}\frac{v^2}{\eta^2}+\frac{1\cdot 3}{2\cdot 4}\frac{v^4}{\eta^4}+\frac{1\cdot 3\cdot 5}{2\cdot 4\cdot 6}\frac{v^6}{\eta^6}+\cdots\end{cases}\quad(3)$$

where η is the information-wave speed of OA(η), and v is the speed of the observer O relative to the observed object P, the Galilean factor $\Gamma_\infty\equiv 1$ is the factor of the Galilean transformation under the idealized observation agent OA$_\infty$, independent of observation, representing the objective and real spacetime; the IOR observational-effect factor $\Delta\Gamma(\eta,v)$ purely depends on the observation agent OA(η), representing pure observational effects and apparent phenomena, rather than the objectively physical existence.

The theory of IOR theoretically derives the IOR mass-speed relation of inertial spacetime related with the IOR factor $\Gamma(\eta,v)$ for the general observation agent OA(η) ($0<\eta<\infty$; $\eta\to\infty$):

$$\text{OA}(\eta):\ \ m(\eta,v)=\Gamma(\eta,v)m_o=\frac{m_o}{\sqrt{1-v^2/\eta^2}}\quad(4)$$

in which, like Einstein special relativity, the observed object P of OA(η) also has two types of mass, the rest mass m_o and the moving mass m.

Like Einstein's mass-speed relation (Eq. (1)), the IOR mass-speed relation (Eq. (4)) is also relativistic, relying on the relative speed v between the observer O and the observed object P. Therefore, the moving mass m of P is also a relativistic mass: $m=m(v)$.

However, the IOR mass-speed relation indicates that, in essence, the moving mass m of the observed object P depends on observation, on the observation agent OA(η), and on the information-wave speed η of OA(η): $m=m(\eta)$. The lower the η is, the more significant the relativistic effects exhibited by P are. Therefore, the theory of OR refers to the relativistic mass m as the observed mass, i.e., the mass observed by the observation agent OA(η).

The theory of IOR is the theory of the general observation agent OA(η). For ease of distinction, we agree to use the following symbols:

(1) m_o: the rest mass;

(2) $m(\eta)=m_I(\eta)$: the moving mass observed by OA(η) or the inertial mass observed by OA(η).

4.2 IOR Mass: the Mass Observed by OA(η)

According to the IOR mass-speed relation, the IOR moving mass $m=m(\eta)$ is the observed mass with the general observation agent OA(η), depending on observation: for the same observed object P, different observation agents have different observed masses. This suggests that the IOR moving mass $m=m(\eta)$ contains the observational effects and apparent phenomena caused by the observational locality ($\eta<\infty$) of the observation agent OA(η), and is not completely objective and real, but only a sort of mass in the sense of observation.

Like Einstein's mass-speed relation (Eq. (1)), the IOR mass-speed relation (Eq. (4)) also has Hawking Singularity: $v=\eta$. Following Einstein's logic, we should set the rest mass of the informons of all observation agents to zero.

Such a paradox stems from Einstein's misconception of Hawking Singularity ($v=c$) in his mass-speed relation.

Of course, this does not mean that the rest mass of the informons of OA(η) (including the photons of OA(c)) is really zero. It only means that, in Hawking's words, the IOR mass-speed relation fails at Hawking Singularity ($v=\eta$), and that, restricted by the observational locality ($\eta<\infty$) of the observation agent OA(η), the speed v observed by OA(η) cannot reach and exceed the information-wave speed η of OA(η): $v<\eta$.

If $v<\eta$, the IOR moving mass $m(\eta,v)$ or inertial mass $m_I(\eta,v)$ can be decomposed in term of the Taylor series (Eq. (3)) of $\Gamma(\eta,v)$ as follows:

$$m(\eta,v)=m_o+\Delta m(\eta,v)\quad(v<\eta)$$
$$\begin{cases}m_o=\Gamma_\infty m_o\ \ (\Gamma_\infty\equiv 1)\\ \Delta m(\eta,v)=\Delta\Gamma(\eta,v)m_o\end{cases}\quad(5)$$

where m_o is the rest mass, i.e., the observed mass with the idealized agent OA$_\infty$, representing the objective and real mass of the observed object P; $\Delta m(\eta,v)=m(\eta,v)-m_o$ is the apparent mass, i.e., the purely observational effect and not the objectively physical existence, entirely depending on the observation agent OA(η).

Given the relative v between the observer O and the observed object P, the higher the information-wave speed η of OA(η), the smaller the apparent mass $\Delta m(\eta,v)$ becomes, and the closer the IOR observed mass $m(\eta,v)$ is to the objective and real rest mass m_o of P.

The observed mass $m(\eta,v)$ in the IOR mass-speed relation has generalized and unified Einstein's relativistic moving mass $m(c)$ and Newton's classical inertial mass $m_\infty=m_{I\infty}$. From the broad perspective of the general observation agent OA(η) ($0<\eta<\infty$; $\eta\to\infty$), we will re-examine Einstein's relativistic moving mass and Newton's classical inertial mass.

4.3 Einstein's Relativistic Moving Mass: the Mass Observed by OA(c)

In fact, Einstein's moving mass $m(c,v)$ or inertial mass $m_I(c,v)$ merely a special case of the IOR observed mass, that is, the mass $m=m(c)$ ($\eta=c$) observed with the optical agent OA(c).

If $\eta\to c$, then OA(η)$\to$OA(c), and the IOR mass-speed relation strictly converges to the mass-speed relation of Einstein special relativity:

$$\text{OA}(c):\ \ m(c)=\lim_{\eta\to c}\frac{m_o}{\sqrt{1-v^2/\eta^2}}=\frac{m_o}{\sqrt{1-v^2/c^2}}\quad(6)$$

Einstein's optical agent OA(c) has the observational locality: $c<\infty$, the observational-effect factor $\Delta\Gamma(c,v)>0$ and the apparent mass Δm(c,v)>0. Therefore, Einstein's moving mass $m(c,v)$ contains the observational effects of OA(c), rather than the completely objective and real mass of the observed object P.

Due to the observational locality ($c<\infty$) of the optical agent OA(c), we cannot employ OA(c) to measure or determine the mass of the observed object P if P reach or exceed the speed of light c.

Einstein's assertion that the rest mass of photons is zero roots from the Hawking Singularity $v=c$ in the mass-speed relation of the optical agent OA(c). It does not mean that the rest mass of photons is really zero, but merely means that the mass-speed relation of OA(c) fails at the Hawking Singularity $v=c$: OA(c) cannot determine the mass of photons (just as you cannot lift yourself up).

If we aspire to measure the objective and real rest mass of photons, then we must be equipped with a superluminal observation agent OA(η) ($\eta>c$).

4.4 Newton's Classical Inertial Mass: the Mass Observed by OA$_\infty$

Newton's classical mass m_∞ or inertial mass $m_{I\infty}$ is also a special case of IOR observed mass, that is, the observed mass $m=m(\infty)$ ($\eta\to\infty$) with the idealized agent OA$_\infty$.

The information-wave speed of OA$_\infty$ is idealized as infinitely large: $\eta\to\infty$, with no observational locality, it takes no time for the information wave of OA$_\infty$ to cross space. So, the idealized agent OA$_\infty$ might be regarded as **the God's eye**: Galileo-Newtonian inertial mechanics represents objective and real inertial spacetime; its classical mass m_∞ or inertial mass $m_{I\infty}$ is the objective and real moving mass or inertial mass of the observed object P.

According to the definition of IOR moving mass, as the observed physical quantity of the idealized agent OA$_\infty$, Newton's inertial mass $m_{I\infty}$ should be the IOR observed mass $m_\infty=m(\infty)$ when $\eta\to\infty$:

$$\text{OA}_\infty\text{:}\quad m_\infty = m_{I\infty} = \lim_{\eta\to\infty}\frac{m_o}{\sqrt{1-v^2/\eta^2}} = m_o \tag{7}$$

Equation (7) has enlightening meanings [1]:

(1) Newton's moving mass m_∞ or inertial mass $m_{I\infty}$ is exactly Einstein's rest mass m_o;

(2) if we had the idealized agent OA$_\infty$, then we could measure and determine the objective and real rest mass m_o of photons.

4.5 Photons like All Other Material Particles Possess the Rest Mass

There is no the idealized observation agent OA$_\infty$ in the objective world: OA$_\infty$ could only exist in human reason.

For a realistic observation agent OA(η) ($0<\eta<\infty$), the IOR mass-speed relation (Eq. (4)) also has Hawking Singularity: $v=\eta$, where the speed v of the informons of OA(η) coincides with Hawking Singularity: $v=\eta$. Theoretically, any materia particle can serve as an informon of OA(η). Of course, this does not imply that it has no rest mass, but that the IOR mass-speed relation fails at the Hawking Singularity $v=\eta$.

According to the IOR mass-speed relation, for any material object P being observed, no matter how fast its speed v is, the idealized agent OA$_\infty$ or an observation agent OA(η) ($\eta>v$) can tell us that P definitely possesses the objective and real rest mass m_o of its own:

$$m_o = m(\eta,v)\sqrt{1-v^2/\eta^2} > 0 \quad (v<\eta) \tag{8}$$

So, the theory of IOR theoretically proves that all matter or material particles, including photons and even gravitons, possess the objective and real rest mass of their own, exhibiting objective and real inertial effects.

This logical consequence conforms to the dialectical materialist view of nature.

If we can be equipped with a superluminal observation agent OA(η) ($\eta>c$), then we can measure and determine the objectively real rest mass m_o of a photon ($v=c$):

$$m_o = m(\eta,c)\sqrt{1-c^2/\eta^2} > 0 \quad (c<\eta) \tag{9}$$

5 GOR Predicts: The Theoretical Value of the Rest Mass of a Photon is $m_o=hf/c^2$

Photon-mass problem 2:
How much does a photon weigh？

According to the theory of IOR: only the rest mass is the intrinsic and objectively real mass of matter; photons, like all other material particles, possess the rest mass of their own, and the objectively real inertial effect of a photon is just the physical effect generated by the rest mass of its own. However, the theory of IOR is still unsure how much a single photon weighs.

The task of calculating the theoretical value of the rest mass of photons is left to the theory of Gravitational Observational Relativity (GOR).

The theory of GOR has generalized and unified Newton's theory of universal gravitation and Einstein's theory of general relativity [1]. According to the theory of GOR, the rest mass of matter not only has inertial effects but also has gravitational effects.

It is based on the gravitational effects of photons that the theory of GOR theoretically calculates and predicts the theoretical value of the rest mass m_o of a photon with frequency f: $m_o=m=hf/c^2$ (see Chapter 18 of the 2$^{\text{nd}}$ volume GOR of OR monograph [2-5]).

