Observational Relativity
—— The Unity of Newton and Einstein

The First Part:
Inertially Observational Relativity (IOR)
—— The Speed of Light is not Really Invariant

Xiaogang Ruan [1*]

1 *Faculty of Information Technology, Beijing University of Technology, Beijing 100124, China.*
* E-mail: adrxg@bjut.edu.cn

Abstract: The Theory of Observational Relativity, the theory of OR for short, is a new discovery and a new theory, which has revealed the root and essence of relativity: All relativistic effects or relativistic phenomena are observational effects and apparent phenomena rather than the objective and true physical reality. In particular, the whole theoretical system of OR has generalized and unified Newton's mechanics and Einstein's theory of relativity, integrating such two great theories in physics into the identical theoretical system under the identical axiom system. The theory of OR is divided into two parts: the theory of inertially observational relativity (IOR); the theory of gravitationally observational relativity (GOR). The theory of IOR takes the definition of time as the most basic logical premise and theoretically deduces the spacetime transformation of IOR, so-called the general Lorentz transformation, which has generalized and unified the Galilean transformation and the Lorentz transformation. The theory of IOR has proved an important theorem: the invariance of information-wave speeds. It suggests that the invariance of light speed is only a special case of the invariance of information-wave speeds. Actually, Einstein's invariance of light speed can only be valid when light acts as the observation medium for transmitting observed information to observers. So, the speed of light is not really invariant. Based on the invariance of information-wave speeds, the author has established the whole theoretical system of IOR which has generalized and unified Newton's inertial mechanics and Einstein's special relativity, and moreover, integrated de Broglie's theory of matter waves into the theory of IOR, marching towards the unification of relativity theory and quantum theory. The theory of IOR is logically consistent not only with Einstein's special relativity but also with Newton's inertial mechanics. Such logical consistency and strict correspondence show that the theory of IOR is logically self-consistent, and from one aspect, confirm the logical rationality and theoretical validity of the theory of IOR. In particular, the theory of IOR is supported by observations and experiments, including the Michelson-Morley experiment.

Key Words: special relativity, invariance of light speed, relativistic effects

Introduction to IOR

The story seems a little old.

It was the last day of the 19th century, it was said, when European scientists gathered, Kevin, a British physicist, had delivered New Year's speech at the party.

Kelvin was optimistic that: the magnificent edifice of human physics had been completed, and only needed to do some decoration work; of course, there were two black clouds floating in the beautiful and clear sky of physics, one is **the ethereal black-cloud** of the Michelson-Morley experiment and the other is **the ultraviolet black-cloud** of the experiment of blackbody radiation.

Soon afterwards, the two black clouds had turned into heavy downpours.

The ethereal black-cloud led to relativity theory, revealing the relativistic effects of spacetime and matter motion; the ultraviolet black-cloud led to quantum theory, revealing the quantum effects of the microscopic physical world.

However, after the downpours, the sky of physics has not been clear yet.

Up to now, for relativistic effects and quantum effects, human physics only knows what but does not know why. Humans have known the phenomena of relativistic effects, but have not known the essence of relativistic effects: why the speed of light invariant and why spacetime is curved. Humans have known the phenomena of quantum effects, but have not known the essence of quantum effects: why material particles are uncertain in the micro-world.

In the sky of human physics, the black clouds have not disappeared, but have accumulated more and more: various confusion, various puzzles, various schools of thought, various misconceptions and misunderstandings, and various superstitions and myths.

It seems that Kelvin's story is far from over.

The Ethereal Black-Cloud and Relativity Theory

The ethereal black-cloud came from the Michelson-Morley experiment.

In 1887, following Maxwell's proposal [1], American physicists Michelson and Morley performed an experiment to search for the ether [2]. Without detecting the ether, they encountered into a problem: Galileo's speed-addition principle appeared to be invalid. The Michelson-Morley experiment showed that the speed of light plus the orbital speed of the Earth remained the speed of light.

This is the ethereal black-cloud in Kelvin's speech for the new century.

To interpret the Michelson-Morley experiment, FitzGerald proposed the hypothesis that all objects physically contract by a factor of $\sqrt{(1-v^2/c^2)}$ along the line of motion [3]. Later, Lorentz added the hypothesis that time dilates by a factor of $1/\sqrt{(1-v^2/c^2)}$ [4-6]. Thus, the Lorentz transformation, or the FitzGerald-Lorentz transformation, was born. So, human physics have had two physical models of spacetime transformation: one is the Galilean transformation; the other is the Lorentz transformation.

Actually, the Lorentz transformation was only a phenomenological model.

In 1905, Einstein seemed to have grasped the key of the Michelson-Morley experiment: the speed of light exhibits no speed-addition effect and is the same and invariant for all inertial observers. So, he proposed the hypothesis of **the invariance of light speed**, that is later referred to as the principle of the invariance of light speed. Based on the principle of the invariance of light speed, Einstein theoretically deduced the Lorentz transformation, and established his special theory of relativity [7], revealing the relativistic property of inertial spacetime and inertial motion.

Thus, the Lorentz transformation becomes a theoretical model.

The principle of the invariance of light speed is not only the cornerstone of Einstein's special theory of relativity, but also the logical premise of Einstein's general theory of relativity. In 1915, on the basis of special relativity, in other words, still taking the principle of the invariance of light speed as a logical premise or an axiom, with the help of the principle of equivalence and the principle of general covariance, Einstein established his general theory of relativity [8], revealing the relativistic property of gravitational spacetime and gravitational interaction.

So, in a sense, the ethereal black-cloud led to Einstein's theory of relativity.

For more than one hundred years, Einstein's theory of relativity, both the special and the general, has been supported by almost all observations and experiments [9,10]. Accordingly, Einstein believed and the mainstream school of modern physics still believe that inertial relativistic effects are the essential property of inertial spacetime and inertial motion, and gravitational relativistic effects are the essential property of gravitational spacetime and gravitational interaction.

However, until today, we still do not fully understand why the speed of light is invariant, why spacetime is curved, why photons have no rest mass, why time dilates, and why simultaneity is relative.

Until today, the ethereal black-cloud has not completely dispersed yet.

The Ultraviolet Black-Cloud and Quantum Theory

The ultraviolet black-cloud came from the experiment of blackbody radiation.

In 1896, Wien built a model of blackbody radiation [11], Wien approximation or Wien's law. Wien's law is consistent with the experiment of blackbody radiation in high-frequency band, but there is much deviation in low-frequency band. In 1900, Rayleigh built another model of blackbody radiation [12], which was later improved by Jeans [13] and is known as Rayleigh-Jeans Law. Rayleigh-Jeans law is consistent with the experiment of blackbody radiation in low-frequency band, but there is much deviation in high-frequency band. In particular, if the frequency tends to infinity, then the energy density of blackbody radiation in Rayleigh-Jeans Law tends to infinity, which is the so-called **ultraviolet catastrophe**.

This is the ultraviolet black-cloud in Kelvin's speech for the new century.

In 1900, based on his quantum hypothesis $E=hf$, Planck deduced Planck's law theoretically. Planck's law is very consistent with the experiment of blackbody radiation [14]. However, the most important is not Planck's law itself, but the hypothetical logical premise, i.e., the hypothesis of energy quantum or energon suggests that the energy of light is discrete rather than continuous [15,16]. Planck's energon hypothesis lays the first cornerstone for quantum theory.

In the 1920s, de Broglie put forward the hypothesis that matter motion possesses wave-particle duality [17], under which de Broglie generalized the Planck equation $E=hf$ from photon to any material particle, built the de Broglie relation $p=h/\lambda$, and established de Broglie's theory of matter waves [18,19]. de Broglie's theory of matter waves lays the second cornerstone for quantum theory.

Inspired by de Broglie's theory of matter waves, Schrödinger established the equation of quantum waves, that is, the famous Schrödinger equation [20]. Schrödinger's equation lays the third cornerstone for quantum theory.

So, the edifice of quantum mechanics or quantum theory has basically been in place, gradually revealing the quantum effects of the micro-world. In a sense, it is the ultraviolet **catastrophe** that confirm Planck's energon hypothesis.

So, in a sense, the ultraviolet black-cloud led to quantum theory.

For more than one hundred years, quantum mechanics or quantum theory has been supported by almost all observations and experiments. Accordingly, the mainstream school of physics believe that quantum effects, including the uncertainty of the micro-world and microparticles, are the essential property of the micro-world and microparticles.

However, until today, we still do not understand the essence of quantum effects, do not understand what Planck's constant essentially implies, and do not understand why microparticles would present uncertainty. So, in quantum mechanics and quantum theory, there are various schools of thought [21-25], each sticks to his own view and excludes the other.

Until today, the ultraviolet black-cloud has not completely dispersed yet.

The Theory of OR [26-30]:
Revealing the Essence of Relativistic Effects and Quantum Effects

Only when the theoretical systems of physics were built on the basis of the most basic axiom systems or the most basic logical premises could we capture the essence through the phenomenon, knowing what and knowing why.

The theory of OR, so-called **Observational Relativity** (OR), is a new theory, which in a relative sense is built on the basis of the most basic axiom system. So, the theory of OR has discovered that

(i) All theoretical models of physics depend on and are restricted by observation: Galileo's doctrine and Newton's mechanics are the theories of idealized observation, being the true portrayal of the objective world; Einstein's theory of relativity, both the special and the general, is the theory of optical observation, being the optical image of the objective world.

(ii) All relativistic effects, including the invariance of light speed, are observational effects and apparent phenomena: the invariance of light speed is only an observational phenomenon; while the invariance of information-wave speeds is the essence.

(iii) All quantum effects, including Heisenberg's uncertainty, are observational perturbation effects

The Theory of OR [26-30]: Unifying Newton and Einstein

As Hawking remarked in his **A Brief History of Time** [31]: physics was increasingly fragmented and divided into more and more partial theories; the ultimate goal of physics is to unify them. Hawking specifically pointed out that relativity theory and quantum theory are two separated theories. Perhaps, Hawking failed to realize that relativity theory and quantum theory are not only two partial theories which are separated, but also two partial theories which belong to different observation agents and are only valid under specific observation agents.

The establishments of relativity theory and quantum theory have led to more partial theories in physics: the Galilean transformation and the Lorentz transformation become two separate models of spacetime transformation; Newton's inertial mechanics and Einstein's special theory of relativity become two separate inertial theories; Newton's theory of universal gravitation and Einstein's general theory of relativity become two separate gravitational theories; relativity theory and quantum theory become two theoretical systems of mechanics separated by macroscopic spacetime and microscopic spacetime.

As Hawking expected, the theory of OR is unifying them.

Only when the theoretical systems of physics were built on the basis of the most basic axiom systems and started from the most basic logical premises could they have universality, generalizing and unifying all partial theories.

The theory of OR is in a relative sense built on the basis of the most basic axiom system. So, the theory of OR has generalized and unified Newton's classical mechanics and Einstein's theory of relativity, and is moving towards the unification of relativity theory and quantum theory.

The OR theory is divided into two parts: the 1st volume expounds the theory of inertially observational relativity (IOR) that is isomorphic to Einstein's special relativity; the 2nd volume expounds the theory of gravitationally observational relativity (GOR) that is isomorphic to Einstein's general relativity.

The theory of OR is a challenge to the thoughts and concepts of Einstein's theory of relativity and the mainstream school of modern physics, and more importantly, is the progress and development of Newton's theory of classical mechanics and Einstein's theory of relativity.

On The formation of OR Theory [26-30]

The theory of OR, beginning with the theory of IOR, is a casual discovery.

The author is a materialist and holds the dialectical materialist view of nature.

In a certain sense, the theory of relativity is an excellent interpretation of the dialectics of nature and the dialectical materialist view of nature. So, like most physicists, the author believes in Einstein's theory of relativity.

However, Einstein's hypothesis of the invariance of light speed leads to two specious inferences in his theory of relativity:

(i) The speed of light is the ultimate speed of the universe that cannot be exceeded by any form of matter motion;

(ii) Photons have no rest mass, or, the rest mass of a photon is zero.

According to the mass-speed relation in Einstein's special relativity:

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

if an object m travels at the speed of light, then its rest mass m_o is zero or its relativistic mass m is infinite. Infinite physical quantities are unrealistic. Therefore, Einstein chose to set the rest mass m_o of photons to zero.

The problem of light speed and the problem of photon mass can be regarded as two focus issues that trigger the controversy of Einstein's theory of relativity.

Firstly, speed is relative. Setting the speed of a real material particle (photon) as **the ultimate speed** of the universe and **the invariant speed** seems to run counter to the notion of the dialectics of nature: all truths or standards are relative.

Secondly, mass is the sign of matter's existence. According to the dialectics of nature, matter possesses two attributes: one is mass, the other is energy; mass and energy are a pair of contradictory unity, depending on each other, and under certain conditions, transforming each other. A photon would have no mass in the eyes of observers who are at rest relative to the photon if the rest mass of photons were zero. Then, what does the energy of the photon depend on? Thus, the existence of the photon as matter would be a problem.

It is unacceptable to the author as a dialectical materialist that a material particle or a material object with energy but no mass.

It is the original intention of the author to give photons a little mass.

Due to the inherent view of nature, some great physicists, such as de Broglie [32,33], Schrödinger [34,35] and Feynman [36], instinctively did not accept that photons have no rest mass, who ever made great efforts to explore the rest mass of photons by means of observation and experiment. Until today, many experimental physicists, including the team of Academician Luo Jun of Huazhong University of Science and Technology of China [37], are still on their way to doing the same.

Different from measuring the rest mass of photons by means of observation or experiment, the author attempts to give photons a little rest mass in theory and to build the theoretical model or formula of photon rest mass.

The author thought: the ultimate speed of the universe was perhaps not the speed of light; **The Ultimate Speed of the Universe** should be defined as Λ: the speed at which the matter-wave frequency of the matter particle tends to infinity. According to such a definition, the speed of any matter particle cannot reach the ultimate speed Λ of the universe, nor can light or photons. Although the frequencies of light waves can be very high, they are still limited. Therefore, the speed c of light must be lower than the ultimate speed Λ of the universe: $c<\Lambda$.

Thus, any photon can obtain its own rest mass: $m_o=m\sqrt{(1-c^2/\Lambda^2)}$.

At first the author thought that Λ was the invariant speed, i.e., the real ultimate speed of the universe, which could not be reached and exceeded by any material object or any material particle, even if it is light or a photon.

In this thought, the author set out to construct a system of axioms: (1) the principle of physical observability; (2) the conditions of wave-particle duality, including the definition of the ultimate speed of the universe; (3) the definition of time that is the most basic logical premise in the axiom system of IOR. Under such an axiom system, the author attempted to deduce a relativistic theoretical model that could endow photons with rest mass.

The logical deduction and theoretical derivation of IOR need a physical quantity that possesses a definite physical significance: the speed of the observation medium at which the observation medium transmits the spacetime information on the observed object to the inertial observer, that is, the speed of the information wave relative to the inertial observer, being denoted as η for the time.

The η involves two important issues:

(i) What is employed as the observation medium for transmitting the information on the observed object to the observer?

(ii) How fast is exactly the observation medium? Is it the speed c of light?

The winding deductive process has been omitted here.

The theoretical derivation has produced an interesting logical conclusion: $\Lambda=\eta$!

This suggests that there is no so-called **the ultimate speed** in the universe.

In fact, the so-called ultimate speed Λ of the universe is only the speed at which the information on the observed object is transmitted by the observation medium, that is, the information-wave speed η of the observation agent OA(η), depending on observation or on the observation medium. So, the invariance of the speed Λ or η is only an observational effect and the embodiment of observational locality ($\eta<\infty$). With light or electromagnetic interaction as the observation medium, you cannot expect to observe the superluminal motion of matter.

It is worth pointing out that, in theory, all forms of matter motion or matter waves, not just light, can be employed as observation media for transmitting the information on observed objects to observers.

Taking the definition of time as the most basic logical premise, the theory of IOR has derived the invariance of time-frequency ratio, and then, has deduced the transformation of IOR spacetime, so-called **the general Lorentz transformation**.

Based on the transformation of IOR spacetime, the theory of IOR has proved an important theorem: the invariance of information-wave speeds. This suggests that Einstein's invariance of light speed is only a special case of the invariance of information-wave speeds, and is valid only if light is employed as the observation medium. The speed of light is not really invariant; the so-called invariance of light speed is actually an apparent phenomenon when light is employed as the observation medium for transmitting the information on observed objects to observers, belonging to observational effects caused by the observational locality ($c<\infty$) of the optical observation system.

At last, based on the invariance of information-wave speeds, the author has established the whole theoretical system of observational relativity: the theory of OR, including IOR and GOR, exceeding the author's original intention and expectations:

(i) OR has obtained the rest mass of photons;

(ii) OR has discovered that there is no so-called the invariant speed or the ultimate speed in the universe;

(iii) OR has discovered that all relativistic phenomena are observational effects and caused by the observational locality of observation media;

(iv) IOR spacetime transformation has generalized and unified the Galilean transformation and the Lorentz transformation;

(v) IOR has generalized and unified Newton's inertial mechanics and Einstein's theory of special relativity;

(vi) IOR has generalized and unified de Broglie's theory of matter waves and Einstein's theory of special relativity;

(vii) GOR gravitational field equation has generalized and unified Newton's field equation and Einstein's field equation;

(viii) GOR gravitational motion equation has generalized and unified Newton's motion equation and Einstein's motion equation;

(ix) GOR has generalized and unified Newton's theory of universal gravitation and Einstein's theory of general relativity.

The theory of GOR will be expounded in **the 2nd volume of OR: Gravitationally Observational Relativity** (GOR for short).

As the first part of OR, now let us start with the theory of IOR.

The Theory of IOR [26-28]: The Unification of Newton's Inertial Mechanics and Einstein's Special Theory of Relativity

The theory of IOR is that of the general observation system or the general observation agent OA(η), which is built on the basis of the axiom system taking the definition of time as the most basic logical premise, and therefore, possesses high universality.

In the theory of IOR, the transformation of IOR spacetime, so-called **the general Lorentz transformation**, has generalized and unified the Lorentz transformation and the Galilean transformation: if $\eta \to c$, then the transformation of IOR spacetime is namely the Lorentz transformation, which suggests that the Lorentz transformation is an optical observation model; if $\eta \to \infty$, then the transformation of IOR spacetime is namely the Galilean transformation, which suggests that the Galilean transformation is an idealized observation model.

The theory of IOR, so-called **Inertially Observational Relativity** (IOR for short), has generalized and unified Newton's inertial mechanics and Einstein's special theory of relativity: if $\eta \to c$, then the theory of IOR strictly converges to Einstein's special theory of relativity, which suggests that Einstein's special theory of relativity is the theory of the optical observation system.; if $\eta \to \infty$, then the theory of IOR strictly converges to Newton's inertial mechanics, which suggests that Newton's inertial mechanics is the theory of the idealized observation system.

The Theory of OR Matter Waves [26-28]:

Towards the Unification of Relativity Theory and Quantum Theory

Particularly, in the theory of IOR, the transformation of IOR spacetime has two forms of spacetime-transformation factors:

(i) The form of particles: $\Gamma(\eta)=\mathrm{d}t(\eta)/\mathrm{d}\tau=m(\eta)/m_o=1/\sqrt{(1-v^2/\eta^2)}$;
(ii) The form of waves: $\Gamma(\eta)=\mathrm{d}t(\eta)/\mathrm{d}\tau=f(\eta)/f_o=1/\sqrt{(1-v^2/\eta^2)}$.

This is the embodiment of wave-particle duality in the theory of IOR: the theory of IOR links relativity theory with quantum theory; or, the theory of IOR links relativistic effects with quantum effects.

Based on the particle form of IOR factor: $\Gamma=m/m_o$, the theory of OR has derived the mass-energy relation of OR: $\boldsymbol{E=m\eta^2}$, so-called **the general Einstein formula**, generalizing Einstein's mass-energy relation: $E=mc^2$.

Based on the wave form of IOR factor: $\Gamma=f/f_o$, the theory of OR has derived **the general Planck equation**: $\boldsymbol{E=h_\eta f}$, in which $\boldsymbol{h_\eta}$ can be called **the general Planck constant**. Obviously, the general Planck equation generalizes Planck equation: $E=hf$. Thus, Planck equation $E=hf$ is no longer a hypothesis, but a logical consequence of IOR theory; as de Broglie wanted, Planck's equation $E=hf$ has been generalized by the theory of IOR to all material particles, not just photons.

Thus, two great formulae, Einstein's formula $E=mc^2$ and Planck's equation $E=hf$, has unified in the same theoretical system under the same axiom system.

Actually, the particle form of IOR factor $\Gamma=m/m_o$ leads to the inertial-motion theory of OR, while the wave form of IOR factor $\Gamma=f/f_o$ leads to the matter-wave theory of OR which generalizes de Broglie's theory of matter waves.

The basic relations of OR matter-wave theory include

(i) The general Planck equation: $E=h_\eta f$;
(ii) The general de Broglie relation: $p=h_\eta/\lambda$;
(iii) The speed relations of OR matter-wave theory: $v_g v_p=\eta^2$, $v_g=v$, and $f\lambda=\eta$.

So, the theory of IOR not only has generalized the whole theoretical system of Einstein's special relativity, but also has generalized de Broglie's theory of matter waves, moving towards the unification of relativity theory and quantum theory.

1 Observation and Physics

Our view of nature stems from our observation of the objective world.

Human being's understanding of the objective world depends on and is restricted by observation. All theories or spacetime models of physics, including the Galilean transformation and the Lorentz transformation, as well as Newton's classical mechanics and Einstein's theory of relativity, and even quantum mechanics, have without exception been branded with the marks of observation.

Since the beginning of its history, however, human physics has never explicitly linked its theories or spacetime models with observation, with observation media, or with the transmission of observation information.

The theory of OR, so-called Observational Relativity (OR for short), will endow observation with the clear role and status in the theoretical systems of physics.

1.1 Preliminary for IOR

The basic task of observation is to employ our senses or observation instruments to obtain the information on observed objects. Naturally, the information of an observed object must be transmitted to our senses or observation instruments by a certain medium in a certain way, so that we can perceive or observe it.

In order to state the theory of IOR, so-called Inertially Observational Relativity (IOR for short), the following preliminary work is done.

1.1.1 Agreements in IOR

As the theory of inertial motion, in order to make the statement of IOR theory and deduce the transformation of IOR inertial spacetime, as depicted in Fig. 1.1, we agree that if no specific instructions:

(i) P stands for the observed object;

(ii) O_o stands for the intrinsic reference system of P, in which P is at rest and time is the intrinsic time τ;

(iii) O and O' stand for P's two inertial frames, their observational times are respectively t and t';

(iv) As shown in Fig. 1.1(a), at $t=t'=\tau=0$, the corresponding coordinate axes and the origins of O and O' and O_o coincide with each other, and P is located at the origin of O_o[1];

(v) As shown in Fig. 1.1(b), P moves along the X axis at the speed u in O and along the X' axis at the speed u' in O'; O' in O moves along the X axis at the speed v relative to O;

[1] It can be considered that P is located at the coordinate $(0, y_{o0}, z_{o0})$ of O_o, but the observers O and O' are required to be located on the same line (x_o, y_{o0}, z_{o0}) of O_o to ensure that the observational spacetime is inertial: the observers are inertial observers; P is an inertial moving object.

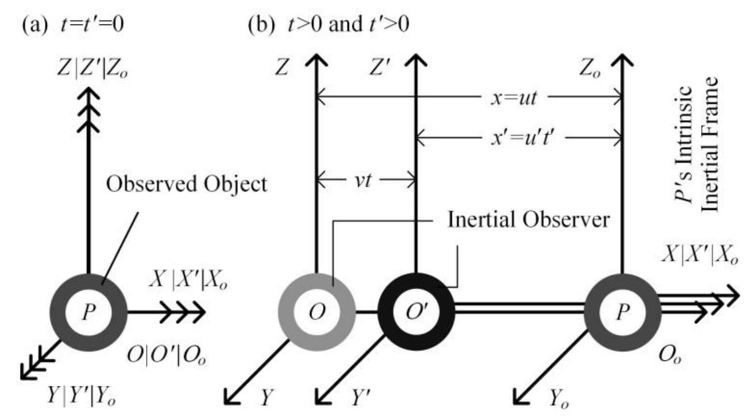

Figure 1.1 The Observed Object and Its Inertial Frame: P is at rest in O_o; naturally, O_o is the intrinsic inertial frame of P, and therefore, any inertial frame of P, such O and O', can be defined relative to O_o, in which u and u' and v are all inertial speeds.

In addition, we agree that O, O', and O_o may stand not only for the inertial reference systems or their origins, but also for their standard clocks or observers resting at their origins.

Naturally, the intrinsic reference system O_o of P is the intrinsic inertial frame of P. So, any inertial frame of P, such as O and O', can be defined relative to O_o.

In particular, P's intrinsic reference system O_o is **the Free Spacetime** S_F, in which there is no matter interaction.

1.1.2 Observation System and its Basic Elements

An observation system can be described as a triple $(P,M(\eta),O)$, involving three basic elements:

(i) P: the observed object, i.e., the emitter of observed information;

(ii) M: the observation medium, i.e., the transmitter of observed information;

(iii) O: the observer, i.e., the receiver of observed information.

In the observation system $(P,M(\eta),O)$, the most important physical quantity is the speed of the observation medium M, that is, the speed of M's transmitting observed information: the speed of P's information relative to O.

In the theory of OR, the speed of the observation medium M is denoted as η.

In Minkowski 4d spacetime, the historical context of P's movement is a world line, i.e., the spatial-temporal trajectory of P's movement or the collection of P's spatial-temporal events. As a point of the world line, the most basic information of an event is the instant (time information) of its occurrence and the location (space information) of its occurrence, so-called **the spacetime information**.

Naturally, the spacetime information of the observed object P is the most basic information about P that the observer O desires to obtain.

Anyway, the spacetime information of the observed object P must be transmitted from P to the observer O by means of a certain observation medium M.

We would like to ask: What could act as the observation medium M?

1.1.3 Related Terms in IOR

The theory of OR coins the following terms related to observation.

Spacetime Information: The basic information of the observed object P, that is, the information on the specific spatial location of P at a specific time, including space information and time information.

Information Wave: The matter wave that in observation or experiment transmits the spacetime information of P for us. In theory, any matter wave or any form of matter motion can act as the information wave.

Informon: The material particles that form information waves. Železnikar ever used **Informon** to refer to the so-called **Information Entity** and compared it with electronics [38]. In theory, any material particle can act as an informon.

Observation Agent: An alternative concept of the observation system $(P,M(\eta),O)$ or its observation medium $M(\eta)$, acting as the messenger between the observer O and the observed object P, detecting or receiving and even radiating informons and information waves, being denoted as OA(η). The intrinsic speed η of the information wave or informons of OA(η) is the speed η of the observation medium M(η) transmitting observed information. Naturally, different observation agents may have different observation media or different information waves, and have different speeds of transmitting observed information.

The Optical Observation Agent: The observation agent employing light or electromagnetic interaction as the observation medium, being denoted as OA(c), whose intrinsic speed of information wave is the speed c of light.

The Idealized Observation Agent: The observation agent denoted as OA_∞, whose speed of information wave is idealized as infinity ($\eta=\infty$).

The Free Spacetime: An alternative concept of inertial reference system or inertial spacetime, being denoted as S_F, in which there is no matter interaction.

The Intrinsic Spacetime: The objective and real spacetime.

Observational Spacetime: The spacetime observed by the observer O with the observation agent OA(η) or the observation system $(P,M(\eta),O)$.

The Intrinsic Physical Quantity: The objective and real physical quantity.

Observational Physical Quantity: The physical quantity observed by the observer O with the observation agent OA(η) or the observation system $(P,M(\eta),O)$.

Observational Locality: An attribute of the general observation agent OA(η) in reality, the intrinsic speed η of whose information wave is limited ($\eta<\infty$).

These terms are the basic concepts of OR (both IOR and GOR).

1.2 Observation and Observation Media

The observation medium of observation system $(P,M(\eta),O)$ or observation agent

OA(η) is the messenger transmitting the information of the observed object P for the observer O. The observer O must rely on a certain observation medium M to obtain the information on the observed object P, including P's spacetime information.

As Železnikar remarked [38], information waves or informons transmitting information must be physical reality, that is, objectively existing matter waves or objectively existing matter particles.

So, what kind of physical realities can be employed as observation media to play the role of messengers between observed objects and observers?

In the 1920s, de Broglie coined the concept of **Matter Wave** and proposed a hypothesis, i.e., de Broglie hypothesis [17-19]: Matter exhibits wave-particle duality, acting like both particles and waves.

Waves have an important physical property: modulability. Hence, waves possess the special capacity to carry and transmit information. In theory, any matter wave or any form of matter motion can act as the messenger or the observation medium of observation system (P,$M(\eta)$,O) to transmit the physical information on the observed object P for the observer O at the specific speed η.

The theory of OR gives the concepts of **Information Wave** and **Informon** [26-30]. The so-called information waves refer to the matter waves as observation media, transmitting the information of observed objects for observers; the so-called informons are the matter particles forming information waves.

If we look at the world with our eyes, then light is namely the information wave and photons are namely the informons; if we listen to the world with our ears, then sound is namely the information wave and phonons are namely the informons.

Light is the observation medium that we are accustomed to. Thanks to light, we can see the world with our eyes. The theory of OR will clarify that [26-30]: Einstein's theory of relativity, including the special and the general, is just the physical theory employing light as the observation medium.

However, light is not the only observation medium we can make use of.

As depicted in Fig. 1.2(a), suppose that there is a thunderbolt event taking place in the sky. Naturally, the most basic information is the spacetime information, that is, the time and the location at which the thunderbolt occurs. Then, how can we determine the spacetime coordinate of the thunderbolt? To perceive or observe thunderbolts, we must employ certain observation media to transmit the information of thunderbolt events. Within human perception, both sound and light can act as the observation media of thunderbolt events. Beyond human perception, by means of human technology, the radio waves and pulsed magnetic fields emitted by thunderbolts can also act as the messengers of thunderbolt events.

Traditional astronomy relies on the naked eyes and optical telescopes to observe celestial phenomena. Radio astronomy extends the observation medium from visible light to almost the entire radio band. Consequently, the radio astronomy has discovered what the traditional astronomy had never discovered: the so-called **Cosmic Microwave Background Radiation** [39] that is regarded as the evidence of the Big Bang theory [40].

Perhaps, in the future, gravitational waves will become information waves and gravitons will become informons, transmitting the information on observed objects including celestial bodies for observers. Actually, the concept of **Gravitational Wave Astronomy** has already been coined [41,42]. However, people do not realize that gravitational waves may be superluminal information waves that exceed or even far exceed the speed of light.

In theory, all matter waves, including sound waves, water waves, light waves, radio waves, seismic waves, and gravitational waves, can be information waves; all matter particles, including photons, electrons, protons, neutrons, atoms, molecules, neutrinos, gravitons, even a rock, and the observed object itself, can be informons. All forms of matter motion can act as observation media to transmit the physical information of observed objects for observers.

So, for observers, for physics, and for the theoretical systems of physics, what difference do different observation media make?

1.3 The Problem of Observational Locality

Naturally, different observation media, different forms of matter motion, and different matter waves, have different speeds.

The speed of sound $v_S \approx 340$ m/s at normal temperature and pressure in the Earth's atmosphere; the speed of ultrasonic $v_U \approx 1450$ m/s under water; the speed of light $c \approx 3\times10^8$ m/s in vacuum; the speed of gravity or gravitational wave $\kappa > 7\times10^6 c$ according to Laplace's calculation [43], far faster than the speed of light. However, no matter what observation medium the observation system $(P,M(\eta),O)$ or the observation agent OA(η) make use of, the information-wave speed of transmitting observed information is bound to be finite.

This is the observational locality of observation agent OA(η): $\eta < \infty$.

The observational locality of observation agents in reality must be reflected in the theoretical systems or spacetime models of physics.

1.3.1 Non-Instantaneity of Spacetime Information

The observation medium $M(\eta)$ of any observation system $(P,M(\eta),O)$ has a limited speed of transmitting observed information. Consequently, there must be an observational delay when the physical information of the observed object P is transmitted from P to the observer O. The delay of observed information is the so-called **non-instantaneity** or **non-realtime** of observed information.

This suggest that the information about the observed object P obtained by the observer O is not necessarily the objective and real physical information of P.

The observational non-instantaneity of observed information includes:

(i) The temporal: the spacetime information of any observed object has a temporal delay, that is, the temporal non-instantaneity;

(ii) The spatial: the spacetime information of any moving object has a spatial delay, that is, the spatial non-instantaneous.

A thunderbolt can be regarded as a static object relative to the observer at rest on the ground. As depicted in Fig. 1.2(a), the spacetime information of thunderbolt events obtained by the observer has a temporal delay, or temporal non-instantaneity, but has seemingly no spatial non-instantaneity.

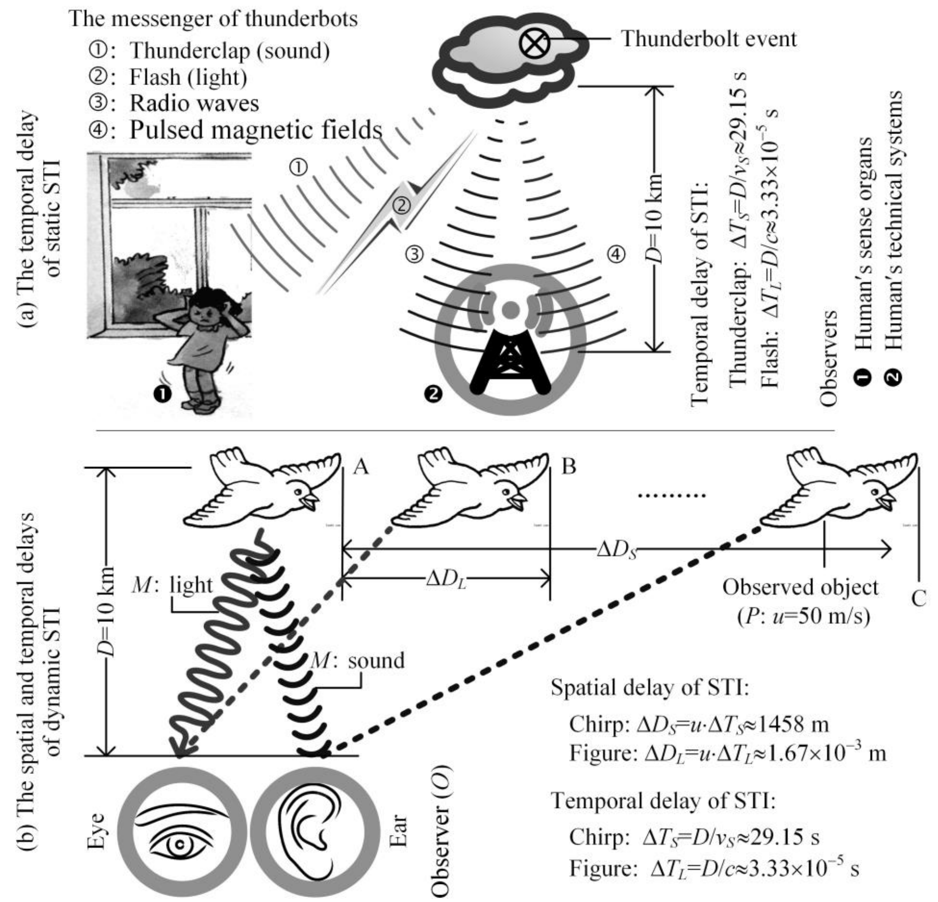

Figure 1.2 The Observational Non-Instantaneity of STI: (a) The temporal delay of the STI of static objects; (b) The spatial and temporal delays of the STI of moving objects. (Here, **STI** is the abbreviation of SpaceTime Information.)

However, most of the observed objects are not static but dynamic. So, how can we perceive or observe the movement of a bird flying in the sky?

We can make use of sound as the medium to hear the bird with our ears; we can also make use of light as the medium to see the bird with our eyes. As depicted in Fig. 1.2(b), no matter sound or light, what it transmits to us can only be the delayed spacetime information on the bird. The spacetime information of the bird is observationally delayed not only in time but also in space: we hear the bird's chirp, but the bird is no longer at the location where it was chirping; we see the bird's figure, but that is just where it was a moment ago.

This is namely the observational non-instantaneity of observed information.

The observational delay of observed information, so-called the non-instantaneity, is linked to the speed η of the observation medium $M(\eta)$ transmitting observed information: the lower η is, the larger the delay, and the more significant the non-instantaneity. Such a delay or non-instantaneity is bound to restrict our observation, and particularly, is bound to be reflected in the theoretical systems or spacetime models of physics. Actually, this has led to the difference between the Galilean transformation and the Lorentz transformation, and has led to the difference between Newton's classical mechanics and Einstein's theory of relativity.

It is remarkable that the observational non-instantaneity of observed information is related to the problem of observational locality and is caused by the observational locality of observation system $(P,M(\eta),O)$ or observation agent $OA(\eta)$.

1.3.2 The Principle of Observational Locality

The locality, or the principle of locality, plays an extremely important role in contemporary physics [44]. Both Newton and Einstein believed that there was no action at a distance in nature.

The principle of locality is generally accepted by physicists.

The Principle of Locality: There is no action at a distance in the universe; in other words, the speed of matter motion must be finite.

Einstein's view on the locality was associated with his hypothesis of the invariance of light speed [45]: the speed of light cannot be exceed by other forms of matter motion. In 1935, based on the view of the locality that the speed of light cannot be exceeded, Einstein and his colleagues Podolsky and Rosen conceived a famous thought experiment: **Quantum Entanglement**, known as the EPR paradox [46], to question the completeness of quantum mechanics.

However, it seems that more and more EPR experiments support the existence of quantum entanglement and superluminal phenomena [47,48].

Whether or not the speed of light cannot be exceeded, one thing is certain: there is no action at a distance in the universe; consequently, matter or information must take time to cross space.

However, physicists seldom link the locality of physical interactions between matters explicitly with observation or the transmission of observed information. To clarify the restriction of the locality of physical interactions on observation, the theory of OR set up the principle of observational locality.

The Principle of Observational Locality (OL) [28]: The speed η at which the observation medium M of a realistic observation system $(P,M(\eta),O)$ transmits observed information, or the intrinsic speed η of the information wave of a realistic observation agent $OA(\eta)$, must be finite, i.e., $\eta<\infty$; consequently, it takes time for observed information to cross space.

It should be noted that: the principle of OL is not the logical premise presupposed by the theory of OR, but the logical consequence of the principle of locality; in a sense, the observational locality is a discovery of OR theory.

The theory of OR has discovered [26-30]: the observational locality of observation systems is the root and essence of all relativistic phenomena.

All relativistic phenomena, including the invariance of light speed in Einstein's special theory of relativity and the effects of spacetime curvature in Einstein's general theory of relativity, are observational effects and apparent phenomena, caused by the observational locality ($\eta<\infty$), rather than the objective and real natural phenomena. The theory of OR will clarify this argument.

1.4 Observation Agents for IOR

Observation Agent is a new concept coined by the theory of OR to replace the previously used concepts of **Observation System** and **Reference System**.

More importantly, **Observation Agent** has its specific connotation. Actually, Minkowski 4d spacetime is namely a specific observation agent, so-called **the optical observation agent**.

1.4.1 Minkowski 4d Spacetime

Einstein had ever said [49]: "We should limit ourselves to a 4d space and the transformation group of continuous real coordinate." What he referred to is Minkowski spacetime, that is, the coordinate framework of 4d spacetime conceived by Minkowski for Einstein's special theory of relativity [50,51].

Minkowski 4d spacetime can be defined as follows:

$$\mathrm{OA}(c) \triangleq \left\{ \begin{array}{l} X^{4\mathrm{d}}(c): \left\{ \begin{array}{l} x^0 = ct; \\ x^1 = x,\, x^2 = y,\, x^3 = z \end{array} \right\} \\ \mathrm{d}s^2 = \eta_{\mu\nu}\mathrm{d}x^{\mu}\mathrm{d}x^{\nu} \quad \left(\eta_{\mu\nu} = \mathrm{diag}\left(+1,-1,-1,-1\right)\right) \end{array} \right\} \tag{1.1}$$

where OA(c) stands for the optical observation system employing light or electromagnetic interaction as the observation medium, $X^{4\mathrm{d}}(c)$ the observational spacetime of OA(c), x^0 is the 1d time coordinate, and (x^1,x^2,x^3) is the 3d space coordinate that can adopt the Cartesian coordinate (x,y,z); ds is the line-element of Minkowski spacetime, so-called **World Line**, $\eta_{\mu\nu}$ is **Minkowski metric**.

$X^{4\mathrm{d}}(c)$ is namely Minkowski 4d spacetime.

Minkowski spacetime $X^{4\mathrm{d}}(c)$ is a metric spacetime, in which the metric $\eta_{\mu\nu}$ of $X^{4\mathrm{d}}(c)$, i.e., Minkowski metric, is a constant: $\eta_{\mu\nu}$=diag(+1,–1,–1,–1).

Consequently, Minkowski spacetime is inertial spacetime, **flat** not **curved**.

Equation (1.1) can be regarded as a formalized expression of the optical observation agent OA(c) or **Minkowski agent** of inertial spacetime, which implies Einstein's hypothesis of the invariance of light speed, and moreover, implies the observational locality of the optical observation agent OA(c): $c<\infty$.

1.4.2 General Observation Agents: Definition

Einstein did not truly realize that his theory of relativity, including the special and the general, was only a theory seeing the world through light.

Einstein failed to understand the essential significance of Minkowski spacetime.

Minkowski spacetime is not only to provide a coordinate framework of 4d spacetime for Einstein's theory of relativity. Actually, OA(c) represents a specific observation system: the optical observation system, in which the observation medium is light transmitting observed information for observers, and naturally, the transmission speed of observed information is the speed c of light.

As stated in 1.2 of this chapter, theoretically, any form of matter motion can be employed as an observation medium to transmit observed information for observers [26-30]. Different observation media mean different observation systems or different observation agents: the eye is a kind of observation agent, taking light as the observation medium; the ear is another kind of observation agent, taking sound as the observation medium.

Human beings can and need to make use of different observation agents to perceive or observe the objective world.

By analogy with the coordinate framework OA(c) of Minkowski 4d spacetime, replacing the light speed c in Eq. (1.1) with the information-wave speed η, then the concept of observation agent can be defined as follows.

Definition 1.1 (Observation Agent): An observation system employing a specific observation medium to transmit observed information for observers is referred to as an observation agent and denoted as OA(η), which in the inertial spacetime of IOR is defined a metric spacetime as

$$\mathrm{OA}(\eta) \triangleq \left\{ \begin{array}{l} X^{4\mathrm{d}}(\eta): \left\{ \begin{array}{l} x^0 = \eta t; \\ x^1 = x,\ x^2 = y,\ x^3 = z \end{array} \right\} \\ \mathrm{d}s^2 = \eta_{\mu\nu} \mathrm{d}x^\mu \mathrm{d}x^\nu \quad \left(\eta_{\mu\nu} = \mathrm{diag}(+1, -1, -1, -1) \right) \end{array} \right\} \tag{1.2}$$

where the observation medium of OA(η) can be any form of matter motion or any matter wave, η is the information-wave speed of OA(η), i.e., the transmission speed of observed information through the observation medium; $X^{4\mathrm{d}}(\eta)$ represents the 4d spacetime observed by OA(η), x^0 is the 1d time coordinate, and (x^1,x^2,x^3) is the 3d space coordinate that can adopt the Cartesian coordinate (x,y,z); ds is the line-element of IOR inertial spacetime, $g_{\mu\nu}=\eta_{\mu\nu}=\mathrm{diag}(+1,-1,-1,-1)$ is the metric of inertial spacetime, that is, Minkowski metric.

Just as Einstein's special theory of relativity can be built on the formalized framework of the optical observation agent OA(c) defined in Eq. (1.1), the theory of IOR, so-called **Inertially observational relativity** (IOR), can be built on the formalized framework of the general observation agent OA(η) defined in Eq. (1.2).

Analogous to Minkowski spacetime, the general observation agent OA(η) defined in Eq. (1.2) implies **the invariance of information-wave speeds**, and moreover, implies the observational locality of OA(η): $\eta<\infty$.

It should be noted that the definition of the general observation agent OA(η) is not the logical premise presupposed by the theory of OR, in which the implied invariance of information-wave speeds is the logical consequence of OR theory.

Both the optical observation agent OA(c) defined in Eq. (1.1) and the general observation agent OA(η) defined in Eq. (1.2) are the formalized coordinate frameworks of inertial spacetime. In the 2^{nd} volume of OR (**Gravitationally Observational Relativity**, GOR), the general observation agent OA(η) will be extended from inertial spacetime to gravitational spacetime, so that the theory of IOR will be extended to the theory of GOR.