5.1 GOR Mass-Speed Relation

The theory of GOR is a theory of gravitational interaction for the general observation agent OA(η) ($0<\eta<\infty$; $\eta\to\infty$), in which the GOR factor $\Gamma(\eta,v,\chi)=1/\sqrt{(1-v^2/\eta^2+2\chi/\eta^2)}$ is the characteristic physical quantity of GOR, characterizing the relativistic effects of the material object P in gravitational spacetime observed by OA(η).

If $\alpha<\eta$ ($\alpha^2=v^2-2\chi$), the GOR relativistic factor $\Gamma(\eta,v,\chi)$ can be decomposed into the Galilean factor Γ_∞ and the observational-effect factor $\Delta\Gamma(\eta,v,\chi)$ in term of the Taylor series:

$$\Gamma(\eta,v,\chi) = \frac{1}{\sqrt{1-(v^2-2\chi)/\eta^2}} = \Gamma_\infty + \Delta\Gamma(\eta,v,\chi)$$

$$\begin{cases} \Gamma_\infty = \lim\limits_{\eta\to\infty}\Gamma(\eta,v,\chi) \equiv 1 \quad (\alpha^2 = v^2-2\chi<\eta^2) \\ \Delta\Gamma(\eta,v,\chi) = \dfrac{1}{2}\dfrac{\alpha^2}{\eta^2} + \dfrac{1\cdot 3}{2\cdot 4}\dfrac{\alpha^4}{\eta^4} + \dfrac{1\cdot 3\cdot 5}{2\cdot 4\cdot 6}\dfrac{\alpha^6}{\eta^6} + \cdots \end{cases} \tag{10}$$

where η is the information-wave speed of the observation agent OA(η), and v is the speed of the observer O relative to the observed object P; $\Gamma_\infty\equiv 1$ is still the Galilean factor, i.e., the factor of the Galilean transformation under the idealized agent OA_∞, independent of OA(η), representing the objectively real spacetime; the GOR observational-effect factor $\Delta\Gamma(\eta,v)$ purely depends on the observation agent OA(η), representing pure observational effects and apparent phenomena, rather than the objectively physical existence and reality.

The theory of GOR theoretically derives the GOR mass-speed relation of gravitational spacetime related with the GOR factor $\Gamma(\eta,v,\chi)$ for the general observation agent OA(η) ($0<\eta<\infty$; $\eta\to\infty$):

$$\mathrm{OA}(\eta):\ \ m(\eta,v,\chi)=\frac{m_o}{\sqrt{1-v^2/\eta^2+2\chi/\eta^2}} \tag{11}$$

where m_o is still the rest mass of the observed object P, $m(\eta,v,\chi)$ is the relativistic mass of P observed by OA(η), related to both the speed v and the Newtonian gravitational potential χ. Therefore, the relativistic mass $m(\eta,v,\chi)$ of P observed by OA(η) contains observational effects and is not entirely objective and real.

The GOR mass-speed relation indicates that, in essence, the relativistic mass m of P dependent on observation, on the observation agent OA(η), and on the information-wave speed η of OA(η): $m=m(\eta)$. The lower the η is, the more significant the relativistic effects exhibited by P are. Therefore, the relativistic mass $m(\eta,v,\chi)$ of the OR gravitational spacetime is also the observational mass observed with the general observation agent OA(η).

If $\alpha<\eta$ ($\alpha^2=v^2-2\chi$), then the GOR observed mass $m(\eta,v,\chi)$ can be decomposed into the objectively real rest mass m_o and the purely apparent mass $\Delta m(\eta,v,\chi)$ in term of the Taylor series (Eq. (10)) of $\Gamma(\eta,v,\chi)$:

$$m(\eta,v,\chi)=m_o+\Delta m(\eta,v,\chi)\quad(\alpha<\eta)$$
$$\begin{cases} m_o=\Gamma_\infty m_o\ \ (\Gamma_\infty\equiv 1) \\ \Delta m(\eta,v,\chi)=\Delta\Gamma(\eta,v,\chi)m_o \end{cases} \tag{12}$$

where m_o is still the rest mass, i.e., the observed mass with the idealized agent OA_∞, representing the objectively real mass of the observed object P; $\Delta m(\eta,v,\chi)=m(\eta,v,\chi)-m_o$ is the apparent mass, i.e., purely observational effect, entirely dependent on the observation agent OA(η), and not the objectively physical existence. So, $\Delta m(\eta,v,\chi)$ has no the objectively inertial and gravitational effects.

Given the moving speed v of the observed object P and the Newtonian gravitational potential χ where P is located, the higher the information-wave speed η of OA(η), the smaller the apparent mass $\Delta m(\eta,v,\chi)$ is, and the closer the GOR observed mass $m(\eta,v,\chi)$ is to the objectively real rest mass m_o of P.

The GOR mass-speed relation (Eq. (11)) generalizes the IOR mass-speed relation (Eq. (4)); the GOR observed mass $m(\eta,v,\chi)$ generalizes the IOR observed mass $m(\eta,v)$.

5.2 GOR Mass: the Mass Observed by OA(η)

Like the theory of IOR, the mass in the theory of GOR as a theory of gravitation for the general observation agent OA(η) ($0<\eta<\infty$; $\eta\to\infty$) is also the observational mass observed by OA(η), or called the GOR observed mass, which may not necessarily be completely objective and true.

However, unlike the theory of IOR, the mass in the theory of GOR not only has inertial effects but also has gravitational effects. It is worth noting that the observed inertial mass and gravitational mass under the realistic observation agent OA(η) ($0<\eta<\infty$) are different.

So, the concepts of inertial mass and gravitational mass, which originated from Newton, truly acquire their existence value and significance in the theory of GOR.

5.2.1 GOR Inertial Mass and Gravitational Mass: Observed by OA(η)

Newton thought matter might have inertial mass and gravitational mass: inertial mass embodied the inertial effects of matter; gravitational mass embodied the gravitational effects of matter.

Einstein introduced the concepts of moving mass and rest mass in his relativity theory. However, it seemed that Einstein had never explicitly used the concept of gravitational mass. People thought that in Einstein's theory of relativity, gravitational mass and inertial mass were equal. In fact, it is also needed for Einstein relativity theory to distinguish between inertial mass and gravitational mass.

Based on the GOR mass-speed relation (Eq. (11)), the theory of GOR defines two concepts on observed mass for the general observation agent OA(η) as below.

The Inertial Mass Observed by OA(η):

$$m_I(\eta)=\Gamma(\eta,v,\chi)|_{\chi=0}m_o=\frac{m_o}{\sqrt{1-v^2/\eta^2}} \tag{13}$$

The Gravitational Mass Observed by OA(η):

$$m_G(\eta)=\Gamma(\eta,v,\chi)|_{v=0}m_o=\frac{m_o}{\sqrt{1+2\chi/\eta^2}} \tag{14}$$

The GOR definitions (Eqs. (13-14)) on observed mass clarifies the concepts of inertial mass and gravitational mass in the theory of OR. Note that the concept of inertial mass in GOR (Eq. (13)) is equivalent to the concept of moving mass in IOR (Eq. (4)).

It is worth noting that the inertial mass $m_I(\eta)=m(\eta,v,0)$ (Eq. (13)) of the observed object P in GOR gravitational spacetime is generally not equivalent to the gravitational mass $m_G(\eta)=m_G(\eta,0,\chi)$ (Eq. (14)) of P: $m_G(\eta)\neq m_I(\eta)$.

In particular, the GOR observed inertial mass (Eq. (13)) has generalized and unified the relativistic inertial mass of Einstein's optical agent OA(c) and the classical inertial mass of Newton's idealized agent OA_∞; the GOR observed gravitational mass (Eq. (14)) has generalized and unified the relativistic gravitational mass of Einstein's optical agent OA(c) and the classical gravitational mass of Newton's idealized agent OA_∞.

So, in the theory of OR, the GOR mass (Eq. (12)) observed by the general observation agent OA(η) (($0<\eta<\infty$; $\eta\to\infty$) has generalized and unified the relativistic mass of Einstein's optical agent OA(c) and the classical mass of Newton's idealized agent OA_∞.

5.2.2 Einstein's Inertial Mass and Gravitational Mass: Observed by OA(c)

Einstein's theory of relativity is also needed to distinguishes between the inertial mass $m_I(c,v,0)$ and the gravitational mass $m_G(c,0,\chi)$. Actually, the relativistic mass in

Einstein general relativity is merely a special case of the GOR observed mass, that is, the observational mass observed by the optical agent OA(c).

As the mass observed by the general observation agent OA(η), the GOR observed mass naturally generalizes the mass observed by the optical agent OA(c) in Einstein general relativity.

If $\eta \to c$, then OA(η)→OA(c), and the GOR inertial mass $m_I(\eta)=m(\eta,v,0)$ (Eq. (13)) observed by OA(η) strictly converges to the inertial mass $m_I(c)=m(c,v,0)$ observed with the optical observation agent OA(c) in Einstein general relativity:

$$m_I(c) = \lim_{\eta\to c}\Gamma(\eta,v,\chi)|_{\chi=0}m_o = \frac{m_o}{\sqrt{1-v^2/c^2}} \quad (15)$$

If $\eta \to c$, then OA(η)→OA(c), and the GOR gravitational mass $m_G(\eta)=m(\eta,0,\chi)$ (式(14)) observed by OA(η) strictly converges to the gravitational mass $m_G(c)=m(c,0,\chi)$ observed with the optical agent OA(c) in Einstein general relativity:

$$m_G(c) = \lim_{\eta\to c}\Gamma(\eta,v,\chi)|_{v=0}m_o = \frac{m_o}{\sqrt{1+2\chi/c^2}} \quad (16)$$

Due to the observational locality of the optical agent OA(c): $c<\infty$, both the inertial mass $m_I(c)=m(c,v,0)$ and the gravitational mass $m_G(c)=m(c,0,\chi)$ in Einstein's general relativity contain the observational effects of OA(c), and are not the completely objective and real.

People, including physicists, often mistakenly thought that, in Einstein theory of relativity, inertial mass was equal to gravitational mass, and frequently incorrectly employed Einstein's relativistic moving mass as gravitational mass in the theoretical models of gravitational interaction.

In fact, in Einstein's theory of general relativity, the moving mass or inertial mass $m_I(c)=m(c,v,0)$ (Eq. (15)) is not equal to the gravitational mass $m_G(c)=m(c,0,\chi)$ (Eq. (16)): $m_G(c)\neq m_I(c)$.

5.2.3 Newton's Inertial Mass and Gravitational Mass: Observed by OA∞

In Eq. (7) of IOR, m_∞ represents only the idealized observed mass in inertial spacetime and does not signify Newton's classical mass. As the observed mass of the idealized observation agent OA∞, Newton's classical mass m_∞ should be the idealized observed mass $m_\infty=m(\infty)$ in the GOR mass-speed relation (Eq. (11)) if the information-wave speed η of the observed agent OA(η) is idealized as infinity ($\eta\to\infty$):

$$\begin{aligned} m_\infty &= m(\infty) = \lim_{\eta\to\infty}\Gamma(\eta,v,\chi)m_o \\ &= \lim_{\eta\to\infty}\frac{m_o}{\sqrt{1-v^2/\eta^2+2\chi/\eta^2}} = m_o \end{aligned} \quad (17)$$

Significantly, Eq (17) indicates that Newton's classical mass m_∞ is exactly the objective and real rest mass of matter or matter particles: $m_\infty=m_o$.

Newton's classical inertial mass $m_I(\infty,v,0)$ and classical gravitational mass $m_G(\infty,0,\chi)$ are also special cases of the GOR observed mass, that is, the observed mass with the idealized observation agent OA∞.

As the mass observed with the general observation agent OA(η), the GOR observed mass naturally generalizes the mass observed with the idealized observation agent OA∞, that is, Newton's classical mass.

If $\eta\to\infty$, then OA(η)→OA∞, and the GOR inertial mass $m_I(\eta)=m(\eta,v,0)$ (Eq. (13)) observed by OA(η) strictly converges to the inertial mass $m_{I\infty}=m(\infty,v,0)$ observed with the idealized agent OA∞ in Newton's classical mechanics:

$$m_{I\infty} = m_I(\infty) = \lim_{\eta\to\infty}\Gamma(\eta,v,\chi)|_{\chi=0}m_o = m_o \quad (18)$$

If $\eta\to\infty$, then OA(η)→OA∞, and the GOR gravitational mass $m_G(\eta)=m(\eta,0,\chi)$ (Eq. (14)) observed by OA(η) strictly converges to the gravitational mass $m_{G\infty}=m(\infty,0,\chi)$ observed with the idealized agent OA∞ in Newton's classical mechanics:

$$m_{G\infty} = m_G(\infty) = \lim_{\eta\to\infty}\Gamma(\eta,v,\chi)|_{v=0}m_o = m_o \quad (19)$$

Just like Eq. (7), Eqs. (17-19) have significant enlightening implications [1]:

(1) Newton's classical mass m_∞, inertial mass $m_{I\infty}$, and gravitational mass $m_{G\infty}$ are all equivalent to the objective and real rest mass m_o of matter or matter particles:

$$m_\infty = m_{I\infty} = m_{G\infty} = m_o \quad (20)$$

(2) The idealized agent OA∞ has no the observational locality ($\eta\to\infty$), and therefore, Newton's classical mass m_∞ represents the objective and real mass of matter or material particles, presenting both the objectively real inertial effects and gravitational effects of matter;

(3) There is no need to distinguish between the inertial mass $m_{I\infty}$ and the gravitational mass $m_{G\infty}$ for the objectively real mass of matter.

5.3 GOR Energy: the Energy Observed by OA(η)

Like the theory of IOR, the energy in the theory of GOR as a theory of gravitation for the general observation agent OA(η) ($0<\eta<\infty$; $\eta\to\infty$) is also the observational energy observed by OA(η), or called the GOR observed energy, which may not necessarily be completely objective and true.

However, unlike the theory of IOR, the energy of matter or material particles in the theory of GOR not only has kinetic energy but also has potential energy.

5.3.1 GOR Kinetic Energy and Potential Energy: Observed by OA(η)

According to the principle of GOR relativity or GOR covariance: all observers are equal or have equal rights; all observation agents are equal or have equal rights [2-5]. So, the laws of physics have the same form or the corresponding relationship of isomorphic consistency for both different observers and different observation agents.

Therefore, in the gravitational spacetime observed by the general observation agent OA(η), the observed object P, like in that observed by the idealized agent OA∞, has both the kinetic energy $K(\eta)$ and the potential energy $V(\eta)$, and the total energy $H(\eta)$, following the principle of energy conservation: $H(\eta)=K(\eta)+V(\eta)$.

Based on the GOR mass-speed relation (Eq. (11)), the theory of GOR defines two concepts on observed energy for the general observation agent OA(η) as below.

The Kinetic Energy Observed by OA(η):

$$K(\eta)=\big(\Gamma(\eta,v,\chi)|_{\chi=0}-1\big)m_o\eta^2 \tag{21}$$

The Potential Energy Observed by OA(η):

$$V(\eta)=(1-\Gamma(\eta,v,\chi)|_{v=0})m_o\eta^2 \tag{22}$$

Then, the total energy of the observed object P in the GOR gravitational spacetime is:

$$\begin{aligned}H(\eta)&=K(\eta)+V(\eta)\\&=\big(\Gamma(\eta,v,\chi)|_{\chi=0}-\Gamma(\eta,v,\chi)|_{v=0}\big)m_o\eta^2\end{aligned} \tag{23}$$

The GOR observed kinetic energy (Eq. (21)) has generalized and unified the relativistic kinetic energy of Einstein's optical agent OA(c) and the classical kinetic energy of Newton's idealized agent OA$_\infty$; the GOR observed gravitational mass (Eq. (22)) has generalized and unified the relativistic potential energy of Einstein's optical agent OA(c) and the classical potential energy of Newton's idealized agent OA$_\infty$.

So, the GOR energy-conservation formula (Eq. (23)) have generalized and unified Einstein's relativistic energy-conservation formula and Newton's classical energy-conservation formula.

5.3.2 Einstein's Kinetic Energy and Potential Energy: Observed by OA(c)

The energy of matter or material particles in Einstein's theory of general relativity is that observed with the optical observation agent OA(c) and is a special case of the GOR observed energy.

If $\eta\to c$, then OA(η)→OA(c), and the GOR kinetic energy $K(\eta)$ (Eq. (21)) observed by OA(η) strictly converges to the kinetic energy $K(c)$ observed with the optical agent OA(c) in Einstein's general relativity:

$$K(c)=\lim_{\eta\to c}K(\eta)=\big(\Gamma(c,v,\chi)|_{\chi=0}-1\big)m_oc^2 \tag{24}$$

If $\eta\to c$, then OA(η)→OA(c), and the GOR potential energy $V(\eta)$ (Eq. (22)) observed by OA(η) strictly converges to the potential energy $V(c)$ observed with the optical agent OA(c) in Einstein's general relativity:

$$V(c)=\lim_{\eta\to c}V(\eta)=(1-\Gamma(c,v,\chi)|_{v=0})m_oc^2 \tag{25}$$

Naturally, if $\eta\to c$, the total energy (Eq. (23)) $H(\eta)$ of the object P in gravitational spacetime observed with the general observation agent OA(η) strictly converges to Einstein's relativistic total energy, that is, the total energy $H(c)$ observed with the optical agent OA(c):

$$\begin{aligned}H(c)&=\lim_{\eta\to c}H(\eta)=K(c)+V(c)\\&=\big(\Gamma(c,v,\chi)|_{\chi=0}-\Gamma(c,v,\chi)|_{v=0}\big)m_oc^2\end{aligned} \tag{26}$$

5.3.3 Newton's Kinetic Energy and Potential Energy: Observed by OA$_\infty$

The energy of matter or material particles in Newton's theory of universal gravitation is that observed with the idealized observation agent OA$_\infty$ and is also a special case of the GOR observed energy.

If $\eta\to\infty$, then OA(η)→OA$_\infty$, and the GOR kinetic energy $K(\eta)$ (Eq. (21)) observed by OA(η) strictly converges to the kinetic energy K_∞ observed with the idealized agent OA$_\infty$ in Newton's gravitation theory:

$$\begin{aligned}K_\infty&=K(\infty)=\lim_{\eta\to\infty}K(\eta)\\&=\lim_{\eta\to\infty}\big(\Gamma(\eta,v,\chi)|_{\chi=0}-1\big)m_o\eta^2=\frac{1}{2}m_ov^2\end{aligned} \tag{27}$$

Equation (27) is exactly Newton's classical-kinetic energy formula: $K_\infty=m_\infty v^2/2$.

If $\eta\to\infty$, then OA(η)→OA$_\infty$, and the GOR potential energy $V(\eta)$ (Eq. (22)) observed by OA(η) strictly converges to the potential energy V_∞ observed with the idealized agent OA$_\infty$ in Newton's gravitation theory:

$$\begin{aligned}V_\infty&=V(\infty)=\lim_{\eta\to\infty}V(\eta)\\&=\lim_{\eta\to\infty}(1-\Gamma(\eta,v,\chi)|_{v=0})m_o\eta^2=-\frac{GMm_o}{r}\end{aligned} \tag{28}$$

Equation (28) is exactly Newton's classical potential-energy formula: $V_\infty=-GMm_\infty/r$.

Naturally, if $\eta\to\infty$, the total energy (Eq. (23)) $H(\eta)$ of the object P in gravitational spacetime observed with the general observation agent OA(η) strictly converges to Newton's classic total energy, that is, the total energy $H_\infty=H(\infty)$ observed with the idealized agent OA$_\infty$:

$$H_\infty=K_\infty+V_\infty=\frac{1}{2}m_\infty v^2-\frac{GMm_\infty}{r} \tag{29}$$

However, as the matter energy from the perspective of the idealized observational agent OA$_\infty$ (the God's eye), Newton's inertial mass and gravitational mass are not that in the observational sense, but the objective and real energy of matter or matter particles.

5.4 GOR Redshift: Gravitational Redshift Observed by OA(η)

Before formally establishing his theory of general relativity, Einstein predicted based on the principle of equivalence that light in a gravitational field would be curved and exhibit gravitational redshift. This is Einstein's famous predictions of the gravitational deflection of light and the gravitational redshift of light.

Actually, Newton's theory of universal gravitation can also predict the gravitational deflection of light and the gravitational redshift of light.

In gravitational fields, all matter or material particles, not just light or photons, may exhibit gravitational deflection and gravitational redshift. Of course, they may also exhibit gravitational blueshift.

In terms of gravitational redshift, suppose a material object moves in a gravitational field, its energy should follow the principle of energy conservation: its kinetic energy and its potential energy constantly change or transform, but the total energy is conserved. Gravitational redshift means the decrease in the kinetic energy of the object; the gravitational blueshift means the increase in the kinetic energy of the object.