1.4.3 The Idealized Observation Agent

The theory of OR discovers that: Einstein's theory of relativity is the theory of optical observation, and the observation system is the optical observation agent OA(c); Galileo's doctrine and Newton's classical mechanics are the theories of ideal observation, the observation system is the idealized observation agent OA_∞.

The information-wave speed of the idealized observation agent OA_∞ is infinite. So, the idealized observation agent OA_∞ has no observational locality.

The optical observation agent OA(c) can be formally expressed by the 4d coordinate framework of Minkowski spacetime. Then, what about the formalized coordinate framework of the idealized observation agent OA_∞?

It is enlightening that the general observation agent OA(η) in Def. 1.1 generalizes and unifies the optical observation agent OA(c) and the idealized observation agent OA_∞, in which, The formalization of OA(c) is naturally the coordinate framework of Minkowski spacetime; while the formalization of OA_∞ is the coordinate framework of Cartesian spacetime.

In the coordinate framework of Minkowski spacetime, space and time are interdependent of each other: space is also time; time is also space. However, in the coordinate framework of Cartesian spacetime, space and time are independent of each other: space is just space; time is just time.

Naturally, if $\eta \to c$, then the general observation agent OA(η) in Eq. (1.2) is namely the optical observation agent OA(c) in Eq. (1.1), or Minkowski agent.

Particularly, if $\eta \to \infty$, then the line-element ds of the general observation agent OA(η) in Eq. (1.2) is split into the time line-element dt and the space line-element dl, being independent of each other:

$$\frac{\mathrm{d}s^2}{\eta^2} = \mathrm{d}t^2 - \left(\frac{\mathrm{d}x^2 + \mathrm{d}y^2 + \mathrm{d}z^2}{\eta^2}\right) \overset{\eta\to\infty}{\Rightarrow} \begin{cases} \mathrm{d}t = \mathrm{d}\tau \ \ (\mathrm{d}\tau = \mathrm{d}s/\eta) \\ \mathrm{d}l^2 = \mathrm{d}x^2 + \mathrm{d}y^2 + \mathrm{d}z^2 \end{cases} \tag{1.3}$$

This suggests that, if $\eta \to \infty$, then the 4d observational spacetime $X^{4d}(\eta)$ of the general observation agent OA(η) in Eq. (1.2) is split into the 1d time t and the 3d space (x,y,z), being independent of each other. The ideal case (without observational locality) is the coordinate framework of Cartesian spacetime created by Descartes, that is, Cartesian coordinate system:

$$OA_\infty = \left\{ \begin{array}{l} X^{4d}{}_\infty : \{x^0 = \eta t \quad (\eta \to \infty);\ x^1 = x,\ x^2 = y,\ x^3 = z\} \\ \mathrm{d}t = \mathrm{d}\tau \ \ (\mathrm{d}\tau = \mathrm{d}s/\eta) \\ \mathrm{d}l^2 = \mathrm{d}x^2 + \mathrm{d}y^2 + \mathrm{d}z^2 \end{array} \right\} \tag{1.4}$$

where X^{4d}_{∞} is the idealized observational spacetime of OA_{∞}, or called **Cartesian spacetime**, the information-wave speed η of OA_{∞} is idealized as infinity; $d\tau$ is the intrinsic time (proper time), that is, the objective and real time. Due to $\eta\to\infty$, the time axis x^0 is meaningless in Cartesian coordinate system.

It is thus clear that the so-called idealized observation agent OA_{∞} is namely the coordinate framework of Cartesian spacetime or Cartesian coordinate system, in which $dt=d\tau$ means that the observational time dt in Cartesian coordinate system is exactly the objective and real time, i.e., proper time: $d\tau$.

Thus, two coordinate systems separated originally, the coordinate framework of Cartesian spacetime in Eq. (1.4) and the coordinate framework of Minkowski spacetime in Eq. (1.1), have now been generalized and unified by the coordinate framework of IOR spacetime in Eq. (1.2); in other words, two separate observation agents, Cartesian agent OA_{∞} and Minkowski agent $OA(c)$, have been generalized and unified by the general observation agent $OA(\eta)$ of IOR theory.

The idealized observation agent, or Cartesian agent, is denoted as OA_{∞}, and the speed η of its information wave is idealized as infinity ($\eta\to\infty$). Therefore, the idealized observation agent OA_{∞} has no observation locality: the observed information of OA_{∞} takes no time to cross space. So, OA_{∞} would present observers the real face of the objective world.

1.4.4 Realistic Observation Agents

In theory, the general observation agent $OA(\eta)$ can employ any form of matter motion as its observation medium, in which the information-wave speed η can be any speed value. A specific observation agent means a specific observation system with a specific observation medium. However, no matter according to the principle of locality or the principle of observational locality, the idealized observation agent OA_{∞} is unrealistic: there is no idealized observation agent in nature; OA_{∞} can only exist in human reason.

So-called realistic observation agents are that of objective existence, which human beings are able to employ to perceive or observe the objective world.

As shown in Tab. 1.1, there exist various kind of realistic observation agents in the physical world: the sonar of land robots is **Bat-Agent** $OA(v_S)$ (v_S is the speed of ultrasonic wave in the atmosphere); the sonar of underwater robots is **Dolphin-Agent** $OA(v_U)$ (v_U is the speed of ultrasonic wave in the water); astronomical telescopes, which employs light or electromagnetic interaction as the medium for astronomical observation, are **the optical agent** $OA(c)$ (c is the speed of light in vacuum); and the future observation agent employing gravitational interaction as the observation medium can be called **the gravitational agent** $OA(\kappa)$ ($\kappa>7\times10^6c$ is the speed of gravity calculated by Laplace [43]).

All realistic observation agents $OA(\eta)$ have observational locality ($\eta<\infty$).

Different observation agents, different observation media, different speeds of information waves, mean different degrees of observational locality, and exhibit different degrees of relativistic effects.

The theory of OR will clarify that [26-30], as shown in Tab. 1.1, different observation agents produce different theoretical systems or spacetime models: the Lorentz transformation and Einstein's theory of special relativity are the products of the optical observation agent OA(c); the Galilean transformation and Newton's inertial mechanics are the products of the idealized observation agent OA_∞.

So, different theoretical systems of physics serve different observation agents.

Table 1.1 Some Observation Agents for Human Beings to Perceive the Objective World

Observation Agent OA(η)	Observed Time dt(η)	Factor of ST $\Gamma(\eta)=\mathrm{d}t/\mathrm{d}\tau=\Gamma_\infty+\Delta\Gamma$	Factor of OE $\Delta\Gamma(\eta)$
Bat-Agent OA(v_S): $v_S\approx340$m/s	$\mathrm{d}t(v_S)>\mathrm{d}t(v_U)$	$\Gamma(v_S)=1/\sqrt{(1-v^2/v_S{}^2)}$	$\Delta\Gamma(v_S)>\Delta\Gamma(v_U)$
Dolphin-Agent OA(v_U): $v_U\approx1450$m/s	$\mathrm{d}t(v_U)>\mathrm{d}t(c)$	$\Gamma(v_U)=1/\sqrt{(1-v^2/v_U{}^2)}$	$\Delta\Gamma(v_U)>\Delta\Gamma(c)$
Optical-Agent OA(c): $c=3\times10^8$m/s	$\mathrm{d}t(c)>\mathrm{d}t(\kappa)$	$\Gamma(c)=1/\sqrt{(1-v^2/c^2)}$	$\Delta\Gamma(c)>\Delta\Gamma(\kappa)$
Gravity-Agent OA(κ): $\kappa>7\times10^6c$	$\mathrm{d}t(\kappa)>\mathrm{d}t_\infty$	$\Gamma(\kappa)=1/\sqrt{(1-v^2/\kappa^2)}$	$\Delta\Gamma(\kappa)>\Delta\Gamma(\infty)$
Idealized-Agent OA_∞=OA(∞): $\eta\to\infty$	$\mathrm{d}t_\infty=\mathrm{d}t(\infty)=\mathrm{d}\tau$	$\Gamma_\infty=\Gamma(\infty)\equiv1$	$\Delta\Gamma(\infty)=0$

Notes: (i) OA(η) is the general observation agents, which generalizes all observation agents, including the realistic ones: Bat-agent OA(v_S), Dolphin-agent OA(v_U), the optical observation agent OA(c), the gravitational agent OA(κ); and the idealized: the idealized observation agent OA_∞. (ii) All realistic observation agents are restricted by observational locality ($\eta<\infty$): the less the η, the larger the $\Delta\Gamma(\eta)$, and the more significant the relativistic effects. (iii) A different observation agent OA(η) presents different observational spacetime $X^{4d}(\eta)$ and has a different observed time dt(η); $\mathrm{d}t(\eta)\neq\mathrm{d}\tau$ suggests that observed times dt(η) are not the objective and real spacetime. (iv) Cartesian spacetime $X^{4d}{}_\infty$ represents the intrinsic spacetime, in which the idealized observed time $\mathrm{d}t_\infty$ is namely the objective and real time dτ: $\mathrm{d}t_\infty=\mathrm{d}\tau$。

The synchronous satellite system of GPS employs radio to communicate, which in fact belongs to the optical observation agent OA(c). Hence, in the GPS system, the measurement and calibration of time has to depend on Einstein's theory of relativity: $\mathrm{d}\tau=\mathrm{d}t(c)\sqrt{(1-v^2/c^2)}$.

The deep sea will be one of the important fields of future human exploration; the cooperative operation of multi robots in the deep sea must employ underwater acoustic communication systems, i.e., Dolphin-agent OA(v_U). In particular, although the speed (1~10m/s) of underwater robots is much lower than the speed (7.9~11.2 km/s) of satellites, their ratio is much higher than the ratio of the underwater acoustic speed (1450m/s) to the light speed (3×10^5km/s). This suggests that the relativistic effects of the cooperative system of underwater robots are more significant than that of GPS satellite system, and therefore, underwater robots depend more on Dolphin's theory of relativity to measure and calibrate the time [52,53]: $\mathrm{d}\tau=\mathrm{d}t(v_U)\sqrt{(1-v^2/v_U{}^2)}$.

It is thus clear that subluminal observation agents and subluminal theories of relativity also have their own practical value and significance.

In the future, humans may invent superluminal observation agents, such as the gravitational observation agent OA(κ); perhaps, just as Laplace's calculation, gravitational waves may travel much faster than light [43]: $\kappa > 7\times10^6 c$. The superluminal observation agents will send us more real-time observed information and present us a more objective and more realistic physical world.

Einstein's theory of relativity, including the special and the general, belongs to the theoretical systems of the optical agent OA(c), which presents us just an optical image of the objective world, and not quite the real objective world. The Galileo's doctrine and Newton's theory belong to the theoretical systems of the idealized agent OA_∞, which presents us the true portrayal of the objective world. The theory of observational relativity (OR for short, including IOR and GOR) is the theoretical system of the general observation agent OA(η) and possesses a broader perspective, which will generalize and unify the Newton's classical mechanics and Einstein's theory of relativity.

1.5 Spacetime in Observation and Observed Physical Quantities

Space and time are the two most important properties of the universe.

Human being's view of space and time, from the plain absolutist view of spacetime to the fancy relativist view of spacetime, has been experiencing a tortuous cognitive process.

Galileo and Newton held the absolutist view of spacetime [54-57]: space is absolute, and time is absolute too; space exists immutably, and time flows silently. The Galilean transformation represents the absolutist view of spacetime: space and time are independent of each other, space is just space and time is just time; different observers share the same time, and there is no need for the transformation of time. Mach and Einstein held the relativist view of spacetime [58-60]: space is relative, and time is relative too. The Lorentz transformation, or the FitzGerald-Lorentz transformation [3-6], represents the relativist view of spacetime: space and time are interdependent of each other; space is also time and time is also space. Thus, space and time merge together to have formed the concept of **spacetime**.

Nowadays the mainstream school of physics is generally in favor of the relativist view of spacetime, for the Lorentz transformation and Einstein's theory of relativity are supported by most of observations and experiments. However, physicists fail to realize that the Lorentz transformation and Einstein's theory of relativity are the products of the optical observation agent OA(c). Most of our observations and experiments rely on OA(c), which is the real reason why most of our observations and experiments support the Lorentz transformation and Einstein's theory of relativity. If we were able to observe the objective world by means of the idealized observation agent OA_∞, then our observations and experiments would tend to support Galileo's doctrine and Newton's theory.

The universe, including spacetime and matter, exists objectively.

Human beings must rely on their own sensory organs, or, take use of the observation instruments invented by themselves, so that they are able to perceive or observe the existence of spacetime and matter. However, by the restriction of observational locality, the spacetime $X^{4d}(\eta)$ any observation agent OA(η) (η<∞) presents to us is just an **observational spacetime**: an image of the objective spacetime, and not quite objective and real.

So, physics has to make a distinction between the observational spacetime $X^{4d}(\eta)$ and the objective and real spacetime $X^{4d}{}_{\infty}$.

The so-called **observational spacetime** refers to the spacetime $X^{4d}(\eta)$ observed by the observer taking use of the specific observation agent OA(η). Restricted by the observational locality of OA(η) (η<∞), the observed values of physical quantities in the observational spacetime $X^{4d}(\eta)$ are not necessarily the same as the objective and real physical quantities. Therefore, physics has to make a distinction between the observed physical quantities and the objective and real physical quantities.

So, what are the real physical quantities?

The observed values of physical quantities depend on observation: relative to different observers or different observation agents, the identical physical quantity of the identical physical system may have different observed values, that is, the **observational physical quantities**. However, the objective or real physical quantities is the **intrinsic physical quantities** independent of observation, independent of observers, independent of observation systems or observation agents.

The theory of OR will clarify that relativistic phenomena are observational effects, caused by the observational locality of observation agents, and depend on two factors: (i) relative motion (in the case of special relativity); (ii) interaction (in the case of general relativity). The theory of OR sometimes takes **free spacetime** as the alternative concept of **inertial spacetime**. There is no force or interaction in the so-called free spacetime. We agree that the free spacetime is denoted as S_F, then the concepts of **observed physical quantity** and **intrinsic physical quantity** can be defined in the free spacetime S_F as follows.

Definition 1.2 (Observed Physical Quantity and Intrinsic Physical Quantity): Suppose there are an observed object *P* and an observer *O* with observation agent OA(η). If *O* detects the physical quantity *U* of *P* with OA(η), then *U* is referred to as the observed physical quantity of *P* observed by *O* with OA(η); if *P* is at rest relative to *O* in the free spacetime S_F, or OA(η) is the idealized observation agent OA_{∞}, then *U* is referred to as the intrinsic physical quantity of *P*, and denoted as U_o.

Definition 1.2 suggests that the observed physical quantity *U* of *P* observed by *O* depends on observation agent OA(η): U=$U(\eta)$. The theory of OR will clarify that, by the restriction of the observational locality (η<∞) of OA(η), the physical quantity *U* observed by *O* with OA(η), i.e., the observed physical quantity *U*, are not equivalent to the intrinsic physical quantities U_o of *P*.

The theory of OR will clarify that, if $\eta\to\infty$, then $U\to U_o$: all the physical quantities of *P* observed by *O* with OA_{∞} are equivalent to the intrinsic physical quantities of *P*. The idealized observation agent OA_{∞} represents the objective and real physical world, hence the intrinsic physical quantity U_o in Def. 1.2 represents the objective and real physical quantity U_{∞}.

In Def. 1.2, the measurement of the intrinsic physical quantity requires that the observer O and the observed object P are relatively at rest, or more strictly, P should be static and the physical quantities of P do not vary with time, unless the observation agent OA(η) of the observer O is the idealized observation agent OA_{∞}.

In a sense, the absolutely objective or absolutely real physical quantities are unobservable or unmeasurable. Just because of this, physics has to make a distinction between the observed physical quantity and the objective and real quantity (or the intrinsic physical quantity).

2 The Axiom System of IOR

As we all know, Einstein's special theory of relativity has two important logical premises: the second is the principle of relativity; the third is the principle of the invariance of light speed.

However, the first is rarely known: the principle of simplicity.

Such so-called **three principles** constitute the axiom system of Einstein's special theory of relativity.

Only when the theoretical systems of physics were built on the basis of the most basic axiom systems or the most basic logical premises could we capture the essence through the phenomenon, knowing what and knowing why.

Up to now, however, the principle of the invariance of light speed (ILS for short) remains only a hypothesis about which we know what but we do not know why:

(i) The ILS is not self-evident, and consequently, has no the basic feature as a principle or an axiom;

(ii) The ILS has no linkage with the other principles or laws or theories of physics, and consequently, cannot be mutually verified;

(iii) The ILS is not like a logical premise (cause), but more like a logical consequence (effect), appearing to be the inversion of cause and effect.

Because of this, so far, physics cannot explain why the speed of light is invariant and why spacetime is curved; we cannot fully understand the relativistic phenomena described by Einstein for us, including inertial relativistic effects in his special relativity and gravitational relativistic effects in his general relativity.

By contrasting with Einstein's theory of special relativity, we know that the theory of inertially observational relativity (IOR for short) is based on a more basic axiom system with more basic premises, including:

(i) The principle of physical observability;
(ii) The conditions of wave-particle duality;
(iii) The definition of time.

It should be pointed out that, in fact, the axiom system of IOR theory is namely the axiom system of OR theory, which is not only the logical premises of IOR theory but also the logical premises of GOR theory.

2.1 The Principle of Physical Observability

Human beings' understanding of the objective world is originated and stemmed from their observation of the objective world.

As a physicist, a materialist against agnosticism, you must hold the belief: physically, the objective world is observable.

Physical observability is the premise for human to cognize the physical world.

Actually, physical observability is implicitly employed as the logical premise of all theoretical systems of physics, including Galileo's doctrine, Newton's classical mechanics, Einstein's relativity, and quantum theory.

2.1.1 Physical Observability: A Principle

The physical world must be observable, or must have observability.

The theory of OR explicitly states physical observability as a principle.

The Principle of Physical Observability (PO): Any physical quantity of matter systems must be observable; the observed value must be definite and finite.

It should be pointed out that the principle of PO does not exclude the uncertainty of quantum theory and the randomness of physical quantities, whether such kind of uncertainty or randomness is the observational effects of observation agents or the essential characteristic of matter systems. However, such uncertainty and randomness must be definite: having definite and finite observed values.

The principle of PO is self-evident, and has the rationality as a basic principle or as an axiom. The principle of physical observability might be one of the most basic principles in physics.

2.1.2 PO Principle and Observational Locality

Actually, **the Principle of Observational Locality** and even **the Principle of Locality** in the first chapter are both the logical consequences or inferences of the principle of PO: the principle of locality suggests that the speeds of matter motion are finite, and it takes time for matter to cross space; the principle of observational locality suggests that the speeds of information transmitted by observation media are finite, and it takes time for information to cross space.

The principle of PO plays an important role in the theory of OR (including IOR and GOR) and is the starting point of the logic route of OR theory. The direct logical consequences of PO principle are the principle of locality and the principle of observational locality. Moreover, the principle of PO promotes the formation of the conditions of wave-particle duality.

Locality, or the principle of locality, plays an important role in Einstein's theory. However, Einstein's view of locality is linked with his hypothesis of the invariance of light speed. The principle of locality tells us that there is no action at a distance in the universe. However, this does not mean that the speed of light cannot be exceeded, but only means that the speed of matter motion cannot be infinite.

Observational locality, or the principle of observational locality, plays an important role in the theory of OR (including IOR and GOR). The principle of observational locality tells us that it takes time for observed information to cross space. However, this does not mean that the speeds of observed information cannot exceed the speed of light, but only means that the speeds of observed information, or the speeds of information waves, cannot be infinite.

2.1.3 PO Principle and Big Bang Singularity

As Hawking remarked in his **A Brief History of Time** [31]: "Mathematics cannot really handle infinite numbers. At singularity, the theory itself breaks down or fails." Hawking said with a hint of humor: "God abhors a naked singularity."

Actually, God does not only abhor a naked singularity. The principle of PO implies that God abhors all kinds of singularities.

The principle of PO suggests that a singularity in a physical theory or a physical model cannot be regarded as the objective physical reality or real physical existence, but that the theory or the model fails at the singularity.

So, the principle of PO can be referred to as **the Principle of Singularity**.

The singularities in Einstein's theory of relativity and its related theoretical models are both fascinating and confusing.

The Big Bang theory has a so-called **Big Bang singularity**, a spacetime point with infinite matter density and infinite spacetime curvature, which is predicted based on Einstein's general theory of relativity. Perhaps, for cosmologists, the Big Bang singularity is both the most fascinating and the most confusing.

On the one hand, cosmologists expect such a singularity with infinite matter density and infinite spacetime curvature, so that the universe could be detonated, and moreover, the Big Bang sounds more ceremonial and looks more beautiful in form. On the other hand, however, such a state of the universe with infinite physical quantities seems to contradict with cosmologists' subconscious thought on the physical observability of the universe.

In 1970, Hawking and Penrose proved the singularity theorems [61]: singularities are inevitable when Einstein's general theory of relativity is used for predicting the beginning of the universe, at which the universe has infinite matter density and infinite spacetime curvature. In the face of singular solutions of the field equation, Einstein even believed that his general theory of relativity was not a complete theory and needed to be replaced by a non-singular unified field theory [62]. Weinberg said in his **The First Three Minutes** [63]: "One possibility is that there never really was a state of infinite density. The Big Bang may have begun when the density of the universe had reached some very high but finite value." Hawking himself did not think that the Big Bang singularity really existed [31]: "Because mathematics cannot really handle infinite numbers, this means that the general theory of relativity predicts that there is a point in the universe where the theory itself breaks down. Such a point is an example of what mathematicians call a singularity."

Such ideas and thoughts are no other than the spontaneous display of great physicists' belief on physical observability.

2.1.4 PO Principle and Lorentz Singularity

Especially, what is worth mentioning is the Lorentz singularity, not only for it had caused photons to lose rest mass, but also for it is the motivation of OR theory: it is the original intention of OR theory to give photons a little mass.

The Lorentz singularity, that is, the singularity of Lorentz factor $\gamma=1/\surd(1-v^2/c^2)$ in the Lorentz transformation: when the speed v of the observed object P reaches the speed c of light, Lorentz factor $\gamma=1/\surd(1-c^2/c^2)=1/0$ is infinite.

Naturally, at the Lorentz singularity, the moving mass m ($=\gamma m_o$) of the observed object P, i.e., the so-called relativistic mass, is infinite, unless the rest mass m_o of P is zero. According to the principle of PO, the relativistic mass m of P is finite ($m<\infty$), hence the rest mass m_o of an object moving at the speed of light (for example a photon) must be zero: $m_o=m\sqrt{(1-c^2/c^2)}=0$.

It is thus clear that Einstein was unconsciously quoting the principle of PO when he told us that photons had have no rest mass.

So, at the Lorentz singularity, the relativistic mass m of photons is unknowable.

According to Einstein's theory: on the one hand, photons have no rest mass; on the other hand, the relativistic mass of photons is unknowable. In Hawking's words, this suggests that, at the Lorenz singularity, the mass-speed relation in Einstein's special theory of relativity breaks down, or fails.

Thus, the relativistic mass m of a photon cannot directly be calculated with Einstein's own theory, and has to be done with the help of Planck equation $E=hf$: $m=E/c^2=hf/c^2$, in which f is the frequency of light and $E=mc^2$ is Einstein formula.

The theory of OR will reveal the formation cause of the Lorenz singularity.

The theory of OR will tell us that no matter the Lorentz singularity of Einstein's special relativity or the Big Bang singularity of the Einstein's general relativity is not the objective and real physical existence, which depends on observation agents, shifting or varying with different observation agents.

The principle of PO is the important ideological basis and guiding principle of physics, and should be taken as the most fundamental principle of physics.

2.2 The Conditions of Wave-Particle Duality

In the axiom system of OR theory, there is a set of logical premises called the conditions of wave-particle duality[2]:

(i) The principle of frequency-speed relation;

(ii) The definition of the cosmic speed;

(iii) The principle of OR speed addition.

The conditions of wave-particle duality have the basic feature of self-evidence, and can be mutually confirmed with the principle of physical observability (PO) and de Broglie's theory of matter waves [17-19].

The wave-particle duality of matter motion suggests that an object acts like both a particle and a wave, which as depicted in Fig. 2.1(a) has both the speed u of the particle and the frequency f of the wave.

So, according to the agreements of Sec. 1.1.1 in Chapter 1, the theory of OR defines the conditions of wave-particle duality as follows.

[2] If you cannot understand or dislike the conditions of wave-particle duality, you can replace them with the principle of simplicity or the principle of relativity that you can understand. But of course you will lose your understanding of **the cosmic speed**.

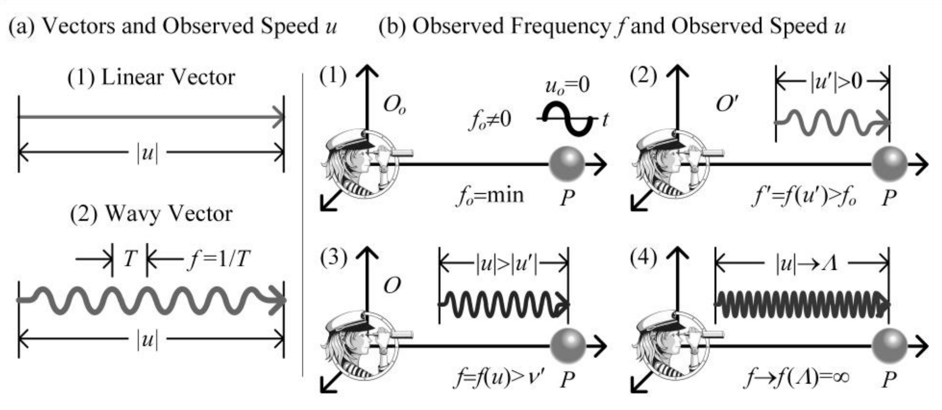

Figure 2.1 Linear Motion and Wavy Motion (with the agreements of Sec. 1.1.1 in Chapter 1**).** (a) Vectors and Observed Speed u: (1) linear vector, (2) wavy vector; (b) Observed Frequency f and Observed Speed u: (1) The observed object P is at rest in the intrinsic reference system O_o, and the intrinsic reference frequency f_o is the minimum of P's observed frequency; (2) P moves at a speed of u', if $|u'|>0$ in O', and the observed frequency is $f'>f_0$; (3) P moves at a speed of u, if $|u|>|u'|$, then $f>f'$; (4) If P's observed frequency f tends to infinity, the observed speed u must reach a certain upper limit (Λ).

2.2.1 The Principle of Frequency-Speed Relation

The velocity or speed of a moving object is often expressed by a vector.

The observed object P is generally regarded as a matter particle. Therefore, as depicted in Fig. 2.1(a1), the speed u of P as a matter particle is often expressed by a linear vector: the arrow direction of the vector is the moving direction of P; the length of the vector is the moving speed value of P.

In the sense of wave-particle duality, however, the matter body P behaves like both a particle and a wave, and as shown in Fig. 2.1(a2), its motion includes both linear motion and wavy motion, which can be described by a wavy vector[3]. Besides the direction, the wavy vector of the observed object P must have two other physical quantities: one is the length $|u|$, representing the particle speed of P as a matter particle or the group speed of P as a matter wave; the other is the observed frequency f of P's matter wave.

In a sense, the wave-particle duality depends on observation agents and is a sort of observational effect: the observed frequency f is related to P's speed or moving rate $|u|$ ($f(u)\propto|u|$). For the same observed object, different observers have different observed speeds and different observed frequencies: the larger the observed rate $|u|$ is, the higher the observed frequency f is.

This can be set as a principle: the principle of frequency-speed relation.

The Principle of Frequency-Speed Relation: Let f and f' be the observed frequencies of the observed object P in the O and O' of inertial reference frames. Then, $f>f'$ if and only if $|u|>|u'|$; $f=f'$ if and only if $|u|=|u'|$.

[3] Here, the wavy vectors are different from the wave vectors in the classical wave theory.

Both linear motion and wavy motion require energy.

We refer to the energy that maintains the linear motion of an inertial object as **the Linear Energy** and refer to the energy that maintains the wavy motion of an inertial object as **the Wavy Energy**.

The higher the observational speed, the higher the observational energy: the higher the observed speed of a matter particle, the higher the observational linear energy; the higher the observed frequency of a matter wave, the higher the observational wavy energy.

There is a noteworthy phenomenon in nature: waves, such as light waves and sound waves, can maintain their specific speeds no matter in the vacuum, in the atmosphere or in the water; therefore, in the identical medium, light waves with different frequencies or sound waves with different frequencies have the identical speed. It is conceivable that a wave has a sort of mechanism to maintain its specific speed: if the linear energy of the wave grows (decays), then the wave will increase (decrease) its wavy energy in the way of increasing (decreasing) the frequency of the wave to maintain the original specific speed of the wave.

To put it briefly, the principle of frequency-speed relation suggests that the higher the observed frequency is, the higher the observed speed is.

2.2.2 The Definition of the Cosmic Speed

Under the principle of frequency-speed relation, one can imagine such a limiting case that the observed frequency of a matter wave tends to infinity.

The principle of frequency-speed relation suggests that the wave-particle duality can lead to the upper bound of speeds: for the observed object P, the increase of the speed of P as a matter particle will lead to the increase of the frequency of P as a matter wave; the increase of P's frequency will consume energy, and therefore, inhibit the growth of the linear speed of P.

It can be imagined that, if the observed frequency of P as a matter wave tends to infinity, then the observed speed of P's as a matter particle must reach the upper bound that the theory of OR calls the ultimate speed of the universe, or the cosmic speed, being denoted as Λ and defined as follows.

Definition 2.1 (The Cosmic Speed): Let P be an inertial moving body, u be the observed speed of P as a matter particle, f is the observed frequency of P as a matter wave. If $f\to\infty$, then $|u|\to\Lambda$ ($<+\infty$) where Λ is referred to as **the ultimate speed of the universe**, or **the cosmic speed**.

The definition of the cosmic speed suggests that if the observed frequency of a moving object as a matter wave tends to infinity, its observed speed would be the ultimate speed of the universe or the cosmic speed Λ. Originally, the author wished that the cosmic speed Λ was beyond the reach of all matter objects in reality, so that the author could endow photons with a little mass or a little rest mass.

Under the definition of the cosmic speed unreachable, however, the logical deduction of OR theory cannot be carried out. Therefore, Def. 2.1 does not require that the observed frequency of a moving object tends to infinity when its observed speed tends to the cosmic speed Λ. Without violating the principle of physical observability (PO), Def. 2.1 does not exclude the possibility that the observed speed of a realistic moving object can reach the cosmic speed Λ.

Definition 2.1 produces the following two direct logical corollaries.

Corollary 2.1 (The Observational Ultimate Speed): Let P be an inertial moving body and u be the observed (or observable) speed of P, then u cannot exceed the cosmic speed Λ in Def. 2.1, that is, $\forall u\ |u|\leq\Lambda$.

Proof:

According to the principle of physical observability (PO), for a moving object P, the observed frequency $f(u)$ at any observed speed u must be finite: $\forall u\ f(u)<\infty$.

Therefore, according to the principle of frequency-speed relation, we have

$$|u| \leq \lim_{f(v)\to\infty} |v| = \Lambda \tag{2.1}$$

where $f(v)$ is the observed frequency of P at the observed speed v of P.

Eq. (2.1) suggests that, according to Def. 2.1 of the cosmic speed 2.1, it holds that $\forall u\ |u|\leq\Lambda$. So, we can conclude that Corol. 2.1 holds.

Q.E.D.

Corollary 2.2 (The Invariance of the Cosmic Speed): The cosmic speed Λ is the same or invariant relative to all inertial observers.

Proof:

Let the observed object P has the speeds u and u' respectively in the inertial frames O and O'. Without loss of generality, suppose $u>u'>0$.

Let us assume that Corol. 2.2 is not true. Thus, if $u'=\Lambda$, then $u>\Lambda$.

This leads us to a contradiction of Corol. 2.1.

So, we can conclude that Corol. 2.2 holds.

Q.E.D.

Now, in the theory of IOR, **the ultimate speed of the universe**, i.e., **the cosmic speed** Λ, replaces the speed c of light in Einstein's special theory of relativity.

Then, what is **the cosmic speed** Λ? Could it be the speed c of light?

The theory of IOR, i.e., **Inertially Observational Relativity**, will tell us that: the speed c of light is not the cosmic speed; as a matter of fact, there exists no the ultimate speed Λ in the universe.

2.2.3 The Principle of OR Speed Addition

Galileo's speed-addition is one of the most well-known kinematic laws that is in fact a direct logical consequence of the Galilean transformation, and conforms to our experience and intuition, as well as to human reason.

According to the agreements in Sec. 1.1.1 of Chapter 1, the law of Galileo's speed-addition can be expressed as the law of the linear vector-addition:

$$\forall u', v \quad u = u' + v \tag{2.2}$$

(1) The same-direction addition: $|u'+v| = |u'| + |v|$ (2.2a)

(2) The opposite-direction addition: $|u'+v| = ||u'| - |v||$ (2.2b)

As depicted in Fig. 2.2(a), Galileo's speed-addition belongs to the linear vector-addition: (1) the same-direction addition in (2.2a) (u' and v in the same direction) where the direction of the linear vector of u is the same as that of u' and v, and the length of the linear vector of u is the sum of that of u' and v; (2) the opposite-direction addition in (2.2b) (u' and v in the opposite direction) where the direction of the linear vector of u is the same as that of u' if $|u'| > |v|$ or v if $|v| > |u'|$, and the length of the linear vector of u is the difference between that of u' and v;

However, the Michelson-Morley experiment showed that the law of Galileo's speed-addition might fail: the speed c of light plus the earth's speed around the sun remained the speed c of light.

Perhaps, the principle of Galileo's speed-addition, as a sort of linear vector-addition, cannot reflect the wave-particle duality of matter motion. In the Michelson-Morley experiment, light is the observed object. As a sort of matter wave, the speed-addition problem of light may belong to the wavy speed-addition, which should reflect the feature of the wavy speed-addition, and obey a certain law or rule of the wavy speed-addition: $u=u'\oplus v$.

Actually, the essential feature of the wavy speed-addition is the mutual transformation between the wavy energy and linear energy of the moving object P. As depicted in Fig. 2.2(b), by combining with the principle of frequency-speed relation in Sec. 2.2.1 and the definition of the cosmic speed in Sec. 2.2.2, it can be expressed as the principle of OR speed addition as follows.

The Principle of OR Speed Addition: According to the agreements in Sec. 1.1.1 of Chapter 1, the speed u of the moving object P in the reference frame O is the superposition of the speed u' in the reference frame O' and the speed v of O' relative to O, which obeys the law of the wavy vector-addition: $u=u'\oplus v$, that is,

(i) The same-direction addition: if $u'\geq 0$ and $v\geq 0$, or, $u'\leq 0$ and $v\leq 0$, then $|u'+v|\geq|u'\oplus v|\geq\max\{|u'|,|v|\}$;

(ii) The opposite-direction addition: if $u'\geq 0$ and $v\leq 0$, or, $u'\leq 0$ and $v\geq 0$, then $\max\{|u'|,|v|\}\geq|u'\oplus v|\geq|u'+v|$,

where the equal sign holds if and only if u' or v is zero or Λ (according to Corol. 2.2); the operators "+" and "⊕" are respectively the linear vector-addition and the wavy vector-addition.

As depicted in Fig. 2.2(b), the law of wavy speed-addition can be stated as:

(i) The same-direction addition (u' and v in the same direction): the observed speed of the moving object P increases after the wavy speed-addition of u' and v. According to the principle of frequency-speed relation, the observed frequency f of P's matter wave increases as well, and part of P's linear energy is converted into P's wave energy. So, the length $|u|$ of the wavy vector of u is longer than $\max\{|u'|,|v|\}$ but shorter than the length $|u'+v|$ of Galileo's linear vector; the direction of u is the same as that of u' or v.

(ii) The opposite-direction addition (u' and v in the opposite direction): the observed speed of the moving object P decreases after the wavy speed-addition of u' and v. According to the principle of frequency-speed relation, the observed frequency f of P's matter wave decreases as well, and part of P's wavy energy is converted into P's linear energy. So, the length $|u|$ of the wavy vector of u is shorter than $\max\{|u'|,|v|\}$ but longer than the length $|u'+v|$ of Galileo's linear vector; the direction of u is the same as that of u' if $|u'|>|v|$ or v if $|v|>|u'|$.

In principle, the law of the wavy vector-addition obeys both the principle of conservation of momentum and the principle of conservation of energy.

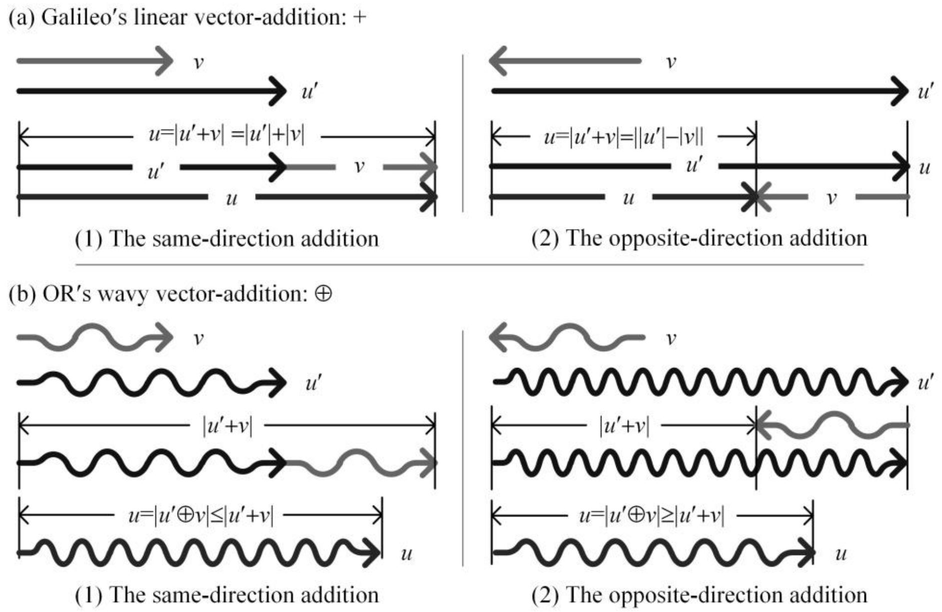

Figure 2.2 Linear Vector-Addition and Wavy Vector-Addition (with the agreements of Sec. 1.1.1 in Chapter 1)**.** (a) The linear vector-addition (i.e., Galileo's speed-addition): $u=u'+v$. (b) The wavy vector-addition (i.e., OR's speed-addition): $u=u'\oplus v$.

2.3 Time and the Invariance of Time-Frequency Ratio

Time is the most basic physical concept and the most basic physical quantity.

The definition of time is part of the axiom system of OR theory, and the most basic and indispensable logical premise of theory of OR including IOR and GOR.

On the basis of the definition of time as the most basic logical premise, the theory of OR provides us with new understanding and insight into Galileo's doctrine, Newton's classical mechanics, Einstein's theory of relativity including the special and the general, and even modern physics.

In the theory of OR, the definition of time has a direct logical inference: the invariance of time-frequency ratio which has profound implication. Based on the invariance of time-frequency ratio, the theory of IOR not only generalizes and unifies the Galilean transformation and the Lorentz transformation, generalizes and unifies Newton's inertial theory and Einstein's special theory of relativity, but also generalizes de Broglie's theory of matter waves, being towards the unification of relativity theory and quantum theory.

2.3.1 The Definition of Time

The definition of time must be based on periodic physical phenomena.

According to de Broglie's hypothesis or the concept of matter wave proposed by de Broglie in the 1920s [17-19], matter possesses wave-particle duality, behaves like both particles and waves, so-called **matter waves**. In a broad sense, any matter or any form of matter motion can be regarded as a matter wave.

Waves have two important physical property:

(i) Periodicity that makes it have the special capacity to measure time;

(ii) Modulability that makes it have the special capacity to carry and transmit information.

Therefore, in the sense of wave-particle duality, any matter body, or an observed object *P*, is natural clock, which can employ the matter wave of *P* to measure time and may be called a **matter-wave clock** [64-66]. Naturally, the period or frequency of *P*'s matter wave can be employed as the most basic unit of time. This is the so-called **A Rock is a Clock** [64,65]. Müller believes that a matter-wave clock can be a more accurate clock than an atomic clock [65,66].

Of course, a practical matter-wave clock is not necessary for the theory of OR.

What the theory of OR needs is only the conceptual and theoretical matter-wave time or matter-wave clock, which can naturally exhibit the relativistic property of time, link *P*'s matter wave with relativistic phenomena, and then link the relativistic effects with quantum effects.

In theory, any periodic phenomena, including matter-waves, can be employed to measure time; the cycle of any periodic physical phenomenon can be employed as the time unit for measuring time: 1 year is 1 cycle of the earth's orbit round the sun; 1 month is 1 cycle of the moon's phase shift, and 1 day is 1 cycle of the alternation of day and night.

The most basic unit of time, that we use today, is the second.

According to the current International System of Unit (SI), the **second** is defined as the time duration of 9 192 631 770 cycles of the radiation corresponding to transition between the two hyperfine levels of the fundamental unperturbed ground-state of the caesium-133 atom.

In his theory of general relativity, Einstein introduced the concepts of the **standard clock** and the **standard time**. Einstein's standard clock is a timer that is stationary in inertial spacetime.

However, neither the atomic clock of SI nor Einstein's standard clock explicitly defines the status and role of observation or observers: who is observing the time, who is watching the standard clock, or who is measuring the radiation of cesium-133;

in particular, who acts as the observation medium or the messenger to transmit the information of time to observers?

The time defined in the International System of Unit (SI) may naturally be regarded as the standard time, and the corresponding atomic clock may naturally be regarded as the standard clock. However, of particular note is that it comes with conditions to employ the atomic clock of SI as the standard clock for defining the **second** of time unit based on the period of cesium atomic radiation: the cesium atom must be stationary in zero magnetic field at absolute zero temperature. In theory, this requires the atomic clock to be stationary in the free spacetime.

The theory of OR has introduced the **free spacetime** as an alternative concept of inertial spacetime. As stated in Sec. 1.1 of Chapter 1, the so-called free spacetime is one in which there exist no force or matter interaction, and denoted as S_F.

Based on the concept of **the free spacetime**, the theory of OR defines **the intrinsic physical quantity** and **the observed physical quantity** in Def. 1.2 of Chapter 1. If the theory of OR defines the standard clock as one located in the free spacetime S_F, then Einstein's standard clock and the atomic clock defined by the international system of units (SI) are consistent and equivalent concepts, and can all be employed to indicate the standard time.

Then, is the time the standard clock indicates to an observer the standard time?

No, of course not. This depends on the observer's observation agent, on the observer's motion state, and on the observer's physical environment.

We have to recognize that:

(i) In theory, any periodic signal source can be employed as the standard clock, but of course, must be stationary in the free spacetime S_F;

(ii) Any observer can observe or measure the standard time, but must be located in the free spacetime S_F and at rest relative to the standard clock, unless observers could employ the idealized observation agent OA_∞ to transmit the information on the time of the standard clock.

The theory of OR needs to clarify the role and status of observation or observers in the measurement of time, and to introduce the concept of the observed time or the observational time to distinguish it from the objective and real time, i.e., the intrinsic time or the proper time.

In theory, any periodic physical phenomenon, including the matter wave of the observed object P, can be employed to define time; the intrinsic period T_o or the intrinsic frequency f_o of any periodic physical phenomenon can be employed as the basic time unit for measuring time.

So, in the theory of OR, time is defined as follows.

Definition 2.2 (Time): Suppose there are a periodic signal source P and an observer O with a specific observation agent $OA(\eta)$; T_o and f_o are respectively the intrinsic period and the intrinsic frequency of P. If O observes N periods of P in the duration of Δt with $OA(\eta)$, then $\Delta t = NT_o = N/f_o$, and Δt is referred to as **the observed time** of P relative to O or $OA(\eta)$; in particular, if Δt is the observed value when O and P are relatively stationary in the free spacetime S_F, then Δt is referred to as **the**

intrinsic time of P and denoted as $\Delta\tau$ $(=N_oT_o=N_o/f_o)$, where N_o is the period number in the duration of the intrinsic $\Delta\tau$ when P is stationary in the free spacetime S_F.

The intrinsic period T_o of the periodic signal source P in Def. 2.2 can be called **the reference period** of time; the intrinsic frequency f_o of the periodic signal source P in Def. 2.2 can be called **the reference frequency** of time.

The theory of OR also needs the standard clock.

The theory of OR requires the standard clock to be stationary in the free spacetime S_F, the essence of which is consistent with or equivalent to the concept of the standard clock in Einstein's theory of relativity.