5.4.1 Einstein's Gravitational Redshift of Light

The gravitational redshift or blueshift of light refers to that, in gravitational spacetime, the frequency of light or photons changes with the variation of gravitational potential: the decrease of light frequency, i.e., redshift, means the decrease in the kinetic energy of photons; the increase of light frequency, i.e., blueshift, means the increase in the kinetic energy of photons.

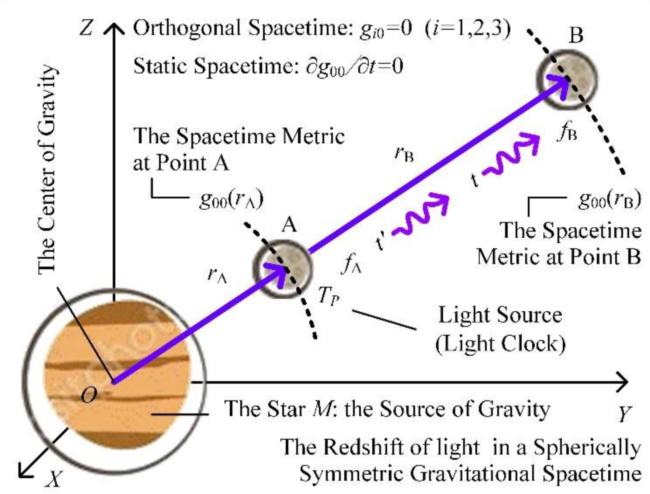

Figure 2 The Redshift of Light in Spherically Symmetric Gravitational Spacetime

Annotations: The star M is the gravitational source and center of spherically-symmetric gravitational spacetime. The light source (light clock) T_P stationary at the point A in the gravitational spacetime of M emits a light signal with the frequency f_A towards the distant point B. The observer stationary at the point B receives the light signal with the frequency f_B. According to Einstein's principle of equivalence and Einstein's theory of general relativity, $f_B<f_A$: the optical signal while propagating in gravitational spacetime exhibits gravitational redshift phenomenon.

Einstein's theory of gravitational redshift of light is the product of his theory of general relativity. Considering the motion scene of light or photons in the spherically-symmetric gravitational spacetime depicted in Fig. 2, Einstein's the gravitational-redshift formula of light can be deduced based on the principle of equivalence and the effect of potential clock [28]:

$$Z_E=\frac{\Delta f}{f}=\frac{f_B-f_A}{f_B}=1-\frac{\sqrt{g_{00}(c,r_B)}}{\sqrt{g_{00}(c,r_A)}} \qquad (30)$$
$$\left(g_{00}(c,r)=1+\frac{2\chi}{c^2};\ \chi=-\frac{GM}{r}\right)$$

where Z_E is the relative value of Einstein's gravitational redshift of light ($Z_E<0$ means redshift), G is the gravitational constant, M is the star or its mass, r_A (where the light source or light clock T_P is stationary) and r_B (where the observer O armed with the optical observation agent OA(c) is stationary) are the distances from the center of gravity to the points A and B, $g_{00}(c,r)$ is the 00-element of the spacetime metric $g_{\mu\nu}$ at the distance r from the center of gravity, f_A and f_B are the frequencies of light at A and B, and Δf is the absolute value of frequency shift of light between A and B.

The simplest and most feasible way to test or verify Einstein's prediction for the gravitational redshift of light is for the observers of the earth to observe the solar spectrum coming from the sun.

Let r_A be the radius R_S of the sun and r_B be the distance R_S+D_{SE} between the sun and the earth, where $D_{SE}>>R_S$, then, based on Einstein's gravitational-redshift formula (Eq. (30)), the gravitational redshift of the solar spectrum can be calculated theoretically:

$$Z_E=1-\frac{\sqrt{g_{00}(c,R_S+D_{SE})}}{\sqrt{g_{00}(c,R_S)}}\approx-\frac{GM_S}{R_S c^2} \qquad (31)$$
$$=-2.12\times10^{-6}$$

where M_S is the mass of the sun, and $Z_E<0$ mean redshift.

Adam (1959 [29]) provided the actual observed value of the redshift in the solar spectrum: Z=–2×10^{-6}. Blamont and Roddier (1961 [30]) and Brault (1963 [31]) provided more accurate observed value: Z=–2.12×10^{-6}, which is consistent with Einstein's prediction within the accuracy range of 5%.

The actual observation and spectral analysis of the sun seem to support Einstein's prediction for the gravitational redshift of light based on his general relativity.

The scenario of observing the solar spectrum by the observers on the earth can be approximately idealized as the scenario of observing the solar spectrum by the observers in the free spacetime S_F: $r_B\to\infty$, $g_{00}(c,r_B)\to1$; $r_A=R_S$, $g_{00}(c,r_A)=1-2GM_S/R_S c^2$.

5.4.2 Pseudo Newtonian Gravitational Redshift of Light

Newton's theory of gravitational redshift of light should naturally be the product of Newtonian mechanics, without the need for the principle of equivalence or the effect of potential clock.

Just as people expect to see the difference in the predictions of the gravitational deflection of light between Einstein and Newton, they also expect to see the difference in the predictions of the gravitational redshift of light between Einstein and Newton.

Unlike the situation of gravitational deflection, however, Einstein's theory of gravitational redshift of light seems to lose the challenge and competition coming from Newtonian mechanics. Newton's prediction of the gravitational redshift of light seems to be the same as Einstein's: they are lack observational distinguishability.

To predict the gravitational redshift of light based on Newtonian mechanics, it is necessary to first determine the inertial mass and gravitational mass of photons. However, in Newtonian mechanics, the mass of photons is uncertain.

At present, the so-called Newtonian gravitational-redshift formula of light [28] takes Einstein's relativistic mass m as Newton's classical inertial mass $m_{I\infty}$ and gravitational mass $m_{G\infty}$, and borrows Einstein formula $E=mc^2$ belonging to Einstein relativity theory and the Planck equation $E=hf$ belonging to quantum mechanics:

$$\begin{aligned} Z_{NP} &= \frac{\Delta f}{f} = \frac{\Delta hf}{hf} \\ &= \frac{\Delta E}{E} = -\frac{\Delta V}{mc^2} = -\frac{V_{\mathrm{B}} - V_{\mathrm{A}}}{mc^2} \\ &= \frac{1}{mc^2}\left(\frac{GM_S m}{R_S + D_{SE}} - \frac{GM_S m}{R_S}\right) \approx -\frac{GM_S}{R_S c^2} \end{aligned} \tag{32}$$

where Z_{PN} is the relative value of the pseudo Newtonian gravitational-redshift formula of light, E is the kinetic energy of a photon in vacuum, ΔE and ΔV are the kinetic-energy difference and potential-energy difference of the photon between the points A and B, and V_{A} and V_{B} are the potential energy of the photon at A (the sun) and at B (the earth), respectively.

By comparing the pseudo Newtonian gravitational-redshift formula (Eq. (32)) and Einstein's gravitational-redshift formula (Eq. (31)), it can be seen that they are highly approximate and extremely difficult to distinguish in observation.

Accordingly, people think that Einstein's theory of general relativity and Newton's theory of universal gravitation are rather consistent in terms of the gravitational redshift of light.

5.4.3 Newton's Gravitational Redshift of Light

In fact, Eq. (32) is not truly the gravitational redshift of light based on Newtonian mechanics, but a mixture of Newton's mechanics, Einstein's relativity theory, and even Planck's quantum theory, which can be called the pseudo Newtonian gravitational-redshift formula of light.

Purely based on Newtonian mechanics, the theory of OR has derived the true Newtonian gravitational-redshift formula of light, and has incorporated it into the theoretical system of GOR.

The essence of the gravitational redshift of light is the transformation of the kinetic and potential energy of photons, following the principle of energy conservation. Therefore, the definition and deduction of the gravitational redshift of light should be based on the perspective of energy or the idea of energy conservation, rather than the principle of equivalence or the effect of potential clock.

Based on the idea of energy transformation and the principle of energy conservation, according to the mass formula (Eq. (20)) and energy formulae (Eqs. (27-29)) of GOR theory, Newton's gravitational redshift of light can be defined as follows:

$$\begin{gathered} Z_N = \frac{\Delta K_\infty}{K_\infty} = -\frac{\Delta V_\infty}{H_\infty - V_\infty} = -\frac{V_\infty(r_{\mathrm{B}}) - V_\infty(r_{\mathrm{A}})}{H_\infty - V_\infty(r_{\mathrm{B}})} \\ \left(H_\infty = K_{F\infty} = \frac{1}{2}m_\infty c^2;\ V_\infty(r) = -\frac{GMm_\infty}{r}\right) \end{gathered} \tag{33}$$

where Z_N is the relative value of the Newtonian gravitational-redshift of light ($Z_N<0$ means redshift), m_∞ is the classical mass of photons in Newtonian mechanics (as stated in Sec. 5.2, m_∞ is equal to the rest mass m_o of photons), K_∞ and ΔK_∞ are the classical kinetic energy and incremental of photons, $V_\infty(r)$ and ΔV_∞ are the classical potential energy and incremental of photons, H_∞ is the total classical energy of photons, that is, the kinetic energy $K_{F\infty}$ of photons in the free spacetime S_F observed with the idealized agent OA_∞).

Thus, by continuing to derive from the definition of Newtonian gravitational redshift of light (equation (33)), the true gravitational redshift equation of Newtonian light can be obtained:

Thus, continuing to derive from the definition of the Newtonian gravitational redshift of light (Eq. (33)), the true Newtonian gravitational-redshift formula of light can be obtained:

$$\begin{aligned} Z_N &= -\frac{(-GMm_\infty/r_{\mathrm{B}}) - (-GMm_\infty/r_{\mathrm{A}})}{(m_\infty c^2/2) - (-GMm_\infty/r_{\mathrm{B}})} \\ &= \frac{2GMr_{\mathrm{B}}}{r_{\mathrm{B}}c^2 + 2GM}\left(\frac{1}{r_{\mathrm{B}}} - \frac{1}{r_{\mathrm{A}}}\right) \end{aligned} \tag{34}$$

Considering the scenario where an observer armed with the idealized agent OA_∞ on the earth or in the free spacetime S_F observes the solar spectrum: $M=M_S$, $r_{\mathrm{A}}=R_S$, $r_{\mathrm{B}}\to\infty$, and then the Newtonian-gravitational formula (Eq. (34)) of light is reduced to:

$$Z_N = \frac{2GMr_B}{r_B c^2}\left(-\frac{1}{r_A}\right) = -\frac{2GM_S}{R_S c^2} = 2Z_E \tag{35}$$

It can be seen that the gravitational redshift Z_N of light based on Newtonian mechanics is twice that of Einstein's gravitational redshift Z_E: $Z_N=2Z_E$, which is not equal to Einstein's theoretical prediction.