More formally, the theory of OR defines the standard clock as follows.

Definition 2.3 (The Standard Clock): Suppose there is a periodic signal source P; T_o and f_o are respectively the intrinsic period and the intrinsic frequency of P. If T_o or f_o is defined as the basic unit of time, then P is namely the standard clock when it is stationary in the free spacetime S_F.

Thus, the observed object P, as the periodic signal source, especially as the signal source of P's matter wave, becomes a matter-wave clock under Def. 2.2 and Def. 2.3, which can be the standard clock, and, under certain conditions, presents to the observer O the standard time.

The observed (observational) time Δt defined in Def. 2.2 is the time observed by the observer O, which in a sense is consistent with or equivalent to the concept of **the coordinate time** in Einstein's theory of relativity; the intrinsic time $\Delta\tau$ is the objectively real time, which is consistent with or equivalent to the concept of **the standard time** in Einstein's theory of relativity.

By contrasting the time duration Δt in Def. 2.2 and the time $t=x^0/c$ in the coordinate framework of Minkowski 4d spacetime in Eq. (1.1), we know that, in the coordinate framework of Minkowski 4d spacetime, the time duration $\Delta t=\Delta x^0/c$ is the observational time observed by the observer O by means of the optical observation agent OA(c).

However, Def. 2.2 implies that the observational time Δt observed by the observer O depends on observation, on the observation agent OA(η), and on the information-wave speed η of OA(η): $\Delta t=\Delta t(\eta)$; naturally, different observation agents may have different information-wave speeds.

So, the observed (observational) time $\Delta t=\Delta t(\eta)$ contains OA(η)'s observational effect and is not equivalent to the objectively real time $\Delta\tau$.

The theory of OR will clarify that, restricted by the observation locality ($\eta<\infty$) of the observation agent OA(η), the observed (observational) time Δt of an observer is not necessarily equivalent to the intrinsic time $\Delta\tau$; the lower the information-wave speed η, the more significant the observational locality of OA(η), and the farther the observational time Δt of OA(η) is from the intrinsic time $\Delta\tau$.

The theory of OR will further clarify, if $\eta\to\infty$, then $\Delta t\to\Delta\tau$: the observed time Δt of the idealized observation agent OA_∞ would be the proper time $\Delta\tau$. The idealized observation agent OA_∞ represents the objective and real physical world, is the agent of the objective world, that is, God's agent with God's perspective.

Therefore, the intrinsic time in Def. 2.2 represents the objectively real time, independent of observation, of observers, and of observation agents.

2.3.2 The Invariance of Time-Frequency Ratio

It is worth noting that Def. 2.2 implies an important observational property of time: the invariance of time-frequency ratio.

The Invariance of Time-Frequency Ratio: Suppose there are a periodic signal source P and an observer O in the observational spacetime $X^{4\mathrm{d}}(\eta)$ of the observation agent OA(η); f_o is the intrinsic frequency of P. According to Def. 2.2 and Def. 2.3, define P as the standard clock, then the ratio of the observed time-element dt of P relative to O to the observed frequency f of P relative to O, dt/f, is an invariant, and identically equal to the ratio of the intrinsic time-element dτ of P to the intrinsic frequency f_o of P: dτ/f_o.

Proof:

The intrinsic physical quantities, including the intrinsic time $\Delta\tau$, are invariants, which are the measuring standard followed and shared by all observers.

According to Def. 2.2, the intrinsic frequency of P is $f_o=N_o/\Delta\tau$; correspondingly, the observed frequency of O is $f=N/\Delta\tau$. Therefore, we have $f/f_o=N/N_o$.

Also, according to Def. 2.2, it holds that $N/N_o=\Delta t/\Delta\tau$.

Therefore, we have $f/f_o=\Delta t/\Delta\tau$.

Let $\Delta\to$d, then it holds that:

$$\frac{\mathrm{d}t}{f}=\frac{\mathrm{d}\tau}{f_o} \quad \text{or} \quad \Gamma=\frac{\mathrm{d}t}{\mathrm{d}\tau}=\frac{f}{f_o} \tag{2.3}$$

Thus, the invariance of time-frequency ratio holds true under the Def. 2.2.

Q.E.D.

It should be pointed out that: the frequencies f_o and f in the invariance of time-frequency ratio are the frequencies of the clock, rather than that of general periodic phenomena; the invariance of time-frequency ratio is the observational relativistic effect of time, rather than the Doppler effect of general periodic phenomena. It should also be pointed out that, in general, the observation agent of Doppler effect is neither the idealized agent OA_∞ nor the optical agent OA(c), but the periodic physical phenomena themselves.

The invariance of time-frequency ratio has profound implications: relativistic effects and quantum effects can be linked by the invariance of time-frequency ratio.

Based on the invariance of time-frequency ratio, the theory of OR or IOR will generalize Einstein's theory of special relativity and de Broglie's theory of matter waves, and unify Einstein formula $E=mc^2$ and Planck equation $E=hf$, two great formulas that originally belong to different theoretical systems, into the identical theoretical system of OR or IOR [26,27].

In fact, the invariance of time-frequency ratio originally exists in Einstein's theory of relativity and classical quantum theory.

The mass-speed relation in Einstein's special theory of relativity implies the invariance of time-mass ratio:

$$m = \frac{m_o}{\sqrt{1 - v^2/c^2}} = \gamma m_o \quad \text{or} \quad \frac{\mathrm{d}t}{m} = \frac{\mathrm{d}\tau}{m_o} \; \left(\gamma = \frac{\mathrm{d}t}{\mathrm{d}\tau}\right) \tag{2.4}$$

where m_o is the intrinsic mass of the observed object P; m the relativistic mass of P, or the so-called observed (observational) mass in the theory of OR.

Actually, the invariance of time-mass ratio is equivalent to the invariance of time-frequency ratio. By combining Einstein formula $E=mc^2$ and the Planck equation $E=hf$ generalized by de Broglie, we can test or verify the invariance of time-frequency ratio in the case of the optical observation agent OA(c):

$$\frac{\mathrm{d}t}{f} = \gamma \frac{\mathrm{d}\tau}{f} = \frac{m}{m_o}\frac{\mathrm{d}\tau}{f} = \frac{mc^2}{m_o c^2}\frac{\mathrm{d}\tau}{f} = \frac{E}{E_o}\frac{\mathrm{d}\tau}{f} = \frac{hf}{hf_o}\frac{\mathrm{d}\tau}{f} = \frac{\mathrm{d}\tau}{f_o} \tag{2.5}$$

Equations (2.4) and (2.5) confirm the invariance of time-frequency ratio of the theory OR or IOR in the case of the general observation OA(η).

The invariance of time-frequency ratio is the law followed by the intrinsic time and the observed time. If you like, you can express it as a basic principle of physics.

If you do not understand the definition of time in Def. 2.2 as an axiom of OR theory, then, you can call the invariance of time-frequency ratio the principle of the invariance of time-frequency ratio, or the principle of time-frequency ratio, and directly employ it to be the logical premise of OR theory.

3 The Invariance of Information-Wave Speeds

The theorem of the **Invariance of Information-Wave Speeds** (IIWSs), or the theorem of IIWSs, is the most important logical consequence of OR theory.

As we all know, the hypothesis of the invariance of light speed is the most important logical premise of Einstein's special theory of relativity. However, many people, even some physicists, have no idea that the hypothesis of the invariance of light speed is also an indispensable logical premise of Einstein's general theory of relativity [52,53]. As stated in Chapter 2, the hypothesis of the invariance of light speed have no the self-evident characteristics that an axiom or a principle should possess. Naturally, Einstein's theory of relativity itself cannot explain why the speed of light is invariant. So, Einstein's theory of relativity cannot explain all relativistic effects, including the inertial relativistic effects in special relativity and the gravitational relativistic effects in general relativity, for they are all the logical consequences of the invariance of light speed.

The theory of IOR derives the invariance of time-frequency ratio from the definition of time as the most basic logical premise, and then, proves the theorem of the invariance of information-wave speeds based on the invariance of time-frequency ratio [26-28].

The theorem of the invariance of information-wave speeds will reveal the essence of the invariance of light speed and even all relativistic phenomena. In particular, the invariance of information-wave speeds, as a logical consequence rather than a hypothesis of IOR theory, will become the most basic logical premise of the theory of GOR.

3.1 The Transformation of IOR Spacetime

In the theory of relativity, including Einstein's theory of relativity and the theory of OR, space and time are a pair of contradictory unity, the so-called **spacetime**. Space and time are interdependent: space is also time, time is also space; and under certain conditions, space and time can be transformed into each other.

The basic or primary task of IOR theory is to establish the models of inertial spacetime, the core of which is the transformation relationship of inertial spacetime between different observers or different observation systems, being called the transformation of IOR spacetime.

3.1.1 Illustration of IOR Transformation

According to the agreements in Sec. 1.1.1 of Chapter 1, the transformation of IOR spacetime is the spacetime transformation model between different inertial observers or different inertial frames O and O', i.e., the transformation of inertial spacetime in the theory of OR or IOR. The theory of OR or IOR attempts to establish the spacetime transformation model between O and O', including

(i) $O \to O'$: to transform the spacetime information of the observed object P from the observational spacetime of O to the observational spacetime of O';

(ii) $O'\to O$: in brief, to transform P's spacetime information from O' to O.

It is worth noting that, the transformation of spacetime, no mater $O\to O'$ or $O'\to O$, must involve the transmission of P's spacetime information, and has to rely on a certain observation medium or a certain information wave with a certain speed.

As depicted in Fig. 3.1, the transmission of P's spacetime information involves the problem of speed addition. According to the principle of OR speed addition (Cf. Sec. 2.2.3 of Chapter 2), the transmission speed η_α of P's spacetime information should be the superposition of the intrinsic information-wave speed η of the observation agent OA(η) and the observed speed (•) of P: $\eta_\alpha(\bullet)=\eta\oplus(\bullet)$, where the intrinsic information-wave speed η must always point to the observer.

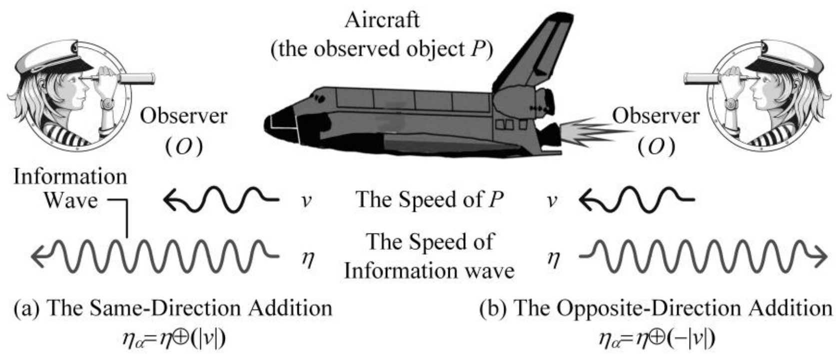

Figure 3.1 The Speed Superposition of the Spacetime Information of an Aircraft. (a) The same-direction addition: $\eta_\alpha(v)=\eta\oplus(|v|)$. (b) The opposite-direction addition: $\eta_\alpha(v)=\eta\oplus(-|v|)$, where the intrinsic information-wave speed η must always point to the observer O.

It is worth noting that the speed superposition of P's spacetime information ($\eta_\alpha(\bullet)=\eta\oplus(\bullet)$) implies an important assumption: the informon momentum of the observation agent OA(η) is small enough. Otherwise, the recoil effect of the informons on the observed object P would have to be considered. If the observed object P is a microparticle in the micro-world, then the momentum problem of informons will be unavoidable or non-negligible. (This is exactly what quantum mechanics needs to consider.)

As depicted in Fig. 3.2, consider the spacetime transformation: $O'\to O$.

As a matter wave, any period of the observed object P or the information wave of P's spacetime information contains 0~2π different phases: the initial phase is 0-phase; the final phase is 2π-phase.

As depicted in Fig. 3.2(a), since P is at rest in its intrinsic inertial frame O_o, it takes the same amount of time for the different phases of P's spacetime information (including 0-phase and 2π-phase) to be transmitted from P to O_o.

However, as depicted in Fig. 3.2(b1), since P moves in O', it takes different amounts of time for the different phases of P's spacetime information to be transmitted from P to O'; similarly, as depicted in Fig. 3.2(b2), since O' moves relative to O, it takes different amounts of time for the different phases of O''s spacetime information to be transmitted from O' to O. Naturally, the initial phase and final phase of the reference time-element dt takes different amounts of time from P to O' and takes different amounts of time from O' to O.

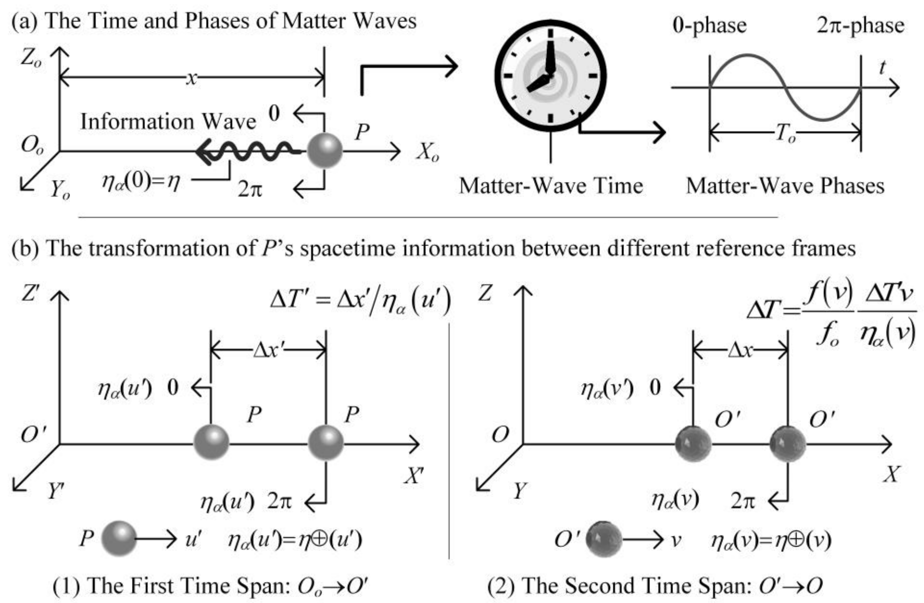

Figure 3.2 The View of Inertial Spacetime Transformation. (a) The time and phases of matter waves: in the intrinsic spacetime O_o of the observed object P, the different phases of spacetime information takes the same amount of time from P to the observer O_o. (b) The transformation of P's spacetime information between different reference frames: the first time span $O_o \to O'$; the second time span $O' \to O$.

According to the agreements in Sec. 1.1.1 of Chapter 1, to deduce the transformation of IOR spacetime in Sec. 3.1.2 and Sec. 3.1.3, suppose that

(i) The observers O and O' have the same observation agent OA(η), in which, under the principle of physical observability (PO), the realistic OA(η) has the observational locality: $\eta<\infty$;

(ii) O and O' as well as the intrinsic observer O_o of the observed object P have the same standard clocks defined with Def. 2.3, and the relative motion between the observers can be regarded as the relative motion between their standard clocks.

3.1.2 The Two Time Spans of IOR Transformation

First, we deduce the spacetime transformation: $O' \to O$.

The transformation $O' \to O$ of spacetime is actually about the problem how the inertial observer O observes the observed object P through the inertial observer O', and as depicted in Fig. 3.2(b), which is divided into two time spans.

(i) The first time span $O_o \to O'$: the observed object P moves relative to O'; P's spacetime information is transmitted from O_o to O';

(ii) The second time span $O' \to O$: the observer O' moves relative to O; O''s spacetime information is transmitted from O' to O.

The First Time Span (Fig. 3.2(b1)):
To transform the spacetime information of *P* from O_o to *O′*

The observed object P at rest in O_o moves at the speed u' relative to O', and P's spacetime information is transmitted from P to O'.

Considering the effect of speed superposition, the speed η_α of information wave transmitting P's spacetime information should be the intrinsic information-wave speed η of the observation agent OA(η) plus the observed speed u' of P in the inertial frame O': $\eta_\alpha(u')=\eta\oplus(u')$. During the observed time-element $\mathrm{d}t'$ in O', P moves a distance $\delta x'$ along the X' axis of O': $\delta x'=u'\mathrm{d}t'$. According to the principle of physical observability (PO), $\eta_\alpha(u')<\infty$, and therefore, from P to O', the final phase of the reference time-element $\mathrm{d}\tau$ needs more or less amount $\delta\mathrm{d}t'$ of time (positive or negative) than the initial phase:

$$\delta \mathrm{d}t' = \frac{\delta x'}{\eta_\alpha(u')} = \frac{u'\mathrm{d}t'}{\eta_\alpha(u')} \tag{3.1}$$

In particular, the principle of PO is quoted here: $\eta_\alpha(u')<\infty$.

Of course, this can be considered to be tacit or acquiescent.

The Second Time Span (Fig. 3.2(b2)):
To transform the spacetime information of *O′* from *O′* to *O*

O' is at rest relative to O'; O' moves relative to O.

So, according to the invariance of the time-frequency ratio in Eq. (2.3) derived from the definition of time, it holds that during the second time span:

$$\frac{\mathrm{d}t}{f(v)} = \frac{\mathrm{d}t'}{f_o} \quad \text{or} \quad \mathrm{d}t = \frac{f(v)}{f_o}\mathrm{d}t' \quad \left(\Gamma = \frac{\mathrm{d}t}{\mathrm{d}t'}, \mathrm{d}t' = \mathrm{d}\tau\right) \tag{3.2}$$

where, $f(v)$ is the observed frequency of O' observed by O, depending on the motion speed v of O' relative to O, while f_o is the intrinsic frequency or reference frequency of the standard clock.

At this time span, O' relative to O moves at the speed v, and O''s spacetime information is transmitted from O' to O.

Considering the effect of speed superposition, the speed η_α of information wave transmitting O''s spacetime information should be the intrinsic information-wave speed η of the observation agent OA(η) plus the observed speed v of O' in the inertial frame O: $\eta_\alpha(v)=\eta\oplus(v)$. According to Eq. (3.2), in O's view, the observed (observational) time difference $\delta\mathrm{d}t'$ in O' should be $(f(v)/f_o)\,\delta\mathrm{d}t'$. During the second time span, O' moves a distance δx along the X axis of O: $\delta x=v(f(v)/f_o)\,\delta\mathrm{d}t'$.

According to the principle of physical observability (PO), $\eta_\alpha(v)<\infty$, and therefore, the observed time difference $\delta \mathrm{d}t'$ in O' is transformed into the observed time difference $\delta \mathrm{d}t$ in O:

$$\delta \mathrm{d}t = \frac{\delta x}{\eta_\alpha(v)} = v\frac{f(v)}{f_o}\frac{\delta \mathrm{d}t'}{\eta_\alpha(v)} \tag{3.3}$$

Likewise, the principle of PO is quoted here: $\eta_\alpha(v)<\infty$.

Of course, this can also be considered to be tacit or acquiescent.

3.1.3 The Time Transformation in IOR Spacetime

Originally, according to the invariance of time-frequency ratio (Eq. (2.3)), it should hold true that:

$$\frac{\mathrm{d}t}{f} = \frac{\mathrm{d}t'}{f'} \quad \text{or} \quad \mathrm{d}t = \frac{f}{f'}\mathrm{d}t' \tag{3.4}$$

However, in the process of $O'\rightarrow O$, i.e., in the process of O's observing P through O', O' is at rest relative to O'; as an inertial observer or an inertial frame, the standard clock of O' presents to O' the standard time (τ) with the intrinsic time-element $\mathrm{d}\tau$. In this case, the observed time-element $\mathrm{d}t'$ of O' is namely the objective and real time-element: $\mathrm{d}t'=\mathrm{d}\tau$; while the $\delta \mathrm{d}t$ in Eq. (3.3) is the observational time delay of the time-element $\mathrm{d}t$ in the process of $O'\rightarrow O$.

Therefore, the time-element $\mathrm{d}t$ of the standard clock of P observed by O should be the observed time $(f(v)/f_o)\mathrm{d}t'$ (Eq. (3.2)) of the standard clock of O' observed by O plus the observed time delay $\delta \mathrm{d}t$ of the time-element $\mathrm{d}t$ in the process of $O'\rightarrow O$.

Thus, according to Eqs. (3.1-3), the observed time-element $\mathrm{d}t$ of O should be:

$$\begin{aligned}
\mathrm{d}t &= \frac{f(v)}{f_o}\mathrm{d}t' + \delta \mathrm{d}t \\
&= \frac{f(v)}{f_o}\left\{1+\frac{u'v}{\eta_\alpha(u')\eta_\alpha(v)}\right\}\mathrm{d}t' \quad (\mathrm{d}x' = u'\mathrm{d}t') \\
&= \Gamma(v)\left\{\mathrm{d}t' + \frac{B(v)}{\eta_\alpha(u')}\mathrm{d}x'\right\} \quad \left(\Gamma(v) = \frac{f(v)}{f_o};\ B(v) = \frac{v}{\eta_\alpha(v)}\right)
\end{aligned} \tag{3.5}$$

where, $\Gamma(v)=f(v)/f_o$, $B(v)=v/\eta_\alpha(v)$, and v is the speed of O' relative to O.

Now, we deduce the spacetime transformation: $O\rightarrow O'$.

The transformation $O\rightarrow O'$ of spacetime is actually about the problem how the inertial observer O' observes the observed object P through the inertial observer O.

Following the same logic of deducing the transformation $O'\rightarrow O$ of spacetime, we deduce the following observed time-element $\mathrm{d}t'$ of O':

$$\mathrm{d}t' = \Gamma(v)\left\{\mathrm{d}t - \frac{B(v)}{\eta_\alpha(u)}\mathrm{d}x\right\} \quad \left(\Gamma(v) = \frac{f(v)}{f_o};\ B(v) = \frac{v}{\eta_\alpha(v)}\right) \tag{3.6}$$

It should be pointed out that: Eq. (3.6) does not employ the principle of relativity as its logical premise; actually, both Eq. (3.6) and Eq. (3.5) have the same logic and the same logical premises.

Equations. (3.5-6) are the relations of time transformation in the theory of IOR.

3.1.4 The Space Transformation in IOR Spacetime

Equations (3.5) and (3.6) can simultaneously be solved to obtain the following relations of space transformation:

$$\mathrm{d}x = \Gamma(v)\left\{\frac{\eta_\alpha(u)}{\eta_\alpha(u')}\mathrm{d}x' + \frac{\eta_\alpha(u)}{B(v)}\left(1-\Gamma^{-2}(v)\right)\mathrm{d}t'\right\} \tag{3.7}$$

$$\mathrm{d}x' = \Gamma(v)\left\{\frac{\eta_\alpha(u')}{\eta_\alpha(u)}\mathrm{d}x - \frac{\eta_\alpha(u')}{B(v)}\left(1-\Gamma^{-2}(v)\right)\mathrm{d}t\right\} \tag{3.8}$$

So, the time transformation (Eqs. (3.5-6)) of IOR spacetime are the most basic relations in the transformation of IOR spacetime; while the space transformation (Eqs. (3.7-8))) are the logical inferences of time transformation.

The deduction of the time and space transformation relations (Eqs. (3.5-8)) in IOR spacetime involves two logical premises of OR axiom system. One is the first item of OR axiom system: the principle of physical observability (PO); the other is the third item of OR axiom system: the definition of time.

If the principle of PO can be considered to be tacit or acquiescent, then we may think that the transformation relations (Eqs. (3.5-8)) of IOR time and IOR space are the logical inferences of the invariance of time-frequency ratio (Eq. (2.3)).

In other words, we may think that the transformation relations (Eqs. (3.5-8)) of IOR time and IOR space are fully based on the definition of time (Def. 2.2).

3.2 The Proof of IIWSs Theorem

Now, on the basis of the transformation relations (3.5-8) of IOR space and IOR time, by means of the conditions of wave-particle duality in the OR axiom system, including (i) the principle of frequency-speed relation, (ii) the definition of the cosmic speed, and (iii) the principle of OR speed addition, we derive and prove the most important theorem in the theory of OR: the invariance of information-wave speeds, or the theorem of IIWSs for short.

The theorem of IIWSs will further deduce important logical inferences, clarify new insights into relativity theory and relativistic phenomena, and moreover, become the most basic logical premise of GOR theory.

3.2.1 From the Time Transformation and the Space Transformation to IIWSs Theorem

With the Simultaneous solution of the transformation (3.5) of IOR time and the transformation (3.7) of IOR space, we get the motion speed *u* of the observed object *P* observed by the observer *O*:

$$u=\frac{\mathrm{d}x}{\mathrm{d}t}=\frac{\left(1-\Gamma^{-2}(v)\right)\eta_\alpha(u')+u'B(v)}{\eta_\alpha(u')+u'B(v)}\frac{\eta_\alpha(u)}{B(v)}\quad\left(u'=\frac{\mathrm{d}x'}{\mathrm{d}t'}\right)\tag{3.9}$$

According to the definition of the cosmic speed (Def. 2.1), if $f(v)\to\infty$, then $v\to\Lambda$ and $\Gamma(v)=f(v)/f_o\to\infty$. According to Corol. 2.2 derived from the principle of frequency-speed relation and the definition of the cosmic speed, if $v=\Lambda$, then

$$\begin{cases}|u|=|u'\oplus v|=|u'\oplus\Lambda|=\Lambda\\ B(v)=v/\eta_\alpha(v)=\Lambda/\eta_\alpha(v)\end{cases}\tag{3.10}$$

Thus, from Eq. (3.9) and Eq. (3.10), we have

$$\Lambda=\lim_{f(v)\to\infty}|u|=\lim_{f(v)\to\infty}\left|\frac{\eta_\alpha(u)}{B(v)}\right|=\frac{1}{\Lambda}\lim_{f(v)\to\infty}\left|\eta_\alpha(v)\eta_\alpha(u)\right|\tag{3.11}$$

According to the principle of OR speed addition, if the directions of u and v are the same as that of η, then the speeds $\eta_\alpha(u)$ and $\eta_\alpha(v)$ of information waves are respectively $\eta_\alpha(u)=\eta\oplus(|u|)$ and $\eta_\alpha(v)=\eta\oplus(|v|)$, and moreover,

$$\lim_{f(v)\to\infty}\left|\eta_\alpha(v)\eta_\alpha(u)\right|=(\eta\oplus\Lambda)^2\tag{3.12}$$

Thus, from Eq. (3.11) and Eq. (3.12), we have

$$(\eta\oplus\Lambda)^2=\Lambda^2\quad\text{or}\quad\eta\oplus\Lambda=\pm\Lambda\tag{3.13}$$

According to the principle of OR speed addition, if the directions of u and v are opposite to the of η, then the speeds $\eta_\alpha(u)$ and $\eta_\alpha(v)$ of information waves are respectively $\eta_\alpha(u)=\eta\oplus(-|u|)$ and $\eta_\alpha(v)=\eta\oplus(-|v|)$, and moreover,

$$\lim_{f(v)\to\infty}\left|\eta_\alpha(v)\eta_\alpha(u)\right|=\left(\eta\oplus(-\Lambda)\right)^2\tag{3.14}$$

Thus, from Eq. (3.11) and Eq. (3.14), we have

$$\left(\eta\oplus(-\Lambda)\right)^2=\Lambda^2\quad\text{or}\quad\eta\oplus(-\Lambda)=\pm\Lambda\tag{3.15}$$

It is worth noting that the transmission direction of the information wave of OA(η) must always point to observers: $\forall u\ \eta_\alpha(u)>0$.

Therefore, "±" in Eq. (3.13) and Eq. (3.15) can only be "+", so we have

$$\eta\oplus\Lambda=\Lambda\quad\text{and}\quad\eta\oplus(-\Lambda)=\Lambda\tag{3.16}$$

According to the principle of OR speed addition,

$$\forall u\in(-\Lambda,\Lambda)\quad\eta\oplus\Lambda\ge\eta\oplus u\ge\eta\oplus(-\Lambda)\tag{3.17}$$

According to Eq. (3.16) and Eq. (3.17), we have that

$$\forall u\in(-\Lambda,\Lambda)\ \ \eta_\alpha(u)=\eta\oplus u=\Lambda\tag{3.18}$$

Let u=0. According to the principle of OR speed addition, we get the intrinsic information-wave speed η of the observation agent OA(η) from Eq. (3.18):

$$\eta = \eta_\alpha(0) = \eta \oplus 0 = \Lambda \tag{3.19}$$

It is thus clear that the so-called cosmic speed Λ turns out to be only the intrinsic information-wave speed η of the observation agent OA(η).

By contrasting Eq. (3.19) with Corol. 2.2 (the invariance of the cosmic speed) in Chapter 2, it can be seen that the intrinsic information-wave speed η of the observation agent OA(η), rather than the so-called cosmic speed Λ, is the same or invariant relative to all inertial observers.

Equations (3.18) and (3.19) suggests that, for an observation agent OA(η), the intrinsic information-wave speed η of OA(η) is an invariant: η=Λ. Interestingly, this invariant in Eq. (3.19) is exactly the cosmic speed Λ that is envisaged and described in Def. 2.1 of the OR axiom system. Thus, the intrinsic information-wave speed η of any observation agent OA(η) is the same and invariant relative to all inertial observers or all inertial frames. In Def. 2.1, the so-called cosmic speed Λ is actually only the observational limit restricted by the information-wave speed η of OA(η) or the observational locality ($\eta<\infty$) of OA(η).

This is the theorem of the invariance of information-wave speeds (IIWSs).

According to Eq. (3.18) and Eq. (3.19), the intrinsic information-wave speed η of an observation agent OA(η), plus an inertial speed u ($\in(-\eta,\eta)$), remains η. So, we have the following theorem of IIWSs.

The Theorem of the Invariance of Information-Wave Speeds (IIWSs): Let OA(η) be an observation agent. the information-wave speed η of OA(η), that is, the speed of the observation medium of OA(η) transmitting the observed information, is the same or invariant relative to all inertial observers: $\forall u\in(-\eta,\eta)\ \eta\oplus u=\eta$.

In a sense, the theorem of the invariance of information-wave speeds, the theorem of IIWSs for short, is the most important logical consequence of OR theory.

3.2.2 The Corollaries of IIWSs Theorem

Unlike the hypothesis of the invariance of light speed, the theorem of IIWSs, the so-called invariance of information-wave speeds, is not a hypothesis, but a logical consequence deduced from the axiom system of OR theory.

The theorem of IIWSs can directly produce the following important logical corollaries, including the invariance of light speed.

The theorem of IIWSs and its corollaries can serve as lemmas and become the starting point of new logical deduction and even the theory of GOR.

According to Eq. (3.19) in the theorem of IIWSs, Corol. 2.1 (the observational ultimate speed), and Corol. 2.2 (the invariance of the cosmic speed), we get the following corollary, i.e., Corol. 3.1.

Corollary 3.1 (The Observational Cosmic Speed Λ): The ultimate speed of the universe or the cosmic speed Λ in Def. 2.1 is actually the information-wave speed η of specific observation agent OA(η), i.e., the observational speed limit of observers with OA(η).

Corollary 3.1 suggests that the so-called cosmic speed Λ is not the objective and real ultimate speed of the universe, but the intrinsic information-wave speed η of specific observation agent OA(η). A specific observation agent OA(η) may possess its specific cosmic speed: $\Lambda=\eta$.

So, the universe has no ultimate speed that cannot be exceeded.

By contrasting Corol. 3.1 (the observational cosmic speed) with Corol. 2.1 (the observational ultimate speed) of Chapter 2, we get Corol. 3.2.

Corollary 3.2 (The Observational Ultimate Speed η): Let P be an inertial moving body and O be an inertial observer, OA(η) be the observation agent of O, and u be the observable speed of P observed by O, then u cannot exceed the intrinsic information-wave speed η of OA(η), that is, $\forall u\ |u|\leq\eta$.

According to Corol. 3.1 (the observational cosmic speed Λ) and Corol. 3.2 (the observational ultimate speed η), the speed that cannot be exceeded is not the so-called cosmic speed Λ in Def. (2.1) of Chapter 2 but the information-wave speed η of observation agent OA(η).

Corollary 3.2 (the observational ultimate speed η) conforms to our intuitive understanding and can be stated as a basic principle of physics [28].

Corollary 3.3 (The Invariance of Light Speed): If the observation agent OA(η) in the theorem of IIWSs is the optical agent OA(c), that is, if light is employed as the observation medium to transmit the observed information for observers, then the speed c of light is the same or invariant relative to all inertial observers.

Thus, the invariance of light speed is no longer a hypothesis or a principle, but a logical consequence of IIWSs theorem of OR theory. However, the invariance of light speed can be valid only under the optical observation agent OA(c).

3.2.3 The IOR Factor of Spacetime Transformation[4]

The Lorentz transformation is the inertial-spacetime transformation of Einstein's special theory of relativity, in which there is an important physical quantity: $\gamma=1/\sqrt{(1-v^2/c^2)}$, i.e., the factor of the Lorentz transformation, or the Lorentz factor.

The Lorenz factor implies the invariance of light speed: c cannot be exceeded.

Likewise, the transformation of IOR spacetime also has the factor of spacetime transformation of its own: the IOR factor, i.e., Γ in Eq. (3.9).

Both the IOR factor Γ and the Lorentz factor η are the factors of inertial-spacetime transformation.

The IOR factor Γ can be derived from the theorem of IIWSs.

Under the general observation agent OA(η), let $u'=\eta$, then $u=\eta$ according to the theorem of IIWSs, and moreover, $\eta_\alpha(u)=\eta_\alpha(u')=\eta_\alpha(v)=\eta$.

Thus, from Eq. (3.9), we have that

[4] The IOR factor of spacetime transformation is the inertial-spacetime transformation factor of OR theory, which is distinguished from the gravitational-spacetime transformation factor of OR theory, that is, the GOR factor of spacetime transformation.

$$\eta = \frac{\left(1-\varGamma^{-2}(v)\right)\eta + \eta B(v)}{\eta + \eta B(v)} \frac{\eta}{B(v)} \quad \text{and} \quad B(v) = \frac{v}{\eta_{\alpha}(v)} = \frac{v}{\eta} \tag{3.20}$$

Now, we get the IOR factor of inertial-spacetime transformation factor:

$$\varGamma(\eta, v) = \frac{\mathrm{d}t}{\mathrm{d}\tau} = \frac{f(\eta, v)}{f_o} = \frac{1}{\sqrt{1-B^2(\eta, v)}} = \frac{1}{\sqrt{1-\dfrac{v^2}{\eta^2}}} \tag{3.21}$$

where the IOR factor $\varGamma=\varGamma(\eta,v)$ depends on the intrinsic information-wave speed η of the general observation agent OA(η) and the speed v of the observer O' relative the observer O.

It is worth noting that the IOR factor $\varGamma$ generalizes the Lorentz factor γ:

$$\lim_{\eta \to c} \varGamma(\eta, v) = \varGamma(c, v) = \frac{1}{\sqrt{1-v^2/c^2}} = \gamma(v) \tag{3.22}$$

The IOR factor of spacetime transformation implies the invariance of information-wave speeds: the intrinsic information-wave speed η of the observation agent OA(η) is invariant observationally and cannot be exceeded observationally.

Spacetime transformation factors, no matter the Lorentz factor γ or the IOR factor $\varGamma$, represents relativistic property and possesses important implications, with which we can understand the essence of relativistic phenomena.

Restricted by the optical observation system or limited by the perspective of the optical agent OA(c), Einstein believed that relativistic phenomena, including the invariance of the speed of light, are the essential characteristics of spacetime and matter motion. Based on the broader perspective of the general observation agent OA(η), however, the theory of OR discovers that: all relativistic phenomena, including the invariance of light speed, are observational effects and apparent phenomena caused by the observational locality ($\eta<\infty$) of OA(η).

The theory of OR will examine and discuss the root and essence of inertial relativistic phenomena based on the IOR factor $\varGamma(\eta,v)$ of spacetime transformation.

3.2.4 From the Principle of Relativity to IIWSs Theorem

In Sec. 2.2 of Chapter 2, we suggest that if you cannot understand or dislike the conditions of wave-particle duality, you can replace them with the principle of simplicity or the principle of relativity. Without the conditions of wave-particle duality, based on the definition of time or the invariance of time-frequency ratio, the theory of OR can also prove the theorem of IIWSs with the principle of relativity.

The principle of relativity originates from the Galilean invariance.

Actually, the principle of relativity is a statement on the symmetry of spacetime. The basic belief supporting the principle of relativity is that all observers have the equal rights. Now, in the view of OR theory, all observers are equal regardless of their observation agents.

The principle of relativity can be divided into the principle of special relativity and the principle of general relativity. The principle of special relativity is the logical premise of Einstein's special theory of relativity; the principle of general relativity is the logical premise of Einstein's general theory of relativity.

The principle of relativity can be simply stated as follows according to the Galilean invariance.

The Principle of Relativity: Spacetime is symmetrical, and therefore, a law or a mathematical model of physics has the same form in different reference systems.

Taking advantage of the principle of relativity, the theory of OR or IOR, even without the conditions of wave-particle duality, can also derive the invariance of information-wave speeds and prove the theorem of IIWSs.

In such a case, the logical premises or axiom system of OR theory are:

(i) The principle of physical observability (PO);

(ii) The definition of time or the invariance of time-frequency ratio;

(iii) The principle of relativity.

As described in Sec. 3.2.1, starting from the principle of PO and the definition of time or the invariance of time-frequency ratio, the time transformation relations (3.5-6) of IOR spacetime can be derived; the simultaneous Eq. (3.5) and Eq. (3.6) can be solved to obtain the space transformation relations (3.7-8) of IOR spacetime.

According to the principle of relativity, O and O' are equal, and hence Eq. (3.7) and Eq. (3.8) should be the same in form or isomorphically consistent.

So, for Eq. (3.7) and Eq. (3.8), the principle of relativity requires

$$\frac{\eta_\alpha(u)}{\eta_\alpha(u')}=\frac{\eta_\alpha(u')}{\eta_\alpha(u)} \quad \text{and} \quad \eta_\alpha(u)\eta_\alpha(v)=\eta_\alpha(u')\eta_\alpha(v) \tag{3.23}$$

Obviously, Eq. (3.23) requires: $\eta_\alpha(u)=\eta_\alpha(u')$.

The arbitrariness of u and u' suggests that there is a constant η_o, for any speed, including v, u and u', we have that $\eta_\alpha(v)=\eta_\alpha(u)=\eta_\alpha(u')=\eta_o$, or that

$$\forall u \;\; \eta_\alpha(u)=\eta\oplus u=\eta_o \tag{3.24}$$

In particular, for the zero speed, we have

$$\eta=\eta_\alpha(0)=\eta\oplus 0=\eta_o \tag{3.25}$$

So, such a constant η_o is exactly the intrinsic information-wave speed η of the general observation agent OA(η).

This suggest that the intrinsic information-wave speed η of the general observation agent OA(η) is constant, that is, η is the same or invariant relative to all inertial observers or all inertial frames (no matter O or O').

This is namely the theorem of **the Invariance of Information-Wave Speeds**.

Taking advantage of the principle of PO, the definition of time or the invariance of time-frequency ratio, and the principle of relativity, even without the conditions of wave-particle duality, we can also deduce the theorem of IIWSs and the whole theoretical system of OR, in which there seems to be certain profound implication.

Different logic routs lead to the same logical consequences, which from one aspect confirms the logical validity of the invariance of information-wave speeds.

The principle of relativity provides one shortcut for our logical deduction.

However, taking a shortcut has to pay a price.

Taking a logic shortcut, we may miss or might have missed many important and beautiful views along the logic route. The hypothesis of the invariance of light speed is exactly a logic shortcut. Einstein deduced the Lorentz transformation and even the whole theoretical system of relativity from the hypothesis of the invariance of light speed, so that, until today, we do not understand why the speed of light is invariant and why spacetime is curved.

It is worth noting that Eqs. (3.24-25) has no information about the cosmic speed Λ: we have missed our understanding of the so-called ultimate speed of the universe due to employing the principle of relativity as a logic shortcut.

3.2.5 From the Principle of Simplicity to IIWSs Theorem

The principle of simplicity, also known as Ockham's razor, is a heuristic method to guide scientists to build their own theoretical models as simple as possible [67].

People's preference for simplicity in scientific methodology stems from the falsifiability criterion. Simple theoretical models are more testable. So, simpler theoretical forms are preferable to complex theoretical forms.

Einstein seemed particularly to prefer the principle of simplicity.

In Einstein's way, the principle of simplicity can be stated as [60]: "Seeking, as far as possible, logical unity in the world picture, i.e. paucity in logical elements." Einstein further elaborated: "The aim of science is, on the one hand, a comprehension, as complete as possible, of the connection between the sense experiences in their totality, and, on the other hand, the accomplishment of this aim by the use of a minimum of primary concepts and relations."

Theoretically, the spacetime transformation between observers have an infinite number of alternative forms. So why do Einstein's special theory of relativity and even Einstein's general theory of relativity have such simple and beautiful forms? In particular, why is the Lorentz transformation linear?

Fitzgerald and Lorenz also preferred the principle of simplicity [3-6]. Therefore, the Lorentz transformation, as a phenomenological model constructed by Fitzgerald and Lorentz, is just a linear model of spacetime transformation.

However, in Einstein's special theory of relativity, the linear form of the Lorentz transformation, as a theoretical model, is the product of the principle of simplicity. Actually, on his logic route to the Lorentz transformation, the principle Einstein first quoted was the principle of simplicity.

According to the principle of simplicity, Einstein set the transformation $O'\to O$ of inertial spacetime to the linear form at the beginning of his special relativity: $x=\gamma(x'+vt')$. Einstein attributed such a linear form to the homogeneity of spacetime [7]: "In the first place it is clear that the equations must be linear on account of the properties of homogeneity which we attribute to space and time."

The Lorentz transformation is of an algebraic form, while the transformation of IOR spacetime is of a differential form.

Based on the principle of simplicity, the transformation $O'\to O$ of OR inertial spacetime or IOR spacetime can be set to a linear differential form:

$$\mathrm{d}x=\Gamma\left(\mathrm{d}x'+vt'\right)\quad\text{or}\quad \mathrm{d}x'=\Gamma'\left(\mathrm{d}x-vt\right) \tag{3.26}$$

Taking advantage of the principle of simplicity, even without the conditions of wave-particle duality, the theory of OR or IOR can also derive the invariance of information-wave speeds and prove the theorem of IIWSs.

In such a case, the logical premises or axiom system of OR theory are:

(i) The principle of physical observability (PO);

(ii) The definition of time or the invariance of time-frequency ratio;

(iii) The principle of simplicity.

As stated in Sec. 3.2.1 and Sec. 3.2.4, starting from the principle of PO and the definition of time or the invariance of time-frequency ratio, the space transformation relations (3.7-8) of IOR spacetime can be derived.

By contrasting Eqs. (3.7-8) with the linear transformation of Eq. (3.26), the principle of simplicity requires that

$$\frac{\eta_\alpha(u')\eta_\alpha(v)}{v^2}\left(1-\Gamma^{-2}(v)\right)=1\quad\text{and}\quad \frac{\eta_\alpha(u)\eta_\alpha(v)}{v^2}\left(1-\Gamma^{-2}(v)\right)=1 \tag{3.27}$$

Obviously, Eq. (3.27) requires: $\eta_\alpha(u)=\eta_\alpha(u')$.

Likewise, the arbitrariness of u and u' suggests that there is a constant η_o, for any speed, including v, u and u', we have that $\eta_\alpha(v)=\eta_\alpha(u)=\eta_\alpha(u')=\eta_o$, or that

$$\forall u\ \ \eta_\alpha(u)=\eta\oplus u=\eta_o \tag{3.28}$$

In particular, for the zero speed, we have

$$\eta=\eta_\alpha(0)=\eta\oplus 0=\eta_o \tag{3.29}$$

So, such a constant η_o is exactly the intrinsic information-wave speed η of the general observation agent OA(η).

This suggest that the intrinsic information-wave speed η of the general observation agent OA(η) is constant, that is, η is the same or invariant relative to all inertial observers or all inertial frames (no matter O or O').

This is namely the theorem of **the Invariance of Information-Wave Speeds**.

Making use of Eqs. (3.28-29), Eq. (3.27) can be rewritten as

$$\frac{\eta^2}{v^2}\left(1-\Gamma^{-2}\right)=1\quad\text{or}\quad \Gamma(\eta,v)=\frac{1}{\sqrt{1-v^2/\eta^2}} \tag{3.30}$$

This is namely the IOR factor of spacetime transformation, which implies the invariance of information-wave speeds.

The IOR factor of spacetime transformation of Eq. (3.30) is consistent with that of Eq. (3.21) in Sec. 3.2.3 derived from the conditions of wave-particle duality rather than the principle of simplicity.

Taking advantage of the principle of PO, the definition of time or the invariance of time-frequency ratio, and the principle of simplicity, even without the conditions of wave-particle duality, we can also deduce the theorem of IIWSs and the whole theoretical system of OR, in which there is also profound implication.

Another logic rout leads to the same logical consequences, which, from another aspect, confirms the logical validity of the invariance of information-wave speeds.

The principle of simplicity provides another shortcut for our logical deduction.

Likewise, taking a shortcut has to pay a price.

Logic shortcuts may make us miss the important and beautiful scenery along the logic route. The hypothesis of the invariance of light speed is exactly a logic shortcut. Einstein deduced the Lorentz transformation and even the whole theoretical system of relativity from the hypothesis of the invariance of light speed, so that, until today, we do not understand why the speed of light is invariant and why spacetime is curved.

It is worth noting that Eqs. (3.28-29) has no information about the cosmic speed Λ: we have missed our understanding of the so-called ultimate speed of the universe due to employing the principle of simplicity as a logic shortcut.

The theory of OR strives to start from the most basic or more basic logical premises. The OR axiom system possesses the conditions of wave-particle duality, including the definition of the cosmic speed. Thus, the intrinsic information-wave speed η of the general observation agent OA(η) is naturally linked with the cosmic speed Λ. Compared with the principle of simplicity and the principle of relativity, the conditions of wave-particle duality are more basic logical premises, which can lead to more universal logical consequences. Therefore, we can understand the relationship between the information-wave speed η and the observational cosmic speed Λ or the observational ultimate speed η, and reveal the root and essence of the invariance of light speed and even all relativistic phenomena.

Perhaps, this is of enlightening significance to scientific methodology.

The principle of simplicity and the principle of relativity are logically consistent.

One often marvels at the simplicity of Einstein's theory in form, and believes that such simplicity in form is the embodiment of Einstein's logic and wisdom.

However, the theory of OR does not need the principle of simplicity or the principle of relativity, and does not need to suppose that the transformation of inertial spacetime is of a linear form. The transformation of IOR spacetime, derived from the most basic or more basic logical premises, naturally exhibits the linear form. And in form, the whole theoretical system of OR theory is isomorphically consistent with Einstein's theory of relativity.

This fully demonstrates that the simplicity of the theoretical models of physics in form is not due to the logical simplicity, but due to the essential simplicity of the physical world.

So, in a sense, the natural world obeys the principle of simplicity.

3.3 The Empirical Support for IIWSs Theorem

Physics is both speculative and empirical.

All logical consequences or theoretical predictions of physics must be tested and verified by observations and experiments.

The theorem of IIWSs, so-called **the Invariance of Information-Wave Speeds**, is the product of logical deduction and theoretical derivation, which is the logical consequence of OR theory and conforms to our intuitive understanding.

So, is the theory of IIWSs supported by observations and experiments? OR, does the theorem of IIWSs has empirical bases?

3.3.1 The Empirical Basis of the Invariance of Light Speed

First, does the invariance of light speed has empirical bases?

The invariance of light speed is a hypothesis conceived by Einstein, and the indispensable logical premise of Einstein's theory of relativity, including the special and the general. As we have repeatedly stressed, however, Einstein's hypothesis of the invariance of light speed is not self-evident, and therefore, has no the basic feature as a principle or an axiom. Although it only a hypothesis and physicists cannot explain why the speed of light is invariant, the mainstream school of physics believe in the invariance of light speed.

So, why does physicists believe in the invariance of light speed?

On the one hand, Einstein's hypothesis of the invariance of light speed is supported by the Michelson-Morley experiment [2]: in the experiment, Michelson and Morley failed to capture the ether and had not observed the speed-addition effect of the light speed c plus the earth's orbital speed v. Thus, the Michelson-Morley experiment forms the most important empirical basis of the invariance of light speed. On the other hand, Einstein's theory of relativity, including the special and the general, based on the invariance of light speed, is supported by most observations and experiments, which in turn is the support for Einstein's hypothesis of the invariance of light speed.

The mainstream school of physics firmly believes that Einstein's hypothesis of the invariance of light speed has been verified and supported by observations and experiments, for example, the Michelson-Morley experiment, and therefore, the invariance of light speed is beyond all doubt.

Now, Einstein's hypothesis of the invariance of light speed is euphemistically called the principle of the invariance of light speed.

3.3.2 The Michelson-Morley Experiment

The Michelson-Morrey experiment [2], conducted by Michelson and Morley in 1887, is depicted and illustrated in Fig. 3.3.

Let us go back to the era of the ether to look into the problem of the ether [68].

In the 1860s, Maxwell built up the dynamical theory of the electromagnetic field [69,70], the core of which is Maxwell equations. In Maxwell's electromagnetic theory, the electromagnetic effect is transmitted in a certain medium at a certain speed, that is, the speed c of light. Such medium seems to be everywhere, so-called **the Ether**. Einstein once took it as the argument for his hypothesis of the invariance of light speed, that, in Maxwell's electromagnetic theory, light travels at the light speed c in the ether medium without reference frame.

Then, the problem of the ether arose: does the ether really exist?

In 1879, Maxwell proposed an experiment: to determine whether the ether exists or not by measuring the effect or influence of the earth's motion around the sun on the speed of light [1]. So, there was the Michelson-Morley experiment [2].

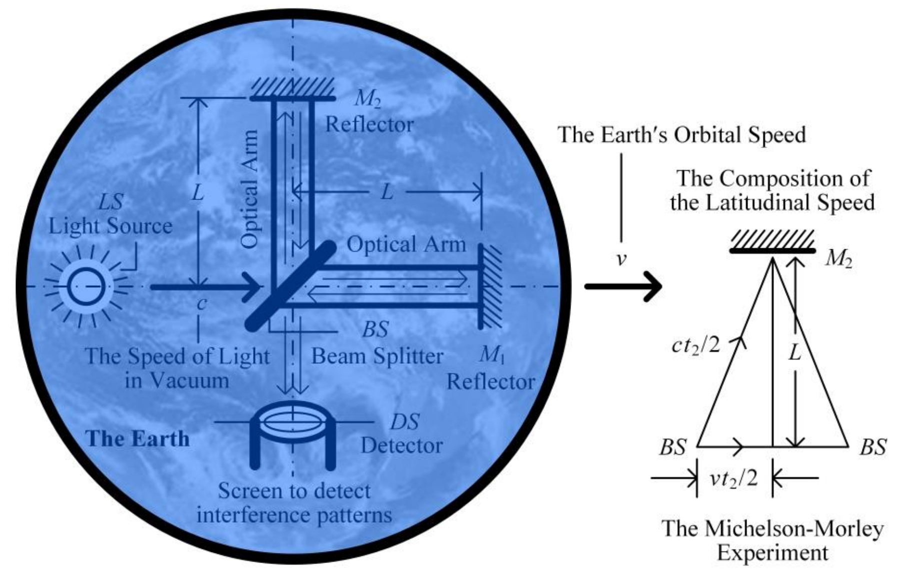

Figure 3.3 The Michelson-Morley Experiment. The light from the light source *LS* is divided into the longitudinal beam and the latitudinal beam by the beam splitter *BS*. According to the law of Galileo's speed-addition, the vacuum speed c of the longitudinal beam plus the earth's orbital speed v forms the speed difference between the longitudinal beam and the latitudinal beam. So, the two beams of light reflected back to the splitter *BS* by M_1 and M_2 respectively should form interference and produce interference fringes. However, no interference pattern had been observed or recorded by the detector *DS*.

Following Maxwell's proposal, Michelson and Morley carried out their experiment with an optical interferometer. It is as depicted in Fig. 3.3 that: (i) *LS* is a light source, emitting monochromatic light with wavelength λ or frequency f; (ii) *BS* is a beam splitter, dividing the beam from *LS* into two beams, one along the longitude of the earth and the other along the latitude of the earth; (iii) M_1 and M_2 are two light reflectors, the longitudinal beam is reflected by M_1, the latitudinal beam is reflected by M_2, and then, both beams go back to the beam splitter *BS*; (iv) The longitudinal beam and latitudinal beam meet at the beam splitter *BS* to produce interference; (v) *DS* is a detector with the screen for observing and recording the interference fringes of the two beams.

The longitudinal beam is along the direction of the earth's orbital speed v. According to the law of Galileo's speed-addition, the speed of light relative to the ether should be the superposition of the speed c of light in vacuum and the earth's orbital speed v. So, the period t_1, that the longitudinal beam takes to go away from BS and then go back to BS, is

$$t_1 = \frac{L}{c+v} + \frac{L}{c-v} = \frac{2Lc}{c^2 - v^2} \tag{3.31}$$

where L is the length of the optical arms of interferometer as depicted in Fig. 3.3.

As depicted Fig. 3.3, the period t_2, that the latitudinal beam takes to go away from BS and then go back to BS, is

$$(vt_2)^2 + L^2 = (ct_2)^2 \quad \text{that is} \quad t_2 = \frac{2L}{\sqrt{c^2 - v^2}} \tag{3.32}$$

where $\sqrt{(c^2 - v^2)}$ can be regarded as the speed c of light relative the beam splitter BS.

Thus, at the beam splitter BS, the time difference Δt between the longitudinal beam and the latitudinal beam is

$$\Delta t = |t_2 - t_1| \approx \beta^2 \frac{L}{c} \quad \left(\beta = \frac{v}{c}\right) \tag{3.33}$$

According to what Ref. [68] states, if the whole optical interferometer is rotated 90°, the longer t_1 and the shorter t_2 in the optical interferometer are exchanged, then, by contrasting the two results, the time difference Δt can be doubled, and the phase difference δ between the longitudinal beam and the latitudinal beam can be up to

$$\delta = 2f\Delta t \approx 2\beta^2 \frac{L}{c} f \tag{3.34}$$

Substitute the actual parameters into Eq. (3.34): c=3×10^8 m/s, f=5×10^{14} s^{-1}, v=3×10^4 m/s, and L=1.1 m. Then the phase difference δ can reach 1/3.

With such a magnitude of phase difference between the longitudinal beam and the latitudinal beam, the corresponding interference fringes should be easily detected by the detector of the optical interferometer [68].

Contrary to expectations, however, Michelson and Morley had not observed the interference pattern they expected.

Nevertheless, the Michelson-Morrey experiment is of great significances:

(i) It shows that there is no the so-called ether in the universe;

(ii) It leads to the formation of the FitzGerald-Lorentz transformation;

(iii) It seems to mean that the speed of light has no the speed-addition effect;

(iv) It prompted Einstein to propose the hypothesis of the invariance of light speed, based on which Einstein theoretically derived the Lorentz transformation, and finally, established his theory of relativity;

(v) The Michelson-Morley experiment won the first Nobel Prize in physics for the United States.

So, can the Michelson-Morley experiment really serve as the empirical basis of Einstein's the hypothesis of the invariance of light speed? OR, can the invariance of light speed really serve as a scientific principle?

3.3.3 The Empirical Basis of the Invariance of Information-Wave Speeds

Before the theorem of IIWSs (so-called the Invariance of Information-Wave Speeds), we only knew the implication of Einstein's hypothesis of the invariance of light speed, but we did not know why the speed of light is invariant.

Now, the theorem of IIWSs has revealed the essence of the invariance of light speed, telling us why the speed of light appeared invariant in the Michelson-Morley experiment. With the theorem of IIWSs, we not only know the implication of the invariance of light speed, but also know why the speed of light appeared invariant in the Michelson-Morley experiment.

Actually, the Michelson-Morley experiment is the support for the invariance of information-wave speeds more than the support for the invariance of light speed.

Human beings have to perceive the objective world by sensors, or through observation agents. All realistic observation agents have the observational locality, and therefore, what they present to observers can only be a certain image of the objective world rather than the objective world itself, that is, the phenomena of the objective world rather than the essence of the objective world. Restricted by the observational locality of observation agents, we would never be able to perceive or observe the completely objective physical world.

The objectively real world could only exist in our reason.

So, what is observed is not necessarily objective and true.
A phenomenon is not necessarily the essence.

Actually, the invariance of light speed in the Michelson-Morley experiment is only a phenomenon rather than the essence.

While you are observing a bird flying in the sky, in the corresponding observation system (O,M,P), you are the observer O, the bird is the observed object P, light is the observation medium M, and naturally, your observation agent is your eyes, belonging to the optical observation agent OA(c): light wave is the information wave of OA(c); photons are the informons of OA(c). Without doubt, at the moment, light or photons is transmitting the spacetime information of birds for you.

In the Michelson-Morley experiment, Michelson or Morley, or their detector *DS*, was the observer O, while the object P observed by Michelson or Morley or *DS* was light or photons emitted by the light source *LS*.

Then, what was the observation agent OA(η) of Michelson and Morley? And what was employed as the observation medium $M(\eta)$ for transmitting the spacetime information of light or photons (the observed object P) to Michelson and Morley?

Actually, in the Michelson-Morley experiment, the observation medium M for transmitting the spacetime information of light or photons to Michelson and Morley was light itself or photons themselves! The corresponding observation agent was naturally the optical observation agent OA(c). In other words, in the

Michelson-Morley experiment, light or photons was not only the observed object *P* but also the observation medium *M*(*c*), in which light wave was the information wave of OA(*c*) and photons were the informons of OA(*c*).

So, according to the theorem of IIWSs, or the invariance of information-wave speeds, the speed *c* of light as the information wave or photons as the informons in the Michelson-Morley experiment should be observationally invariant.

This is exactly the embodiment of the invariance of information-wave speeds.

It is thus clear that the invariance of light speed presented in the Michelson-Morley experiment is only a phenomenon, while the invariance of the speed of light as the information wave is the essence.

The invariance of information-wave speeds, including the invariance of light speed in the case of the optical observation agent OA(*c*), is only an observation effect and an apparent phenomenon caused by the observational locality ($\eta<\infty$) of observation agent OA(η). The invariance of light speed is only a special case of the invariance of information-wave speeds under the optical agent OA(*c*).

As a matter of fact, the Michelson-Morley experiment is exactly the empirical basis for the invariance of information-wave speeds.

3.4 The IIWSs Theorem and Relativistic Property

New doctrines, new insights.

Now, we seemingly begin to understand why the speed of light is invariant.

The theorem of IIWSs, so-called the invariance of information-wave speeds, is of great significance: to reveal not only the essence of the phenomenon of invariance of light speed but also the essence of all relativistic phenomena.

Based on the theorem of IIWSs, the theory of OR has discovered that: **All relativistic phenomena are observational effects!**

3.4.1 The Lorentz Factor and Relativistic Property

Einstein's theory of relativity, including the special and the general, has been around for more than 100 years. Before the theorem of IIWSs or before the theory of OR, however, we did not understand why the speed of light was invariant, and why spacetime, matter motion, or matter interactions would exhibit relativistic effects or relativistic phenomena.

Einstein believed and the mainstream school of physics believe that relativistic phenomena, including the invariance of light speed, are the essential characteristics of the natural world.

The relativistic property in Einstein's special theory of relativity can be characterized by the Lorentz factor of the Lorentz transformation:

$$\gamma(v)=\frac{\mathrm{d}t}{\mathrm{d}\tau}=\frac{1}{\sqrt{1-v^2/c^2}} \tag{3.35}$$

where *v* is the inertial speed of the observed object *P*, $\mathrm{d}\tau$ is the objectively real time (proper time), and d*t* is the observational time observed by the observer *O* with the optical observation agent OA(c).

Actually, the Lorentz factor implies the invariance of light speed.

The theory of OR has clarified that the Lorentz transformation is an optical observation model, and Einstein's special theory of relativity is an optical observation theory, of which the observation system is the optical observation agent OA(c). As stated in Sec. 1.4 of Chapter 1, the coordinate framework of Minkowski 4d spacetime is a formalized representation of the optical Agent OA(c).

According to the definition of the optical agent OA(c) in Eq. (1.1) of Chapter 1, the line-element ds of inertial spacetime follows that

$$\mathrm{d}s^2 = c^2\mathrm{d}t^2 - \mathrm{d}x^2 - \mathrm{d}y^2 - \mathrm{d}z^2 \quad \begin{cases} \mathrm{d}t = \dfrac{\mathrm{d}x^0}{c} = \sqrt{\dfrac{\mathrm{d}s^2 + \mathrm{d}y^2 + \mathrm{d}z^2}{c^2}} \\ \mathrm{d}\tau = \dfrac{\mathrm{d}s}{c} \ \left(\mathrm{d}x = \mathrm{d}y = \mathrm{d}z = 0\right) \end{cases} \tag{3.36}$$

from which, we can also derive the Lorentz factor γ:

$$\gamma(v) = \frac{\mathrm{d}t}{\mathrm{d}\tau} = \frac{1}{\sqrt{1 - v^2/c^2}} \quad \left(v = \frac{\sqrt{\mathrm{d}x^2 + \mathrm{d}y^2 + \mathrm{d}z^2}}{\mathrm{d}t}\right) \tag{3.37}$$

Equation (3.37) is consistent with Eq. (3.5), that is, the Lorentz factor of the Lorentz transformation in Einstein's special theory of relativity. In fact, the coordinate framework of Minkowski 4d spacetime itself, or the optical observation agent OA(c) itself, implies the invariance of light speed. In essence, the observational spacetime $X^{4\mathrm{d}}(c)$ of the optical observation agent OA(c) defined in Eq. (1.1) is the formalized representation of the invariance of light speed: the time axis x^0=ct of $X^{4\mathrm{d}}(c)$ represents the invariance of light speed.

It is worth noting that: according to the Lorentz factor of Eq. (3.35) or Eq. (3.37), the time dt observed by the observer O is the objectively real time (the proper time) $\mathrm{d}\tau$ only if the observed object P is at rest relative to O ($|v|$=0); if P is moving ($|v|$>0), then the observed time dt of O will **dilate**: $\mathrm{d}t > \mathrm{d}\tau$.

Both **time dilation** and, the invariance of light speed are relativistic phenomena. The point is: how should we view or understand relativistic effects or relativistic phenomena.

In the Lorentz factor γ, the speed c of light is a cosmic constant or an invariant. So, $\gamma=\gamma(v)$ is the function of the speed variable v, only depending on the speed v of the observed object P.

Restricted by the perspective of the optical observation agent OA(c), Einstein believed that the dilation of time dt ($\mathrm{d}t > \mathrm{d}\tau$) was owing to the motion ($|v|$>0) of the observed object P. Accordingly, Einstein believed and the mainstream school of physics believe that relativistic property is the essential characteristic of the physical world. For relativistic effects, Einstein had only seen the phenomena, but had not seen the essence. So have the mainstream school of physics.

3.4.2 The IOR Factor and Relativistic Property

Now, based on the theorem of IIWSs, the theory of OR has discovered that all relativistic effects are observational effects and all relativistic phenomena are apparent phenomena, which are not objectively real physical characteristics.

Like Einstein's special theory of relativity, the inertial relativistic property in the theory of OR can be characterized by the IOR factor of spacetime transformation.

Based on the theorem of IIWSs, the theory of OR derives the IOR factor $\varGamma$ of spacetime transformation in Sec. 3.2.3 (Eq. (3.21)), which has the same form as the Lorentz factor γ. In particular, IOR factor $\varGamma$ generalizes the Lorentz factor γ.

The theory of OR is the theory of the general observation agent OA(η), and the transformation of IOR spacetime is the model of inertial spacetime of the general observation agent OA(η). According to Def. 1.1 in Sec. 1.4.2 of Chapter 1, in the theory of IOR, the general observation agent OA(η) satisfies that

$$\mathrm{d}s^2 = \eta^2 \mathrm{d}t^2 - \mathrm{d}x^2 - \mathrm{d}y^2 - \mathrm{d}z^2 \quad \begin{cases} \mathrm{d}t = \dfrac{\mathrm{d}x^0}{\eta} = \sqrt{\dfrac{\mathrm{d}s^2 + \mathrm{d}y^2 + \mathrm{d}z^2}{\eta^2}} \\ \mathrm{d}\tau = \dfrac{\mathrm{d}s}{\eta} \ \left(\mathrm{d}x = \mathrm{d}y = \mathrm{d}z = 0\right) \end{cases} \tag{3.38}$$

from which, we can also derive the same IOR factor $\varGamma$ as that derived from the theorem of IIWSs:

$$\varGamma(\eta, v) = \frac{\mathrm{d}t}{\mathrm{d}\tau} = \frac{1}{\sqrt{1 - v^2/\eta^2}} \quad \left(v = \frac{\sqrt{\mathrm{d}x^2 + \mathrm{d}y^2 + \mathrm{d}z^2}}{\mathrm{d}t} \right) \tag{3.39}$$

By contrasting Eq. (3.39) with Eq. (3.37), we know that, unlike the Lorentz factor $\gamma=\gamma(v)$, the IOR factor of spacetime transformation $\varGamma=\varGamma(\eta,v)$ is a function of η and v, depending not only on the speed v of the observed object P but also on the intrinsic information-wave speed η of observation agent OA(η).

Based on the Lorentz factor γ, Einstein could only examine the relativistic property of the physical world from the perspective of the optical agent OA(c). However, based on the IOR factor of spacetime transformation, the theory of OR has got a broader perspective, that is, the perspective of the general observation agent OA(η), so that we can examine the relativistic property of the physical world from the perspectives of different observation agents.

The IOR factor of spacetime transformation in Eq. (3.39) implies the invariance of information-wave speeds: observationally, the information-wave speed η of observation agent OA(η) is invariant, and cannot be exceeded.

The general observation agent OA(η) in Def. 1.1 of Chapter 1 is the coordinate framework of OR spacetime, which implies the invariance of the information-wave speeds. In essence, the observational spacetime $X^{4\mathrm{d}}(\eta)$ of the general observation agent OA(η) defined in Eq. (1.2) is the formalized representation of the invariance of information-wave speeds: the time axis $x^0=\eta t$ of $X^{4\mathrm{d}}(\eta)$ represents the invariance of information-wave speeds.

However, the fundamental reason for the so-called time dilation is not the motion ($|v|>0$) of matter, but the observational locality ($\eta<\infty$) of observation agent OA(η). If the observer *O* could employ the idealized observation agent OA_∞ that has no observational locality ($\eta\to\infty$), then the time d*t* observed by *O* would be the objectively real time (the proper time) dτ:

$$\begin{cases} \varGamma_\infty = \lim\limits_{\eta\to\infty} \varGamma(\eta,v) = \lim\limits_{\eta\to\infty} 1\Big/\sqrt{1-v^2/\eta^2} = 1 \\ \mathrm{d}t_\infty = \lim\limits_{\eta\to\infty} \mathrm{d}t = \lim\limits_{\eta\to\infty} \mathrm{d}\tau\Big/\sqrt{1-v^2/\eta^2} = \mathrm{d}\tau \end{cases} \tag{3.40}$$

where $\varGamma_\infty\equiv1$ is the Galilean factor of the Galilean transformation.

Equations (3.39) and (3.40) indicate that all relativistic effects, including time dilation, the invariance of light speed, and even the invariance of information-wave speeds, are in essence not owing to the motion ($|v|>0$) of matter, but owing to the observational locality ($\eta<\infty$) of observation agent OA(η).

According to Eq. (3.22) and Eq. (3.40), the IOR factor $\varGamma(\eta,v)$ of spacetime transformation not only generalizes the Lorentz factor $\gamma=\varGamma(c,v)$, but also generalizes the Galileo factor $\varGamma_\infty=\varGamma(\infty,v)$.

The Lorentz factor $\gamma=\varGamma(c,v)$ characterizes the matter motion under the optical observation agent OA(c); while the Galilean factor $\varGamma_\infty=\varGamma(\infty,v)$ characterizes the matter motion under the idealized observation agent OA_∞, that is, the objective and real matter motion in the physical world.

3.4.3 What does the Theorem of IIWSs Mean?

With the theorem of IIWSs, so-called the invariance of information-wave speeds, we have finally understood why the speed of light is invariant: the speed of light is not really invariant. The so-called invariance of light speed is actually only a special case of the invariance of information-wave speeds, which is valid if and only if light acts as the observation medium or as the information wave.

Only this is the essence of the invariance of light speed.

Actually, both the invariance of information-wave speeds under the general observation agent OA(η) and the invariance of light speed under the optical observation agent OA(c) are observational effects or apparent phenomena. The invariance of information-wave speeds roots from the observational locality ($\eta<\infty$) of the general observation agent OA(η), and in particular, Einstein's invariance of light speed roots from the observational locality ($c<\infty$) of the optical agent OA(c).

According to Corol. 3.2 (the observational ultimate speed η) derived from the theorem of IIWSs, the inertial speed v observed by an observer cannot exceed the speed η at which the observed information is transmitted by the observation medium. By contrasting Corol. 2.1 (the observational ultimate speed $\varLambda$) with Corol. 3.2 (he observational ultimate speed η) and Eq. (3.19), we know that the so-called cosmic speed $\varLambda$ is actually the intrinsic information-wave speed η of observation agent OA(η): $\varLambda=\eta$. This fully demonstrates that the so-called cosmic speed $\varLambda$ is only an observational speed limit: the ultimate speed in the sense of observation, which is restricted by the information-wave speeds of observation agents, and does not really represent the cosmic speed or the ultimate speed of the universe. Employing sound waves to transmit observed information, the speed of sound is the cosmic speed Λ: bats cannot rely on sound to detect the supersonic motion; employing light waves to transmit observed information, the speed of light is the cosmic speed Λ: you cannot rely on light to detect the superluminal motion.

According to the theorem of IIWSs, a specific observation agent OA(η) has its own invariant speed η or its own specific **cosmic speed** Λ ($=\eta$). This suggests that both the so-called **invariant speed** η and the so-called **cosmic speed** Λ depend on the observation agent OA(η). So, it turns out that the universe has no so-called invariant speed and has no so-called ultimate speed or so-call cosmic speed.

All the relativistic effects in Einstein's theory of relativity, both the inertial effects in special relativity and the gravitational effects in general relativity, stems from Einstein's hypothesis of the invariance of light speed.

Now, the theorem of IIWSs, so-called the invariance of information-wave speeds, has revealed the root and essence of the invariance of light speed, and naturally at the same time, has revealed the root of essence of all the relativistic effects in Einstein's theory of relativity. According to the IOR factor of spacetime transformation, i.e., the IOR relativistic factor or the IOR factor for short, all relativistic effects are observational effects and apparent phenomena.

In a sense, the theorem of IIWS is the most important logical consequence of OR theory, and **All Relativistic Effects are Observational Effects and Apparent Phenomena** is the most important scientific discovery of OR theory.

In particular, the theorem of IIWSs plays the important role of connecting the preceding and the following in the theory of OR. The whole theoretical system of OR, including IOR and GOR, will be built on the basis of the invariance of information-wave speeds.

4 The General Lorentz Transformation

Physics has two important models of spacetime transformation:

(i) The Galilean transformation;
(ii) The Lorentz transformation.

Both the Galilean transformation and the Lorentz transformation are the transformation of inertial spacetime. The Galilean transformation is in line with human reason and human intuition. The law of Galileo's speed-addition is the most direct inference of the Galilean transformation, and conforms to our intuitive understanding: $u=u'+v$. It is what our reason can understand that, in the view of the observer O on the platform, the speed u of a person walking on a train should be the sum of the speed u' of the train and the speed v of the person walking. The Lorentz transformation is not in line with human reason and human intuition. The law of Einstein's speed-addition as the most direct inference of the Lorentz transformation is very puzzling: $u=(u'+v)/(1+vu'/c^2)$.

However, the mainstream school of physics seem to prefer the Lorentz transformation to the Galilean transformation.

The mainstream school of physics believes that the Lorentz transformation and Einstein's speed-addition represent the laws of nature, while the Galilean transformation and Galileo's speed-addition are only some approximations.

The Lorentz transformation is the core of Einstein's special theory of relativity and employs the principle of the invariance of light speed as its most direct logical premise. However, the so-called principle of the invariance of light speed is itself only an inexplicable hypothesis.

In Chapter 3, the theory of OR has derived and proved the theorem of the invariance of information-wave speeds (IIWSs) based on the time definition in Def. 2.2 as the most basic logical premise. On the basis of theorem of IIWSs, this chapter will construct the IOR transformation of inertial spacetime, so-called **the General Lorentz Transformation**. The general Lorentz transformation of IOR theory will be one of the most fundamental relations in the theory of Inertially Observational Relativity (IOR).

The general Lorentz transformation will generalize and unify the Galilean transformation and the Lorentz transformation, and provide us new insight into both the Galilean transformation and the Lorentz transformation.

It turns out that only the Galilean transformation represents the law of nature, while the Lorentz transformation is only an approximation.

4.1 The Galilean Transformation

The Galilean transformation seems to have originated from the most basic relationship between space and time:

$$\text{Spacetime Distance}\,(s) = \text{Speed}\,(v) \times \text{Time}\,(t) \tag{4.1}$$

which is the most basic kinematic model in physics.

It should be pointed out that Eq. (4.1) implies an important assumption: the speed at which the observation medium transmits the spacetime information about moving objects, or the so-called information-wave speed, is infinite. In other words, the kinematics model $s=v\times t$ is actually the product of the idealized observation system and serves the idealized observation agent OA_∞.

According to the agreements of Sec. 1.1.1 in Chapter 1, as depicted in Fig. 1.1, at $t=t'=0$, the observed object P is located at the origins of its intrinsic reference frame O_o and the inertial reference frames O and O', or respectively at the space coordinates $(0,y_{o0},z_{o0})$ of O_o, $(0,y_0,z_0)$ of O, and $(0,y_0',z_0')$ of O' ($y_0=y_0'=y_{o0}$, $z_0=z_0'=z_{o0}$); if $t>0$ and $t'>0$, then P and its intrinsic frame O_o move along the X axis of O and the X' axis of O' or in the direction parallel to the X and X' axes. Suppose that P is located at (x,y_0,z_0) of O at t and at (x',y_0',z_0') of O' at t', where $y_0=y_0'=y_{o0}$ and $z_0=z_0'=z_{o0}$. The inertial observer O is located at the coordinates $(0,y_0,z_0)$ of O, and the inertial observer O' is located at the coordinates $(0,y_0',z_0')$ of O'; P has no displacement in the directions of Y and Y' as well as Z and Z'.

According to Eq. (4.1), the displacement of O' relative to O along the X axis is $s'=vt'$ at time t', but O' has no displacement in the directions of Y and Z. Therefore, the transformation $O'\to O$ can be formulized as

$$O'\to O:\quad \begin{cases} x=x'+s'=x'+vt' \\ y=y'=y_0' \\ z=z'=z_0' \\ t=t' \end{cases} \tag{4.2}$$

Likewise, according to Eq. (4.1), the displacement of O relative to O' along the X' axis is $s=-vt$ at time t, but O has no displacement in the directions of Y' and Z'. Therefore, the transformation $O\to O'$ can be formulized as

$$O\to O':\quad \begin{cases} x'=x+s=x-vt \\ y'=y=y_0 \\ z'=z=z_0 \\ t'=t \end{cases} \tag{4.3}$$

Generally, the Galilean transformation can be formulized as

$$\begin{array}{ll} O'\to O: & O\to O': \\ x=x'+vt' & x'=x-vt \\ y=y' & y'=y \\ z=z' & z'=z \\ t=t' & t'=t \end{array} \tag{4.4}$$

where different observers or different reference frames O and O' share the same time: $t=t'$, without the time transformation between t and t'.

According to Eq. (4.4), the spacetime transformation of inertial motion focuses on the spacetime transformation in the direction of P's moving, i.e., the transformation between the X axis of O and the X' axis of O'.

Perhaps because of this, people have not realized that there are some doubts about the transformation between Y and Y' as well as between Z and Z' in the Galilean transformation and even in the Lorentz transformation[5].

Inertial motion and inertial observation require that:

(i) The values of y and z as well as y' and z' in Eq. (4.4) are fixed or invariant;

(ii) The inertial observers O and O' are collinear with the observed object P.

The Galilean transformation in Eqs. (4.2-3) meets the requirements of inertial observation. By contrasting Eq. (4.4) with Eqs. (4.2-3), however, we see that there are some doubts about $y=y'$ and $z=z'$ in the Galilean transformation (Eq. (4.4)).

Naturally, the law of Galileo's speed-addition can be derived from the Galilean transformation in Eq. (4.4):

$$\begin{array}{ll} O' \to O: & O \to O': \\ u_x = \dfrac{\mathrm{d}x}{\mathrm{d}t} = u'_x + v & u'_x = \dfrac{\mathrm{d}x'}{\mathrm{d}t'} = u_x - v \\ u_y = \dfrac{\mathrm{d}y}{\mathrm{d}t} = u'_y & u'_y = \dfrac{\mathrm{d}y'}{\mathrm{d}t'} = u_y \\ u_z = \dfrac{\mathrm{d}z}{\mathrm{d}t} = u'_z & u'_z = \dfrac{\mathrm{d}z'}{\mathrm{d}t'} = u_z \qquad (u = u_x,\, u' = u'_x) \end{array} \tag{4.5}$$

Likewise, the speed-addition of inertial motion focuses on the speed-addition in the direction of P's moving, i.e., the speed-addition of the direction of X or X' in Eq. (4.5). People are not very concerned about the speed-addition of the direction of Y or Y' as well as the direction of Z or Z'. So, the doubts in the Galilean transformation (Eq. (4.4)) are extended to Galileo's speed-addition (Eq. (4.5)).

According to Eqs. (4.2-3), the observed object P has no displacement in the directions of Y and Y' as well as Z and Z'. Therefore, it should hold true that: $\mathrm{d}y=\mathrm{d}y'=\mathrm{d}z=\mathrm{d}z'=0$; $u_y=u_y'=u_z=u_z'=0$.

If you are interested, you may wish to examine this issue.

It seems that people are not very clear about the course of the logical deduction on the Galilean transformation and the law of Galileo's speed-addition. Perhaps, the Galilean transformation came first, and then the law of Galileo's speed-addition followed; or, on the contrary.

Anyway, the Galilean transformation is more like a phenomenological model.

The theory of OR will tell us that the Galilean transformation represents the law of nature even though it is ancient and old.

---

[5] According to the agreements of Sec. 1.1.1 in Chapter 1, the observed object P moves in the direction parallel to the X axis and the X' axis. To ensure that the observational spacetime is inertial, it is required that P is stationary at the coordinates $(0,y_{o0},z_{o0})$ of P's intrinsic inertial frame O_o, while $y=y'=y_{o0}$ and $z=z'=z_{o0}$ are fixed values. Meanwhile, the inertial observers O and O' are located in the straight line (x_o,y_{o0}, z_{o0}) of O_o.

4.2 The Lorentz Transformation

Originally, the Lorentz transformation, or the FitzGerald-Lorentz transformation [3-6], was only a phenomenological model.

Phenomenology is the methodology of physics for inducing and summarizing empirical facts or physical phenomena in observations and experiment, which focuses on empirical evidence not speculation, and on physical phenomena not the essence. Phenomenologists pursue the consistency between physical models and physical phenomena, but ignore the understanding of the essence and intrinsic roots of physical phenomena.

Phenomenology can know what and the hows, but cannot know the whys.

Human understanding of the objective world must have gone from the shallower to the deeper, from the outside to the inside, from the simple to the complex, from the experience and intuition to the theory, from the phenomenon to the essence, and from knowing what and the hows to knowing the whys.

In 1905, Einstein proposed the hypothesis of the invariance of light speed according to the Michelson-Morley experiment [2]. Based on the hypothesis of the invariance of light speed, Einstein theoretically derived the Lorentz transformation, and established his theory of relativity, including the special [7] and the general [8]. Perhaps, reviewing Einstein's logic of deducing the Lorentz transformation will contribute to our understanding of the transformation of OR inertial spacetime or the general Lorentz transformation.

The Lorentz transformation theoretically deduced by Einstein is based on the axiom system of Einstein's special theory of relativity, which involves three logical premises, i.e., the so-called three principles:

(i) The principle of simplicity;

(ii) The principle of relativity;

(iii) The principle of the invariance of light speed

In Einstein's special theory of relativity, the logical deduction of the Lorentz transformation can be divided into three steps.

The first step: from the principle of simplicity

According to the principle of simplicity, the theoretical models of physics should be in form as simple or concise as possible.

In his special theory of relativity, Einstein attributed the formal simplicity of the transformation of inertial spacetime to the homogeneity of inertial spacetime. Einstein believed that the transformation of inertial spacetime should have a linear form owing to the homogeneity of inertial spacetime.

So, first of all, Einstein set the transformation $O'\to O$ of inertial spacetime to the following linear equation:

$$O'\to O: \quad x=\gamma(x'+vt') \tag{4.6}$$

where γ is the factor of spacetime transformation or the Lorentz factor, that is, the linear-transformation coefficient of inertial spacetime.

The second step: from the principle of relativity

According to the principle of relativity, the inertial observers or the inertial frames O and O' are equal, and therefore, the transformation $O \to O'$ should have the same form as the transformation $O' \to O$, that is,

$$O \to O': \quad x' = \gamma(x - vt) \tag{4.7}$$

The third step: from the principle of the invariance of light speed

After determining the form of the transformation (Eq. (4.6) and Eq. (4.7)) of inertial spacetime, the key issue is how to determine the linear-transformation coefficient γ of inertial spacetime in the linear-transformation relations (4.6-7).

Equations (4.6) and (4.7) can simultaneously be solved to obtain the following relations of time transformation:

$$O' \to O: \quad t = \gamma\left(t' + \left(1 - \gamma^{-2}\right) x'/v\right) \tag{4.8}$$

$$O \to O': \quad t' = \gamma\left(t - \left(1 - \gamma^{-2}\right) x/v\right) \tag{4.9}$$

With the definitions of the speed u=dx/dt observed by O and the speed u'=dx/dt' observed by O', deriving the space-element dx from Eq. (4.6) and deriving the time-element dt from Eq. (4.8), Einstein had

$$u = \frac{\mathrm{d}x}{\mathrm{d}t} = \frac{u' + v}{1 + \left(1 - \gamma^{-2}\right) u'/v} \quad \left(u' = \frac{\mathrm{d}x'}{\mathrm{d}t'}\right) \tag{4.10}$$

Based on the principle of the invariance of light speed, let u'=c, then u=c. Thus, from Eq. (4.10), Einstein got the Lorentz factor γ:

$$c = \frac{c + v}{1 + \left(1 - \gamma^{-2}\right) c/v} \quad \text{that is} \quad \gamma = \frac{1}{\sqrt{1 - v^2/c^2}} \tag{4.11}$$

Finally, the Lorentz factor γ in Eq. (4.11) is substituted into Eqs. (4.6-9). So, Einstein had theoretically derived the Lorentz transformation.

Generally, suppose that the observed object P is stationary at the coordinates $(0, y_{o0}, z_{o0})$ of O_o rather than the origin of O_o, and P moves in the direction parallel to the X axis of O and the X' axis of O' but has no displacement in the directions of Y and Y' as well as Z and Z': $y=y'=y_{o0}$ and $z=z'=z_{o0}$.

Then, the Lorentz transformation can be formulized as follows [6]:

$$\begin{array}{ll} O' \to O: & O \to O': \\ x = \gamma\left(x' + vt'\right) & x' = \gamma\left(x - vt\right) \\ y = y' & y' = y \\ z = z' & z' = z \\ t = \gamma\left(t' + vx'/c^2\right) & t' = \gamma\left(t - vx/c^2\right) \end{array} \quad \left(\gamma = 1\Big/\sqrt{1 - v^2/c^2}\right) \tag{4.12}$$

[6] there are the doubts of the same nature about $y=y'$ and $z=z'$ in the Lorentz transformation (Eq. (4.12)) as that in the Galilean transformation (Eq. (4.4).

where different inertial observers or different inertial frames (O and O') hold different times: $t \neq t'$; space and time are interdependent: $x=x(t',x')$ and $x'=x'(t,x)$ as well as $t=t(t',x')$ and $t'=t'(t,x)$.

So far, at the age of 25, Einstein had completed the foundational work of his special theory of relativity.

As a result, the Lorentz transformation is no longer a phenomenological model, but a theoretical model deduced by Einstein on the basis of the principle of the invariance of light speed.

Likewise, inertial motion and inertial observation require that:

(i) The values of y and z as well as y' and z' in Eq. (4.12) are fixed or invariant;

(ii) The inertial observers O and O' are collinear with the observed object P.

So, similar to the Galilean transformation (Eq. (4.4)), there are some doubts about $y=y'$ and $z=z'$ in the Lorentz transformation (Eq. (4.12)).

Naturally, with the definitions of the speed $u=\mathrm{d}x/\mathrm{d}t$ observed by O and the speed $u'=\mathrm{d}x/\mathrm{d}t'$ observed by O', the law of Einstein's speed-addition can be derived from the Lorentz transformation (Eq. (4.12)) [7]:

$$\begin{array}{ll} O' \to O: & O \to O': \\ u_x = \dfrac{\mathrm{d}x}{\mathrm{d}t} = \dfrac{u'_x + v}{1 + vu'_x/c^2} & u'_x = \dfrac{\mathrm{d}x'}{\mathrm{d}t'} = \dfrac{u_x - v}{1 - vu_x/c^2} \\ u_y = \dfrac{\mathrm{d}y}{\mathrm{d}t} = \dfrac{u_y\sqrt{1-v^2/c^2}}{1 + vu_x/c^2} & u'_y = \dfrac{\mathrm{d}y'}{\mathrm{d}t'} = \dfrac{u_y\sqrt{1-v^2/c^2}}{1 - vu_x/c^2} \\ u_z = \dfrac{\mathrm{d}z}{\mathrm{d}t} = \dfrac{u_z\sqrt{1-v^2/c^2}}{1 + vu_x/c^2} & u'_z = \dfrac{\mathrm{d}z'}{\mathrm{d}t'} = \dfrac{u_z\sqrt{1-v^2/c^2}}{1 - vu_x/c^2} \end{array} \tag{4.13}$$

Similar to the situation in the Galilean transformation and the law of Galileo's speed-addition, the doubts in the Lorentz transformation (Eq. (4.12)) extend to the law of Einstein's speed-addition (Eq. (4.13)).

Originally, the observed object P has no displacement in the directions of Y and Z as well as Y' and Z', that is, $\mathrm{d}y=\mathrm{d}y'=\mathrm{d}z=\mathrm{d}z'=0$. Therefore, it should hold true that: $u_y=u_y'=u_z=u_z'=0$.

By observing the Lorentz transformation (Eq. (4.12)), it can be seen that, if the speed v of P's moving is far lower than the speed c of light, then the Lorentz transformation (Eq. ((4.12)) degenerates into or approximates to the Galilean transformation (Eq. ((4.4)):

[7] there are the doubts of the same nature about $y=y'$ and $z=z'$ in the law of Einstein's speed-addition (Eq. (4.13)) as that in the law of Galileo's speed-addition (Eq. (4.5).

$$
\forall |v| \ll c \quad \frac{v^2}{c^2} \approx 0
$$

$$
\gamma = 1 \Big/ \sqrt{1 - v^2/c^2} \approx 1
$$

$$
\begin{array}{lcl}
O' \to O: & & O' \to O: \\
\begin{cases} x = \gamma\left(x' + vt'\right) \\ y = y' \\ z = z' \\ t = \gamma\left(t' + vx'/c^2\right) \end{cases} & \approx & \begin{cases} x = x' + vt' \\ y = y' \\ z = z' \\ t = t' \end{cases}
\end{array}
\tag{4.14}
$$

According to this, the mainstream school of physics has concluded that the Lorentz transformation is a better model of spacetime transformation, while the Galilean transformation is only an approximation of the Lorentz transformation at lower speeds ($|v|<<c$).

However, the theory of OR will tell us that the Galilean transformation is the exact model of spacetime transformation and the true portrayal of the objective world; while the Lorentz transformation is only an optical image of the objective world, not entirely objective and real.

By observing the law of Einstein's speed-addition (Eq. (4.13), it can be seen that if the speed v of P's moving is far lower than the speed c of light, the law of Einstein's speed-addition (Eq. ((4.13)) degenerates into or approximates to the law of Galileo's speed-addition (Eq. ((4.5)):

$$
\forall |v| \ll c \quad \frac{v^2}{c^2} \approx 0
$$

$$
\begin{array}{lcl}
O' \to O: & & O' \to O: \\
\begin{cases} u_x = \left(u_x' + v\right) \Big/ \left(1 + vu_x'/c^2\right) \\ u_y = u_y \sqrt{1 - v^2/c^2} \Big/ \left(1 + vu_x'/c^2\right) \\ u_z = u_z \sqrt{1 - v^2/c^2} \Big/ \left(1 + vu_x'/c^2\right) \end{cases} & \approx & \begin{cases} u_x = u_x' + v \\ u_y = u_y \\ u_z = u_z \end{cases}
\end{array}
\tag{4.15}
$$

According to this, the mainstream school of physics has concluded that the law of Einstein's speed-addition is a better model of speed addition, while the law of Galileo's speed-addition is only an approximation of the law of Einstein's speed-addition at lower speeds ($|v|<<c$).