This is in line with the logic of the theory of OR: different observational agents, Newton's idealized agent OA_∞ and Einstein's optical agent $\mathrm{OA}(c)$, should have observed different gravitational redshift of light.

Later, we will verify the validity of the true Newtonian gravitational-redshift formula (Eq. (34)) of light.

5.4.4 GOR Gravitational Redshift of Light

As stated in Sec. 5.3.3, the essence of the gravitational redshift of light is the transformation of the kinetic and potential energy of photons, following the principle of energy conservation.

Based on the idea of energy transformation and the principle of energy conservation, according to the GOR mass formulae (Eqs. (13-14)) and energy formulae (Eqs. (21-23)), the gravitational redshift of light observed by the general observation agent $\mathrm{OA}(\eta)$ ($\eta \geq c$) can be defined as:

$$\begin{gathered} Z_{\mathrm{GOR}} = \frac{\Delta K_\eta}{K_\eta} = -\frac{\Delta V_\eta}{H_\eta - V_\eta} = -\frac{V_\eta(r_{\mathrm{B}}) - V_\eta(r_{\mathrm{A}})}{H_\eta - V_\eta(r_{\mathrm{B}})} \\ \begin{cases} H_\eta = K_{F\eta} = \begin{cases} mc^2 & \eta = c \\ \left(\Gamma|_{\chi=0\,|\,v=c} - 1\right)m_o\eta^2 & \eta > c \end{cases} \\ V_\eta(r) = (1 - \Gamma|_{v=0})m_o\eta^2 \end{cases} \end{gathered} \tag{36}$$

where Z_{GOR} is the relative value of the gravitational redshift of light observed by $\mathrm{OA}(\eta)$ ($Z_N<0$ means redshift), m_o is the rest mass of the photon, and $m=m(c)$ is the moving mass of photons observed by the optical agent $\mathrm{OA}(c)$, K_η and ΔK_η are the kinetic energy and incremental of photons observed by $\mathrm{OA}(\eta)$, $V_\eta(r)$ and ΔV_η are the potential energy and incremental of photons observed by $\mathrm{OA}(\eta)$ by $\mathrm{OA}(\eta)$, H_η is the total energy of photons observed by

OA(η) (i.e., the kinetic energy $K_{F\eta}$ of photons in the free spacetime S_F observed by OA(η)), and $\Gamma=\Gamma(\eta,v,\chi)$ is the GOR factor.

Thus, based on Eqs. (21-23), from the definition (Eq. (36)) of the gravitational redshift of light observed by the general observation agent OA(η) ($\eta\geq c$), one can derived the GOR gravitational-redshift formula of light:

$$Z_{\mathrm{GOR}}=\frac{\left(\frac{m_o\eta^2}{\sqrt{g_{00}(\eta,r_{\mathrm{B}})}}\right)-\left(\frac{m_o\eta^2}{\sqrt{g_{00}(\eta,r_{\mathrm{A}})}}\right)}{K_{F\eta}-\left(1-1/\sqrt{g_{00}(\eta,r_{\mathrm{B}})}\right)m_o\eta^2} \tag{37}$$

Later, we will verify the validity of the GOR gravitational-redshift formula (Eq. (37)) of light.

5.5 How Much does a Photon Weigh?

The theory of IOR has proven that photons, like all other material particles, possess the rest mass of their own. However, the theory of IOR fails to theoretically calculate the rest mass or weight of photons.

Now, the GOR gravitational-redshift definition (Eq. (36) and formula (Eq. (37)) of light provides us with the important information about the rest mass of photons.

If $\eta\to c$, then the Z_{GOR} in Eq. (37) observed by OA(η) ($\eta\geq c$) is reduced to the gravitational redshift of light observed by the optical agent OA(c), that is. Einstein's gravitational redshift Z_E of light, where the kinetic energy of a photon in absolute vacuum (the free spacetime S_F) observed by OA(c) is $K_{F\eta}=K_F(c)=mc^2$.

For the gravitational-redshift scene of light depicted in Fig. 2, according to the GOR gravitational-redshift formula (Eq. (37)) of light, it should hold true in the observation of Einstein's optical agent OA(c) that:

$$\begin{aligned} Z_{\mathrm{OA}(c)}&=\lim_{\eta\to c}Z_{\mathrm{GOR}}\\ &=\frac{\left(\frac{m_oc^2}{\sqrt{g_{00}(c,r_{\mathrm{B}})}}\right)-\left(\frac{m_oc^2}{\sqrt{g_{00}(c,r_{\mathrm{A}})}}\right)}{mc^2-\left(1-1/\sqrt{g_{00}(c,r_{\mathrm{B}})}\right)m_oc^2}\end{aligned} \tag{38}$$

It is worth noting that, in Eq. (38), m_o represents the objectively true rest mass of the photon, whereas $m=m(c)$ represents Einstein's relativistic moving mass of the photon, i.e., the mass observed by the optical agent OA(c).

Consider the scenario where an observer in the free spacetime S_F observes the solar spectrum through OA(c): $M=M_S$, $r_{\mathrm{A}}=R_S$, $g_{00}(c,r_{\mathrm{A}})=1-2GM_S/R_Sc^2$; $r_{\mathrm{B}}\to\infty$, $g_{00}(c,r_{\mathrm{B}})=1-2GM_S/r_{\mathrm{B}}c^2\to 1$. Then Eq. (38) is reduced to:

$$\begin{aligned} Z_{\mathrm{OA}(c)}&=\frac{(m_oc^2)-\left(m_oc^2/\sqrt{g_{00}(c,r_{\mathrm{A}})}\right)}{mc^2}\\ &=-\frac{GM_S}{R_Sc^2}\frac{m_o}{m}\end{aligned} \tag{39}$$

Compare Eq. (31) and Eq. (39):

Equation (39) is the gravitational redshift formula of the solar spectrum for OA(c) with $Z=\Delta K/K$ defined based on the GOR energy-shift theory; whereas equation (31) is based on Einstein's theory of general relativity, which defines the gravitational redshift of light with $Z=\Delta f/f$ based on the frequency-shift theory.

The theoretical prediction value $Z_E=-2.12\times10^{-6}$ of gravitational redshift of the solar spectrum based on Eq. (31), has been validated by the observations and experiments through the optical agent [29-31].

In the view of the equivalence between the energy-shift definition of $Z=\Delta K/K$ and the frequency-shift definition of $Z=\Delta f/f$ for the gravitational redshift of light, and under the optical agent OA(c), the kinetic energy $E=mc^2=hf$ of a photon with the frequency f, it holds true from Eq. (31) and Eq.(39) that:

$$\begin{aligned} &Z_{\mathrm{OA}(c)}=Z_E\quad\text{and}\quad\frac{GM_S}{R_Sc^2}\frac{m_o}{m}=\frac{GM_S}{R_Sc^2}\\ &\text{that is}\quad m_o=m=\frac{hf}{c^2}\quad(E=mc^2=hf)\end{aligned} \tag{40}$$

It turns out that, in Einstein's relativity theory of the observation optical agent OA(c), the rest mass m_o of photons is exactly the relativistic moving mass $m=m(c)$, and so, the m_o is not really zero: $m_o=m>0$.

Perhaps we are now able to understand why experimental physicists fail to find the rest mass of photons after going through countless hardships.

By substituting $m_o=m$ into Eq. (38), it can be seen that the GOR gravitational redshift Z_{GOR} or $Z_{\mathrm{OA}(\eta)}$ (Eq. (37)) of light in the case of $Z_{\mathrm{OA}(c)}$ is exactly Einstein's gravitational redshift Z_E (Eq. (30)) of light:

$$\begin{aligned} Z_{\mathrm{OA}(c)}&=\lim_{\eta\to c}Z_{\mathrm{GOR}}\\ &=\frac{\left(\frac{m_oc^2}{\sqrt{g_{00}(c,r_{\mathrm{B}})}}\right)-\left(\frac{m_oc^2}{\sqrt{g_{00}(c,r_{\mathrm{A}})}}\right)}{m_oc^2-\left(1-1/\sqrt{g_{00}(c,r_{\mathrm{B}})}\right)m_oc^2}\\ &=1-\frac{\sqrt{g_{00}(c,r_{\mathrm{B}})}}{\sqrt{g_{00}(c,r_{\mathrm{A}})}}=Z_E\end{aligned} \tag{41}$$

This suggests that the GOR gravitational-redshift formula (Eq. (37)) of light has generalized Einstein's gravitational-redshift formula (Eq. (30)) of light: if $\eta\to c$, then Z_{GOR} in Eq. (37) is strictly reduced to Einstein's gravitational redshift Z_E in Eq. (30).

In particular, the GOR gravitational-redshift formula (Eq. (37)) of light has also generalized the true Newtonian gravitational-redshift formual (Eq. (34)) of light.

if $\eta\to\infty$, then $K_{F\infty}=m_\infty c^2/2=m_oc^2/2$, Z_{GOR} in Eq. (37) is strictly reduced to Newton's gravitational redshift Z_N of light in Eq. (34):

$$\begin{aligned} Z_{\mathrm{OA}(\infty)}&=\lim_{\eta\to\infty}Z_{\mathrm{GOR}}\\ &=\lim_{\eta\to\infty}\frac{(1+GM/r_{\mathrm{B}}\eta^2)-(1+GM/r_{\mathrm{A}}\eta^2)}{c^2/2\eta^2+GM/r_{\mathrm{B}}\eta^2}\\ &=\frac{2GMr_{\mathrm{B}}}{r_{\mathrm{B}}c^2+2GM}\left(\frac{1}{r_{\mathrm{B}}}-\frac{1}{r_{\mathrm{A}}}\right)=Z_N\end{aligned} \tag{42}$$

In this way, the GOR gravitational-redshift theory of light has generalized and unified Einstein's gravitational-redshift theory of light and Newton's gravitational-redshift theory of light. This confirms the logical consistency and theoretical validity of the GOR gravitational-redshift formula of light, and also confirms the validity of Newton's gravitational-redshift formula (Eq. (34)) which is based on the energy-shift definition of $Z_N=\Delta K_\infty/K_\infty$.

Meanwhile, from one aspect, this confirms the correctness of the theoretical value of the rest mass of photons predicted by the theory of GOR: $m_o=m_\infty=m=m(c)$.

According to the GOR theoretical prediction value of Eq. (40), photons of different frequencies have different rest masses or different objectively real masses: the rest mass m_o of a photon with frequency f is $m_o=hf/c^2$.

The recommended values of physical constants:

Light speed $c=2.99792458\times10^8$ m/s

Planck constant $h=6.62607015\times10^{-34}$ J·s

The rest mass of a visible red photons with the frequency of $f=4.5\times10^{14}$ Hz is

$$m_o=\frac{6.62607015\times10^{-34}\times4.5\times10^{14}}{(2.99792458\times10^8)^2} \tag{43}$$
$$=3.31762380\times10^{-36}\ \text{(kg)}$$

And whereas the rest mass of a gamma photon with the frequency of $f=10^{20}$ Hz can reach

$$m_o=\frac{6.62607015\times10^{-34}\times10^{20}}{(2.99792458\times10^8)^2} \tag{44}$$
$$=7.37249732\times10^{-31}\ \text{(kg)}$$

Now, the task to measure and determine the rest mass of photons by observations and experiments is left to experimental physicists.

It should be pointed out that both Einstein theory of relativity and the theory of OR imply an important idealized assumption in the concept of the rest mass: the rest mass m_o of a material object or a matter system is static or time-invariant, that is,

$$\frac{\partial}{\partial t}m_o=0 \tag{45}$$

Actually, all material objects or matter systems constantly radiate gravitons and gravitational waves outward, and interact with external gravitons and gravitational waves at all times. According to the theory of OR, all material particles, including gravitons, have their objectively true rest mass. So, the mass of any material body must be time-variant: $m_o=m(t)$.

6 Discussion

According to the theory of OR, Einstein's relativistic mass contains observational effect and apparent phenomenon, not completely objective and real; the objective and real mass of matter or material particles should be Newton's classical mass, i.e., Einstein's rest mass, which has the objectively real inertial and gravitational effects.

The theory of IOR has proven that photons, like all other matter particles, possess the rest mass of their own. The theory of GOR has further proven that the rest mass of photons, like all other matter particles, is both the inertial mass and the gravitational mass, possessing not only inertial effects but also gravitational effects.

In particular, the theory of GOR has predicted that the theoretical value of the objective and real rest mass of a photon with frequency f is $m_o=m_\infty=m=m(c)=hf/c^2$.

So, what does it mean for photons to have rest mass?

6.1 Photons: Energy Quanta or Mass Quanta?

The theory of OR supports the materialist view of nature: the natural world is the world of matter, a material object or a matter system, no matter a massive star or a tiny photon, must have the mass of its own if it objectively exists, otherwise it does not exist. According to the theory of OR, the objectively real mass of matter is the rest mass, that is, exactly Newton's classical mass rather than Einstein's relativistic mass.

As early as 1756, Mikhail Lomonosov proposed the law of the conservation of matter or mass [32]: the mass of matter is conserved. This law links the existence of matter and the mass of matter, and even, makes them equivalent.

The law of the conservation of energy that is widely accepted and Lomonosov's law of the conservation of mass can be regarded as the most important dual principles in the objectively physical world.

As clarified by the theory of OR, Lomonosov's and Newton's views on energy and mass are correct: the energy of matter and the mass of matter are independent of each other: mass is mass; energy is energy. The mass of matter is conserved; and the energy of matter is conserved, too. Whereas Einstein's mass-energy relation $E=mc^2$ is not the objectively physical existence.

Mankind needs to reacquaint and re-understand Lomonosov's law of the conservation of matter or mass.

The theory of OR has clarified that all matter or material particles have the objectively real mass, that is, exactly Newton's classical mass and Einstein's rest mass. This suggests that all matter or mater particles, no matter celestial bodies, photons, or gravitons, are mass quanta rather than energy quanta.

The fact that photons possess the rest mass confirms the conclusion of the theory of OR: there are no the energy quanta with no mass in the objectively physical world.

6.2 Photons and Quantum Effects

In 1900, Planck theoretically derived the Planck formula for blackbody radiation based on his energy-quantum hypothesis, which was highly consistent with blackbody radiation experiments, and known as Planck's law [33].

However, the most important thing is not Planck's law itself, but the hypothetical logical premise: $E=hf$, which suggests that the energy of light is discrete rather than continuous, which laid the first foundation stone for quantum theory, and marked the birth of quantum mechanics [34,35].

However, Planck himself did not seem to enjoy the quantization of the energy of light. In people's traditional beliefs, the energy of matter or material particles should be continuous rather than discrete. Planck had no choice but to construct the hypothesis $E=hf$ of energy quanta: in order to theoretically derive the blackbody-radiation formula, Planck had to employ the energy-quantum hypothesis as his logical premise.

Now, the theory of OR tells us that photons have the rest mass. This suggests that photons are mass quanta, not energy quanta with no mass. Thus, both the momentum and energy of photons are the physical effects of the objective and real mass of photons.

The theory of OR has elucidated [2-5]: quantum mechanics based on the Planck hypothesis $E=hf$ of energy quanta is also a partial theory in Hawking's words [24], belonging to the optical agent OA(c). Like relativistic effects, quantum effects are also observational effects, where photons act as the informons of OA(c) and perturb the objects observed by OA(c).

Actually, in Planck's blackbody radiation experiment, the object observed by Planck was light, and the observation medium that transmitted the information about the observed object to Planck was also light. Photons, as mass quanta with the rest mass, act as informons for the optical agent OA(c), representing the highest resolution of the optical agent OA(c). Naturally, the minimum scale for measuring energy by OA(c) must be the energy $\varepsilon=hf$ of a single photon.

Therefore, the quantization of energy measured with the optical agent OA(c) is natural and inevitable. Continuous energy measurement could only occur in idealized observation scenarios of the idealized agent OA_∞.

So, Mr. Planck would not have had to worry about his hypothesis of energy quanta and his quantization of photon energy. What truly cannot be accepted by our reason should be the non-discrete continuity of mass and energy.

It should be pointed out, the fact that photons have the rest mass tells us: the quantum effects in the quantum mechanics based on the Planck equation $E=hf$ are in essence not the physical effects of photons as energy quanta, but the physical effects of photons as mass quanta.

In essence, the quantum effects observed in the microphysical world are due to the quantization of matter mass rather than the quantization of matter energy.

6.3 Photons and Wave-Particle Duality

In the history of human physics, there have always been two doctrines about the materiality of light: Newton's Corpuscular Theory of Light (1675 [23]); Huygens' Wave Theory of Light (1678 [36])

Nowadays, it is widely accepted that light or photons possesses the wave-particle duality: a photon itself is a wave, or in other words, a single photon has the properties of wave. De Broglie further extended the wave-particle duality of light or photons to all matter: a single particle of matter is a wave, known as a de Broglie wave [37-39].

In fact, there is no such thing as de Broglie wave in the objectively physical world. As the theory of OR has clarified [2-5], de Broglie wave is actually just the information wave of the optical observation agent OA(c), which loads with the information about the observed object P, including its mass, momentum and energy.

The doctrine of the wave-particle duality of light confuses the two different existence forms of photons and light waves, and confuses the individual behavior of a sing photon as an individual and the collective behavior of light as the group of photons.

According to the theory of OR, photons, like all other material particles, have the rest mass. This fact tells us that Newton's corpuscular theory of light is correct [23]: light is composed of microscopic material particles, we now call them photons; all material particles, including photons, obey the same laws and rules of physics.

Of course, this does not mean that Huygens' wave theory of light is wrong.

Newton's corpuscular theory of light describes the material composition of light; Huygens' wave theory of light describes the wave characteristics of light.

Particles are particles, waves are waves.

A material particle, as a physical entity, is the smallest or most fundamental unit of a specific substance; A wave is a group of material particles, which exhibits the behavioral characteristics of waves.

Newton tells us that light is composed of microscopic material particles: countless photons form light, converging into an ocean of light or photons, just like countless H_2O molecules form water, lakes, rivers, and seas.

Huygens tells us that light, as a group of photons, exhibits wave effects. Huygens' wave theory of light systematically elaborates the wave nature of light, including the reflection and refraction phenomena of light.

We are familiar with the story of Einstein and light: photons had no mass; therefore, the speed of light was invariant and photons could never stop.

So, does light or photons really never stop?

Waves, such as light waves, sound waves, water waves, gravitational waves, and even all matter waves, seem to have a certain mechanism that can maintain the intrinsic speeds of their own. This unique mechanism of maintaining speed is the collective effect or aggregate effect exhibited by countless material particles converging into waves. The material particles in a matter wave move with the wave. As the kinetic energy of material particles decreases, the frequency of the wave decreases, so that the intrinsic speed of the wave remains unchanged; as the kinetic energy of material particles increases, the frequency of the wave increases, so that the intrinsic speed of the wave remains unchanged.

However, it is difficult for a single particle to possess such a mechanism to maintain the speed of its own.

The physical properties of matter waves require frequency f and wavelength λ as their characteristic physical quantities. However, our reason tells us that it is difficult for an isolated matter particle or photon in the free spacetime or absolute vacuum to exhibit the physical properties of waves and to describe its physical effects with frequency f and wavelength λ.

We repeatedly emphasize that photons possess the rest mass and are in essence mass quanta rather than energy quanta. Therefore, the momentum p and kinetic energy K of an isolated photon depend on its rest mass m_o: in the free spacetime observed by the idealized agent OA_∞, $p=m_oc$ and $K=m_oc^2/2$ (we temporarily regard c as the initial speed of photons when being emitted in absolute vacuum). As an isolated photon moves in the universe that is not an absolute vacuum, like a bullet moving in the earth's atmosphere, its momentum and kinetic energy will inevitably gradually decay. You cannot expect the photon to abandon some mass to maintain its intrinsic speed *c*. The only result is that, like the bullet, the photon must be slower and slower, and finally stop.

Actually, both photons and light waves are not what Einstein imagined: they cannot fly forever. The unique mechanism of maintaining speed of light as a group of photons must be relative: the decrease in the kinetic energy of photons must lead to the redshift in the frequency of light, which means the decrease in the total energy of light. As the total energy of light as a group of photons is consumed to a certain extent, the speeds of light and photons must be unable to continue to maintain.

This is the essence of Hubble's Cosmological Redshift, involving the Big-Bang theory, which will be interpreted in the later OR serial reports.

6.4 The Physical Effects of Photon Mass

The mass of matter, i.e., the quantity of matter contained in a matter object or a matter system, is the sign of whether matter objectively exists or not: matter must have mass if it objectively exists, otherwise, it would have not existed.