However, the theory of OR will tell us that the law of Galileo's speed-addition is the exact model of speed addition and the true portrayal of the objective world; while the law of Einstein's speed-addition is only an optical image of the objective world, not entirely objective and real.

4.3 The General Lorentz Transformation

The transformation of OR inertial spacetime, or the transformation of IOR spacetime, is referred to as **the General Lorentz Transformation**.

Suppose that the invariance of information-wave speeds is employed as a basic principle instead of Einstein's hypothesis of the invariance of light speed. Then, the three principles as the axiom system of Einstein's special theory of relativity can be transformed into **IOR's three principles**:

(i) The principle of simplicity;

(ii) The principle of IOR relativity;

(iii) The principle of Invariance of information-wave speeds

Naturally, by analogizing and following the Einstein's logic of deducing the Lorentz transformation, we can deduce the transformation of IOR spacetime that is isomorphically consistent with the Lorentz transformation, and then establish the whole theoretical system of IOR.

However, unlike the deduction of the Lorentz transformation in Einstein's special theory of relativity, the deduction of the transformation of IOR spacetime in the theory of OR has its own logical route: to start from the most basic logical premise as far as possible.

4.3.1 The Transformation of IOR Spacetime in Differential Form

The theory of OR takes the definition of time as the most basic logical premise.

In Chapter 3, based on the invariance of time-frequency ratio derived from the time definition (Def. 2.2) in the axiom system of IOR, the theory of OR has deduced the time transformation (Eqs. (3.5-6)) and the space transformation (Eqs. (3.7-8)), and proved the theorem of the invariance of information-wave speeds (IIWSs), from which the IOR factor (Eq. (3.21)) of spacetime transformation has been derived.

According to the theorem of IIWSs, for a given observation agent OA(η), it holds true that: $\eta_\alpha(u)=\eta_\alpha(u')=\eta_\alpha(v)=\eta$. According to the agreements of Sec. 1.1.1 in Chapter 1, suppose that there is no displacement of the observed object P in the directions of the Y axis and the Z axis of O as well as the Y' axis and the Z' axis of O': dy=dy'=0 and dz=dz$'$=0. By substituting the IOR factor $\Gamma=1/\sqrt{(1-v^2/\eta^2)}$ of spacetime transformation and $\eta_\alpha(u)=\eta_\alpha(u')=\eta_\alpha(v)=\eta$ into the time transformation (Eqs. (3.5-6) and the space transformation (Eqs. (3.7-8)), we have that

$$\begin{array}{ll} O' \to O: & O \to O': \\ \mathrm{d}x = \Gamma\left(\mathrm{d}x' + v\mathrm{d}t'\right) & \mathrm{d}x' = \Gamma\left(\mathrm{d}x - v\mathrm{d}t\right) \\ \mathrm{d}y = \mathrm{d}y' & \mathrm{d}y' = \mathrm{d}y \\ \mathrm{d}z = \mathrm{d}z' & \mathrm{d}z' = \mathrm{d}z \\ \mathrm{d}t = \Gamma\left(\mathrm{d}t' + \dfrac{v\mathrm{d}x'}{\eta^2}\right) & \mathrm{d}t' = \Gamma\left(\mathrm{d}t - \dfrac{v\mathrm{d}x}{\eta^2}\right) \end{array} \qquad \left(\Gamma = 1\Big/\sqrt{1-v^2/\eta^2}\right) \tag{4.16}$$

This is the transformation of inertial spacetime in the theory of OR, so-called **the transformation of IOR spacetime**.

It should be pointed out that, the transformation (Eq. (4.16)) of IOR spacetime is derived from more basic logical premises than that of the Lorentz transformation, and therefore, it presents the form of differential equations, and has a universal and profound significance than Lorentz transformation.

4.3.2 The Law of IOR Speed-Addition

Based on the differential form (Eq. 4.16) of the transformation of IOR spacetime, with the definitions of the speed u=dx/dt observed by O and the speed u'=dx/dt' observed by O', the following law of IOR speed-addition can be derived directly:

$$
\begin{array}{ll}
O' \to O: & O \to O': \\
u_x = \dfrac{\mathrm{d}x}{\mathrm{d}t} = \dfrac{\mathrm{d}x' + v\mathrm{d}t'}{\mathrm{d}t' + v\mathrm{d}x'/\eta^2} = \dfrac{u'_x + v}{1 + vu'_x/\eta^2} & u'_x = \dfrac{\mathrm{d}x'}{\mathrm{d}t'} = \dfrac{u_x - v}{1 - vu_x/\eta^2} \\
u_y = \dfrac{\mathrm{d}y}{\mathrm{d}t} = \dfrac{\mathrm{d}y'}{\Gamma\left(\mathrm{d}t' + v\mathrm{d}x'/\eta^2\right)} = \dfrac{u'_y\sqrt{1 - v^2/\eta^2}}{1 + vu'/\eta^2} & u'_y = \dfrac{\mathrm{d}y'}{\mathrm{d}t'} = \dfrac{u_y\sqrt{1 - v^2/\eta^2}}{1 - vu_x/\eta^2} \\
u_z = \dfrac{\mathrm{d}z}{\mathrm{d}t} = \dfrac{\mathrm{d}z'}{\Gamma\left(\mathrm{d}t' + v\mathrm{d}x'/\eta^2\right)} = \dfrac{u'_z\sqrt{1 - v^2/\eta^2}}{1 + vu'/\eta^2} & u'_z = \dfrac{\mathrm{d}z'}{\mathrm{d}t'} = \dfrac{u_z\sqrt{1 - v^2/\eta^2}}{1 - vu_x/\eta^2}
\end{array}
\qquad (4.17)
$$

Since the observed object P has no displacement in the directions of Y and Z as Y' and Z', the line-elements dy and dy' as well as the line elements dz and dz′ in the transformation of IOR spacetime (Eq. (4.16)) should be zero: dy=dy'=0, and dz=dz′=0. Thus, in the law of IOR speed-addition (Eq. (4.17)), it should hold true that:: u_y=u_y'=0 and u_z=u_z'=0.

4.3.3 The Transformation of IOR Spacetime in Algebraic Form

According to the agreements of Sec. 1.1.1 in Chapter 1, given the initial conditions: at t=t'=0, x=x'=0, y=y'=y_{o0}, and z=z'=z_{o0}, integrate the both ends of the transformation of IOR spacetime (Eq. (4.16)). Considering that the observed object P has no displacement in the directions of the Y and Z as well as the Y' and Z', it can be seen that dy=dy'=0 and dz=dz′=0, and therefore, the theory of OR gets the following transformation of IOR spacetime in algebraic form:

$$
\begin{array}{ll}
O' \to O: & O \to O': \\
x = \Gamma\left(x' + vt'\right) & x' = \Gamma\left(x - vt\right) \\
y = y' & y' = y \\
z = z' & z' = z \\
t = \Gamma\left(t' + \dfrac{vx'}{\eta^2}\right) & t' = \Gamma\left(t - \dfrac{vx}{\eta^2}\right)
\end{array}
\qquad \left(\Gamma = 1\Big/\sqrt{1 - v^2/\eta^2}\right) \qquad (4.18)
$$

It should be pointed out that since the observed object P has no displacement in the directions of Y and Z as well as Y' and Z': dy=dy'=0 and dz=dz′=0, it should hold true for the transformation (Eq. (4.18)) of IOR spacetime that: y=y'=y_{o0} and z=z'=z_{o0}.

Obviously, the transformation of IOR spacetime in algebraic form (Eq. (4.18)) is isomorphically consistent with the Lorentz transformation. So, in the theory of OR, Eq. (4.18) is called **the General Lorentz Transformation**.

The establishment of the general Lorentz transformation means that the theory of IOR has completed the groundwork.

The general Lorentz transformation has a special significance: to generalize and unify the Galilean transformation and the Lorentz transformation.

4.4 The Unity of the Galilean Transformation and the Lorentz Transformation

It is owing to starting from the most basic logical premises that the theory of OR can reveal the essence of relativistic phenomena. Based on the most basic axiom system, the theory of OR has a high degree of generality and unity, and therefore, can generalize and unify different theoretical systems. In particular, it has an important symbolic significance that the general Lorentz transformation generalizes and unifies the Galilean transformation and the Lorentz transformation.

It is worth noting that, in the sense of Bohr's correspondence principle [71], the general Lorentz transformation is strictly corresponding not only to the Lorentz transformation but also to the Galilean transformation.

4.4.1 Generalizing the Lorentz Transformation

By observing Eq. (4.17) and Eq. (4.13), it can be seen that, if $\eta\to c$, then the law of IOR speed-addition (Eq. (4.17)) strictly converges to the law of Einstein's speed-addition (Eq. (4.13)):

$$\begin{array}{ccc} O'(\eta)\to O(\eta): & & O'(c)\to O(c): \\ \lim\limits_{\eta\to c}\begin{cases} u_x=\dfrac{u'_x+v}{1+vu'_x/\eta^2} \\ u_y=\dfrac{u'_y\sqrt{1-v^2/\eta^2}}{1+vu'/\eta^2} \\ u_z=\dfrac{u'_z\sqrt{1-v^2/\eta^2}}{1+vu'/\eta^2} \end{cases} & = & \begin{cases} u_x=\dfrac{u'_x+v}{1+vu'_x/c^2} \\ u_y=\dfrac{u'_y\sqrt{1-v^2/c^2}}{1+vu'/c^2} \\ u_z=\dfrac{u'_z\sqrt{1-v^2/c^2}}{1+vu'/c^2} \end{cases} \end{array} \tag{4.19}$$

By observing Eq. (4.18) and Eq. (4.12), it can be seen that, if $\eta\to c$, then the IOR factor of spacetime transformation $\mathit{\Gamma}$ strictly converges to the Lorentz factor γ, and the general Lorentz transformation (Eq. (4.18)) strictly converges to the Lorentz transformation (Eq. (4.12)):

$$\lim_{\eta\to c}\mathit{\Gamma}=\lim_{\eta\to c}\frac{1}{\sqrt{1-v^2/\eta^2}}=\frac{1}{\sqrt{1-v^2/c^2}}=\gamma \tag{4.20a}$$

$$O'(\eta) \to O(\eta): \qquad O'(c) \to O(c):$$

$$\lim_{\eta\to c}\begin{cases} x = \Gamma\left(x' + vt'\right) \\ y = y' \\ z = z' \\ t = \Gamma\left(t' + \dfrac{vx'}{\eta^2}\right) \end{cases} = \begin{cases} x = \gamma\left(x' + vt'\right) \\ y = y' \\ z = z' \\ t = \gamma\left(t' + \dfrac{vx'}{c^2}\right) \end{cases} \tag{4.20b}$$

Equations (4.19) and (4.20) have the following two important meanings.

Firstly, it is shown that both the Lorentz transformation (Eq. (4.12)) and the corresponding Einstein's speed-addition (Eq. (4.13)) are optical observation models, and serve the optical observation agent OA(c).

Secondly, it is shown that the general Lorentz transformation of IOR theory generalizes the Lorentz transformation, and the law of IOR speed-addition generalizes the law of Einstein's speed-addition.

4.4.2 Generalizing the Galilean Transformation

By observing Eq. (4.17) and Eq. (4.5), it can be seen that, if $\eta \to \infty$, then the law of IOR speed-addition (Eq. (4.17)) strictly converges to the law of Galileo's speed-addition (Eq. (4.5)):

$$O'(\eta) \to O(\eta): \qquad O'_\infty \to O_\infty:$$

$$\lim_{\eta\to\infty}\begin{cases} u_x = \left(u'_x + v\right) \big/ \left(1 + vu'_x/\eta^2\right) \\ u_y = u'_y\sqrt{1 - v^2/\eta^2} \big/ \left(1 + vu'/\eta^2\right) \\ u_z = u'_z\sqrt{1 - v^2/\eta^2} \big/ \left(1 + vu'/\eta^2\right) \end{cases} = \begin{cases} u_x = u'_x + v \\ u_y = u'_y \\ u_z = u'_z \end{cases} \tag{4.21}$$

By observing Eq. (4.18) and Eq. (4.4), it can be seen that, if $\eta \to \infty$, then the IOR factor of spacetime transformation Γ strictly converges to the Galilean factor $\Gamma_\infty \equiv 1$ (Eq. (3.4)), and the general Lorentz transformation (Eq. (4.18)) strictly converges to the Galilean transformation (Eq. (4.4)):

$$\lim_{\eta\to\infty}\Gamma = \lim_{\eta\to\infty}\frac{1}{\sqrt{1 - v^2/\eta^2}} = 1 = \Gamma_\infty \tag{4.22a}$$

$$O'(\eta) \to O(\eta): \qquad O'_\infty \to O_\infty:$$

$$\lim_{\eta\to\infty}\begin{cases} x = \Gamma\left(x' + vt'\right) \\ y = y' \\ z = z' \\ t = \Gamma\left(t' + vx'/\eta^2\right) \end{cases} = \begin{cases} x = x' + vt' \\ y = y' \\ z = z' \\ t = t' \end{cases} \tag{4.22b}$$

Equations (4.21) and (4.22) have the following two important meanings.

Firstly, it is shown that both the Galilean transformation (Eq. (4.4)) and the corresponding Galileo's speed-addition (Eq. (4.5)) are idealized observation models, and serve the idealized observation agent OA_∞.

Secondly, it is shown that the general Lorentz transformation of IOR theory generalizes the Galilean transformation, and the law of IOR speed-addition generalizes the law of Galileo's speed-addition.

4.4.3 The Unity of Galileo and Lorentz

It is thus clear that the Galilean transformation and the Lorentz transformation are originally two independent and separated spacetime models, which are the products of different observation systems and serve different observation agents. The Galilean transformation and the law of Galileo's speed-addition are the products of the idealized observation agent OA_∞, representing the objectively real spacetime and matter motion; the Lorentz transformation and the law of Einstein's speed-addition are the products of the optical observation agent OA(c), representing the optical image of the objectively real spacetime and matter motion.

The general Lorentz transformation of IOR theory is a spacetime model under the general observation agent OA(η), in which the Galilean transformation and the Lorentz transformation are only two special cases, so-called **Partial Theories** in Hawking's words [31].

Now, the general Lorentz transformation has generalized and unified the Galilean transformation and the Lorentz transformation. Thus, two well-known models of spacetime transformation, the Galilean transformation and the Lorentz transformation has been unified by the theory of OR into the same theoretical system under the same axiom system.

The unification of the Galilean transformation and the Lorentz transformation under the general Lorentz transformation suggests that the transformation of IOR spacetime, so-called the general Lorentz transformation, is logically consistent not only with the Lorentz transformation but also with the Galilean transformation. In particular, such logical consistency and correspondence relationship indicates that the transformation of IOR spacetime, so-called the general Lorentz transformation, is logically self-consistent. This, from one aspect, confirms the logical rationality and theoretical validity of the transformation of IOR spacetime.

As stated before, the unification of the Galilean transformation and the Lorentz transformation has an important symbolic significance.

The theory of OR including IOR and GOR will demonstrate the more universal unification. Finally, the theory of IOR will generalize and unify Newton's inertial mechanics and Einstein's special theory of relativity; the theory of GOR will generalize and unify Newton's theory of universal gravitation and Einstein's general theory of relativity.

5 The Basic Formulae in IOR Theory

Since the general Lorentz transformation is isomorphically consistent with the Lorentz transformation, all the kinematical and dynamical equations in Einstein's special theory of relativity can be logically extended to the theoretical system of OR, forming the whole theoretical system of IOR theory, so-called the theory of **Inertially Observational Relativity** (IOR for short).

The whole theoretical system of Einstein's special theory of relativity is based on the three principles as its axiom system or logical premises:

(i) The principle of simplicity;
(ii) The principle of relativity;
(iii) The principle of the invariance of light speed.

Naturally, by analogizing or following the logic of Einstein's special theory of relativity, the whole theoretical system of IOR can be established based on the following three principles of IOR:

(i) The principle of simplicity
(ii) The principle of IOR relativity;
(iii) The principle of the invariance of information-wave speeds.

The difference is that Einstein's invariance of light speed is only a hypothesis, while the invariance of information-wave speeds is a theorem, a logical consequence proved by the theory of OR. So, the theory of IOR and the theory of GOR are able to clarify the rationale of relativistic effects, reveal the essence of relativistic phenomena, and unify the separated theoretical systems of Newton and Einstein.

The theory of IOR has established on the basis of the axiom system of IOR. Of cause, the theory of IOR can also be based on the three principles of IOR. So, analogizing and following the logic of Einstein's special theory of relativity, we can derive the basic concepts, definitions, and formulae of IOR theory, and establish the whole theoretical system of IOR.

The theory of IOR is that of the general observation agent OA(η). Predictably, Einstein's special theory of relativity as the theory of the optical observation agent OA(c) and Newton's inertial mechanics as the theory of the idealized observation agent OA_∞ will become two special cases of IOR theory. The transformation of IOR spacetime and the law of IOR speed-addition can be said to be the most basic formulae in theory of IOR. As stated in Chapter 4: the Galilean transformation and the Lorentz transformation are two special cases of the transformation of IOR spacetime; the law of Einstein's speed-addition and the law of Galileo's speed-addition law are two special cases of the law of IOR speed-addition.

In particular, the basic formulae of IOR theoretical system includes the mass-energy relation of IOR theory: $E=m\eta^2$, so-called **the general Einstein formula** that generalizes Einstein's famous mass-energy relation: $E=mc^2$.

5.1 IOR Mass-Speed Relation

In Einstein's special theory of relativity, in addition to the Lorentz transformation and the law of Einstein's relativistic speed-addition, the relativistic mass-speed relation can be said to be the most basic formula. Likewise, in the theory of IOR, in addition to the transformation of IOR spacetime and the law of IOR relativistic speed-addition, the relativistic mass-speed relation of IOR theory can be said to be the most basic formula.

In Newton's classical mechanics, mass is the intrinsic property of matter, independent of the motion state of matter and observers. However, in the theory of special relativity, Einstein introduced the concepts of **Relativistic Mass** and **Rest Mass**. Relativistic mass is also known as **Moving Mass**.

In Einstein's special theory of relativity, the mass of the observed object *P* depends on *P*'s motion speed v:

$$m(v) = \gamma(v) m_o = \frac{m_o}{\sqrt{1 - v^2/c^2}} \tag{5.1}$$

where m and m_o are respectively the relativistic mass and rest mass of *P*.

This is Einstein's relativistic mass-speed relation, which plays an important role in Einstein's special theory of relativity.

In the theory of IOR, the observed object *P* also have the relativistic mass m (or moving mass) and rest mass m_o of its own. The theory of IOR calls the relativistic mass or moving mass m as **the observed (observational) mass**. Moreover, the theory of IOR also has the relativistic mass-speed relation of its own.

The difference is that: in Einstein's special theory of relativity, relativistic mass or moving mass m is regarded as the objective physical existence with objective mass effects, including the effect of universal gravitation; in the theory of IOR, however, only the rest mass m_o is the objectively real mass of an object.

5.1.1 The Derivation of IOR Mass-Speed Relation

There are different methods for deriving the mass-speed relation (Eq. (5.1)) of Einstein's special theory of relativity, which can be extended to the theory of IOR for deriving the relativistic mass-speed relation of IOR theory.

According to the agreements of Sec. 1.1.1 in Chapter 1, as depicted in Fig. 1.1, suppose that O and O' are the inertial observers or inertial frames with the general observation agent OA(η): O' moves relative to O along the X axis of O at the inertial speed v. Let P and P' be two small balls with the same rest mass (m_o): P is stationary in the X axis of O; P' is stationary in the X' axis of O'. Thus, in the view of O, the relativistic mass or observed mass of P' is $m(\eta,v)$, then, according to the principle of relativity, in the view of O', the relativistic mass or observed mass of P should be the same $m(\eta,v)$. Assume that the small balls P and P' merge into one body $P'P$ after collision: the speed of $P'P$ relative to O is u; the speed of $P'P$ relative to O' is u'.

According to the principle of relativity, the principle of momentum conservation equally holds true in O and O':

$$O: \quad mv = (m + m_o)u \tag{5.2a}$$

$$O':\quad -mv=\left(m+m_o\right)u' \tag{5.2b}$$

By solving Eq. (5.2), we have $u=-u'$.

Substitute $u=-u'$ into the law of IOR speed-addition (Eq. (4.17)):

$$\begin{aligned} &u'=\frac{u-v}{1-uv/\eta^2}=-u \\ \text{or}\quad &\left(\frac{v}{u}\right)^2-2\left(\frac{v}{u}\right)+\frac{v^2}{\eta^2}=0\quad (v>u) \end{aligned} \tag{5.3}$$

By solving Eq. (5.3), we have

$$\frac{v}{u}=1+\sqrt{1-\frac{v^2}{\eta^2}} \tag{5.4}$$

Substitute Eq. (5.4) into Eq. (5.2a), we get that

$$m(\eta,v)=\frac{m_o}{\frac{v}{u}-1}=\frac{m_o}{\sqrt{1-\frac{v^2}{\eta^2}}} \tag{5.5}$$

where is $m(\eta,v)$ is the IOR relativistic mass of the observed object P, i.e., the observational mass observed with the general observation agent OA(η); m_o is the rest mass of P, i.e., the intrinsic mass of P.

Equation (5.5) is namely the mass-speed relation of IOR theory.

The mass-speed relation (5.5) of IOR theory is isomorphically consistent with Einstein's mass-speed relation (5.1). This meets our expectation.

Actually, based on the three principles of IOR, by analogizing and following the logic of Einstein's special theory of relativity, each relation derived from the theory of IOR must be isomorphically consistent with the corresponding relation of Einstein's special theory of relativity.

It is worth noting that, in the mass-speed relation of IOR theory, the relativistic mass, or the observational mass $m=m(\eta,v)$, is the function of the information-wave speed η of the observation agent OA(η) and the motion speed v of the observed object P. As a matter of fact, the relativistic mass m depends more on the information-wave speed η of OA(η), rather than on the motion speed v of P.

As a physical model of the general observation agent OA(η), the mass-speed relation of IOR theory provides us new insight into the mass of matter.

5.1.2 IOR's Observational Mass: with Observational Effects

According to the mass-speed relation (Eq. (5.5)), the IOR mass is a sort of relativistic mass or observational mass observed with the general observation agent OA(η), which depends on observation or observation agents: for the same observed object P, different observation agents have different observational masses.

For the observation systems (P,$M(\eta)$,O) and (P,$M(\eta)$,O') in Fig. 1.1, suppose that the inertial frame O' is namely the intrinsic inertial frame O_o of the observed object P, then P is stationary at O', $u'=0$, and $u=v$. Thus, the mass of P in the inertial frame O is the relativistic mass or observational mass $m(\eta,v)$ of P at the speed v; the mass of P in the inertial frame O' or O_o is the rest mass m_o of P.

It is worth noting that the rest mass m_o of the observed object P in O' or O_o is intrinsic and invariant to P, and does not depend on the observation, does not depend on the observation agent OA(η), which is the objectively real mass. However, the relativistic mass $m(\eta,v)$ of P in O depends on the observation, depends on the observation agent OA(η), depends on the information-wave speed η of OA(η).

Suppose that the information-wave speed η of the observation agent OA(η) is greater than the inertial speed v of the observed object P, then the mass-speed relation (5.5) of IOR theory can be decomposed in terms of Taylor series:

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

$$\begin{cases}\Gamma(\eta,v)=1+\dfrac{1}{2}\dfrac{v^2}{\eta^2}+\dfrac{1\cdot 3}{2\cdot 4}\dfrac{v^4}{\eta^4}+\dfrac{1\cdot 3\cdot 5}{2\cdot 4\cdot 6}\dfrac{v^6}{\eta^6}+\cdots=\Gamma_\infty+\Delta\Gamma(\eta,v) \\ \begin{cases}m_o=\Gamma_\infty m_o \\ \Delta m(\eta,v)=\Delta\Gamma(\eta,v)m_o\end{cases} \qquad \left(\Gamma_\infty\equiv 1,\ \Delta\Gamma(\eta,v)=\Gamma(\eta,v)-1\right)\end{cases} \tag{5.6}$$

where m_o is the rest mass of the observed object P, i.e., the objectively real mass of P, independent of observation or observation agents, and has the effects of real mass, including the effect of momentum and the effect of gravitation; $\Delta m(\eta,v)$ purely belongs to observational effects, depending on the observation and the observation agent OA(η), has no the effects of real mass: neither the effect of momentum nor the effect of gravitation.

In Eq. (5.6), the IOR factor $\Gamma(\eta,v)$ of spacetime transformation is decomposed into the Galilean factor $\Gamma_\infty\equiv1$ and the observational-effect factor $\Delta\Gamma=\Delta\Gamma(\eta,v)$. The Galilean factor $\Gamma_\infty\equiv1$ is the spacetime-transformation factor of the idealized observation agent OA_∞, independent of observation and observation agents, representing the objective and real physical world; the observational-effect factor $\Delta\Gamma=\Delta\Gamma(\eta,v)$ purely represents observational effects or apparent phenomena, depending on observation and the observation agent OA(η).

For the observed object P moving at the speed v, the higher the information-wave speed η, the closer $m(\eta,v)$ is to the rest mass m_o of P, that is, the objectively real mass; on the contrary, the lower the η, the greater the $\Delta m(\eta,v)$, and the more significant the observational effect of $m(\eta,v)$.

It is thus clear that $\Delta m(\eta,v)>0$ due to the observational locality ($\eta<\infty$) of the observation agent OA(η). So, the observational mass $m(\eta,v)$ observed with the observation agent OA(η) contains the unreal mass component: $\Delta m(\eta,v)$.

The mass-speed relation (5.5) of IOR theory is a physical model of the general observation agent OA(η), with which we can understand the essence of Einstein's relativistic mass under the optical agent OA(c) and the essence of Newton's classical mass under the idealized agent OA_∞.

5.1.3 Einstein's Relativistic Mass: not Completely Objective and Real

Einstein's relativistic mass is the observational mass of the optical observation agent OA(c), which contains the observational effects of OA(c), and therefore, is not completely objective and real.

The mass-speed relation (5.5) of IOR theory generalizes the mass-speed relation (5.1) of Einstein's special theory of relativity: Einstein's mass-speed relation is only a special case of IOR mass-speed relation, which holds true only under the optical observation agent OA(c).

Obviously, if $\eta \to c$, then IOR's mass-speed relation (5.5) strictly converges to Einstein's mass-speed relation (5.1):

$$\begin{aligned}\lim_{\eta\to c} m(\eta,v) &= \lim_{\eta\to c} \Gamma(\eta,v)\, m_o \\ &= \lim_{\eta\to c} \frac{m_o}{\sqrt{1-v^2/\eta^2}} = \frac{m_o}{\sqrt{1-v^2/c^2}} = \Gamma(c,v)\, m_o = m_o + \Delta m(c,v)\end{aligned} \tag{5.7}$$

Equation (5.7) shows that:

(i) The mass-speed relation (5.1) of Einstein's special theory of relativity is an optical observation model, in which the relativistic mass m is the observational mass $m(c,v)$ of the optical observation agent OA(c);

(ii) The optical observation agent OA(c) has the observational locality ($c<\infty$), and therefore, the observational mass $m(c,v)$ of the object P observed with OA(c) is not completely objective and real, and contains the unreal mass component $\Delta m(c,v)$.

It is thus clear that the relativistic mass of Einstein's special theory of relativity is only an observed physical quantity, not completely objective and real.

5.1.4 Newton's Classical Mass: the Objectively Real Mass

Newton's classical mass is non-relativistic mass of the idealized observation agent OA_∞, which is the objectively real mass without observational effects.

The mass-speed relation (5.5) of IOR theory not only generalizes the mass-speed relation (5.1) of Einstein's special theory of relativity but also generalizes Newton's classical mass m_∞ in classical mechanics.

If $\eta \to \infty$, then IOR's mass-speed relation (5.5) strictly converges to Newton's classical mass m_∞ in classical mechanics:

$$m_\infty = \lim_{\eta\to\infty} m(\eta,v) = \lim_{\eta\to\infty} \Gamma(\eta,v)\, m_o = \lim_{\eta\to\infty} \frac{m_o}{\sqrt{1-v^2/\eta^2}} = m_o \tag{5.8}$$

This suggests that, as a matter of fact, Einstein's so-called rest mass m_o is exactly Newton's classical mass m_∞.

Equation (5.8) shows that:

(i) Newton's classical mass is the idealized observational mass, that is, the observational mass $m_\infty = m(\infty, v)$ of the idealized observation agent OA_∞;

(ii) The idealized observation agent OA_∞ represents the objective world, has no observational locality, and therefore, the classical mass m_∞ of the object P observed with OA_∞ is exactly the objectively real mass: $m_\infty = m_o$, that is, the intrinsic mass of P, has no the component of observational effects.

So, Newton's classical mass is exactly the objectively real mass.

5.1.5 The Problem of Photon Rest Mass

The mass of matter is the amount of matter contained in an object.

Based on the mass-speed relation in his theory of special relativity:

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

Einstein believed that, if the speed v of the observed object P reaches the speed c of light, then its rest mass m_o must be zero, or its relativistic mass m would be infinite.

According to the theory of OR, the rest mass is the intrinsic mass of the observed object P, which is the objectively real mass of P. Therefore, if a photon had no rest mass, then the photon would have no mass. Based on the dialectical materialist view of nature, the author, like some other physicists, cannot accept Einstein's doctrine of photon zero mass.

As stated in the introduction to IOR, it is the original intention of the author and the theory of OR to give photons a little mass.

According to Einstein's logic and based on the IOR mass-speed relation:

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

the rest mass m_o of the informons of observation agent OA(η) must be zero, or the relativistic mass or observational mass m would be infinite.

In theory, any material particle (not just photons) can be an informon. Thus, according to Einstein's logic, the rest mass of all matter particles would be zero, or their relativistic masses would be infinite.

Obviously, this is a paradox.

The zero mass of photons occurs at the singularity of Einstein's mass-speed relation: $v=c$; while the zero mass of informons occurs at the singularity of IOR mass-speed relation: $v=\eta$. As Hawking remarked in his **A Brief History of Time** [31]: "Mathematics cannot really handle infinite numbers. At singularity, the theory itself breaks down or fails." The inference that photons have no rest mass is drawn from the singularity of Einstein's mass-speed relation; the inference that informons have no rest mass is drawn from the singularity of IOR mass-speed relation. Actually, both of the inferences cannot represent the objective real existence of matter or physical reality. According to Hawking: Einstein's mass-speed relation (5.1) does not mean that photons have no rest mass, but only that Einstein's mass-speed relation (5.1) breaks down or fails at its singularity: $v=c$; IOR's mass-speed relation (5.5) does not mean that the informons have no rest mass, but only that IOR's mass-speed relation (5.5) breaks down or fails at its singularity: $v=\eta$.

According to the IOR mass-speed relation (5.5), the informons are not really massless. But restricted by its observational locality ($\eta<\infty$), the observation agent OA(η) is unable to detect or measure the rest mass of a particle moving at the speed equal to or greater than the information-wave speed η of OA(η). So, the optical observation agent OA(c), so-call **Minkowski agent**, are unable to detect or measure the rest mass of photons.

However, armed with the superluminal observation agent, one can discover and measure the rest mass of photons.

Based on the relativistic mass-speed relation (5.5) the theory of IOR draws the following conclusion: all matter particles, including photons, have their own rest masses; the rest mass of photons is not really zero.

According to the mass-speed relation of IOR theory, there is no matter particle without rest mass in the universe.

Let OA(η_1) and OA(η_2) be two different observation agents ($\eta_2>\eta_1$), the observed object P as a particle have the rest mass m_o and move at the speed $v=\eta_1$. According to the IOR mass-speed relation (5.5), it holds true that:

$$\mathrm{OA}(\eta_1):\quad m_o=\Gamma^{-1}(\eta_1,\eta_1)m(\eta_1,\eta_1)=m(\eta_1,\eta_1)\sqrt{1-\eta_1^2/\eta_1^2}=0 \qquad (5.9a)$$

$$\mathrm{OA}(\eta_2):\quad m_o=\Gamma^{-1}(\eta_2,\eta_1)m(\eta_2,\eta_1)=m(\eta_2,\eta_1)\sqrt{1-\eta_1^2/\eta_2^2}>0 \qquad (5.9b)$$

Equation (5.9a) seems to mean that the observed object P has no the rest mass of its own: m_o=0; however, equation (5.9b) clarifies that the observed object P has its own rest mass: m_o>0. Actually, Eq. (5.9a) only means that the observation agent OA(η_1) cannot detect or measure the rest mass m_o of P owing to $v=\eta_1$; while Eq. (5.9b) means that the observation agent OA(η_2) can detect or measure the rest mass m_o of P owing to $v<\eta_2$.

Suppose P is an arbitrary particle of matter, for example, a photon or a graviton, moving at the inertial speed v. According to the relativistic mass-speed relation of IOR theory, if the information-wave of the observation agent OA(η) is fast enough ($\eta>v$), then we can detect or measure the rest mass m_o of P:

$$m_o=\Gamma^{-1}(\eta,v)m(\eta,v)=m(\eta,v)\sqrt{1-v^2/\eta^2}>0 \quad (\eta>v) \qquad (5.10)$$

It turns out that all matter particles, including photons and gravitons, have the rest masses of their own.

So, how much is the rest mass of a photon?

In **The 2nd volume of OR: Gravitationally Observational Relativity** (GOR), based on the analysis of the gravitational redshift of light waves as well as the classical kinetic and potential energies of photons, **the theory of General Observational Relativity** or **the theory of Gravitational Observational Relativity**, or **the theory of GOR** for short, will give the theoretical prediction and calculation for the rest mass of photons.

5.2 IOR Observational Momentum

In Newton's classical mechanics, **momentum** is an important concept. The classical momentum p_∞ of a moving object or the observed object P is defined as the product of P's classical mass m_∞ and P's motion speed v: $p_\infty=m_\infty v$. Newton's momentum, i.e., classical momentum, is non-relativistic.

In Einstein's special theory of relativity, the concept of momentum is magnified. Einstein relativistically characterized the momentum of moving objects, thereby forming the concept of relativistic momentum. On the basis of his relativistic mass-speed relation (5.1), Einstein defined the relativistic momentum p as the product of P's relativistic mass m and P's motion speed v:

$$p = mv = \gamma m_o v = \frac{m_o v}{\sqrt{1 - v^2/c^2}} \tag{5.11}$$

Unlike Newton's momentum, Einstein's momentum replaces the non-relativistic mass, i.e., Newton's classical mass m_∞, with the relativistic mass m.

So, is the objectively real momentum of a moving object Newton's classical momentum $p_\infty=m_\infty v$ ($m_\infty=m_o$) or Einstein's relativistic momentum $p=mv$ ($m=\gamma m_o$)?

5.2.1 The Definition of Momentum in IOR

In the theory of OR, the concept of momentum is linked to observation and observation agents. Therefore, the theory of OR calls the momentum defined in IOR theory as **observed momentum observational momentum** or.

As depicted in Fig. 1.1, Consider inertial observers or inertial frames O and O' with the general observation agent OA(η): O' moves relative to O along the X axis of O at an inertial speed v. Let the moving object or observed object P be stationary in the X' axis of O': $u'=0$ and $u=v$. Thus, in the view of O, the momentum of P in O is the relativistic momentum of P moving at the inertial speed v, i.e., the observed (observational) momentum $p(\eta,v)$; while in the view of O', the momentum of P in O' is naturally zero. On the basis of the IOR mass-speed relation (5.5), following the logic of Einstein's special relativity, the theory of OR or IOR defines the relativistic momentum of the moving object P in the inertial frame O, or the observed (observational) momentum $p(\eta,v)$ of OA(η), as follows:

$$p(\eta,v) = m(\eta,v)v = \Gamma(\eta,v) m_o v = \frac{m_o v}{\sqrt{1 - v^2/\eta^2}} \tag{5.12}$$

where v is the motion speed of the moving object P, $m(\eta,v)$ the IOR relativistic mass or observational mass of the general observation agent OA(η), $m_o=m_\infty$ the rest mass or classical mass of P.

Like the Einstein's momentum, the IOR momentum defined in Eq. (5.12) is also relativistic. However, this relativistic property belongs to observational effects.

According to Eq. (5.12), the IOR momentum $p(\eta,v)$ defined in Eq. (5.12) is the observational momentum observed with the general observation agent OA(η).

5.2.2 IOR's Observational Momentum: with Observational Effects

According to the definition of IOR momentum (Eq. (5.12)), the momentum in IOR theory is not only relativistic momentum but also observational momentum, which depends on observation and observation agents: different observation agents have different observational momentums.

In the theory of OR, the relativistic momentum or observational momentum $p=p(\eta,v)$ of a moving object P is actually the function of the information-wave speed η of the general observation agent OA(η) and the motion speed v of the moving object P, which depends more on the information-wave speed η of OA(η) rather than on the motion speed v of the moving object P.

Suppose that the information-wave speed η of the observation agent OA(η) is greater than the inertial speed v of the observed object P: $\eta>v$, then the IOR momentum (Eq. (5.12)) can be decomposed in terms of Taylor series:

$$p(\eta,v)=\varGamma(\eta,v)m_o v=\frac{m_o v}{\sqrt{1-v^2/\eta^2}}=p_\infty+\Delta p(\eta,v)$$

$$\begin{cases}\varGamma(\eta,v)=1+\dfrac{1}{2}\dfrac{v^2}{\eta^2}+\dfrac{1\cdot 3}{2\cdot 4}\dfrac{v^4}{\eta^4}+\dfrac{1\cdot 3\cdot 5}{2\cdot 4\cdot 6}\dfrac{v^6}{\eta^6}+\cdots=\varGamma_\infty+\Delta\varGamma(\eta,v) \\ \begin{cases}p_\infty=\varGamma_\infty m_\infty v=\varGamma_\infty m_o v \\ \Delta p(\eta,v)=\Delta\varGamma(\eta,v)m_o v\end{cases} \quad \left(\varGamma_\infty\equiv 1,\ \Delta\varGamma(\eta,v)=\varGamma(\eta,v)-1\right)\end{cases} \tag{5.13}$$

where $p_\infty=m_\infty v=m_o v$ is the classical momentum of the moving object P, i.e., the objectively real momentum of P, independent of observation and observation agents, and has the effects of real momentum; $\Delta p(\eta,v)$ purely belongs to observational effects, depending on observation and observation agents, or depending on the information-wave speed η of OA(η), and has no the effects of real momentum.

In Eq. (5.13), the IOR factor $\varGamma(\eta,v)$ of spacetime transformation is decomposed into the Galilean factor $\varGamma_\infty\equiv 1$ and the observational-effect factor $\Delta\varGamma=\Delta\varGamma(\eta,v)$. The Galilean factor $\varGamma_\infty\equiv 1$ is the spacetime-transformation factor of the idealized observation agent OA_∞, independent of observation and observation agents, representing the objectively real physical world; the observational-effect factor $\Delta\varGamma=\Delta\varGamma(\eta,v)$ purely represents observational effects or apparent phenomena, depending on observation and observation agents.

For the observed object P moving at a specific speed v, the higher the information-wave speed η, the closer the $p(\eta,v)$ is to the classical momentum p_∞, that is, the objectively real momentum of P; on the contrary, the lower the η, the greater the $\Delta p(\eta,v)$, and the more significant the observational effect of $p(\eta,v)$.

It is thus clear that $\Delta p(\eta,v)>0$ due to the observational locality ($\eta<\infty$) of the observation agent OA(η). So, the observational momentum $p(\eta,v)$ observed with the observation agent OA(η) contains the unreal momentum component: $\Delta p(\eta,v)$.

The definition of IOR momentum $p(\eta,v)$ in Eq. (5.12) is a physical model of the general observation agent OA(η). Therefore, based on the definition of IOR momentum, we can understand both the essence of Einstein's relativistic momentum under the optical observation agent OA(c) and the essence of Newton's classical momentum under the idealized observation agent OA_∞.

5.2.3 Einstein's Relativistic Momentum: not Completely Objective and Real

Einstein's relativistic momentum is the observational momentum of the optical observation agent OA(c), which contains the observational effects of OA(c), and therefore, is not completely objective and real.

The definition of IOR momentum (Eq. (5.12)) generalizes the definition of Einstein's momentum (Eq. (5.11)): the relativistic momentum in Einstein's special relativity is only a special case of the observational momentum in IOR theory, which holds true only under the optical observation agent OA(c).

Obviously, if $\eta\to c$, then the observational momentum (Eq. (5.12)) of IOR theory strictly converges to Einstein's relativistic momentum (Eq. (5.11)):

$$\begin{aligned}\lim_{\eta\to c} p(\eta,v) &= \lim_{\eta\to c}\Gamma(\eta,v)m_o v \\ &= \lim_{\eta\to c}\frac{m_o v}{\sqrt{1-v^2/\eta^2}} = \frac{m_o v}{\sqrt{1-v^2/c^2}} = p(c,v) = p_\infty + \Delta p(c,v)\end{aligned} \tag{5.14}$$

Equation (5.14) shows that:

(i) The definition of Einstein's momentum (Eq. (5.11)) is an optical observation model, in which the relativistic momentum p is the observational momentum $p(c,v)$ of the optical observation agent OA(c);

(ii) The optical observation agent OA(c) has the observational locality ($c<\infty$), and therefore, the observational momentum $p(c,v)$ of the object P observed with OA(c) is not completely objective and real, and contains the unreal momentum component $\Delta p(c,v)$.

It is thus clear that the relativistic momentum of Einstein's special theory of relativity is only an observational physical quantity, contains the observational effects of the optical agent OA(c).

5.2.4 Newton's Classical Momentum: the Objectively Real Momentum

Newton's classical momentum is non-relativistic momentum of the idealized agent OA_∞, which is the objectively real momentum without observational effects.

The IOR momentum (Eq. (5.12)) not only generalizes Einstein's relativistic momentum (Eq. (5.11)) but also generalizes Newton's classical momentum p_∞.

If $\eta \to \infty$, then the definition of IOR momentum (Eq. (5.12)) strictly converges to Newton's classical momentum p_∞ in classical mechanics:

$$p_\infty = \lim_{\eta\to\infty} p(\eta, v) = \lim_{\eta\to\infty} \Gamma(\eta, v) m_o v = \lim_{\eta\to\infty} \frac{m_o v}{\sqrt{1 - v^2/\eta^2}} = m_o v = m_\infty v \qquad (5.15)$$

Equation (5.15) shows that:

(i) Newton's classical momentum is the idealized observational momentum, that is, the observational momentum $p_\infty=p(\infty,v)$ of the idealized agent OA_∞;

(ii) The idealized observation agent OA_∞ represents the objective world, has no observational locality, and therefore, the classical momentum p_∞ of the object P observed with OA_∞ is exactly the objectively real momentum of P: $p_\infty=m_\infty v=m_o v$, has no the component of observational effects.

So, Newton's classical momentum is the objectively real momentum.

5.3 IOR Mass-Energy Relation

Matter has two essential attributes: one is mass; the other is energy.

In Newton's classical mechanics, mass and energy are independent of each other: mass is just mass; energy is just energy. A matter object has two kinds of classical energies: one is classical kinetic-energy (K_∞); the other is classical potential energy (V_∞). Therefore, the total classical energy (E_∞) of a matter object is the sum of the kinetic-energy K_∞ and the potential energy V_∞: $E_\infty=K_\infty+V_\infty$. There is no potential field in inertial spacetime. Therefore, a matter object in inertial spacetime only has classical kinetic-energy but no classical potential energy.

In his special theory of relativity, however, Einstein introduced the concept of **Rest Energy** for inertial mechanics: in inertial spacetime, a matter object with rest mass m_o not only has the kinetic-energy K, but also has the rest-energy E_o. The concept of rest energy originates from Einstein formula: $E=mc^2$, that is, the famous Einstein Mass-Energy Relation. According to Einstein's mass-energy relation, the rest-energy E_o of a matter object is proportional to its rest mass m_o: $E_o=m_oc^2$. This suggests that: firstly, a matter object in inertial spacetime, even though at rest, has its own energy; secondly, the rest mass of a matter object represents energy, so under certain conditions, mass can be transformed into energy.

Einstein's mass-energy relation $E=mc^2$ suggests that the mass of matter and the energy of matter are interdependent: mass is also energy and energy is also mass; under certain conditions, mass and energy can be transformed into each other. So, the energy E in Einstein formula $E=mc^2$ can be referred to as **Mass Energy**.

The theory of Inertially Observational Relativity, the theory of IOR for short, also has its own mass-energy relation and the concept of rest energy. In the theory of IOR, mass and energy are also interdependent, and under certain conditions, can also be transformed into each other.

However, the theory of OR discovers that: originally, mass and energy are independent of each other; in fact, the so-called mass-energy relation, as a sort of relativistic effect, belongs to observational effects and apparent phenomena.

The theory of OR will unveil the mystery of Einstein formula $E=mc^2$.

5.3.1 Einstein's Mass-Energy Relation: $E=mc^2$

Perhaps, in Einstein's special theory of relativity, the most famous formula is Einstein formula: $E=mc^2$, that is, Einstein's mass-energy relation. There are various methods for deriving Einstein formula or Einstein's mass-energy relation, but the basic logical premises cannot be separated from Einstein's hypothesis of the invariance of light speed.

Referring to literature [68], based on the mass-speed relation (Eq. (5.1)) and the definition of momentum (Eq. (5.11)) in Einstein's special theory of relativity, deducing and reviewing Einstein's mass-energy relation can provide a reference for the deduction of the mass-energy relation of IOR theory.

Let P be an inertial moving object: the inertial speed v, the rest mass m_o, the relativistic mass m, and the mass-speed relation Eq. (5.1); the relativistic momentum p defined with Eq. (5.11).

Following the logic of classical mechanics, the force F on the object P can be defined with the momentum p of P:

$$F=\frac{\mathrm{d}p}{\mathrm{d}t}\quad\left(p=mv=\gamma m_o v=\frac{m_o v}{\sqrt{1-v^2/c^2}}\right)\tag{5.16}$$

where the momentum p of P is no longer the classical, but the relativistic.

Following Einstein's logic, the total energy of the object P should be: $E=K+E_o$, where K and E_o are P's kinetic-energy and P's rest-energy, respectively.

By analogizing the definition of classical kinetic-energy, the relativistic kinetic-energy K of the object P can be defined and calculated as follows:

$$\begin{aligned}K&=\int_0^v F\mathrm{d}x=\int_0^v\frac{\mathrm{d}p}{\mathrm{d}t}\mathrm{d}x=\int_0^v v\mathrm{d}p\\&=\int_0^v\gamma^3 m_o v\mathrm{d}v=m_o c^2\,\gamma(v)\big|_0^v=m_o c^2\left(\gamma(v)-1\right)\end{aligned}\quad\left(\gamma=\frac{1}{\sqrt{1-v^2/c^2}}\right)\tag{5.17}$$

where γ is namely the Lorentz factor.

Naturally, if v=0, then K=0 and $E=E_o$.

Let $E_o=m_oc^2$ and $E=K+E_o$, we get Einstein formula from Eq. (5.17):

$$\begin{gathered}E=K+E_o=\gamma m_o c^2=\frac{m_o c^2}{\sqrt{1-v^2/c^2}}=mc^2\\ \begin{cases}E_o=m_o c^2\\ K=E-E_o=\left(\gamma(v)-1\right)m_o c^2\end{cases}\end{gathered}\tag{5.18}$$

where K and E_o are P's kinetic-energy and P's rest-energy, respectively; E is the total energy of the object P, or, as stated before, the mass-energy of P.

It is worth noting that the kinetic-energy K in Einstein formula $E=mc^2$ is Einstein's relativistic kinetic-energy which is different from Newton's classical kinetic-energy K_∞. According to Eq (5.18), if the inertial speed v of the inertial moving object P is much smaller than the speed of light: $v<<c$, then Newton's classical kinetic-energy K_∞ approximates Einstein's relativistic kinetic-energy K:

$$\begin{aligned}\forall\, v \ll c \quad K &= m_o c^2\left(\gamma - 1\right) \\ &= m_o c^2\left(\frac{1}{\sqrt{1-v^2/c^2}} - 1\right) \approx \frac{1}{2}m_o v^2 = \frac{1}{2}m_\infty v^2 = K_\infty\end{aligned} \tag{5.19}$$

Accordingly, the mainstream school of physics believe that Einstein formula is the profound and accurate statement of the relationship between mass and energy, while Newton's classical kinetic-energy K_∞ is only an approximation of Einstein's relativistic kinetic-energy $K=(\gamma(v)-1)\,m_o c^2$.

However, the mass-energy relation of IOR theory will clarify that Newton's classical kinetic-energy K_∞ is the objectively real energy of the inertial moving object P, while Einstein's relativistic kinetic-energy K is only an approximation of Newton's classical kinetic-energy K_∞, i.e., the observational kinetic-energy observed with the optical observation agent OA(c), and in particular, Einstein's so-called rest-energy E_o is not the objectively real physical existence.

5.3.2 The Deduction of IOR Mass-Energy Relation: $E=m\eta^2$

By replacing the three principles of Einstein's special relativity with the three principles of IOR theory, and following Einstein's logic, the theory of OR can certainly deduce the IOR mass-energy relation that is isomorphically consistent with Einstein's mass-energy relation.

Naturally, the logic of Einstein formula or Einstein's mass-energy relation can be extended to the theory of OR to deduce the mass-energy relation of IOR theory.

Suppose the observer O is observing the inertial moving object P by means of the observation agent OA(η). Let m_o be the rest mass of P, m be the relativistic or observational mass of P, following the IOR mass-speed relation (5.5); let p the relativistic or observational momentum of P, being defined in Eq. (5.12).

Firstly, by analogizing Eq. (5.16) of the optical observation agent OA(c), the force F on P can be defined according to the IOR observational momentum $p(\eta,v)$ (Eq. (5.12)) under the general observation agent OA(η):

$$F = \frac{\mathrm{d}p(\eta,v)}{\mathrm{d}t} \quad \left(p(\eta,v) = m(\eta,v)v = \Gamma(\eta,v)m_o v = \frac{m_o v}{\sqrt{1-v^2/\eta^2}}\right) \tag{5.20}$$

where $p(\eta,v)$ is the relativistic momentum of IOR theory, that is, the observational momentum of the general observation agent OA(η).

Following the logic of Einstein's mass-energy relation $E=mc^2$, the total energy of the inertial moving object P should be $E=K+E_o$ where K and E_o are the kinetic energy of P and the rest energy of P, respectively.

Let v be the inertial motion speed of P. By analogizing Einstein's definition of relativistic kinetic-energy (Eq. (5.17)), The relativistic or observational kinetic-energy K in the theory of IOR should be defined and calculated as follows:

$$\begin{aligned} K &= \int_0^v F\mathrm{d}x = \int_0^v \frac{\mathrm{d}p}{\mathrm{d}t}\mathrm{d}x = \int_0^v v\mathrm{d}p \\ &= \int_0^v \Gamma^3 m_o v\mathrm{d}v = m_o\eta^2\, \Gamma(\eta,v)\Big|_0^v = m_o\eta^2\left(\Gamma(\eta,v)-1\right) \end{aligned} \tag{5.21}$$

$$\left(\Gamma = 1\Big/\sqrt{1-v^2/\eta^2}\right)$$

where $\Gamma(\eta,v)$ is the IOR factor of spacetime transformation.

Naturally, if v=0, then K=0 and E=E_o. Let E_o=m_oc^2 and E=K+E_o, we get the IOR mass-energy relation from Eq. (5.21):

$$\begin{aligned} &E = K + E_o = \Gamma m_o\eta^2 = \frac{m_o\eta^2}{\sqrt{1-v^2/\eta^2}} = m\eta^2 \\ &\begin{cases} E_o = m_o\eta^2 \\ K = E - E_o = \left(\Gamma(\eta,v)-1\right)m_o\eta^2 \end{cases} \end{aligned} \tag{5.22}$$

where K and E_o are P's kinetic-energy and P's rest-energy, respectively; E is the total energy of the object P, or, as in Einstein formula, the mass-energy of P.

This is namely the mass-energy relation of IOR theory, that is, the observational mass-energy relation of the general observation agent OA(η).

Obviously, the IOR mass-energy relation (5.22) is the same as Einstein's mass-energy relation (5.18) in form, or is isomorphically consistent with Einstein formula E=mc^2. In the theory of IOR, the IOR mass-energy relation E=$m\eta^2$ is referred to as **the General Einstein Formula**.

The IOR mass-energy relation (5.22) generalizes Einstein's mass-energy relation (5.18): the IOR mass-energy relation is the observational energy of the general observation agent OA(η); Einstein's mass-energy is the observational energy of the optical observation agent OA(c), which is a special case of the IOR mass-energy relation, and is only valid if and only if light is the observation medium or OA(η) is the optical observation agent OA(c).

The IOR mass-energy relation will provide us new insight into Einstein formula E=mc^2 and new understanding on the relationship between mass and energy.

As shown in Eqs. (5.18) and (5.22), no matter in the IOR mass-energy relation or in Einstein's mass-energy relation, the so-called mass-energy (E) consists of two parts: one is the rest-energy E_o; the other is the kinetic-energy K.

Based on the IOR mass-energy relation, the theory of OR will clarify that, no matter in the IOR mass-energy relation or in Einstein's mass-energy relation, the rest-energy E_o does not objectively exist and has no real physical effect.

5.3.3 The Rest-Energy E_o: not an Objective Existence

The mass-energy relation $E=m\eta^2$ of IOR theory generalizes Einstein's mass-energy relation $E=mc^2$, in which the total energy E of the inertial moving object P is the observational energy observed with of the general observation agent OA(η), not completely objective and real. Based on the broader perspective of the general observation agent OA(η), the IOR mass-energy relation (5.22) will unveil the mystery of Einstein formula $E=mc^2$, and reveal the essence of Einstein's mass-energy relation (Eq. (5.18)).

It is worth noting that the so-called mass-energy $E=E(\eta,v)$ in the mass-energy relation of IOR theory is a function of the information-wave speed η of the observation agent OA(η) and the motion speed v of the inertial object P. So, it depends both the η and the v. As a matter of fact, the mass-energy E depends in essence on the information-wave speed η of the observation agent OA(η), rather than the motion speed v of the inertial object P.

This suggests that the IOR mass-energy contains observational effect: for the same inertial object P with the same motion speed v, different observation agents have different observational mass energies.

According to the IOR mass-energy relation (5.22), if OA(η) is the idealized observation agent, then

$$\lim_{\eta\to\infty} E_o = \lim_{\substack{\eta\to\infty \\ v\to 0}} E(\eta,v) = \lim_{\substack{\eta\to\infty \\ v\to 0}} \frac{m_o\eta^2}{\sqrt{1-v^2/\eta^2}} = \lim_{\eta\to\infty} m_o\eta^2 = \infty \tag{5.23}$$

Equation (5.23) means that the so-called rest-energy $E_o=E(\eta,0)=m_o\eta^2$ purely depends on the information-wave speed η of observation agent OA(η), and therefore, is not the objectively physical existence.

Actually, the theoretical model $E=mc^2$ (Eq. (5.18)) of the optical observation agent OA(c) derived by Einstein in Sec. 5.3.1 was originally the kinetic-energy formula $K(c,v)=(\Gamma(c,v)-1)m_oc^2$ (Eq. (5.17)) for the inertial moving objects observed with the optical agent OA(c), rather than the so-called mass-energy formula $E=mc^2$ (Eq. (5.18)); the theoretical model $E=m\eta^2$ (Eq. (5.22)) of the general observation agent OA(η) derived by OR theory in Sec. 5.3.2 was originally the kinetic-energy formula $K(\eta,v)=(\Gamma(\eta,v)-1)m_o\eta^2$ (Eq. (5.21)) for the inertial moving objects observed with the idealized agent OA(η), rather than the so-called mass-energy formula $E=m\eta^2$ (Eq. (5.22)).

It is thus clear that both the formula (5.17) deduced by Einstein and the formula (5.21) deduced by OR theory are just the kinetic-energy formulae of inertial moving objects, but not the so-called mass-energy relations. There is no mass-energy E or rest-energy E_o in the objective world. Actually, the so-called mass-energy, including the rest-energy E_o, is just Einstein's conjecture about the kinetic-energy formula (5.17) that he deduced in his special theory of relativity.

Since the rest-energy $E_o=m_oc^2$ or $E_o=m_o\eta^2$ is not objectively physical existence, what exactly does m_oc^2 or $m_o\eta^2$ mean?

Actually, m_oc^2 is only an integral constant of Einstein's kinetic-energy formula (5.17), and does not represent the energy of inertial objects at rest; $m_o\eta^2$ is also an integral constant of the IOR kinetic-energy formula (5.21), and also does not represent the energy of inertial objects at rest.

Now, let's return to the topic of the IOR mass-energy relation (5.21) or the IOR observational kinetic-energy $K(\eta,v)$ in the theory of IOR:

(i) To reexamine Newton's classical kinetic-energy: $K_\infty=K(\infty,v)=m_\infty v^2/2$;
(ii) To reexamine Einstein's relativistic kinetic-energy: $K(c,v)=(\Gamma(c,v)-1)m_oc^2$;
(iii) To reexamine IOR's observational kinetic-energy: $K(\eta,v)=(\Gamma(\eta,v)-1)m_o\eta^2$.

5.3.4 IOR's Observational Kinetic-Energy: with Observational Effects

According to the IOR kinetic-energy formula (5.21), the IOR kinetic-energy is not only relativistic but also observational, which depends on observation agents: different observation agents have different observational kinetic energies.

In the theory of OR, the relativistic or observational kinetic-energy $K=K(\eta,v)$ essentially depends on the information-wave speed η of the general observation agent OA(η), rather than the motion speed v of the inertial object of P.

Suppose that the information-wave speed η of the observation agent OA(η) is greater than the inertial speed v of the observed object P, the formula (5.21) of IOR observational kinetic-energy can be decomposed in Taylor series:

$$\begin{aligned}K(\eta,v)&=\left(\Gamma(\eta,v)-1\right)m_o\eta^2=\left(\frac{1}{\sqrt{1-v^2/\eta^2}}-1\right)m_o\eta^2\\&=\left(\frac{1}{2}\frac{v^2}{\eta^2}+\frac{1\cdot 3}{2\cdot 4}\frac{v^4}{\eta^4}+\frac{1\cdot 3\cdot 5}{2\cdot 4\cdot 6}\frac{v^6}{\eta^6}+\cdots\right)m_o\eta^2=K_\infty+\Delta K(\eta,v)\end{aligned}\tag{5.24}$$

$$\begin{cases}K_\infty=\dfrac{1}{2}m_\infty v^2=\dfrac{1}{2}m_o v^2\\ \Delta K(\eta,v)=\left(\dfrac{1\cdot 3}{2\cdot 4}\dfrac{v^4}{\eta^4}+\dfrac{1\cdot 3\cdot 5}{2\cdot 4\cdot 6}\dfrac{v^6}{\eta^6}+\cdots\right)m_o\eta^2\end{cases}$$

where $K_\infty=m_\infty v^2/2=m_o\,v^2/2$ is the classical kinetic-energy, i.e., the objectively real kinetic-energy of the observed object P, independent of observation and observation agents and has the real effects of kinetic energy; while $\Delta K(\eta,v)$ is purely an observational effect and has no the objectively real effects of kinetic energy.

It is thus clear that $\Delta K(\eta,v)>0$ due to the observational locality ($\eta<\infty$) of the observation agent OA(η). So, the observational kinetic-energy $K(\eta,v)$ observed by the observer O with the observation agent OA(η) contains the unreal kinetic-energy component: $\Delta K(\eta,v)$ that is not the objectively physical existence. The objectively real kinetic-energy K_∞ is only part of $K(\eta,v)$.

The IOR observational kinetic-energy $K(\eta,v)$ is an observed physical quantity of the general observation agent OA(η). Therefore, based on the IOR kinetic-energy formula, we can understand both the essence of Einstein's relativistic kinetic-energy under the optical observation agent OA(c) and the essence of Newton's classical kinetic-energy under the idealized observation agent OA_∞.

5.3.5 Einstein's Relativistic Kinetic-Energy: not Completely Objective and Real

Einstein's relativistic kinetic-energy is the observational kinetic-energy of the optical observation agent OA(c), which contains the observational effects of OA(c), and therefore, is not completely objective and real.

The formula (5.21) of IOR kinetic-energy generalizes Einstein's kinetic-energy formula (5.17): the relativistic kinetic-energy in Einstein's special relativity is only a special case of the observational kinetic-energy in IOR theory, which holds true only under the optical observation agent OA(c).

Obviously, if $\eta \to c$, then the observational kinetic-energy (Eq. (5.21)) of IOR theory strictly converges to Einstein's relativistic kinetic-energy (Eq. (5.17)):

$$\begin{aligned}\lim_{\eta\to c} K(\eta,v) &= \lim_{\eta\to c}\big(\Gamma(\eta,v)-1\big)m_o\eta^2 \\ &= \lim_{\eta\to c}\left(\frac{1}{2}\frac{v^2}{\eta^2}+\frac{1\cdot 3}{2\cdot 4}\frac{v^4}{\eta^4}+\frac{1\cdot 3\cdot 5}{2\cdot 4\cdot 6}\frac{v^6}{\eta^6}+\cdots\right)m_o\eta^2 = K_\infty + \Delta K(c,v) \quad (5.25)\end{aligned}$$

$$\begin{cases} K_\infty = \dfrac{1}{2}m_\infty v^2 = \dfrac{1}{2}m_o v^2 \\ \Delta K(c,v) = \left(\dfrac{1\cdot 3}{2\cdot 4}\dfrac{v^4}{c^4}+\dfrac{1\cdot 3\cdot 5}{2\cdot 4\cdot 6}\dfrac{v^6}{c^6}+\cdots\right)m_o c^2 \end{cases}$$

where K_∞ is Newton's classical kinetic-energy; $\Delta K(c,v)$ is the component of the observational effects of OA(c), and not the objectively physical existence.

Equation (5.25) shows that:

(i) Einstein's relativistic kinetic-energy (Eq. (5.17)) is an optical observation model, in which the relativistic kinetic-energy K is the observational kinetic-energy $K(c,v)$ of the optical observation agent OA(c);

(ii) The optical observation agent OA(c) has the observational locality ($c<\infty$), and therefore, the observational kinetic-energy $K(c,v)$ ($>K_\infty$) of the object P observed with OA(c) is not completely objective and real, and contains the unreal kinetic-energy component $\Delta K(c,v)$.

It is thus clear that the relativistic kinetic-energy of Einstein's special theory of relativity is only an observational physical quantity of the optical agent OA(c), and not completely objective and real.

5.3.6 Newton's Classical Kinetic-Energy: the Objectively Real Kinetic-Energy

Newton's classical kinetic-energy is non-relativistic kinetic-energy, or the observational kinetic-energy of the idealized observation agent OA_∞, that is, the objectively real kinetic-energy without observational effects.

The formula (5.21) of IOR kinetic-energy not only generalizes Einstein's kinetic-energy formula (5.17) but also generalizes the formula $K_\infty = m_\infty v^2/2$ of Newton's classical kinetic-energy.

If $\eta \to \infty$, then the formula (5.21) of IOR kinetic-energy strictly converges to Newton's classical kinetic-energy K_∞ in classical mechanics:

$$\begin{aligned} K_\infty &= \lim_{\eta\to\infty} K(\eta, v) = \lim_{\eta\to\infty}\left(\Gamma(\eta, v) - 1\right) m_o \eta^2 \\ &= \lim_{\eta\to\infty}\left(\frac{1}{\sqrt{1 - v^2/\eta^2}} - 1\right) m_o \eta^2 = \frac{1}{2} m_o v^2 = \frac{1}{2} m_\infty v^2 \quad \left(m_\infty = m_o\right) \end{aligned} \tag{5.26}$$

Equation (5.26) shows that:

(i) Newton's classical kinetic-energy $K_\infty = K(\infty, v)$ is the idealized observational kinetic-energy observed with the idealized observation agent OA_∞;

(ii) The idealized observation agent OA_∞ represents the objective world, has no observational locality, and therefore, the classical kinetic-energy K_∞ of the object P observed with OA_∞ is exactly the objectively real kinetic-energy of P: $K_\infty = m_\infty v^2/2 = m_o v^2/2$, has no the component of observational effects.

So, Newton's classical kinetic-energy $K_\infty = m_\infty v^2/2$ is independent of observation and observation agents, and has the objectively real effects of kinetic energy.

5.4 The Four-Speed in OR Spacetime

Originally, the concept of four-dimensional (4d) speed or four-speed belongs to Einstein's special theory of relativity, which implies the hypothesis of the invariance of light speed, and is linked to the definition of the coordinate framework of Minkowski 4d spacetime (Eq. (1.1) in Chapter).

The concept of four-speed is the extension of three-dimensional (3d) speed or three-speed: from Cartesian 3d space to Minkowski 4d spacetime. Actually, the four-speed in Einstein's special theory of relativity is the four-speed in the observational 4d spacetime $X^{4\mathrm{d}}(c)$ of the optical observation agent OA(c).

Based on the definition of the optical observation agent OA(c) in Eq. (1.1):

$$\mathrm{OA}(c) \triangleq \left\{ \begin{array}{l} X^{4\mathrm{d}}(c) : \left\{ \begin{array}{l} x^0 = ct; \\ x^1 = x,\, x^2 = y,\, x^3 = z \end{array} \right\} \\ \mathrm{d}s^2 = \eta_{\mu\nu} \mathrm{d}x^\mu \mathrm{d}x^\nu \quad \left(\eta_{\mu\nu} = \mathrm{diag}(+1, -1, -1, -1)\right) \end{array} \right\},$$

the four-speed in Minkowski 4d spacetime is defined as

$$\begin{gathered} \left\{ \begin{array}{l} u^\mu = \left(u^0, u^1, u^2, u^3\right) \\ v^\mu = \left(v^0, v^1, v^2, v^3\right) \end{array} \right. \quad \left(u^\mu = \frac{\mathrm{d}x^\mu}{\mathrm{d}\tau},\, v^\mu = \frac{\mathrm{d}x^\mu}{\mathrm{d}t} = \gamma^{-1} u^\mu \quad (\mu = 0, 1, 2, 3) \right) \\ \left(x^0 = ct,\, x^1 = x,\, x^2 = y,\, x^3 = z\right) \end{gathered} \tag{5.27}$$

where $\mathrm{d}\tau$ is the intrinsic time (proper time), $\mathrm{d}t = \mathrm{d}t(c, v)$ is the observational time observed with the optical agent OA(c); u^{μ} can be referred to as 3d **Proper Speed**, and $v^{\mu}=v^{\mu}(c)$ is the observed (observational) 3d speed of the optical agent OA(c); $\eta_{\mu\nu}$=diag(+1,–1,–1,–1) is namely Minkowski metric.

Naturally, the concept of four-speed can be further extended: from Einstein's theory of special relativity to the theory of OR; from the optical observation agent OA(c) to the general observation agent OA(η).

Actually, substituting the information-wave speed η for the speed c of light in Eq. (5.27), the four-speed concept of the optical observation agent OA(c) can be isomorphically and uniformly transformed into the four-speed concept of the general observation agent OA(η), and become the four-speed of OR theory.

According to the definition of the general observation agent OA(η) (Def. 1.1 or Eq. (1.2) in Chapter 1):

$$\mathrm{OA}(\eta) \triangleq \left\{ \begin{array}{l} X^{4\mathrm{d}}(\eta): \left\{ \begin{array}{l} x^0 = \eta t; \\ x^1 = x,\, x^2 = y,\, x^3 = z \end{array} \right\} \\ \mathrm{d}s^2 = \eta_{\mu\nu} \mathrm{d}x^{\mu} \mathrm{d}x^{\nu} \quad \left(\eta_{\mu\nu} = \mathrm{diag}(+1,-1,-1,-1) \right) \end{array} \right\},$$

following the logic of Einstein's special relativity, analogizing the definition of the four-speed in the optical observation agent OA(c), the four-speed in OR theory or the four-speed concept of the general observation agent OA(η) can be defined as

$$\left\{ \begin{array}{l} u^{\mu} = \left(u^0, u^1, u^2, u^3\right) \\ v^{\mu} = \left(v^0, v^1, v^2, v^3\right) \end{array} \right. \quad \left(u^{\mu} = \frac{\mathrm{d}x^{\mu}}{\mathrm{d}\tau},\, v^{\mu} = \frac{\mathrm{d}x^{\mu}}{\mathrm{d}t} = \Gamma^{-1} v^{\mu} \quad \left(\mu = 0,1,2,3\right) \right) \tag{5.28}$$
$$\left(x^0 = \eta t,\, x^1 = x,\, x^2 = y,\, x^3 = z \right)$$

where $\mathrm{d}\tau$ is the intrinsic time (proper time), $\mathrm{d}t=\mathrm{d}t(\eta,v)$ is the observational time observed with the general observation agent OA(η); u^{μ} can be referred to as 3d **Proper Speed**, and $v^{\mu}=v^{\mu}(\eta)$ is the observatioal 3d speed of the general observation agent OA(η); $\eta_{\mu\nu}$=diag(+1,–1,–1,–1) is namely Minkowski metric.

Thus, the concept of the four-speed or 4d-speed (Eq. (5.28)) of the general observation agent OA(η) can be applied to the theory of OR, including the theory of IOR and the theory of GOR.

In **The 2nd volume of OR: Gravitationally Observational Relativity** (GOR), the theory of GOR will employ the four-speed concept of the general observation agent OA(η) to define the **Energy-Momentum Tensor**: $T^{\mu\nu}$, and based on the logical idea of **idealized convergence**, calibrate the coefficient of the GOR field equation to establish the gravitational field equation in the theory of. In particular, GOR' gravitational-field equation will generalize and unify Einstein's field equation and Newton's field equation.

5.5 D' Alembert Operator in OR Theory

Originally, d' Alembert Operator also belongs to Einstein's special theory of relativity, also implies the hypothesis of the invariance of light speed, and is also linked to the definition of the coordinate framework of Minkowski 4d spacetime (Eq. (1.1) in Chapter), which is a second-order partial differential operator of the observational 4d spacetime $X^{4\text{d}}(c)$ of the optical observation agent OA(c).

D' Alembert Operator "□" is the extension of Laplace operator $\Delta=\nabla^2$:

$$\begin{cases} \Delta = \nabla^2 = \dfrac{\partial^2}{\partial x^2} + \dfrac{\partial^2}{\partial y^2} + \dfrac{\partial^2}{\partial z^2} \\ \square = \eta^{\alpha\beta} \dfrac{\partial}{\partial x^\alpha} \dfrac{\partial}{\partial x^\beta} = \dfrac{1}{c^2} \dfrac{\partial^2}{\partial t^2} - \nabla^2 \end{cases} \quad \begin{pmatrix} x^0 = ct,\, x^1 = x,\, x^2 = y,\, x^3 = z \\ \eta^{\alpha\beta} = \operatorname{diag}(+1,-1,-1,-1) \end{pmatrix} \tag{5.29}$$

from Cartesian 3d space (x,y,z) to Minkowski 4d spacetime (x^0,x^1,x^2,x^3), from the idealized agent OA_∞ to the optical agent OA(c).

Thus, Laplace operator "Δ" in Cartesian 3d space is extended to be d' Alembert operator "□" in Minkowski 4d spacetime. Actually, d' Alembert operator "□" is only that of the observational 4d spacetime $X^{4\text{d}}(c)$ of the optical observation agent OA(c).

Based on the definition of the optical observation agent OA(c) in Eq. (1.1):

$$\text{OA}(c) \triangleq \begin{Bmatrix} X^{4\text{d}}(c): \begin{Bmatrix} x^0 = ct; \\ x^1 = x,\, x^2 = y,\, x^3 = z \end{Bmatrix} \\ \text{d}s^2 = \eta_{\mu\nu} \text{d}x^\mu \text{d}x^\nu \quad \left(\eta_{\mu\nu} = \operatorname{diag}(+1,-1,-1,-1)\right) \end{Bmatrix},$$

d' Alembert operator "□", i.e., the second-order partial differential operator of the observational spacetime $X^{4\text{d}}(c)$ of the optical agent OA(c), is defined as

$$\begin{gathered} \square = \frac{\partial}{\partial x^\alpha} \frac{\partial}{\partial x^\beta} \eta^{\alpha\beta} = \frac{\partial^2}{c^2 \partial t^2} - \frac{\partial^2}{\partial x^2} - \frac{\partial^2}{\partial y^2} - \frac{\partial^2}{\partial z^2} = \frac{\partial^2}{c^2 \partial t^2} - \nabla^2 \\ \begin{pmatrix} \nabla^2 = \dfrac{\partial^2}{\partial x^2} + \dfrac{\partial^2}{\partial y^2} + \dfrac{\partial^2}{\partial z^2} \\ x^0 = ct,\, x^1 = x,\, x^2 = y,\, x^3 = z \end{pmatrix} \end{gathered} \tag{5.30}$$

where the speed c of light in vacuum is exactly the information-wave speed of the optical observation agent OA(c); $\eta_{\mu\nu}$=diag(+1,−1,−1,−1) is Minkowski metric; ∇ is the 3d partial differential operator, and $\Delta=\nabla^2$ is namely Laplace operator.

Actually, no matter in Einstein's special relativity, or in electromagnetic theory or wave mechanics, d' Alembert operator "□" is just an operator of the optical observation agent OA(c).

Naturally, d' Alembert operator "□" can be further extended: from Einstein's theory of special relativity to the theory of OR; from the optical observation agent OA(c) to the general observation agent OA(η).

Actually, substituting the information-wave speed η for the speed c of light in Eq. (5.30), d' Alembert operator "□" of the optical observation agent OA(c) can be isomorphically and uniformly transformed into the general d' Alembert operator of in the theory of OR, and become the second-order partial differential operator of the general observation agent OA(η).

According to the definition of the general observation agent OA(η) (Def. 1.1 or Eq. (1.2) in Chapter 1):

$$\mathrm{OA}(\eta) \triangleq \left\{ \begin{array}{l} X^{4\mathrm{d}}(\eta): \left\{ \begin{array}{l} x^0 = \eta t; \\ x^1 = x,\, x^2 = y,\, x^3 = z \end{array} \right\} \\ \mathrm{d}s^2 = \eta_{\mu\nu} \mathrm{d}x^\mu \mathrm{d}x^\nu \ \left(\eta_{\mu\nu} = \mathrm{diag}(+1,-1,-1,-1)\right) \end{array} \right\},$$

following the logic of Einstein's special relativity, analogizing the definition (Eq. (5.30)) of d' Alembert operator in the optical observation agent OA(c), the general d' Alembert operator in OR theory, i.e., the second-order partial differential operator of the general observation agent OA(η), can be defined as

$$\begin{array}{l} \Box = \dfrac{\partial}{\partial x^\alpha} \dfrac{\partial}{\partial x^\beta} \eta^{\alpha\beta} = \dfrac{\partial^2}{\eta^2 \partial t^2} - \dfrac{\partial^2}{\partial x^2} - \dfrac{\partial^2}{\partial y^2} - \dfrac{\partial^2}{\partial z^2} = \dfrac{\partial^2}{\eta^2 \partial t^2} - \nabla^2 \\ \left(\begin{array}{l} \nabla^2 = \dfrac{\partial^2}{\partial x^2} + \dfrac{\partial^2}{\partial y^2} + \dfrac{\partial^2}{\partial z^2} \\ x^0 = \eta t,\, x^1 = x,\, x^2 = y,\, x^3 = z \end{array} \right) \end{array} \tag{5.31}$$

where η is the information-wave speed of the general observation agent OA(η); $\eta_{\mu\nu}$=diag(+1,–1,–1,–1) is Minkowski metric; ∇ is the 3d partial differential operator, and $\Delta=\nabla^2$ is namely Laplace operator.

Thus, the general d' Alembert operator "□" (Eq. (5.31)) of the general observation agent OA(η), can be applied to the theory of OR, including the theory of IOR and the theory of GOR.

In **The 2nd volume of OR: Gravitationally Observational Relativity** (GOR), the deductions of GOR's gravitational-field equation and GOR's information-wave equation will need the 4d second-order partial differential operator "□" (Eq. (5.31)) of OR theory, that is, the general d' Alembert operator of the observational 4d spacetime $X^{4\mathrm{d}}(\eta)$ of the general observation agent OA(η)

6 The Theory of OR Matter Waves

The theory of OR, based on the axiom system with the most basic logical premises, has derived the invariance of time-frequency ratio in Chapter 2, proved the theorem of the invariance of information-wave speeds in Chapter 3, and deduced the integral form of the transformation of IOR spacetime and the law of IOR's speed-addition in Chapter 4. The algebraic form of IOR's spacetime-transformation is isomorphically consistent with the Lorentz transformation, and therefore, referred to as the general Lorentz transformation. Subsequently, in Chapter 5, we have derived IOR's mass-speed relation, defined the concept of IOR's relativistic momentum, and deduced IOR's mass-energy relation $E=m\eta^2$ generalizing Einstein formula $E=mc^2$. So, all relativistic concepts and definitions of IOR theory, as well as all relativistic formulae or relations of IOR theory, can be deduced and built up on the basis of the OR axiom system or the IOR three principles.

At this point, the whole theoretical system of IOR theory has been established.

As stated before, **the theory of Observational Relativity**, the theory of OR for short, is not designed and manufactured for challenging or criticizing Einstein's theory of relativity. It is only an unexpected discovery: it turns out that relativistic effects are observational effects, rather than the objectively physical reality.

However, such an unexpected discover seemingly not only implies the theory of OR relativity, but also the theory of OR matter waves: it turns out that, like relativistic effects, quantum effects are also observational effects.

In this chapter, based on the invariance of time-frequency ratio, the theory of OR deduces the so-called t**he theory of OR matter waves** [26,27].

The theory of OR matter waves links relativity theory and quantum theory together, which generalize not only de Broglie's theory of matter waves, but also the famous formulae that serve as the three cornerstones of quantum mechanics:

(i) The first cornerstone: Planck equation [14-16];
(ii) The second cornerstone: de Broglie relation [17-19];
(iii) The third cornerstone: Schrödinger equation [20].

The theory of OR matter waves heralds the unification of relativity theory and quantum theory.

6.1 The Wave-Like Form of IOR Factor

The definition of time (Def. 2.2 in Chapter 2) is the most basic logical presupposition in the OR axiom system, which is the indispensable logical premise for the theory of OR. The definition of OR time leads to a direct logical consequence: the invariance of time-frequency ratio (Eq. (2.3) in Chapter 2).

It is exactly **the invariance of time-frequency ratio** $\mathrm{d}t/f=\mathrm{d}\tau/f_o$ that links quantum effects with relativistic effects.

According to the invariance of time-frequency ratio (Eq. (2.3)) as well as the OR mass-speed relation (Eq. (5.5)), the IOR factor $\Gamma(\eta)=\mathrm{d}t/\mathrm{d}\tau$ of spacetime transformation can be expressed in the following two forms:

(i) The wave-like form: $$\Gamma(\eta,v)=\frac{\mathrm{d}t(\eta,v)}{\mathrm{d}\tau}=\frac{f(\eta,v)}{f_o}=\frac{1}{\sqrt{1-v^2/\eta^2}} \tag{6.1}$$

(ii) The particle-like form: $$\Gamma(\eta,v)=\frac{\mathrm{d}t(\eta,v)}{\mathrm{d}\tau}=\frac{m(\eta,v)}{m_o}=\frac{1}{\sqrt{1-v^2/\eta^2}} \tag{6.2}$$

where η is the information-wave speed of the general observation agent OA(η), v is the particle speed, i.e., the speed of the observed object P as a matter particle; m and m_o are respectively the observed mass and the rest mass of P as a matter particle, f and f_o are respectively the observed frequency and the rest frequency of P as a matter wave or an information wave.

Equations (6.1-2) suggests that moving objects or observed objects in the theory of OR exhibit the wave-particle duality.

In a sense, the particle-like form $\Gamma=m/m_o$ of the IOR factor leads to the theory of OR relativity; The wave-like form $\Gamma=f/f_o$ of the IOR factor leads to the theory OR matter waves.

Actually, the wave-like form $\Gamma=f/f_o$ of the IOR factor is the representation of the invariance of time-frequency ratio; the particle-like form $\Gamma=m/m_o$ of the IOR factor is the representation of the OR mass-speed relation.

Logically speaking, all relativistic effects and even all quantum effects are related to the **dilation** of the observational time $\mathrm{d}t$: $\mathrm{d}t=\mathrm{d}t(\eta,v)=\Gamma(\eta,v)\mathrm{d}\tau\geq\mathrm{d}\tau$.

The particle-like form $\Gamma=m/m_o$ of the IOR factor represents relativistic effects; the wave-like form $\Gamma=f/f_o$ of the IOR factor represents quantum effects.

Based on the invariance of time-frequency ratio $\mathrm{d}t/f=\mathrm{d}\tau/f_o$ or the wave-like form $\Gamma=\mathrm{d}t/\mathrm{d}\tau=f/f_o$ of the IOR factor, the theory of OR or the theory of IOR is able to deduce the theory of OR matter waves.

The theory of OR matter waves will generalize de Broglie's theory of matter waves, including the core formulae: (i) the general Planck equation $E=h_\eta f$, (ii) the general de Broglie relation $p=h_\eta/\lambda$. The general Planck equation $E=h_\eta f$ will generalize Planck equation $E=hf$; The general de Broglie relation $p=h_\eta/\lambda$ will generalize the de Broglie relation $p=h/\lambda$.

So, Einstein formula $E=mc^2$ and Planck equation $E=hf$, two great formulae, will be generalized and unified by the theory of OR into the theoretical system of OR under the OR axiom system.

6.2 The Frequency-Speed Relation of OR

In the axiom system of OR theory, the conditions of wave-particle duality include the principle of frequency-speed relation, which qualitatively characterizes the relationship between the frequency f of the matter wave or information wave of the observed object P and the particle speed v of P. The OR Frequency-Speed Relation (Eq. (6.1)) is the product of the logical and theoretical derivation of OR theory, which quantitatively characterizes the relationship between the frequency f

of the matter wave or information wave of *P* and the particle speed *v* of *P*.

The OR mass-speed relation (Eq. (6.2)) is a basic relation in the relativistic-effect relations of IOR theory; the OR frequency-speed relation (Eq. (6.1)) is a basic relation in the quantum-effect relations of IOR theory.

Actually, the particle-like form of the IOR factor (Eq. (6.2)) is exactly the OR mass-speed relation (Eq. (5.5)); the wave-like form of the IOR factor (Eq. (6.1)) is exactly the OR frequency-speed relation:

$$f(\eta,v)=\Gamma(\eta,v)\,f_o=\frac{f_o}{\sqrt{1-v^2/\eta^2}} \tag{6.3}$$

where η is the information-wave speed of the general observation agent OA(η), v is the particle speed, i.e., the speed of the observed object *P* as a matter particle; f and f_o are respectively the observed frequency and the rest frequency of *P* as a matter wave or an information wave.

By contrasting the OR frequency-speed relation (Eq. (6.3)) with the OR mass-speed relation (Eq. (5.5) or (6.2)), we know that the OR frequency-speed relation is of both quantum effects and relativistic effects. The frequency $f=f(\eta,v)$ in the OR frequency-speed relation (Eq. (6.3)) is a function of the information-wave speed η of the observation agent OA(η) and the motion speed v of the observed object *P*, depending not only on the v of *P* but also on the η of OA(η), which can be referred to as the observed (observational) frequency of OA(η), containing the observational effects of OA(η): for the same matter wave of the same object *P*, different observation agents present different observational frequencies.

This suggests that both relativistic effects and quantum effects are observational effects, that is caused by the information waves or informons of observation agents.

Suppose that the information-wave speed η of the observation agent OA(η) is greater than the speed v of the moving object *P*, as in the OR mass-speed relation (Eq. (5.5)), the OR frequency-speed relation (Eq. (6.3)) can also be decomposed in terms of Taylor series:

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

$$\begin{cases}\Gamma(\eta,v)=1+\dfrac{1}{2}\dfrac{v^2}{\eta^2}+\dfrac{1\cdot 3}{2\cdot 4}\dfrac{v^4}{\eta^4}+\dfrac{1\cdot 3\cdot 5}{2\cdot 4\cdot 6}\dfrac{v^6}{\eta^6}+\cdots=\Gamma_\infty+\Delta\Gamma(\eta,v) \\ \begin{cases} f_o=\Gamma_\infty f_o \\ \Delta f(\eta,v)=\Delta\Gamma(\eta,v)\,f_o\end{cases} \quad \left(\Gamma_\infty\equiv 1,\ \Delta\Gamma(\eta,v)=\Gamma(\eta,v)-1\right)\end{cases} \tag{6.4}$$

where f_o is the rest frequency of the observed object *P* as a matter wave or an information wave, independent of observation or observation agents; $\Delta f(\eta,v)$ is purely the component of observational effects, depending on observation and observation agents, being an inflated frequency.

For a given speed v of the moving object *P*, the higher the information-wave η of the observation OA(η), the closer the $f(\eta,v)$ is to the rest frequency f_o of *P* as a matter wave or an information wave; on the contrary, the lower the η, the large the $\Delta f(\eta,v)$, and the more significant the observational quantum effects.

It is thus clear that, restricted by the observational locality ($\eta<\infty$) of the observation agent OA(η), $\Delta f(\eta,v)>0$. So, the observational frequency $f(\eta,v)$ of the observer O with OA(η) contains the component of observational effects: $\Delta f(\eta,v)$.

The OR frequency-speed relation (Eq. (6.3)) generalizes the frequency-speed relation in de Broglie's theory of matter waves: de Broglie's frequency-speed relation is only a special case of the OR frequency-speed relation, and can be valid only under the optical observation agent OA(c).

Obviously, if $\eta\to c$, then the OR frequency-speed relation (Eq. (6.3)) strictly converges to the frequency-speed relation in de Broglie's theory of matter waves:

$$\begin{aligned}\lim_{\eta\to c} f(\eta,v) &= \lim_{\eta\to c} \Gamma(\eta,v)\, f_o \\ &= \lim_{\eta\to c} \frac{f_o}{\sqrt{1-v^2/\eta^2}} = \frac{f_o}{\sqrt{1-v^2/c^2}} = \Gamma(c,v)\, f_o > f_o \qquad (6.5)\end{aligned}$$

Equation (6.5) shows that:

(i) De Broglie's frequency-speed relation (Eq. (6.5)) is an optical observation model, in which the quantum frequency f is the observational frequency $f=f(c,v)$ of the optical observation agent OA(c);

(ii) The optical agent OA(c) has the observational locality ($c<\infty$), with an inflated observational frequency $f(c,v)>f_o$, and therefore, de Broglie waves also contain the component of optical observational effects $\Delta f(c,v)$ (>0).

It is thus clear that the quantum frequency f of a de Broglie wave is only an observed (observational) quantity of the optical observation agent OA(c). Therefore, de Broglie waves and even the wave-particle duality in de Broglie's theory of matter waves contain the observational effects of OA(c).

Of course, the root and essence of quantum effects is not entirely due to the observational locality of observation agents or the limited information-wave speeds of observation agents. In addition to the observational locality, observation agents have the observational effects of quantum perturbation: the informons of observation agents have their own masses, momentums, or energies, and therefore, exert the quantum-perturbation effects on observed objects, so that, the observed objects present quantum effects.

6.3 The Invariance of Mass-Frequency Ratio and the Invariance of Energy-Frequency Ratio

According to de Broglie's theory of matter waves: mass means matter and an object of matter means a matter wave; the mass and energy of an object are both proportional to the frequency of its matter wave.

In the theory of OR, an object of matter can also be regarded as a matter wave or an information wave, which also exhibits the wave-particle duality.

The wave-like form of the IOR factor $\Gamma=f/f_o$ suggests that, in the theory of OR, the motion of matter not only has relativistic effects, but also has quantum effects. It is exactly the wave-like form of the IOR factor $\Gamma=f/f_o$ that leads to the formation of the theory of OR matter waves, in which the mass and energy of an object are also proportional to the frequency of its matter waves.

As stated before, the observed (observational) physical quantities in the theory of OR, whether they are of relativistic effects or of quantum effects, are related to the dilation of the observational time $\mathrm{d}t=\mathrm{d}t(\eta,v)$. In the theory of OR matter waves, there are not only the invariance of time-frequency ratio, but also the invariance of mass-frequency ratio and the invariance of energy-frequency ratio.

6.3.1 The Invariance of Mass-Frequency Ratio

For a given observation agent OA(η), by combining the OR mass-speed relation (Eq. (5.5)) and the OR frequency-speed relation (Eq. (6.3)), we get that

$$\frac{m(\eta,v)}{f(\eta,v)}=\frac{m_o}{f_o}=k_\eta \tag{6.6}$$

where η is the information-wave speed of the observation agent OA(η), v is the particle speed of the matter particle or the observed object P, m and m_o are respectively the observed mass and the rest mass of P as a matter particle, f and f_o are respectively the observed frequency and the rest frequency of P as a matter wave or an information wave, k_η is the constant of mass-frequency ratio: the mass of the matter wave per hertz of an informon of OA(η).

Actually, k_η is a constant of the general observation agent OA(η), i.e., the ratio of the informon mass of OA(η) to the informaon frequency of OA(η).