There are two types of important physical effects of matter mass: one is the inertia effect; the other is the gravitational effect. According to the theory of OR, the objective and real mass of matter is exactly Newton's classical mass and also Einstein's rest mass, but not Einstein's relativistic mass. The objectively real inertial and gravitational effects are rooted from Newton's classical mass.

Photons, as Newton said [23], are the microscopic particles of matter called **Corpuscles** or **Photons** that obey the same laws of physics as all other particles of matter. It is exactly because photons possess the rest mass that, like all other particles of matter, they exhibit the objectively real inertial and gravitational effects.

The fact that photons exhibit the objectively real inertial and gravitational effects confirms the logical conclusion of OR: photons have the objectively real rest mass.

6.4.1 The Mass of Photons and the Inertial Effects of Photons

The inertia effect of photons is evident.

The fact that photons have mass and the fact that photons has inertia effect can be mutually confirmed.

The quantum effect of light or photons is a sort of inertial effect of light or photons: photons with the rest mass move at the speed of light *c*, and therefore, they have momentum and kinetic energy. As they act as the informons for the optical agents OA(*c*), they must perturb the observed object *P*, causing *P* to exhibit quantum effects.

Or, conversely, the quantum effects as inertial effects of light or photons confirms that photons possess the objectively real mass, i.e., the rest mass.

The Compton effect is an example of the quantum and inertial effects of light or photons.

In the 1920s, Compton discovered the photon-scattering effect [40]. Let X-rays enter certain substances, the photons collide with the electrons in the atoms of the substances and scatter. The scattered photons become softer, their wavelength exhibits redshift and the amount of redshift is related to the scattering angle θ. Such a scattering phenomenon does not seem to conform to Newton's classical laws of momentum conservation and energy conservation, but conforms to Einstein's relativistic laws of momentum conservation and energy conservation.

It is based on Einstein special relativity as well as Planck equation $E=hf$ and de Broglie relation $p=h/\lambda$ that Compton derived the photon-scattering formula which conforms to observations and experiments:

$$\Delta\lambda = \lambda_S - \lambda_I = \frac{h}{m_e c}(1-\cos\theta) \qquad (46)$$

where λ_I and λ_S are the incident wavelength and scattering wavelength of light photons, h is the Planck constant, c is the speed of light, m_e is the rest mass of electrons, and θ is the photon-scattering angle.

The basic idea behind the logical deduction of Compton's photon-scattering formula (Eq. (46)) is that the photon-electron system in photon-scattering experiments follows Einstein's relativistic laws of momentum conservation and energy conservation.

Accordingly, Compton was awarded the 1927 Nobel Prize in Physics.

The Compton effect has become one of the important empirical evidence supporting Einstein theory of special relativity. In essence, however, the Compton effect is not the support for Einstein theory of special relativity, but the support for the theory of IOR.

Actually, just like Planck's blackbody-radiation experiment, the observation agent of Compton's photon-scattering experiment is also the optical agent OA(*c*): the object observed by Compton is light and photons, and the observation medium that transmits the information about the observed object for Compton is also light and photons. Naturally, the photon-scattering effects presented by OA(*c*) should be more in line with Einstein's theory of relativity as the theory of optical observation. However, as the theory of OR repeatedly emphasizes, this does not mean that Einstein is more right than Newton.

If we could be equipped with the idealized observation agent OA_∞, we would observe the photon-scattering effects that conform to Newton's classical laws of momentum conservation and energy conservation.

For the general observation agent OA(η) ($c\leq\eta<\infty$; $\eta\to\infty$), The redshift amount $\Delta\lambda$ of photon-scattering wavelength can be equivalently defined by the momentum $p(\eta)$ and kinetic energy $K(\eta)$ observed by OA(η); and based on the principle of general correspondence [1], the photon-scattering formula (Eq. (46)) for the optical agent OA(*c*) can be transformed into the photon-scattering formula for the general observation agent OA(η):

$$\frac{K_I(\eta)-K_S(\eta)}{p_I(\eta)p_S(\eta)} = \frac{1}{m_e}(1-\cos\theta) \quad (\eta\geq c) \qquad (47)$$

where $p_I(\eta)$ and $p_S(\eta)$ are the incident momentum and scattering momentum of photons observed by OA(η),

$K_I(\eta)$ and $K_S(\eta)$ are the incident kinetic energy and scattering kinetic energy of photons observed by OA(η), and m_e is the rest mass of electrons.

In a scattering experiment of photons, once OA(η) observes the momentum $p_I(\eta)$ and kinetic energy $K_I(\eta)$ of the incident photons as well as the momentum $p_S(\eta)$ and kinetic energy $K_S(\eta)$ of the scattered photons, the photon-scattering angle θ observed by OA(η) can be calculated with the photon-scattering formula (Eq. (47)).

As $\eta \to c$, the photon-scattering formula (Eq. (47) for the general observation agent OA(η) strictly converges to the Compton photon-scattering formula (Eq. (46)) for the optical agent OA(c):

$$\begin{aligned}\lim_{\eta\to c}\frac{K_I(\eta)-K_S(\eta)}{p_I(\eta)p_S(\eta)} &= \frac{hf_I(c)-hf_S(c)}{h^2/\lambda_I(c)\lambda_S(c)}\\ &= \frac{c}{h}\Big(\lambda_S(c)-\lambda_I(c)\Big) = \frac{1}{m_e}(1-\cos\theta)\end{aligned} \tag{48}$$

where $\lambda_I(c)$ and $\lambda_S(c)$ are the incident wavelength and scattering wavelength of light observed by OA(c), and $f_I(c)$ and fS (c) are the incident frequency and scattering frequency of light observed by OA(c).

As $\eta \to \infty$, the photon-scattering formula (Eq. (47)) for the general observation agent OA(η) strictly converges to the Newtonian photon-scattering formula for the idealized agent OA$_\infty$:

$$\begin{aligned}\lim_{\eta\to\infty}\frac{K_I(\eta)-K_S(\eta)}{p_I(\eta)p_S(\eta)} &= \frac{K_{I\infty}-K_{S\infty}}{p_{I\infty}p_{S\infty}}\\ &= \frac{1}{m_e}(1-\cos\theta)\end{aligned} \tag{49}$$

where $p_{I\infty}$ and $p_{S\infty}$ are the incident momentum and scattering momentum of photons observed by OA$_\infty$, and $K_{I\infty}$ and $K_{S\infty}$ are the incident kinetic energy and scattering kinetic energy of photons observed by OA$_\infty$.

If we had the idealized observation agent OA$_\infty$, we could observe Newton's classical momentum $p_{I\infty}$ and classical kinetic energy $K_{I\infty}$ of incident photons as well as the Newton's classical momentum $p_{S\infty}$ and classical kinetic energy $K_{S\infty}$ of scattered photons, and then, we could calculate the Newtonian scattering angle θ of photons observed by the idealized agent OA$_\infty$ based on Eq. (49).

Like all the formulas in the theory of OR, the OR photon-scattering formula (Eq. (47)) for the general observation agent OA(η) has generalized and unified the photon-scattering formula (Eq. (46 or (48)) for Einstein's optical agent OA(c) and the photon-scattering formula (Eq. (49)) for Newton's idealized agent OA$_\infty$.

Thus, the photon-scattering formula (Eq. (47)) for the general observation agent OA(η) ($\eta \geq c$) in the theory of OR can be called the general Compton formula.

It should be pointed out that Compton formula (Eq. (46)) and even the general Compton formula (Eq. (47)) are that for light rather than for a single photon, and may not necessarily conform to the experimental scene of an isolated photon.

Similar to Compton formula, the basic idea behind the logical deduction of the general Compton formula is that the photon-electron system in the photon-scattering experiment follows the principles of momentum conservation and energy conservation for the general observation agent OA(η) ($\eta \geq c$).

According to the theory of OR, the objectively real momentum or kinetic energy of matter particles are actually the inertial effects generated by the rest mass of matter particles. The logical deductions of Compton formula and the general Compton formula indicate that photons have objectively real inertial effects.

This confirms the logical conclusion of OR from one aspect: photons have the rest mass.

6.4.2 The Mass of Photons and the Gravitational Effects of Photons

The gravitational effect of photons is also evident.

The fact that photons have mass and the fact that photons has gravitational effect can also be mutually confirmed.

According to the theory of OR, the rest mass m_o of matter or material particles is exactly Newton's classical mass m_∞, which is both Newton's classical inertial mass $m_{I\infty}$ and Newton's classical gravitational mass $m_{G\infty}$: m_o=m_∞ =$m_{I\infty}$=$m_{G\infty}$. Therefore, the rest mass of matter, including the rest mass of photons, not only has inertial effects, but also has gravitational effects.

The gravitational redshift and gravitational deflection of light are both the objectively real gravitational effects generated by the rest mass of photons: a photon with the rest mass m_o=m_∞, in a gravitational field, not only has the kinetic energy K_∞=$m_\infty c^2/2$ but also has the potential energy V_∞=$-GMm_\infty/r$. The gravitational redshift and gravitational deflection of light have been verified by observations and experiments. And, as clarified by the theory of OR, if we had the idealized observation agent OA$_\infty$, we could observe the gravitational redshift and gravitational deflection of light that must conform to Newton's theory of universal gravitation.

This suggests that photons in a gravitational field obey Newton's law of universal gravitation and Newton's law of energy conservation: the total energy of classical kinetic plus classical potential energy of a material object in a gravitational spacetime is conserved. As Newton speculated: photons, as particles of matter, obey the same laws of physics as all other material particles do.

The gravitational redshift and gravitational deflection of light confirm that photons have the rest mass.

Therefore, photons, as mass quanta, are inevitably subject to gravitational forces; in other words, like all material objects or matter particles, photons must be gravitationally interacted with all matter.

Spacetime Curvature or Gravitational Interaction?

Originally, according to Newton's law of universal gravitation, gravity is one of the four fundamental interactions in the physical world, that is, a force. After the birth of Einstein theory of general relativity, however, gravitational interactions were geometrically transformed into the effects of spacetime curvature: matter makes spacetime curved; the curved spacetime makes matter move.

So, the rotation of the earth around the sun is no longer due to the gravitational interaction between the sun and earth but due to the spacetime curvature around the sun.

However, it is worth considering that we can feel the gravity of the earth but we cannot feel the curvature of spacetime around the earth; and that we can attribute the deflection of the solar eclipse starlight to the curvature of spacetime around the sun but we cannot attribute the redshift of the solar spectrum to the curvature of spacetime around the sun.

The theory of OR has clarified that the speed of light is not really invariant; spacetime is not really curved. The effects of spacetime curvature, like the invariance of light speed, is not the objectively physical reality, but a sort of observational effect and a sort of apparent phenomenon caused by the observational locality ($c<\infty$) of Einstein's optical agent OA(c).