Equation (6.6) can be rewritten as the following mass-frequency formula:

$$m=k_\eta f \tag{6.7}$$

By analogizing Planck equation $E=hf$, it can be seen that, under the general observation agent OA(η), the mass of matter is also **quantized**. However, such mass quantization depends on observation agents, and does not necessarily mean that the mass of matter is quantized. This mass quantization only means that the masses of the informons of observation agents are quantized, and therefore, the observational masses of observation agents are quantized.

The mass-frequency formula (Eq. (6.7)) has a profound implication: restricted by the observation agent OA(η), one cannot detect or observe matter particles with a smaller mass than the informons of OA(η).

The constant $k_\eta=m_o/f_o$ of mass-frequency ratio is that of the informons of the general observation agent OA(η), depending on observation and observation agents. Different observation agents have different constants of mass-frequency ratio:

$$k_\eta=\frac{m_o}{f_o}=\frac{E_o}{\eta^2 f_o}=\frac{h_\eta}{\eta^2}\quad\left(E_o=m_o\eta^2=h_\eta f_o\right) \tag{6.8}$$

where E_o is the rest energy of the observed object P; h_η is constant of energy-frequency ratio, that we will later refer to as **the general Planck constant**.

Naturally, if the observation agent OA(η) is the optical agent OA(c), then we get that $k_\eta = k_c = h/c^2$ of OA(c).

Equation (6.6) can be stated as a principle as follows.

The Invariance of Mass-Frequency Ratio: For a given observation agent OA(η), the ratio of the observed mass m of OA(η) to the observed frequency f of OA(η) is an invariant that is identically equal to the ratio $k_\eta = m_o/f_o$ of the rest mass m_o to the rest frequency f_o.

6.3.2 The Invariance of Energy-Frequency Ratio

For a given observation agent OA(η), by combining the OR mass-energy relation (Eq. (5.22)) and the OR frequency-speed relation (Eq. (6.3)), we get that

$$\frac{E(\eta,v)}{f(\eta,v)} = \frac{E_o}{f_o} = h_\eta \tag{6.9}$$

where η is the information-wave speed of the observation agent OA(η), v is the particle speed of the matter particle or the observed object P, E and E_o are respectively the observed energy and the rest energy of P as a particle or a matter wave, f and f_o are respectively the observed frequency and the rest frequency of P as a matter wave or an information wave, h_η is the constant of energy-frequency ratio: the energy of the matter wave per hertz of an informon of OA(η).

Actually, h_η is a constant of the general observation agent OA(η), i.e., the ratio of the informon energy of OA(η) to the informon frequency of OA(η).

Equation (6.9) can be rewritten as the following energy-frequency formula:

$$E = h_\eta f \tag{6.10}$$

This is **the general Planck equation**, and h_η is **the general Planck constant**.

Planck equation $E=hf$ suggests that the energy of photons is discrete or quantized. Thereby, Planck equation $E=hf$, i.e., Planck's hypothesis of energy quanta, led to the birth of quantum mechanics.

In the same logic, the general Planck equation $E=h_\eta f$ suggests that the energy of the informons of any observation agent OA(η) is discrete or quantized. However, such energy quantization depends on observation agents: different observation agents have different energy quanta, that is, the informons of observation agents.

The energy quantization of the general Planck equation $E=h_\eta f$ does not necessarily mean that the energy of matter is quantized. This energy quantization only means that: the energies of the informons of observation agents are quantized, and therefore, the observational energies of observation agents are quantized.

The general Planck equation (Eq. (6.10)) has a profound implication: restricted by the observation agent OA(η), one cannot detect or observe matter particles with a smaller energy than the informons of OA(η).

It should be pointed out that, the constant $h_\eta=E_o/f_o$ of energy-frequency ratio is that of the informons of the general observation agent OA(η), depending on observation and observation agents. So, different observation agents have different constants of energy-frequency ratio, in other worlds, have different Planck constants:

$$h_\eta=\frac{E_o}{f_o}=\frac{m_o}{f_o}\eta^2=k_\eta\eta^2 \quad \left(E_o=m_o\eta^2=h_\eta f_o\right) \tag{6.11}$$

where E_o is the rest energy of the observed object P.

Naturally, if the observation agent OA(η) is the optical agent OA(c), then the general Planck constant is exactly Planck's constant: $h_\eta=h=6.6260693\times10^{-34}$ J·s. It is thus clear that the Planck constant h is only a constant of the optical observation system, or the observation constant of the optical observation agent OA(c).

Equation (6.9) can also be stated as a principle as follows.

The Invariance of Energy-Frequency Ratio: For a given observation agent OA(η), the ratio of the observed energy E of OA(η) to the observed frequency f of OA(η) is an invariant that is identically equal to the ratio $h_\eta=E_o/f_o$ of the rest energy E_o to the rest frequency f_o.

6.4 The General Planck Equation

Planck equation $E=hf$ is the first cornerstone of quantum mechanics [14-16].

Originally, Planck equation $E=hf$ was a hypothesis of light quanta (photons) proposed by Planck in order to theoretically derive the formula of blackbody radiation [14]. Later, de Broglie extended it to all matter particles and even all moving objects [17-19], not just photons. Planck equation extended by de Broglie is known as de Broglie's second formula: $f=E/h$. It is worth noting that both Planck equation and de Broglie's second formula are only the physical models of the optical observation agent OA(c), and moreover, are only hypotheses or heuristic models. In particular, they are independent of Einstein formula $E=mc^2$, or in other words, independent of Einstein's special theory of relativity.

Now, the theory of OR theoretically derives and generalizes Planck equation.

6.4.1 Deriving the General Planck Equation

In the theory of OR, the IOR factor $\Gamma=f/f_o$ of spacetime transformation has two forms, one of which is the wave-like form of (Eq. (6.1)), and naturally forms the OR frequency-speed relation (Eq. (6.3)). By combining the OR frequency-speed relation (Eq. (6.3)) and the general Einstein formula $E=m\eta^2$ (Eq. (5.22)), the theory of OR matter waves can easily get the general Planck equation:

$$\begin{aligned} E&=m\eta^2=\Gamma(\eta,v)m_o\eta^2=\frac{f(\eta,v)}{f_o}m_o\eta^2 \\ &=\frac{m_o}{f_o}\eta^2 f(\eta,v)=h_\eta f(\eta,v) \quad \left(h_\eta=\frac{m_o}{f_o}\eta^2=k_\eta\eta^2\right) \end{aligned} \tag{6.12}$$

This is exactly the energy-frequency formula (Eq. (6.10)) implied in the invariance of energy-frequency ratio (Eq. (6.9)).

Actually, without the OR mass-energy relation $E=m\eta^2$ (Eq. (5.22)), the theory of OR, or the theory of OR matter waves, can also deduce the general Planck equation $E=h_\eta f$ through the following basic logical approach.

For a given observation agent OA(η), based on the wave-like form of the IOR factor $\Gamma=f/f_o$ of spacetime transformation, we have

$$\begin{aligned}
&\mathrm{d}\Gamma=\frac{1}{f_o}\mathrm{d}f \quad \text{and} \quad \mathrm{d}\Gamma=\frac{\Gamma^3}{\eta^2}v\mathrm{d}v \\
&\text{i.e.,}\quad \Gamma^3 v\mathrm{d}v=\frac{\eta^2}{f_o}\mathrm{d}f \quad \left(\Gamma=\Gamma(\eta,v)=\frac{f(\eta,v)}{f_o}=\frac{1}{\sqrt{1-v^2/\eta^2}}\right)
\end{aligned} \tag{6.13}$$

Based on the same starting point of deducing the OR mass-energy relation $E=m\eta^2$ (Eq. (5.22)), let P be an inertial object: the motion speed v, the total energy $E=K+E_o$, where K is the relativistic kinetic-energy of P and E_o is the rest energy of P. By substituting Eq. (6.13) into the definition of the force F (Eq. (5.20)) and the definition of the kinetic-energy K (Eq. (5.21)), the general Planck equation of the theory of OR matter waves can be logically and theoretically deduced:

$$\begin{aligned}
K&=\int_0^v F\mathrm{d}x \\
&=\int_0^v \frac{\mathrm{d}p}{\mathrm{d}t}\mathrm{d}x=\int_0^v v\mathrm{d}p \\
&=\int_0^v \Gamma^3 m_o v\mathrm{d}v=\int_0^v m_o\frac{\eta^2}{f_o}\mathrm{d}f \\
&=h_\eta f\Big|_0^v=h_\eta\left(f(\eta,v)-f_o\right) \\
&\left(h_\eta=\frac{m_o}{f_o}\eta^2=k_\eta\eta^2;\ \Gamma=\Gamma(\eta,v)=\frac{f(\eta,v)}{f_o}=\frac{1}{\sqrt{1-v^2/\eta^2}}\right)
\end{aligned} \tag{6.14}$$

Let $E_o=h_\eta f_o$ be the rest energy of P in inertial spacetime, then we have

$$K(\eta,v)+E_o=h_\eta\left(f(\eta,v)-f_o\right)+h_\eta f_o=h_\eta f(\eta,v) \tag{6.15}$$

Thus, $E(\eta,v)=K(\eta,v)+E_o$ can be regarded as the total energy of the observed object P in inertial spacetime observed with the observation agent OA(η):

$$E(\eta,v)=h_\eta f(\eta,v) \quad \left(h_\eta=\frac{m_o}{f_o}\eta^2=k_\eta\eta^2\right) \tag{6.16}$$

where η is the information-wave speed of the observation agent OA(η); h_η is the general Planck constant, i.e., the constant of energy-frequency ratio of OA(η), that is consistent with Eq. (6.11).

Equation (6.16) is namely the general Planck equation, which is isomorphically consistent with Planck equation $E=hf$.

6.4.2 Generalizing Planck Equation *E=hf*

Planck equation $E=hf$ is a physical model of the optical observation agent OA(c), while the general Planck equation $E=h_\eta f$ in the theory of OR matter waves is a physical model of the general observation agent OA(η).

The general Planck equation $E=h_\eta f$ (Eq. (6.16)) generalizes Planck equation $E=hf$, and transcends de Broglie's imagination. It extends Planck equation not only from photons to all matter particles, but also more importantly, from the optical observation agent OA(c) to the general observation agent OA(η).

Obviously, $\eta \to c$, then the general Planck equation $E=h_\eta f$ (Eq. (6.16)) strictly converges to Planck equation $E=hf$:

$$\begin{aligned}\lim_{\eta\to c} E(\eta,v) &= \lim_{\eta\to c} h_\eta f(\eta,v) \\ &= h_c f(c,v) = hf \quad \left(h_c = \frac{m_o}{f_o}c^2 = k_c c^2 = h\right)\end{aligned} \tag{6.17}$$

Equation (6.17) shows that Planck equation $E=hf$, including that extended by de Broglie, is the optical observation model of the optical agents OA(c).

Thus, Planck equation $E=hf$ is no longer a hypothesis, but becomes a logical consequence of OR theory, a special case of the general Planck equation $E=h_\eta f$ (Eq. (6.16)), which is true or valid only under the optical agent OA(c).

Now, Einstein formula $E=mc^2$ in relativity theory and Planck equation $E=hf$ in quantum theory, the two great formulae, are unified by OR theory into the same theoretical system under the same axiom system, which implies that relativity theory and quantum theory are moving towards the unification of both. In the theoretical system of OR, Einstein formula $E=mc^2$ and Planck equation $E=hf$ become dual formulae that are the different representations of the energy of matter: Einstein formula $E=mc^2$ represents the energy of matter particles, that is, the energy of matter as particles; Planck equation $E=hf$ represents the energy of matter waves, that is, the energy of matter as matter waves.

It should be pointed out that, since Planck equation $E=hf$ has become the logical consequence of the theoretical system of OR, Planck's law of blackbody radiation [14], as well as Wien approximation [72] and Stefan-Boltzmann's law [73,74], can naturally be derived from the theory of OR matter waves and become the motion equations of matter waves in the theoretical system of OR.

6.4.3 The General Planck Constant h_η

For a long time, it has been believed that the Planck constant h is a cosmic constant, or in other words, one of the most basic physical constants.

However, the theory of OR or the theory of OR matter waves has discovered that: as a matter of fact, the Planck constant h is not a cosmic constant.

In the theory of OR, the general Planck equation $E=h_\eta f$ has an important physical quantity: the general Planck constant h_η. The general Planck constant h_η in Eq. (6.16)), i.e., the constant of energy-frequency ratio in Eq. (6.11), is the observation constant of the general observation agent OA(η), depending on observation and observation agents: different observation agents have different constants h_η of energy-frequency ratio.

Obviously, if $\eta \to c$, then the general Planck constant h_η strictly converges to Planck's constant h:

$$\lim_{\eta \to c} h_\eta = h_c = \frac{m_o}{f_o} c^2 = k_c c^2 = h \tag{6.18}$$

Equation (6.18) shows that the Planck constant h is not a general cosmic constant or one of the most basic physical constants, but rather the constant of energy-frequency ratio of photons. Under the optical observation agent OA(c), $h_\eta = h = 6.6260693 \times 10^{-34}$ J·s is namely the famous Planck constant.

Originally, Planck equation $E=hf$ was Planck's hypothesis of energy quanta or equation of energy quanta, and the Planck constant h could be referred to as the constant of energy quanta (photons).

It should be pointed out that Planck's energy quanta are photons, or more exactly, the informons of the optical agent OA(c). Therefore, the Planck constant h is actually the constant of energy-frequency ratio of OA(c) informons.

It is thus clear that the general Planck constant h_η of the general Planck equation $E=h_\eta f$ is actually the constant of energy-frequency ratio of the informons of the general observation agent OA(η). So, different observation agents have different constants of energy-frequency ratio or different Planck constants.

The theory of OR matter waves has an identical equation: $h_\eta \eta = hc$, a heuristic physical model, which formulizes the relationship between the general Planck constant h_η and the Planck constant h, and will be discussed in Sec. 6.7.

6.5 The General de Broglie Relation

De Broglie relation $p=h/\lambda$ is the second cornerstone of quantum mechanics[17-19].

De Broglie relation $\lambda=h/p$, known as de Broglie's first formula, is the most important formula in de Broglie's theory of matter waves, and the product of de Broglie's combination of Einstein's formula $E=mc^2$ and Planck's equation $E=hf$, which is an optical observation model of the optical observation agent OA(c).

Naturally, by analogizing and following the logic of de Broglie [17-19], the theory of OR can deduce de Broglie relation under the general observation agent OA(η), so-called **the general de Broglie relation**.

6.5.1 Deriving the General de Broglie Relation

In the sense of wave-particle duality, any moving object or observed object P, in addition to the particle speed v of P as a matter particle, should have the phase speed v_p and the group speed v_g of P as a matter wave.

In de Broglie's theory of matter waves, the observation agent OA(η) is the optical agent OA(c), the information-wave is light wave, and therefore, the intrinsic information-wave speed η is the speed c of light in vacuum.

So, the relationship between the particle speed v and the phase speed v_p or the group speed v_g is $v=v_g=c^2/v_p$.

For a given observation agent OA(η), the relationship between the particle speed v and the phase speed v_p or the group speed v_g should be $v=v_g=\eta^2/v_p$ (Cf. Sec. 6.6).

Thus, based on the definition of IOR relativistic momentum $p=mv$ in Eq. (5.12) and the wave-like form of the IOR factor $\Gamma=f/f_o$ of spacetime transformation, the general de Broglie relation for the general observation agent OA(η) can be derived:

$$\begin{aligned} p(\eta,v) &= mv = \Gamma(\eta,v)m_o v \\ &= \frac{f(\eta,v)}{f_o}m_o v = \frac{v_p}{\lambda(\eta,v)}\frac{m_o\eta^2}{f_o}\frac{v}{\eta^2} \\ &= \frac{h_\eta}{\lambda(\eta,v)} \quad \left(h_\eta = \frac{m_o}{f_o}\eta^2 = k_\eta\eta^2;\, v_p = \lambda f,\, v_p v = \eta^2\right) \end{aligned} \tag{6.19}$$

where $p(\eta,v)$ is the observational momentum of the observed object P as a matter particle observed with OA(η), $f(\eta,v)$ is the observational frequency of P as a matter wave observed with OA(η), and $\lambda(\eta,v)=v_p/f(\eta,v)$ is the observational wavelength of P as a matter wave observed with OA(η).

Equation (6.19) is namely the general de Broglie relation, which is isomorphically consistent with de Broglie relation $p=h/\lambda$.

6.5.2 Generalizing de Broglie Relation $p=h/\lambda$

De Broglie relation $p=h/\lambda$ is a physical model of the optical observation agent OA(c), while the general de Broglie relation $p=h_\eta/\lambda$ in the theory of OR matter waves is a physical model of the general observation agent OA(η).

The general de Broglie relation $p=h_\eta/\lambda$ (Eq. (6.19)) generalizes de Broglie relation $p=h/\lambda$, which extends de Broglie relation from the optical observation agent OA(c) to the general observation agent OA(η).

Obviously, $\eta\to c$, then the general de Broglie relation $p=h_\eta/\lambda$ (Eq. (6.19)) strictly converges to de Broglie relation $p=h/\lambda$:

$$\lim_{\eta\to c} p(\eta,v) = \lim_{\eta\to c}\frac{h_\eta}{\lambda(\eta,v)} = \frac{h_c}{\lambda(c,v)} = \frac{h}{\lambda} \quad \left(h_c = \frac{m_o}{f_o}c^2 = k_c c^2 = h\right) \tag{6.20}$$

Equation (6.20) shows that:

(i) De Broglie relation $p=h/\lambda$ is only a special case of the general de Broglie relation $p=h_\eta/\lambda$ (Eq. (6.19)), an optical observation mode, which is valid only under the optical agent OA(c);

(ii) De Broglie relation $p=h/\lambda$ is no longer a heuristic physical model, but a logical consequence of the theory of OR matter waves.

In summary, the theory of OR matter waves has deduced two important formulae of matter waves: the first is the general Planck equation $E=h_\eta f$ (Eq. (6.16)); the second is the general de Broglie relation $p=h_\eta/\lambda$ (Eq. (6.19)).

The general Planck equation and the general de Broglie relation can be stated as

The general de Broglie's first formula: $p(\eta,v)=\hbar_\eta k(\eta,v)$ (6.21)

The general de Broglie's second formula $E(\eta,v)=\hbar_\eta \omega(\eta,v)$ (6.22)

where is $k=2\pi/\lambda$ is the wave number, $\omega=2\pi f$ is the angular frequency, and $\hbar_\eta=h_\eta/2\pi$ is the general reduced Planck constant.

6.6 The Relationships among the Speeds of OR Matter Waves

Einstein's theory of special relativity is the kinematics of matter particles, in which the motion speed of matter is the particle speed v of matter; de Broglie's theory of matter waves is the kinematics of matter waves, in which the motion speed of matter is token as two parts: one is the phase speed v_p of matter waves; the other is the group speed v_g of matter waves.

In the logical deduction above, the general de Broglie relation $p=h_\eta/\lambda$ (Eq. (6.19)) refers without proof to the speed relation: $v=v_g=\eta^2/v_p$. In fact, this is the logical consequence of OR theory, and the speed relation of OR matter-wave theory. Naturally, the speed η in $v=v_g=\eta^2/v_p$ is the information-wave speed of the general observation agent OA(η). In de Broglie's theory of matter waves, light plays the role of the information wave, and the information-wave speed is naturally the speed c of light. So, it holds true for the optical agent OA(c) and for de Broglie's theory of matter waves that $v=v_g=c^2/v_p$.

6.6.1 Deriving the Speed Relations of OR Matter Waves

The theory of OR matter waves is that of the general observation agent OA(η).

Under of the general observation agent OA(η), moving objects also have the wave-particle duality, the observed object P is both particle-like and wave-like. Therefore, the relationship $v=v_g=\eta^2/v_p$ between the particle speed v of P as a matter particle and the phase speed v_p group speed v_g of P as a matter wave can be naturally derived from the theory of OR matter waves.

The Definitions of the Phase Speed v_p and the Group Speed v_g in the Theory of OR Matter Waves:

According to the classical wave theory, the phase speed v_p of P as a matter wave can be defined as $v_p=\omega/k$; the group speed v_g of P as a matter wave can be defined as $v_g=d\omega/dk$. Therefore, based on the general de Broglie's first formula (Eq. (6.21)) and the general de Broglie's second formula (Eq. (6.22)), under the general observation agent OA(η), the phase speed v_p of P as a matter wave and the group speed v_g of P as a matter wave can be redefined as:

$$v_{\mathrm{p}} = \frac{\omega}{k} = \frac{\hbar_\eta \omega}{\hbar_\eta k} = \frac{E}{p} \quad \text{and} \quad v_{\mathrm{g}} = \frac{\mathrm{d}\omega}{\mathrm{d}k} = \frac{\mathrm{d}(\hbar_\eta \omega)}{\mathrm{d}(\hbar_\eta k)} = \frac{\mathrm{d}E}{\mathrm{d}p} \tag{6.23}$$

The Relationship between the Phase Speed v_{p} and the Group Speed v_{g} in the Theory of OR Matter Waves:

Based on the IOR mass-speed relation (Eq. (5.5)), we have that

$$m = \frac{m_o}{\sqrt{1 - v^2/\eta^2}} \quad \text{or} \quad \left(1 - \frac{v^2}{\eta^2}\right) m^2 = m_o^2$$

$$\text{that is} \quad m^2\eta^2 = m_o^2\eta^2 + m^2 v^2 \tag{6.24}$$

According to the OR mass-energy relations $E=m\eta^2$ and $E_o=m_o\eta^2$, as well as the OR momentum $p=mv$, it holds true that

$$\begin{cases} E^2 = E_o^2 + p^2\eta^2 \\ E\mathrm{d}E = \eta^2 p\mathrm{d}p \quad \text{or} \quad \dfrac{E}{p}\dfrac{\mathrm{d}E}{\mathrm{d}p} = \eta^2 \end{cases} \tag{6.25}$$

Thus, under the general observation agent OA(η), there are the following relationships among the particle speed v of P as a particle as well as the phase speed v_{p} and group speed v_{g} of P as a matter wave:

$$v_{\mathrm{p}} v_{\mathrm{g}} = \frac{E}{p}\frac{\mathrm{d}E}{\mathrm{d}p} = \eta^2$$

$$v_{\mathrm{p}} = \frac{E}{p} = \frac{m\eta^2}{mv} = \frac{\eta^2}{v} \quad \text{and} \quad v_{\mathrm{g}} = \frac{\mathrm{d}E}{\mathrm{d}p} = \eta^2 \frac{p}{E} = \eta^2 \frac{mv}{m\eta^2} = v \tag{6.26}$$

In summary, the formulae (Eq. (6.26)) of the speeds (v,v_{p},v_{g}) of the observed object P can be rewritten as follows:

$$v = v_{\mathrm{g}} = \eta^2 / v_{\mathrm{p}} \tag{6.27}$$

This is the speed relation of the theory of OR matter waves.

Perhaps, we should hold the view that the nature of matter particles is the property of mass, and the particle speed v of matter as a particle is the transmission speed of mass; the nature of matter waves is the property of energy, and the group speed v_{g} of matter as a wave is the transmission speed of energy. Equation (6.27) suggests that the transmission speed of the mass m of the moving object P is the same as the transmission speed of the energy E of the moving object P.

Actually, the speed relation (Eq. (6.27)) of the theory of OR matter waves has more profound significance.

6.6.2 Analyzing de Broglie Waves and OR Matter Waves

The matter-wave speed relation $v=v_{\mathrm{g}}=\eta^2/v_{\mathrm{p}}$ (Eq. (6.27)) in the theory of OR matter waves is that of the general observation agent OA(η), which is isomorphically consistent with the speed relation $v=v_g=c^2/v_p$ of de Broglie waves under the optical agent OA(c).

Naturally, the speed relation $v=v_g=\eta^2/v_p$ of OR matter waves generalizes the speed relation $v=v_g=c^2/v_p$ of de Broglie waves, the theory of OR matter waves generalizes de Broglie's theory of matter waves, and OR matter waves generalized de Broglie waves: a de Broglie wave is only a special case of OR matter waves.

Before the theory of OR, people did not understand what the speed c of light in Einstein's theory of special relativity and de Broglie's theory of matter waves mean.

Now, the theory of OR and the theory of OR matter waves tell us that it is the information-wave speed, that is, the speed at which the observation medium of the optical agent OA(c) transmits the spacetime information of observed objects.

Before the theory of OR, people believed that matter waves in de Broglie's theory of matter waves, so-called **de Broglie waves**, was the objectively real waves of observed moving objects.

Now, the theory of OR and the theory of OR matter waves tell us that is not a so-called matter wave of the observed objects P, but the information wave of the optical agent OA(c), which carries and transmits the spacetime information of the observed object P, and can be called as a **Carrier Wave**. The speed relation $v=v_g=\eta^2/v_p$ of OR matter waves means that the information wave of OA(η) has loaded the information of P's particle speed v.

It should be pointed out that, in the speed relation $v=v_g=\eta^2/v_p$ of OR matter waves, the phase speed $v_p=v_p(\eta,v)$ depends on both the particle speed v of the moving object P and the information-wave speed η of the observation agent OA(η). Therefore, the same observed object P has different phase speeds observed by the same observer with different observation agents.

Let OA(η_1) and OA(η_2) ($\eta_2\neq\eta_1$) be two different observation agents observing the same object P moving at the inertial speed v. According to the speed relation (Eq. (6.27)) of the theory of OR matter waves, after loading the spacetime information of P, the group speed v_{g1} observed by OA(η_1) and the group speed v_{g2} observed by OA(η_2) are the same, that is, the particle speed v of P, while the phase speed v_{p1} observed by OA(η_1) and the phase speed v_{p2} observed by OA(η_2) are different:

$$\begin{cases} v_{g1}=v_{g2}=v \\ v_{p1}\neq v_{p2}: \quad v_{p1}=\dfrac{\eta_1^2}{v_{g1}}=\dfrac{\eta_1^2}{v} \quad \text{and} \quad v_{p2}=\dfrac{\eta_2^2}{v_{g2}}=\dfrac{\eta_2^2}{v} \quad (\eta_2\neq\eta_1) \end{cases} \tag{6.28}$$

How could the same moving object and the same matter wave present different phase speeds under different observation agents?

Equations (6.27-28) suggest that no matter de Broglie waves or OR matter waves, they are not the objectively real waves (or physical effects) possessed (or carried) by moving objects themselves, but rather the information-waves of observation agents for transmitting the spacetime information of moving objects.

6.7 GPC Identity: $h_\eta\eta=hc$

Regarding the general Planck constant h_η, the theory of OR matter waves has an important identical equation, i.e., **the identity of general Planck constant**:

$$h_\eta \eta = C \quad (C \equiv hc) \tag{6.29}$$

where h is Planck's constant, h_η is the general Planck constant; c is the speed of light in vacuum, η is the information-wave speed of the general observation agent OA(η); $C \equiv hc$ is naturally a constant.

The identity $h_\eta \eta = hc$ is a heuristic model that is the product of OR theory and Bohr's correspondence principle. It first appeared in the e-Preprint of OR theory in Archive Freedom in 2017 and in CHINA: Sciencepaper Online in 2018 [26,27].

For the convenience of statement, we refer to the identity $h_\eta \eta \equiv hc$ of the General Planck Constant as **GPC identity** for short.

6.7.1 GPC Identity and Bohr's Correspondence Principle

Naturally, GPC identity $h_\eta \eta = hc$ is the extension of the general Planck equation $E = h_\eta f$ of the theory of OR matter waves, where h_η is the general Planck constant.

It should be pointed out that GPC identity $h_\eta \eta = hc$ is the mathematical formulization for Bohr's correspondence principle.

Bohr believed that [71]: there was an intrinsic connection or corresponding relationship between quantum mechanics and classical mechanics, and under certain conditions, both could be transformed into each other.

Based on this basic idea, Bohr proposed the principle of correspondence, which can be simply stated as follows.

Bohr's Correspondence Principle [71]: As the Planck constant $h \to \infty$, the models of quantum mechanics would converge to the corresponding models of classical mechanics.

It is based on the basic idea of the principle of correspondence that Bohr developed and built up the Bohr model of the atom [75-77].

According to the theory of OR matter waves (as stated in Sec. 6.4.3), the general Planck constant h_η in the general Planck equation $E = h_\eta f$ is actually the ratio of the informon energy to the informon frequency of the general observation agent OA(η), which depends on the observation agent OA(η): $h_\eta = h(\eta)$, different observation agents have different Planck constants.

The Planck constant $h = h(c)$ is only a special case of the general Planck constant h_η, that is, the constant of energy-frequency ratio of the informons (photons) of the optical agent OA(c), which is an optical observation constant, rather than a general cosmic constant or one of the most basic physical constants.

This is an important discovery of OR theory.

Regarding Bohr's correspondence principle, it is worth noting that, on the one hand, the quantum case in Bohr's correspondence principle naturally means the case of the optical observation agent: OA(η)=OA(c), the information-wave speed η is exactly the speed c of light, and $h_\eta = h$; on the other hand, the classical case in Bohr's correspondence principle naturally means the case of the idealized observation agent: OA(η)=OA$_\infty$, the information-wave speed η is infinite, and $h_\eta \to 0$.

In summary, we have that

$$h_\eta \to 0 \text{ iff } \eta \to \infty \quad \text{and} \quad h_\eta \to h \text{ iff } \eta \to c \tag{6.30}$$

Under the principle of simplicity, the most concise mathematical relation for **x→0 iff y→∞** should be the formula of inverse proportion: **xy=k** (where k is a constant). Therefore, Eq. (6.30) can be stated as:

$$h_\eta \eta = C \ \ (C \equiv hc) \quad \begin{cases} h_\eta \to 0 \text{ iff } \eta \to \infty \\ h_\eta \to h \text{ iff } \eta \to c \end{cases} \tag{6.31}$$

where C is a constant; naturally, according to $\boldsymbol{h_\eta \to h}$ **iff** $\boldsymbol{\eta \to c}$, we get $\boldsymbol{C \equiv hc}$.

Equation (6.31) is namely **GPC identity**.

GPC identity $h_\eta \eta = hc$ is the product of the theory of OR matter waves, derived from the general Planck equation $E=h_\eta f$ of OR theory. Simultaneously, GPC identity implies the basic idea of Bohr's correspondence principle, which is as stated above the formalization in mathematics for Bohr's correspondence principle.

However, GPC identity has transcended Bohr's correspondence principle.

6.7.2 GPC Identity and the Fine-Structure Constant

In physics, there is a dimensionless constant, that is, the fine-structure constant:

$$\alpha = \frac{v_1}{c} = \frac{\mathrm{e}^2}{2\varepsilon_0 hc} = \frac{\mathrm{e}^2}{4\pi\varepsilon_0 \hbar c} = \frac{1}{137.03599976} \tag{6.32}$$

where e is the elementary charge of electrons, v_1 is the speed of an electron in Bohr's first orbit, ε_0 is the permittivity in vacuum, c is the speed of light in vacuum, h and $\hbar$ are respectively the Planck constant and the reduced Planck constant.

As is known to all, **the fine-structure constant**, or **the electromagnetic fine-structure constant**, is an important fundamental constant of physics, which is defined as the ratio of the speed v_1 of an electron in the first circular orbit of the Bohr model of the atom to the speed c of light in vacuum, and generally denoted by the Greek letter α. In a certain sense, it quantifies the strength of electromagnetic interaction between elementary charged particles.

In the fine-structure constant α, hc as an important component appears in pairs, which seemingly has no special meaning, except for the Planck constant h multiplied by the speed c of light in vacuum: $h \times c$. The constant $C \equiv hc$ in GPC identity seemingly has no relationship with the fine-structure constant α.

According to Sec. 6.7.1, GPC identity $h_\eta \eta = hc$ is a heuristic model based on the principle of simplicity and the principle of correspondence.

Based on the fine-structure constant α (Eq. (6.32)), by analogizing the strength of electromagnetic interaction and the strength of gravitational interaction, we can verify the logical validity of GPC identity $h_\eta \eta = hc$.

Suppose that the electron m_e of a hydrogen atom orbits the nucleus m_H at a linear speed v with an orbital radius r. Let F_E and F_G be the electromagnetic force and the gravitational force between m_H and m_e, respectively, then:

$$F_E = K\frac{\mathrm{e}^2}{r^2} = \frac{\mathrm{e}^2}{4\pi\varepsilon_0 r^2} = m_\mathrm{e}\frac{v_E^2}{r} \quad \text{and} \quad F_G = \frac{Gm_H m_\mathrm{e}}{r^2} = m_\mathrm{e}\frac{v_G^2}{r} \tag{6.33}$$

where G is Newton's constant of universal gravitation, K is Coulomb's constant of electrostatic force, v_E is the orbital speed of the electron m_e under electromagnetic force, and v_G is the orbital speed of the electron m_e under gravitational force, and m_H and m_e are respectively the masses of the electron and the nucleus.

Let κ be the speed of gravity or gravitational radiation. According to Laplace's calculations [43]: $\kappa > 7\times10^6 c$, much greater than the speed c of light[8].

Following the logic of Bohr's building his atomic model, based on the general Planck equation $E=h_\eta f$, we can calculate the orbital radius r_G and orbital speed v_G of the electron m_e attracted by the gravity of the nucleus m_H:

$$r_G = \frac{\hbar_\kappa^2}{Gm_H m_\mathrm{e}^2} \quad \text{and} \quad v_G = \frac{Gm_H m_\mathrm{e}}{\hbar_\kappa} \quad \left(\hbar_\kappa = \frac{h_\kappa}{2\pi}\right) \tag{6.34}$$

where h_κ is the general Planck constant of gravitational observation, i.e., the constant of energy-frequency ratio of the gravitational agent OA(κ) ($\eta=\kappa$).

Define the strength of electromagnetic interaction: $\alpha_E=v_E/c$; analogically, define the strength of gravitational interaction: $\alpha_G=v_G/\kappa$. Then, in the same orbit (with a certain orbital radius r) of the electron m_e, we have

$$\frac{\alpha_G}{\alpha_E} = \frac{F_G}{F_E} = \frac{Gm_H m_\mathrm{e}}{r^2}\frac{4\pi\varepsilon_0 r^2}{\mathrm{e}^2} = \frac{4\pi\varepsilon_0 Gm_H m_\mathrm{e}}{\mathrm{e}^2} \tag{6.35}$$

By substituting $\alpha_E=\alpha$ (Eq. (6.32)) into Eq. (6.35), we get the speed κ of gravity or gravitational radiation:

$$\kappa = \frac{v_G}{\alpha_G} = \frac{v_G F_E}{\alpha_E F_G} = \frac{Gm_H m_\mathrm{e}}{\hbar_\kappa}\frac{4\pi\varepsilon_0\hbar c}{\mathrm{e}^2}\frac{\mathrm{e}^2}{4\pi\varepsilon_0 r^2}\frac{r^2}{Gm_H m_\mathrm{e}} = \frac{\hbar c}{\hbar_\kappa} = \frac{hc}{h_\kappa} \tag{6.36}$$

$$\text{that is} \quad h_\kappa \kappa = hc$$

Obviously, Eq. (6.36) is consistent with GPC identity $h_\eta\eta=hc$.

Of course, Eq. (6.36) does not mean that GPC identity $h_\eta\eta=hc$ has been strictly proven. However, taking advantage of the fine-structure constant α and the gravitational observation agent OA(κ), Eq. (6.36) ($h_\kappa\kappa=hc$) confirms the logical rationality or theoretical validity of GPC identity $h_\eta\eta=hc$.

According to the general Planck equation $E=h_\eta f$, the general Planck constant $h_\eta=h(\eta)$ depends on the observation agent OA(η). So, the Planck constant h is not a

[8] We will discuss the problem of the speed κ of gravitational radiation or gravitational waves in **the 2nd volume of OR: Gravitational Observational Relativity** (the theory of GOR).

cosmic constant, but rather the constant of energy-frequency ratio of photons as the informons of the optical agent OA(c). However, according to GPC identity $h_\eta\eta=hc$, both $h_\eta\eta$ and hc do not depend on observation and observation agents, and therefore, the electromagnetic fine structure constant α in Eq. (6.32) can still be a general cosmic constant, or one of the most basic physical constants.

6.7.3 The Significance of GPC Identity

GPC identity $h_\eta\eta=hc$, as the extension of the general Planck equation $E=h_\eta f$ of the theory of OR matter waves, and as the mathematical formulization for Bohr's correspondence principle, its significance has transcended the general Planck equation $E=h_\eta f$ and the general Planck constant h_η, transcended the theory of OR matter waves, transcended Bohr's correspondence principle, and even transcended relativity theory and quantum mechanics.

I. All Quantum Effects are Observational Perturbation Effects

According to GPC identity $h_\eta\eta=hc$, different observation agents have different information-wave speeds and different constants of energy-frequency ratio, and therefore, have different Planck constants.

For the general observation agent OA(η), the information-wave speed η represents relativistic effects: different observation agents present different degrees of relativistic effects due to different information-wave speeds. For the general observation agent OA(η), the general Planck constant h_η, i.e., the ratio of the energy to frequency of OA(η) informons, represents quantum effects: different observation agents present different degrees of quantum effects due to different constants of energy-frequency ratio.

So, the theory of OR discovers that, like relativistic effects, all quantum effects, including the quantum uncertainty, depend on observation and observation agents, which are observational effects or **observational perturbation effects**.

II. The Quantum Effects of the Idealized Agent OA_∞ vs the Quantum Effects of the Optical Agent OA(c)

According to GPC identity $h_\eta\eta=hc$:

(i) The ratio of the energy to frequency of OA(c) informons is $h_\eta=h_c=h$;
(ii) The ratio of the energy to frequency of OA_∞ informons is $h_\eta=h_\infty=0$.

In Bohr's correspondence principle, the case $h_\eta=h_c=c$ of the general Planck constant h_η is the quantum case is that of the optical agent: OA(c) has quantum physical effects; while the case $h_\eta=h_\infty=0$ of the general Planck constant h_η is that of the idealized agent: OA_∞ has no quantum physical effects.

III. Different Observation Agents Present Different Degrees of Quantum Effects

According to GPC identity $h_\eta\eta=hc$, the quantum effects of the observed object P depend on observation and the observation agent OA(η):

(i) A different observation agent OA(η) has a different h_η, and therefore, P exhibits a different degree of quantum effect;

(ii) The higher the η of OA(η), the smaller the h_η, and the weaker the quantum effects P exhibits, on the contrary, the lower the η of OA(η), the greater the h_η, and the stronger the quantum effects P exhibits

In particular, if $\eta \to \infty$, i.e., the case of the idealized agent OA$_\infty$, then $h_\eta \to 0$, moving objects or the observed object P no longer exhibit quantum physical effects and the quantum uncertainty.

IV. $h_\eta \to \infty$ or $\eta \to 0$

According to GPC identity $h_\eta \eta = hc$: $h_\eta \to \infty$ as $\eta \to 0$, which means that quantum physical effects or the quantum uncertainty are infinite.

According to Heisenberg's uncertainty principle [78], $h_\eta \to \infty$ means that the quantum uncertainty of the observed object P is infinite; and $\eta \to 0$ means that there is no observation agent OA(η) or observation medium $M(\eta)$ to transmit the information on the observed object P for observers. Naturally, for observers, the existence of P is unknowable. So, for observers, everything about P is uncertain.

This is the infinite uncertainty, which conforms to the logic of OR theory and the implication of GPC identity.

V. $h_\eta \to 0$ or $\eta \to \infty$

According to GPC identity $h_\eta \eta = hc$, $h_\eta \to 0$ as $\eta \to \infty$, in which both $\eta \to \infty$ and $h_\eta \to 0$ represent classical physics, or in other words, respectively represent the two idealized observation conditions of Newton's mechanics:

(i) The information-wave speed η of OA$_\infty$ is infinite ($\eta \to \infty$), so OA$_\infty$ has no the observational locality: it takes no time for information to cross space.

(ii) The constant h_η of energy-frequency ratio of OA$_\infty$ informons is infinitesimal ($h_\eta \to 0$), and the momentum of OA$_\infty$ informons is zero, so OA$_\infty$ has no the quantum-perturbation effects: the informons of OA$_\infty$ have no perturbation effects on the observed object P.

GPC identity $h_\eta \eta = hc$ shows that the idealized agent OA$_\infty$ implies both the idealized hypothesis of infinite information-wave speed and the idealized hypothesis of the infinitesimal informon momentum.

$\eta \to \infty$ means that the information-wave speed η of OA$_\infty$ is infinite, so that OA$_\infty$ has no observational locality and has no observational relativistic effects; $h_\eta \to 0$ means that the energy-frequency ratio h_η of OA$_\infty$ informons is infinitesimal, so that the energy of the information wave of OA$_\infty$ is continuous rather than discrete, and OA$_\infty$ has no observational perturbation effects.

So, in the observational spacetime $X^{4d}{}_\infty$ of the idealized agent OA$_\infty$, there are neither the relativistic effects caused by observational locality nor the quantum effects caused by observational perturbation.

6.8 The General Schrödinger Equation

De Broglie's theory of matter waves is the second cornerstone of quantum theory, in which matter waves mean quantum effects.

Inspired by de Broglie's theory of matter waves, Schrödinger developed and built up the following wave equation:

$$\mathrm{i}\hbar\frac{\partial\Psi}{\partial t}=-\frac{\hbar^2}{2m}\nabla^2\Psi+V\Psi\quad\left(\hbar=\frac{h}{2\pi}\right)\tag{6.37}$$

where m is the mass of the observed particle P, $\hbar$ Is the reduced Planck constant, Ψ is the wave function, and V is the potential function.

This formula (Eq. (6.37) is exactly the famous Schrödinger equation [20], which is the third cornerstone of quantum mechanics.

Naturally, like Planck equation $E=hf$ and the de Broglie relation $p=h/\lambda$, Schrödinger equation (Eq. (6.37)) also belongs to the physical models of optical observation, and the corresponding observation agent is the optical agent OA(c); like de Broglie's matter waves, the OR matter waves also mean quantum effects.

In **the 2nd volume of OR: Gravitational Observational Relativity** (the theory of GOR), the theory of OR proposes a principle, so-called **the principle of general correspondence**. Based on the principle of general correspondence, by substituting the general Planck constant h_η for the Planck constant h, the theory of OR matter waves can extend Schrödinger equation (Eq. (6.37)) of the optical observation agent OA(c) to the general observation agent OA(η), and develop **the general Schrödinger equation** of the general observation agent OA(η):

$$\mathrm{i}\hbar_\eta\frac{\partial\Psi}{\partial t}=-\frac{\hbar_\eta^2}{2m}\nabla^2\Psi+V\Psi\quad\left(\hbar_\eta=\frac{h_\eta}{2\pi}\right)\tag{6.38}$$

where m is the observational mass of the particle P observed with the general observation agent OA(η), $\hbar_\eta$ is the general reduced Planck constant, $\Psi=\Psi(\eta)$ is the general wave function, and V is the potential function.

The general Schrödinger equation (Eq. (6.38)) in the theory of OR matter waves generalizes Schrödinger equation (Eq. (6.37)): $h_\eta\to h_c=h$ as OA(η)→OA(c) or $\eta\to c$, then the general Schrödinger equation is exactly the Schrödinger equation. In particular, according to GPC identity $h_\eta\eta=hc$, $h_\eta\to 0$ as OA(η)→OA_∞ or $\eta\to\infty$, then, in the general Schrödinger equation, $\Psi\to 0$, which suggests that the observed particle P no longer exhibits wave effects or wave properties.

According to GPC identity $h_\eta\eta=hc$, the general Schrödinger equation (Eq. (6.38)) can be rewritten as

$$\begin{cases}\mathrm{i}\hbar\dfrac{c}{\eta}\dfrac{\partial\Psi}{\partial t}=-\dfrac{\hbar^2}{2m}\dfrac{c^2}{\eta^2}\nabla^2\Psi+V\Psi\\ \Psi\to 0\ \text{ if }\ \eta\to\infty\end{cases}\tag{6.39}$$

So, in the free spacetime, under the idealized observation agent OA_∞, matter particles would no longer have quantum effects or quantum uncertainty.

6.9 The Principle of General Uncertainty

Based on GPC identity $h_\eta\eta=hc$, the theory of OR discovers that: **all quantum effects are observational perturbation effects**. In particular, based on GPC identity $h_\eta\eta=hc$, the theory of OR or the theory of OR matter waves can analyze the uncertainty in quantum theory and reveal the essence of the uncertainty in Heisenberg's uncertainty principle.

In 1927, Heisenberg established the principle of uncertainty [78]:

$$\sigma_x\sigma_p \geq \frac{\hbar}{2} = \frac{h}{4\pi} \quad \left(\hbar = \frac{h}{2\pi}\right) \tag{6.40}$$

where σ_x is the standard deviation of the position x of the observed object P, σ_p is the standard deviation of the momentum p of P, h is the Planck constant, and $\hbar$ is the reduced Planck constant.