The theory of OR has proven that the objectively real spacetime must not be curved.

So, we have reasons to believe that, no matter the gravitational redshift of light or the gravitational deflection of light, it is caused by the gravitational effect of photon mass, or in other words, by the gravitational interaction between the gravitational fields of photons and the gravitational fields of celestial bodies.

It should be pointed out that the photon mass that generate gravitational effects here is not referred to Einstein's relativistic mass, but Newton's classical mass, that is, the objectively real rest mass of photons.

The Mass of Photons and the Gravitational Redshift of Light

The gravitational redshift of light cannot be explained with the curvature of spacetime.

According to the theory of GOR, for the gravitational redshift of light, the decay of the frequency of light are merely phenomena, whereas the essence is the decay of the kinetic energy of light or photons, a gravitational effect caused by the rest mass of photons. In a gravitational field, photons with the rest mass not only have the kinetic energy but also have the potential energy. Based on the principle of energy conservation, as photons move in the gravitational field, the total energy of photons is conserved, the kinetic energy and potential energy of photons continuously transform: the kinetic energy either decrease or increases, resulting in the redshift or blueshift in the frequency of light waves.

The fact that light exhibits redshift or blueshift in gravitational fields suggests that photons have the rest mass. Thus, the GOR gravitational-redshift formula of light and the redshift phenomenon of solar spectra provide us with the information about the rest mass of photons.

It is based on the GOR gravitational-redshift formula of light that the theory of OR calculates and predicts the theoretical value of the rest mass of a photon with the frequency f: $m_o = m_\infty = m(c) = hf/c^2$.

The Mass of Photons and the Gravitational Deflection of Light

The gravitational deflection of light is Einstein's most famous prediction from his general relativity.

In 1919, a team led by British astronomer Eddington observed a solar eclipse on the island of Príncipe in West Africa and determined the gravitational-deflection angle δ of starlight passing over the surface of the sun: δ=1.61″ ±0.40″, verifying Einstein's theoretical prediction of gravitational deflection of starlight: δ_E=1.75″.

In fact, Newton's theory of universal gravitation can also make a theoretical prediction about the gravitational deflection of starlight. But Newton's starlight deflection angle δ_N is only half of Einstein's starlight deflection angle δ_E: $\delta_N = \delta_E/2$=0.875″.

The conclusion of the Edington team's observation for solar eclipse starlight tends to support Einstein's theory of general relativity rather than Newton's theory of universal gravitation. However, just as the theory of OR repeatedly emphasizes that this does not mean that Einstein's theory of general relativity is more correct than Newton's theory of universal gravitation.

Edington's observation for solar eclipse starlight employed the optical agent OA(c), and naturally, should be more in line with or inclined to support Einstein's theory of general relativity. As the theory of OR repeatedly emphasizes, if we had the idealized agent OA_∞, we would observe the objectively real deflection of solar-eclipse starlight that must be more in line with Newton's theory of universal gravitation.

After the observation of the 1919 total solar eclipse, Eddington wrote a poem to express his insights:

"*Oh, leave the wise our measures to collate*
One thing at least is certain, light also has weight
One thing is certain and the rest debate
Light rays, when near the Sun, do not go straight."

Eddington's insights are rational and discreet.

In Eddington's view, his solar eclipse observation could be very certain that **Light also has weight**. Here, Eddington conveyed two important messages to us:

(1) Light or photons has weight, and here, Eddington's concept of **Weight** seems to be more in line with Newton's gravitational mass;

(2) the deflection of starlight is due to the weight of light or photons, that is, due to gravity rather than spacetime curvature.

Eddington's understanding of the mass or weight of light or photons is simple and plain, in which the concepts of **Weight** and **Gravitational Mass** should be equivalent, in line with the logical conclusion of OR: photons have the objectively real rest mass.

So, why did experimental physicists after Eddington turn a blind eye to the obvious weight of photons, which is presented in the gravitational deflection of solar-eclipse starlight?

6.5 Why have Physicists Failed to Find the Rest Mass of Photons?

As mentioned earlier, many physicists, including the great Feynman, de Broglie, and Schrödinger [11-15], subconsciously refuse to accept Einstein's judgment that photons have no rest mass. Both in the past and at present, many experimental physicists have been attempting to determine the rest mass of photons through observations and experiments [17-19]. However, all the attempts have failed, only leaving a string of upper bounds of the rest mass of photons that is gradually approaching zero.

The upper limit 1.5×10^{-54} kg of the rest mass of photons, which was provided by PDG [20] in 2014 is already very close to Einstein's speculation based on his mass-speed relation: photons have no rest mass.

Since the gravitational effects of light, including the gravitational redshift and deflection of light, are caused by the rest mass of photons rather than spacetime curvature, since the inertial effects of light suggests that photons have the inertial mass and the gravitational effect of light suggests that photons have the gravitational mass, since the theory of OR has proven that photons have the objectively real rest mass like all other matter particles, and since the theory of OR has theoretically predicted the rest mass of photons to be $m_o=m_\infty=m_{I\infty}=m_{G\infty}=hf/c^2$, why have experimental physicists, after countless hardships, been unable to find the rest mass of photons?

Physicists have come up with many ways to determine the rest mass of photons. According to Proca's massive-photon correction scheme for Maxwell's electromagnetic equations [16], if a photon has the rest mass, there would be corresponding physical effects and, by examining these possible physical effects, the rest mass of photons might be determined: the test of the dispersion effect of light speed in vacuum, the test of Coulomb's inverse square law, the test of Ampere's loop law, the test of Schrödinger's external field, the test of interstellar-magnetohydrodynamic effects, and etc.

By the way, as discussed earlier, light, like other matter waves, has the unique mechanism for maintaining its intrinsic speed. So, we may not be able to observe or measure the dispersion effect of light. But this is not involved with the rest mass of photons.

Why have they failed to find the rest mass of photons?

Firstly, photons could not lift themselves up.

Experimental physicists did not realize that, at present, the observation agent they employ to observe or measure the rest mass of photons is the optical agent OA(c). According to the theory of OR, due to the observational locality ($c<\infty$) and observational perturbation-effect ($h>0$) of OA(c), the information wave (light wave) and informons (photons) of OA(c) cannot determine the mass of photons themselves.

Secondly, physicists turn a blind eye to the rest mass of photons that is right in front of them.

The Compton effect, gravitational deflection of light, and the gravitational redshift of light have presented the objective and real mass of photons before our eyes.

The theory of OR tells us that the relativistic moving mass m of photons in Einstein theory of special relativity is in fact the rest mass m_o of photons. Experimental physicists regard Einstein's photon moving mass as the objective and real mass of photons, and then, try to find the rest mass m_o of photons beyond the so-called moving mass m of photons. This is tantamount to turning a blind eye to the objective and real rest mass of photons in front of them.

Physicists' understanding of the rest mass of photons might be described in the verses of an ancient Chinese poet as: They failed to see the true face of Mount Lu, but only because they were right in Mount Lu.

Maybe now the theoretical prediction of the theory of OR for the rest mass of photons can help experimental physicists measure and determine the rest mass of photons through observations and experiments.

Conclusion

As a new theory in human being's physics, the theory of Observational Relativity (OR), both IOR and GOR, has brought us new discoveries and new insights. OR serial report 1 reported the significant discoveries of OR: the speed of light is not really invariant; spacetime is not really curved. This article, OR serial report 2, has reported to readers another significant discovery of OR: the rest mass of photons is not really zero.

The original intention of the theory of OR was just to explore the objective and real mass of photons.

The theory of Inertial Observational Relativity (IOR for short) has theoretically proven that photons, like all other particles of matter, have the objectively real mass, which is Einstein's so-called rest mass m_o, and is also Newton's classical mass m_∞, both Newton's inertial mass $m_{I\infty}$ and Newton's gravitational mass $m_{G\infty}$: $m_o=m_\infty=m_{I\infty}=m_{G\infty}$.

The theory of Gravitational Observational Relativity (GOR for short) has theoretically calculated and predicted the rest mass of photons: $m_o=m_\infty=m(c)=hf/c^2$, which is based on the gravitational redshift effect of photons and the observation of solar spectra.

According to the theory of OR, only the rest mass is the objectively real mass of matter. The fact that photons possess the objective and real rest mass is in line with the dialectical materialist view of nature: a matter system, no matter a massive star or a tiny photon, if it objectively exists, must have the rest mass of its own; otherwise, it must not exist objectively.

According to the theory of OR, both Einstein's relativistic effects and Planck's quantum effects are the observational effects of the optical agent OA(c), and not completely the objective and real physical existence. Due to the observational locality ($c<\infty$) and perturbation effects ($h<0$), the optical agent OA(c) is unable to measure the mass of photons. Einstein's speculation that the rest mass of a photon is zero from the mass-speed relation of his special relativity does not conform to the objectively physical reality, but only means that his relativity theory fails at Hawking Singularity ($v=c$).

Light and photons play a special role in modern physics: the information wave of the optical agent OA(c) is light and the informons of OA(c) is photons.

The relativity theory established by Einstein and the quantum theory laid the basis by Planck are the most important theoretical foundations of modern physics. Thus, modern physics, like Einstein's relativity theory and

Planck's quantum theory, also is in essence the product of the optical observation agent OA(c). As the theory of optical observation, modern physics does not represent the objectively physical world, which is valid or effective only under the optical agent OA(c).

Naturally, the doctrine of the null rest mass of photons as the product of OA(c), does not conform to the objectively physical existence and reality.

The Swedish physicist Alfvén, a Nobel Prize winner, ever in his book **Cosmology: Myth or Science** bluntly criticized the scientific superstition that have spread after Einstein relativity theory [41]. In Alfvén's view, science is becoming more and more like a myth and increasingly contrary to common sense. The mission of science seems to be no longer to discover natural laws and explore scientific truths, but to manufacture scientific superstition and create scientific myths.

Now, the theory of OR has cleared photons' name: photons possess the objectively real mass; photons are mass quanta not energy quanta. There are no energy quanta with no mass in the objectively physical world.

So, mankind needs to re-examine his physics, re-examine the relativistic effects of light and the quantum effects of light, re-examine Einstein's relativity theory and Planck's quantum theory, re-examine modern physics, including gauge field theory, quantum gravity theory, string theory, black hole theory, dark matter theory, Hubble's theory of cosmological redshift, the Big Bang theory, and all the doctrines of modern physics belonging to the optical observation agent OA(c).

Mankind needs to re-examine his view of matter and mass, and to re-examine his view of nature.

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