Thus, Heisenberg's uncertainty principle can be stated as follows.

The Principle of Uncertainty: Observers cannot accurately measure both the position x and the momentum p of a matter particle at the same time.

The mainstream school of physics and the mainstream school of quantum mechanics believe that the uncertainty of moving matter particles is the essential characteristic of the objective world.

However, it should be pointed out that: what we are discussing is not the problem of whether there exists uncertainty in the objective world, or whether the uncertainty is the essential characteristic of the objective world, but rather the problem of what does Heisenberg's uncertainty principle mean.

Based on GPC identity $h_\eta\eta=hc$, the theory of OR discovers that the so-called **uncertainty** in Heisenberg's uncertainty principle is actually related to observation and depends on observation agents: under different observation agents, moving objects or observed objects exhibit different degrees of uncertainty.

This suggest that Heisenberg's uncertainty in the principle of uncertainty is an observational effect: a sort of observational uncertainty.

Actually, Heisenberg's uncertainty in the principle of uncertainty is only the observational uncertainty of the optical observation agent OA(c), which only holds true if the observation agent OA(η) is the optical agent OA(c).

Taking the advantage of the principle of general correspondence developed in **the 2nd volume of OR: Gravitational Observational Relativity** (the theory of GOR) and substituting the general Planck constant h_η for the Planck constant h, the theory of OR matter waves can extend Heisenberg's uncertainty principle from the optical agent OA(c) to the general observation agent OA(η), and develop **the principle of general uncertainty** under the general observation agent OA(η):

$$\sigma_x\sigma_p \geq \frac{\hbar_\eta}{2} = \frac{h_\eta}{4\pi} \quad \left(\hbar_\eta = \frac{h_\eta}{2\pi}\right) \tag{6.41}$$

where σ_x is the standard deviation of the position x of the observed object P, σ_p is the standard deviation of the momentum p of P, h_η is the general Planck constant, and $\hbar_\eta$ is the general reduced Planck constant.

Thus, the principle of general uncertainty of OR theory can be stated as follows.

The Principle of General Uncertainty: Let OA(η) be an observation agent ($\eta<\infty$), according to Eq. (6.41), the observers of OA(η) cannot accurately measure both the position x and the momentum p of a matter particle at the same time.

The principle of general uncertainty in the theory of OR generalizes the Heisenberg's uncertainty principle: $h_\eta \to h_c = h$ as OA(η)$\to$OA(c) or $\eta \to c$, then the principle of general uncertainty of OR matter-wave theory is exactly the Heisenberg's uncertainty principle.

Based on GPC identity $h_\eta \eta = hc$, the principle of general uncertainty (Eq. (6.41)) in the theory of OR matter waves can be rewritten as

$$\sigma_x \sigma_p \geq \frac{\hbar_\eta}{2} = \frac{h_\eta}{4\pi} = \frac{h}{4\pi}\frac{c}{\eta} \tag{6.42}$$

According to Eq. (6.42), the principle of general uncertainty of OR theory suggests that actually the uncertainty of quantum mechanics is also an observational effect, depending on observation agents: for a given observation agent OA(η), the higher the information-wave speed η, the smaller the observational uncertainty; in particular, under the idealized agent OA_∞, $\eta \to \infty$, the so-called quantum uncertainty would disappear from our observations and experiments.

Perhaps because of this, in Galileo's doctrine and Newton's theory, spacetime and matter motion has no uncertainty.

It is thus clear that, according to the principle of general uncertainty (Eq. (6.41-42)), the essence of quantum uncertainty is observational uncertainty.

6.10 All Quantum Effects are Observational Effects

The theory of OR matter waves tells us that: **de Broglie waves, the so-called matter waves, do not objectively physical existence**.

The theory of OR matter waves reveals the essence of quantum effects: **all quantum effects, including the uncertainty in Heisenberg's uncertainty principle, are observational perturbation effects**.

All relationships or formulae in the theory of OR matter waves, including

(i) The invariance of time-frequency ratio: $\mathrm{d}t_\eta/f_\eta = \mathrm{d}\tau/f_o$;

(ii) The invariance of mass-frequency ratio: $m_\eta/f_\eta = m_o/f_o$;

(iii) The invariance of energy-frequency ratio: $E_\eta/f_\eta = E_o/f_o$;

(iv) The OR frequency-speed relation: $f_\eta = f_o/\surd(1-v^2/\eta^2)$;

(v) The speed relation of OR matter waves: $v = v_\mathrm{g} = \eta^2/v_\mathrm{p}$;

(vi) The general Planck equation: $E = h_\eta f$;

(vii) The general de Broglie relation: $p = h_\eta/\lambda$;

(viii) The general Schrödinger equation: $\mathrm{i}\hbar_\eta \partial\Psi/\partial t = -(\hbar_\eta^2/2m)\nabla^2\Psi + V\Psi$;

(ix) The principle of general uncertainty: $\sigma_x\sigma_p \geq \hbar_\eta/2$; and

(x) GPC identity: $h_\eta\eta = C$ ($C \equiv hc$),

depend on observation, involving observation media, involving observation agents, and involving the information-wave speeds of observation agents.

So, all quantum physical quantities in the theory of OR matter waves are observed or observational physical quantities $U=U(\eta,v)$ that depend on observation agents OA(η): under different observation agents, the same moving particle or the same observed object exhibits different degrees of quantum effects and uncertainties; in other words, under different observation agents, the same moving particle or the same observed object exhibits different matter waves.

This shows that:

(i) The so-called quantum effects of matter particles are observational effects; Heisenberg's uncertainty is only observational uncertainty;

(ii) The so-called matter waves that matter particles present are the information waves of observation agents, rather than the objectively physical existence or the intrinsic waves of matter particles.

In the theoretical models of quantum mechanics, all quantum effects, including the uncertainty of matter motion, are observational perturbation effects.

The theory of OR matter waves is that of the general observation agent OA(η); while de Broglie's theory of matter waves, and even the whole theoretical system of quantum mechanics, are only that of the optical observation agent OA(c).

So, the theory of OR matter waves generalize the basic formulae of de Broglie's theory of matter waves and even quantum mechanics, including Planck equation, de Broglie relation, Schrödinger equation, and even the uncertainty inequality (Eq. (6.40)) of Heisenberg's uncertainty principle.

If $\eta \to c$ or OA(η)$\to$OA(c), then $h_\eta \to h_c = h$, and all the relationships or formulae in the theory of OR matter waves are correspondingly reduced to that of de Broglie's theory of matter waves or quantum mechanics.

This shows that:

(i) The quantum effects (including uncertainty) in de Broglie's theory of matter waves and even the whole theoretical system of quantum mechanics are all optical observation effects, that is, the quantum effects in the sense of optical observation or the uncertainty in the sense of optical observation.

(ii) The so-called de Broglie waves are actually the information waves of the optical observation agent OA(c).

In particular, Galileo's doctrine and Newton's mechanics are the theory of the idealized observation agent OA_∞.

If $\eta \to \infty$ or OA(η)$\to \mathrm{OA}_\infty$, then $h_\eta \to 0$, and all the relationships or formulae in the theory of OR matter waves are reduced to that of classical mechanics, and the moving particles or observed objects no longer exhibit observational quantum effects or observational uncertainty. As what GPC identity $h_\eta \eta = hc$ has clarified, in the observational spacetime $X^{4d}{}_\infty$ of the idealized agent OA_∞, there is no relativistic effects caused by the observational locality ($\eta<\infty$) nor the quantum effects caused by the observational perturbation ($h_\eta>0$).

So, all quantum effects would disappear as $\eta \to \infty$.

This indicates that matter particles themselves have no the so-called de Broglie waves, and have no the so-called quantum effect or uncertainty described in de Broglie's theory of matter waves and quantum mechanics.

However, it is worth noting that the so-called **All Quantum Effects** here refer to the quantum effects or uncertainty of all relationships or physical quantities in quantum mechanics, and refer to the quantum effects or uncertainty caused by the perturbation exerted by the informons of observation agents on observed objects. So, the quantum effects described in quantum mechanics including de Broglie's theory of matter waves are only the observational perturbation effects.

According to the theory of OR, both the relativistic effects in relativity theory and the quantum effects in quantum theory are observational effects.

However, the difference between relativistic effects and quantum effects is that: the relativistic effects in relativity theory are purely apparent phenomena, and do not represent the objectively physical changes of observed objects due to observation; the quantum effects in quantum theory are not apparent phenomena, but rather the objectively physical changes of observed objects due to being perturbed by the informons of observation agents.

In this sense, the quantum effects in quantum theory, including the uncertainty of matter motion, are objectively physical reality.

In any case, the idealized observation agent OA_∞ is extremely idealized, in which the idealized conditions are unrealistic: a realistic observation agent $OA(\eta)$ would have no information wave with infinite speed ($\eta<\infty$) and would have no informon with infinitesimal momentum ($p_\eta=h_\eta/\lambda_\eta>0$). Particularly, in the objective and real physical world, the spacetime environment of observed objects is not the vacuum or the free spacetime. Therefore, in addition to the informons of observation agents, observed objects will inevitably be perturbed by other electromagnetic fields or gravitational field, or other matter particles, and present additional quantum effects and uncertainties.

It should be pointed out that such quantum effects and quantum uncertainty are not included in the theoretical models of quantum mechanics.

6.11 Toward the Unity of Quantum Theory and Relativity Theory

Originally, the theory of observational relativity, the theory of OR for short, was that about the relativistic problems of spacetime and matter motion. Its original intention did not involve the problem of quantum effects.

However, based on the axiom system of OR, starting from the most basic logical premises, the theory of OR has been endowed with the high degree of generality and unity. The theory of OR not only unifies Einstein's theory of relativity and Newton's classical mechanics, but also deduces the theory of OR matter waves, integrates de Broglie's theory of matter waves and even the fundamental formulae of quantum mechanics into the theoretical system of OR, marching towards the unification of quantum theory and relativity theory.

Einstein formula $E=mc^2$ and Planck equation $E=hf$ originally belong to different theoretical systems: Einstein formula $E=mc^2$ is one of formulae in relativity theory, rooted from Einstein's hypothesis of the invariance of light speed; Planck equation $E=hf$ is one of formulae in quantum mechanics, being Planck's hypothesis of energy quanta and the first cornerstone of quantum mechanics.

As stated above, based on the definition of time (Def. 2.2 in Chapter 2), the IOR factor Γ of spacetime transformation obtains two forms:

(i) The wave-like form: $\Gamma=f/f_o$ (Eq. (6.1));
(ii) The particle-like form: $\Gamma=m/m_o$ (Eq. (6.2)).

The particle-like form of the IOR factor $\Gamma=m/m_o$, i.e. the OR mass-speed relation $m=m_o/\sqrt{(1-v^2/\eta^2)}$, leads to the OR mass-energy relation, that is, so-called **the general Einstein formula**: $E=m\eta^2$, generalizing Einstein formula $E=mc^2$. The wave-like form of the IOR factor $\Gamma=f/f_o$, i.e. the OR frequency-speed relation $f=f_o/\sqrt{(1-v^2/\eta^2)}$, leads to so-called **the general Planck equation**: $E=h_\eta f$, generalizing Planck equation $E=hf$.

So, Einstein formula $E=mc^2$ and Planck equation $E=hf$, two great formulae, have been unified into the theoretical system of OR under the OR axiom system.

This betokens the unification of relativity theory and quantum theory.

Actually, the IOR factor of spacetime transformation in the wave-like form originates from the most direct logical inference of the definition of time (Def. 2.2): the invariance of time-frequency ration ($\mathrm{d}t/f=\mathrm{d}\tau/f_o$). It is the invariance of time-frequency ratio that links quantum effects and relativistic effects together, and leads to the formation of the OR matter-wave theory.

The theory of OR matter waves is not a simple repetition of de Broglie's theory of matter waves, but the development of de Broglie's theory of matter waves and quantum mechanics. The theory of OR matter waves generalizes de Broglie's theory of matter waves, as well as the basic relationships or formulae of quantum theory, including Planck equation [14-16], de Broglie relation [17-19], Schrödinger equation [20], and the uncertainty inequality in Heisenberg's uncertainty principle [78].

As shown in Tab. 6.1, the theory of OR matter waves demonstrates the high degree of generality and unity of OR theory.

In Tab. 61, the first column lists the formulae of OR matter-wave theory for the general observation agent OA(η); the second column lists the formulae of de Broglie's matter-wave theory for the optical observation agency OA(c). According to the first and second columns of Tab. 6.1, if $\eta\to c$ or OA(η)$\to$OA(c), then all the formulae of OR matter-wave theory strictly converge to the corresponding formulae of de Broglie's matter-wave theory.

In particular, as shown in Tab. 6.1, the theory of OR matter waves generalizes the most fundamental formulae of quantum theory:

(i) If $\eta\to c$, then the general Planck equation $E=h_\eta f$ converges to Planck equation $E=hf$ (Eq. (6.17));

(ii) If $\eta\to c$, then the general de Broglie relation $p=h_\eta/\lambda$ converges to de Broglie relation $p=h/\lambda$ (Eq. (6.20));

(iii) If $\eta \to c$, then the general Schrödinger equation $\mathrm{i}\hbar_\eta \partial \Psi/\partial t = -(\hbar_\eta^2/2m)\nabla^2 \Psi + V\Psi$ converges to Schrödinger equation $\mathrm{i}\hbar\partial\Psi/\partial t = -(\hbar^2/2m)\nabla^2\Psi + V\Psi$;

(iv) If $\eta \to c$, then the principle of general uncertainty $\sigma_x\sigma_p \geq \hbar_\eta/2$ converges to Heisenberg's uncertainty principle $\sigma_x\sigma_p \geq \hbar/2$ (Eq. (6.40)).

This indicates that the whole theoretical system of de Broglie's theory of matter waves, as well as the most fundamental formulae or principles of quantum mechanics, have been integrated into the theory of OR.

So, the theory of OR is moving towards the unification of relativity theory and quantum theory.

Table 6.1 The Theory of OR Matter Waves:
Generalizing de Broglie's Theory of Matter Waves and even Newton's Mechanics

OR Matter Waves (OA(η) and h_η)	de Broglie Matter Waves (OA(c): $\eta \to c$; $h_\eta \to h$)	Classical Physical Models (OA$_\infty$: $\eta \to \infty$; $h_\eta \to 0$)
GPC Identity: $h_\eta \eta = hc:\ h_\eta = hc/\eta$	$h_\eta \eta = hc:\ h_c = \dfrac{hc}{c} = h$	$h_\eta \eta = hc:\ h_\infty = \lim\limits_{\eta\to\infty}\dfrac{hc}{\eta} = 0$
The Invariance Time-Frequency Ratio: $\mathrm{d}t_\eta / f_\eta = \mathrm{d}\tau / f_o(\eta,0)$	$\mathrm{d}t_c / f_c = \mathrm{d}\tau / f_o(\eta,0)$	$\mathrm{d}t_\infty = \mathrm{d}\tau;\ f_\infty = f_o = \infty$ The f_o and f_∞ has no physical significance.
The Invariance Mass-Frequency Ratio: $m_\eta / f_\eta = m_o / f_o(\eta,0)$	$m_c / f_c = m_o / f_o(\eta,0)$	$m_\infty = m_o;\ f_\infty = f_o = \infty$ The f_o and f_∞ has no physical significance.
The Invariance Energy-Frequency Ratio: $E_\eta / f_\eta = E_o / f_o(\eta,0)$	$E_c / f_c = E_o / f_o(\eta,0)$	$E_\infty = E_o = \infty;\ f_\infty = f_o = \infty$ The energy-frequency ratio has no physical significance.
Frequency-Speed Relation: $f_\eta = f_o \big/ \sqrt{1 - v^2/\eta^2}$	$f_\eta = \dfrac{f_o}{\sqrt{1 - v^2/c^2}}$	$f_\infty = f_o = \infty$ The frequency-speed relation has no physical significant.
The Speed Relation of Matter Waves: $v = v_\mathrm{g} = \eta^2 / v_\mathrm{p}$	$v = v_\mathrm{g} = \dfrac{c^2}{v_\mathrm{p}}$	$v = v_\mathrm{g}$ and $v_\mathrm{p} = \infty$ The phase speed v_p has no physical significance.
The General Planck Equation: $E(\eta,v) = h_\eta f_\eta$	$E(c,v) = h_c f_c = hf_c$	$K_\infty = \lim\limits_{\eta\to\infty}(\Gamma - 1)h_\eta f_o = \dfrac{1}{2}m_\infty v^2$ It is exactly Newton's classical kinetic energy.
The General de Broglie Relation: $p(\eta,v) = h_\eta / \lambda_\eta$	$p(c,v) = \dfrac{h_c}{\lambda_c} = \dfrac{h}{\lambda_c}$	$p_\infty = \lim\limits_{\eta\to\infty} h_\eta / \lambda_\eta = m_\infty v$ It is exactly Newton's classical momentum.

The General Schrödinger equation: $$\mathrm{i}\hbar_\eta \frac{\partial \Psi}{\partial t} = -\frac{\hbar_\eta^2}{2m}\nabla^2\Psi + V\Psi$$	$$\mathrm{i}\hbar \frac{\partial \Psi}{\partial t} = -\frac{\hbar^2}{2m}\nabla^2\Psi + V\Psi$$	$$\Psi_\infty = \lim_{\eta\to\infty}\Psi(\eta) = 0$$ The properties of waves and the effects of quantum disappear accordingly.
The Principle of General Uncertainty: $$\sigma_x\sigma_p \le \frac{\hbar_\eta}{2} = \frac{h}{2\pi}\frac{c}{\eta}$$	$$\sigma_x\sigma_p \le \frac{\hbar_c}{2} = \frac{h}{4\pi}$$	$$\sigma_x\sigma_p \le \frac{\hbar_\infty}{2} = 0 \ \ (\hbar_\infty = 0)$$

in which, OA(η) is the general observation agent, η is the information-wave speed of OA(η); OA(c) is the optical agent, OA_∞ is the idealized agent; $d\tau$ is the intrinsic time-element, dt is the observed time-element, v is the particle speed of the observed object P, v_g is the group speed of P, v_p is the phase speed of P; $f_o=f_o(\eta,0)$ is the rest frequency, f is the observed frequency; λ is the observed wavelength, $\lambda f=v_p$; m_o is the rest mass, m is the observed mass; $E_o=E_o(\eta,0)$ is the rest energy, E is the observed energy; K is the observed kinetic energy, K_∞ is the classical kinetic energy; p is the observed momentum, p_∞ is the classical momentum; h is Planck's constant, h_η is the general Planck constant, c is the speed of light in vacuum; σ_x is the standard deviation of the position x of the observed object P, σ_p is the standard deviation of the momentum p of P; $\Psi=\Psi(\eta)$ is the wave function of the general Schrödinger equation

The first column: the theory of OR matter waves for the general observation agent OA(η);
The second column: de Broglie's theory of matter waves for the optical agent OA(c);
The third column: the classical models of Newton's mechanics for the idealized agent $OA\infty$.

Note: (i) The theory of OR matter waves is that of the general observation agent OA(η), generalizing de Broglie's theory of matter waves for the optical agent OA(c). As $\eta\to c$, all the relationship or formulae in the theory of OR matter waves converge to that in de Broglie's theory of matter waves; (ii) The formulae of OR matter-wave theory generalizes that of Newton's mechanics for the idealized agent OA_∞. As $\eta\to\infty$, all the formulae in the theory of OR matter waves converge to that of classical mechanics, and are logically consistent with Newton's theory of classical mechanics.

6.12 Toward the Unity of Quantum Mechanics and Classical Mechanics

Obviously, the theory of OR matter waves is isomorphically consistent with de Broglie's theory of matter waves, so we are able to anticipate that the theory of OR matter waves will generalize de Broglie's theory of material waves. However, we may not be able to anticipate the correspondence or logical consistency between the theory of OR matter waves and Newton's mechanics. Actually, the models or formulae of OR matter-wave theory are also isomorphically consistent with the corresponding models or formulae of classical mechanics.

On the basis of the most basic axioms system, starting from the most basic logical premises, the theory of OR matter waves is marching towards the unification of quantum mechanics and classical mechanics.

As shown in Tab. 6.1, the theory of OR matter waves not only generalizes de Broglie's theory of matter waves and the basic formulae of quantum mechanics, moving towards the unification of quantum theory and relativity theory, but also demonstrates the high degree of logical consistency with Newton's mechanics, moving towards the unification of quantum physics and classical physics.

The third column of Tab. 6.1 lists the corresponding formulae of classical physics for the idealized agent OA_∞. According to the first and third columns of Tab. 6.1, if $\eta\to\infty$ or $OA(\eta)\to OA_\infty$, then all the formulae (as listed in Sec. 6.10) of OR matter-wave theory strictly converge to the corresponding formulae of classical physics, being logically consistent with Newton's mechanics.

GPC Identity: $h_\eta\eta=hc$

There is a unique identity in the theory of OR matter waves, i.e., **the identity of general Planck constant**, or **GPC identity** for short, which the generalization and formulization of Bohr's correspondence principle.

GPC identity $h_\eta\eta=hc$ suggest that: different observation agents, lead to different quantum systems or different quantum models, have different Planck constants, present different degrees of quantum effects; in particular, the idealized observation agent OA_∞ leads to classical systems or classical models, the corresponding Planck constant h_∞ is zero. So, GPC identity $h_\eta\eta=hc$ reflects the corresponding relationship between quantum physics and classical physic: $h_\eta\to 0$ as $\eta\to\infty$.

GPC identity $h_\eta\eta=hc$ indicates that: as $\eta\to\infty$, the quantum models of the general observation agent $OA(\eta)$ would converge to the classical physical models of the idealized observation agent OA_∞.

According to GPC identity $h_\eta\eta=hc$, the general Planck constant h_η of the general observation agent $OA(\eta)$ varies with the information-wave speed η: $h_\eta=h(\eta)$. In particular, the general Planck constant of the optical agent $OA(c)$ ($\eta=c$) is exactly Planck's constant: $h_\eta=h(c)=h$; the general Planck constant of the idealized agent OA_∞ ($\eta=\infty$) tends to zero: $h_\eta=h(\infty)=0$.

Therefore, the general Planck constants of $OA(c)$ and OA_∞ can be formulated as:

$$\begin{cases} \mathrm{OA}(\eta): \quad h_\eta = h(\eta) = \dfrac{hc}{\eta} \\ \mathrm{OA}(c): \quad h_\eta = h(c) = \dfrac{hc}{c} = h \quad \text{and} \quad \mathrm{OA}_\infty: \quad h_\eta = h(\infty) = \dfrac{hc}{\infty} = 0 \end{cases} \tag{6.43}$$

which is in line with both the case of quantum physics for the optical agent $OA(c)$ and the case of classical physics for the idealized agent OA_∞.

The Frequency Relation and Speed Relation of OR Matter Waves

As shown in Tab. 6.1, under the idealized agent OA_∞, the invariance of time-frequency ratio, the invariance of mass-frequency ratio, and the invariance of energy-frequency ratio, split into two parts in the theory of OR matter wave theory:

$$\begin{cases} \mathrm{d}t_\eta / f_\eta = \mathrm{d}\tau / f_{\eta o}: \quad \mathrm{d}t_\infty = \mathrm{d}\tau \quad \text{and} \quad f_\infty = f_{\infty o} = \infty \\ m_\eta / f_\eta = m_o / f_{\eta o}: \quad m_\infty = m_o \quad \text{and} \quad f_\infty = f_{\infty o} = \infty \\ E_\eta / f_\eta = E_o / f_{\eta o}: \quad E_\infty = E_o \quad \text{and} \quad f_\infty = f_{\infty o} = \infty \end{cases} \tag{6.44}$$

where, dt_η is the observed time of OA(η), $d\tau$ is the intrinsic time (proper time, that is, the objectively real time); m_η is the observed mass of OA(η), m_o is the intrinsic mass (that is, the objectively real mass); f_η is the observed frequency of OA(η), $f_{\eta o}$ is the rest frequency; E_η is the observed energy of OA(η), and $E_{\eta o}$ is the rest energy.

It should be noted that the rest frequency $f_{\eta o}$ and the rest energy $E_{\eta o}$ are observed or observational physical quantities, depending on the observation agent OA(η). According to GPC identity $h_\eta\eta=hc$, under the idealized agent OA_∞, $f_\infty=f_{\infty o}=\infty$ and $E_\infty=E_{\infty o}=\infty$. This means that, under OA_∞, f_∞ and $f_{\infty o}$ as well as E_∞ and $E_{\infty o}$, have no physical significance. This is in line with the situation of classical physics: there is no quantum effect in classical physics or Newton's mechanics.

So, under the situation of classical physics or the idealized agent OA_∞, the invariance of energy-frequency ratio no longer makes sense.

Under the situation of classical physics or the idealized agent OA_∞, the significant part of the invariance of mass-frequency ratio is only $m_\infty=m_o$: the observed mass m_∞ of the idealized agent OA_∞ is exactly the objectively real mass m_o, which is classically consistent with classical physics.

Under the situation of classical physics or the idealized agent OA_∞, the significant part of the invariance of time-frequency ratio is only $dt_\eta=d\tau$: the observed time dt_∞ of the idealized agent OA_∞ is exactly the objectively real time $d\tau$, which is classically consistent with classical physics.

Under the situation of classical physics or the idealized agent OA_∞, matter particles no longer exhibit wave effects and quantum effects.

Thus, as shown in Tab. 6.1, under the situation of classical physics or the idealized agent OA_∞, the frequency-speed relation no longer makes sense; the phase speed v_p tends to infinity, and a single particle no longer acts as a wave, and so, the phase speed v_p and the group speed v_g has no physical significance.

The General Planck Equation: $E=h_\eta f$

In the theory of OR, the general Einstein formula $E=m\eta^2$ and the general Planck equation $E=h_\eta f$ are dual formulae. $E=m\eta^2$ belongs to the inertially observational relativity of OR, while $E=h_\eta f$ belongs to the matter-wave theory of OR. Actually, $E=m\eta^2$ and $E=h_\eta f$ are the two different forms of the inertial energy E of the observed object P: in $E=m\eta^2$, E is regarded as the particle energy of P, including the rest energy $E_o=m_o\eta^2$; in $E=h_\eta f$, E is regarded as the wave energy of P, including the rest energy $E_o=h_\eta f_o$. For the same observed object P, Einstein's particle energy in $E=m\eta^2$ and Planck's wave energy in $E=h_\eta f$ are the same physical quantity.

As stated in Sec. 5.3 of Chapter 5, there is no the so-called **rest energy** E_o for an objectively real matter particle P like in Einstein formula $E=mc^2$ and like in the general Einstein formula $E=m\eta^2$. According to the general Einstein formula $E=m\eta^2$, under a different observation agent OA(η), the particle energy $E=E(\eta,v)$ of P is different, and the rest energy $E_o=E(\eta,0)$ of P is also different. In particular, under the classical situation or the idealized agent OA_∞ ($\eta\to\infty$), $E_o\to\infty$ and $E\to\infty$, both the particle energy E of P and the rest energy E_o of P have no significance.

Likewise, there is no the so-called **rest energy** E_o for an objectively real matter particle P like in Planck equation $E=hf$ and like in the general Planck equation $E=h_\eta f$. Under the classical situation or the idealized agent OA_∞ ($\eta\to\infty$), $E_o\to\infty$ and $E\to\infty$, both the wave energy E and the rest energy E_o of P have no significance.

Like in the general Einstein formula $E=m\eta^2$, the significant part in the general Planck equation $E=h_\eta f$ is only the kinetic energy K_η of the observed object P. Actually, the kinetic energy $K_\eta=K(\eta,v)$ in the general Planck equation $E=h_\eta f$ also depends on the observation agent OA(η):

$$\begin{aligned} K_\eta &= K(\eta,v)=E(\eta,v)-E_o(\eta,0)=\left(\varGamma(\eta,v)-1\right)h_\eta f_o(\eta,0) \\ &=\left(\frac{1}{\sqrt{1-v^2/\eta^2}}-1\right)h_\eta f_o(\eta,0) \end{aligned} \tag{6.45}$$

which suggests that a different observation agent OA(η) presents a different observed kinetic-energy K_η. Therefore, the observed kinetic-energy K_η includes observational effects, unless OA(η) were the idealized observation agent OA_∞.

As shown in Tab. 6.1, under the classical situation or the idealized agent OA_∞, the kinetic energy $K_\infty=K(\infty,v)$ in the general Planck equation $E=h_\eta f$ does indeed strictly converge to the case of classical physics:

$$\begin{aligned} K_\infty &= \lim_{\eta\to\infty}\left(\varGamma(\eta,v)-1\right)h_\eta f_o(\eta,0) \\ &=\lim_{\eta\to\infty}\left(\frac{1}{\sqrt{1-v^2/\eta^2}}-1\right)m_o\eta^2=\frac{1}{2}m_o v^2=\frac{1}{2}m_\infty v^2 \end{aligned} \tag{6.46}$$

This is exactly the classical formula of kinetic energy in Newton's mechanics.

Equation (6.46) indicates that the general Planck equation $E=h_\eta f$ of OR matter-wave theory is consistent with and strictly corresponding to the classical formula of kinetic energy: $K_\infty=m_\infty v^2/2$.

The General de Broglie Relation: $p=h_\eta/\lambda$

As shown in Tab. 6.1, under the classical situation or the idealized agent OA_∞, the momentum $p_\infty=p(\infty,v)$ in the general de Broglie relation $p=h_\eta/\lambda$ also strictly converges to the case of classical physics. According to the OR mass-energy relation $E=m\eta^2$ and the speed relation $v=v_{\mathrm{g}}=\eta^2/v_{\mathrm{p}}$ as well as $\lambda_\eta f_\eta=v_{\mathrm{p}}$ of OR matter-wave theory, it holds true that

$$\begin{aligned} p_\infty &= \lim_{\eta\to\infty}p_\eta=\lim_{\eta\to\infty}\frac{h_\eta}{\lambda_\eta}=\lim_{\eta\to\infty}\frac{h_\eta f_\eta}{v_{\mathrm{p}}}=\lim_{\eta\to\infty}\frac{m\eta^2}{v_{\mathrm{p}}}=\lim_{\eta\to\infty}mv_{\mathrm{g}}=\lim_{\eta\to\infty}mv \\ &=\lim_{\eta\to\infty}\frac{m_o v}{\sqrt{1-v^2/\eta^2}}=m_o v=m_\infty v \quad \left(m_o=m_\infty\right) \end{aligned} \tag{6.47}$$

where v is the particle speed of the observed object P, m_∞ and m_o are respectively the classical mass and rest mass of P as a particle, and v_{p} and v_{g} are respectively the phase speed and group speed of P as a matter wave.

This is exactly the classical formula of momentum in Newton's mechanics.

Equation (6.47) indicates that the general de Broglie relation $p=h_\eta/\lambda$ of OR matter-wave theory is consistent with and strictly corresponding to the classical formula of momentum: $p_\infty=m_\infty v$.

The General Schrödinger Equation: $\mathrm{i}\hbar_\eta\partial\Psi/\partial t=-(\hbar_\eta^2/2m)\nabla^2\Psi+V\Psi$

As shown in Tab. 6.1, under the classical situation or the idealized agent OA_∞, the wave function Ψ_∞ of the general Schrödinger equation (Eq. (6.38)) reduces to zero as shown in Eq. (6.39): $\eta\to\infty$ 时 $\Psi_\infty=\Psi(\infty)\to 0$. This suggests that, under the classical situation or the idealized agent OA_∞, the observational wave effects and quantum effects of matter particles disappear.

This is logically consistent with classical physics.

The Principle of General Uncertainty: $\sigma_x\sigma_p\geq\hbar_\eta/2$

The theory of OR matter waves has developed an important principle: the principle of general uncertainty, which generalizes Heisenberg's uncertainty principle. Actually, Heisenberg's uncertainty principle is the special case of the principle of general uncertainty under the optical agent OA(c). In particular, the principle of general uncertainty is also consistent with classical physics

According to the theory of OR or the theory of OR matter waves, no matter Heisenberg's uncertainty principle $\sigma_x\sigma_p\geq\hbar/2$ or the principle of general uncertainty $\sigma_x\sigma_p\geq\hbar_\eta/2$, the uncertainty is only observational uncertainty and does not represent the intrinsic uncertainty of the objectively physical world.

According to GPC identity $h_\eta\eta=hc$, the principle of general uncertainty $\sigma_x\sigma_p\geq\hbar_\eta/2$ (Eq. (6.41)) of OR matter-wave theory can be expressed as the form of Eq. (6.42). So, as shown in Tab. 6.1, it holds true that

$$\begin{cases}\mathrm{OA}(\eta):\quad \sigma_x(\eta)\sigma_p(\eta)\geq\dfrac{h}{4\pi}\dfrac{c}{\eta}\quad\text{and}\quad \mathrm{OA}(c):\quad \sigma_x(\eta)\sigma_p(\eta)\geq\dfrac{h}{4\pi}\\ \mathrm{OA}_\infty:\quad \lim\limits_{\eta\to\infty}\sigma_x(\eta)\sigma_p(\eta)\geq\lim\limits_{\eta\to\infty}\dfrac{h}{4\pi}\dfrac{c}{\eta}=0\end{cases}\tag{6.48}$$

Equation (6.48) indicates that the principle of general uncertainty $\sigma_x\sigma_p\geq\hbar_\eta/2$ of OR matter-wave theory is logically consistent with classical physics: there is no quantum effect or uncertainty in classical physics under the idealized agent OA_∞.

By inducing and analogizing the corresponding relationships listed in Tab. 6.1 between the theory of OR matter waves of OA(η) and de Broglie's theory of matter waves of OA(c) or classical physics of OA_∞, it can be concluded that: the theory of OR matter waves not only generalizes the basic formulae and principles of de Broglie theory of matter waves and quantum mechanics, but also generalizes the corresponding relations and laws of classical physics; So, the theory of OR is not only moving towards the unification of quantum theory and relativity theory, but also moving towards the unification of quantum mechanics and classical mechanics.

7 On the Essence of Relativistic Phenomena

In 1905, Einstein established his special theory of relativity [7], revealing the relativistic phenomena of spacetime and matter motion.

Einstein believed and the mainstream school of physics also believe that relativistic effects are the objectively natural phenomena, the intrinsic and essential attributes of spacetime as well as matter motion and matter interactions.

After the birth of Einstein's theory of relativity, people have been both curious and puzzled about relativistic phenomena or relativistic effects. Although the mainstream school of physics insist that relativistic effects are the essential characteristics of spacetime as well as matter motion and matter interactions, people still cannot fully understand why spacetime as well as matter motion and matter interactions exhibit relativistic phenomena and relativistic effects, why the speed of light is invariant, and why spacetime is curved.

In the theory of OR, spacetime, matter motion, and matter interactions, also have relativistic phenomena and relativistic effects.

So, what are the root and essence of relativistic phenomena?

New theories lead to new discoveries; new theories lead to new insights.

The theory of OR discover that all relativistic effects, including the special (inertial) relativistic effects characterized by the invariance of light speed, the general (gravitational) relativistic effects characterized by spacetime curvature, and even quantum effects characterized by uncertainty, are observational effects, that is, the perturbation effects on observed objects exerted by observation systems or by the informons of observation agents.

Chapter 6 of **the 1st volume of OR: Inertially Observational Relativity** (IOR) has already expounded the essence of quantum effects including uncertainty, while the essence of the relativistic effects of gravitational spacetime and gravitational interactions are left to be discussed in **the 2nd volume of OR: Gravitationally Observational Relativity** (GOR). This chapter, on the basis of the theory of inertially observational relativity, i.e., the theory of IOR that has already been built up in 1st volume of OR, discusses and expounds the problem on the essence of relativistic phenomena of inertial spacetime and inertial motion of matter.

7.1 The Essence of the Invariance of Light Speed

If it is regarded as the important discovery of the theory of OR that **all relativistic phenomena are observational effect**, then the most important of it is that **the speed of light is not really invariant**.

The invariance of light speed itself is a sort of relativistic phenomenon.

The principle of the invariance of light speed is an axiom presupposed by Einstein for his theory of relativity, which is not only the logical prerequisite for his special theory of relativity but also the logical prerequisite for his general theory of relativity. As far as Einstein's theoretical system of relativity, the invariance of light speed is the root of all the relativistic effects or phenomena in Einstein's theory.

Therefore, in order to recognize the root and essence of relativistic effects or phenomena in Einstein's theory, it is necessary to first understand Einstein's principle of the invariance of light speed, or it is necessary to first understand the root and essence of the phenomenon of the invariance of light speed.

Essentially, the principle of the invariance of light speed is only a hypothesis, which has no the self-evident or axiomatic characteristic that a principle or a logical premise should have.

Because of this, up to now, people cannot correctly understand why the speed of light is invariant. Naturally, people also cannot correctly understand the logical consequences, including all relativistic effects or relativistic phenomena, such as the relativistic effect of **time dilation and length contraction**, **the relativity of simultaneity**, **the zero-mass problem of Photons**, and even **spacetime curvature**, that derived from the invariance of light speed as a principle or a logical premise.

The theory of OR discovers: the speed of light is not really invariant.

Chapter 3 has proved the most important theorem of OR theory: the theorem of **the invariance of information-wave speeds** (IIWSs), revealing the essence of the invariance of light speed. The theorem of IIWSs indicates that the speed of a matter wave or a matter particle looks invariant or observes invariant if and only if the matter wave or the matter particle acts as the observation medium to carry and transmit the observed information on observed objects for inertial observers.

It turns out that the speed of light is not really invariant: the invariance of light speed is only a special case of the invariance of information-wave speeds; the invariance of light speed can only hold true under the optical observation agent OA(c). According to the theorem of IIWSs, the speed of light appears to be invariant only if light is employed as the observation medium to carry and transmit observed information for inertial observers.

According to the theorem of IIWSs of OR theory, there is no really invariant speed in the physical world. The so-called **invariant speed** can only be invariant observationally: an inertial observer armed with the observation agent OA(η) could never observe the speed beyond η. If there were the invariant speed, it could only be the infinity. Such infinite speed can only exist in our reason, such as the idealized observation system of Galileo and Newton, or the idealized observation agent OA_∞.

In Sec. 3.2 **The Proof of IIWSs Theorem** and Sec. 3.3 **The Empirical Support for IIWSs Theorem** of Chapter 3, the theory of OR has clarified that the theorem of IIWSs, as a logical consequence of OR theory, not only has theoretical basis, but also has empirical basis, being supported by observations and experiments.

Although people do not understand the invariance of light speed, they believe in the principle of the invariance of light speed, one important reason of which is that Einstein's hypothesis of the invariance of light speed seems to be supported by observations and experiments.

Einstein's hypothesis of the invariance of light speed indeed stems from observations and experiments.

In 1887, the famous experiment [2] of Michelson and Morley for capturing the ether revealed the phenomenon of the invariance of light speed: the addition of the light speed c and Earth's orbital speed v remained the speed of light.

This is known as **the invariance of light speed**.

Based on the Michelson-Morley experiment, Fitzgerald and Lorenz conceived a phenomenological model [3-6]: the Fitzgerald-Lorentz transformation that had already implied the invariance of light speed.

Einstein had a keen insight. He had grasped the significance implied in the Michelson-Morley experiment: the light speed plus an inertial speed seemed to still be the speed of light. Thereupon, Einstein then proposed the principle of the invariance of light speed, on the basis of which, Einstein established the theory of relativity, including the special [7] and the general [8].

However, Einstein failed to truly realize and understand the Michelson-Morley experiment as well as the phenomenon of light-speed invariance. For the invariance of light speed, Einstein knew what and how, but did not know why.

The observational may not necessarily the objectively real; phenomena may not necessarily represent the essence.

As clarified in Sec. 3.3 **The Empirical Support for IIWSs Theorem** of Chapter 3, in fact, the Michelson-Morley experiment is not a support for Einstein's hypothesis of the invariance of light speed, but rather a support for the theorem of the invariance of information-wave velocity of OR theory.

As depicted in Fig. 3.3, in the Michelson-Morley experiment, the observer O is Michelson or Morley, or the detector DS, while the object P observed by Michelson and Morley is light or photons emitted by the light source LS, and the observation medium to transmit the spacetime information on light or photons for Michelson and Morley is light itself or photons themselves. Naturally, the observation agent of Michelson and Morley is the optical agent OA(c), in which light is exactly the information wave of OA(c); photons are exactly the informons of OA(c).

So, according to the theorem of IIWSs, in the Michelson-Morley experiment, the speed of light as the information wave or photons as the informons should be invariant. This is exactly the invariance of information-wave speeds, rather than the invariance of light speed.

It is thus clear that, in the Michelson-Morley experiment, the invariance of light speed is only a sort of phenomenon, while the invariance of the speed of light acting as the information wave is the essence.

However, no matter the invariance of information-wave speeds, or the invariance of light speed when light acts as the information wave of OA(c), is only an observational effect or an apparent phenomenon, caused by the observational locality ($\eta<\infty$ or $c<\infty$) of the observation agent OA(η) or OA(c).

So, the theory of OR has revealed the essence of the invariance of light speed.

Since the invariance of light speed, that acts as the logical premise of Einstein's theory of relativity, is only an observational effect but not the objectively natural phenomenon, according to the theory of OR, all relativistic effects or relativistic phenomena described in Einstein's theory of relativity, including the special and the general, essentially are observational effects and apparent phenomena, and rooted in the observational locality of observation agents. Based on the transformation of IOR spacetime and the IOR factor of spacetime transformation in the theory of IOR, we will further recognized and understand the root and essence of the relativistic effects or phenomena of inertial spacetime and inertial motion, whether they are rooted from the general observation agent OA(η) of OR theory or from the optical observation agent OA(c) of Einstein's theory of relativity.

7.2 The IOR factor and Relativistic Phenomena

Naturally, inertial theory of relativity, including Einstein's special theory of relativity and the theory of IOR, are that of inertial spacetime. The spacetime transformation is the most basic theoretical model of inertial theory of relativity: the transformation of inertial spacetime in Einstein's special relativity is the Lorentz transformation, and the factor of inertial-spacetime transformation is the Lorentz factor γ; the transformation of inertial spacetime in theory of IOR is the transformation of IOR spacetime, and the factor of inertial-spacetime transformation factor is the IOR factor Γ of spacetime transformation, or the IOR factor for short.

The factor of spacetime transformation is the most important physical quantity in theory relativity, including Einstein's theory of relativity and the theory of OR, which characterizes the relativistic property of spacetime as well as matter motion and matter interactions. The factor of inertial-spacetime transformation, including the Lorentz factor γ and the IOR factor Γ, characterizes the relativistic property of inertial spacetime and inertial motion, and implies the root and essence of the relativistic phenomena of inertial spacetime and inertial motion.

So, as far as the understanding of the root and essence of inertial relativistic effects or phenomena, what is the difference between the IOR factor Γ of the IOR transformation and the Lorentz factor γ of the Lorentz transformation?

7.2.1 Einstein's View based on the Lorentz Factor

In a sense, Einstein's understanding of the relativistic effects or relativistic phenomena of inertial spacetime and inertial motion in his special relativity was based on his understanding of the Lorentz factor γ.

The Galilean transformation (Eq. (4.4)) is the classical transformation of inertial spacetime, and is nonrelativistic, the spacetime-transformation factor of which is the Galilean factor: $\Gamma_\infty \equiv 1$. By contrasting the Galilean transformation (Eq. (4.4)) and the Lorentz transformation (Eq. (4.12)), we know that: the Galilean factor $\Gamma_\infty \equiv 1$ is a constant, and therefore, the Galilean transformation has no relativistic effects; while the Lorentz factor $\gamma=\gamma(v)\geq 1$ ($0\leq v\leq c$) depends on the speed v of the observed object P, and therefore, the Loren transformation presents relativistic effects.

According to Einstein's special theory of relativity [7]:

The Lorentz factor γ of the Lorentz transformation is $\gamma = \gamma(v) = \dfrac{1}{\sqrt{1 - v^2 / c^2}}$,

where the speed c of light is a cosmic constant, an invariant. Therefore, the Lorentz factor $\gamma=\gamma(v)$ depends on the speed v of the observed object P, the higher the v the more significant the relativistic effects of P.

According to the Lorentz factor: if v=0, then $\gamma=\gamma(0)=1=\Gamma_\infty$, the observed object P at rest in inertial spacetime has no relativistic effects and relativistic phenomena; if $v\neq 0$, then $\gamma=\gamma(v)>\Gamma_\infty$, the observed object P moving in inertial spacetime presents relativistic effects and relativistic phenomena.

Accordingly, Einstein believed that: relativistic phenomena were the essential characteristics of inertial spacetime and inertial motion

Einstein's view on relativistic effects and relativistic phenomena seems to be supported by observations and experiments, and to this day, it still represents the view of the mainstream school of physics.

Of course, the observations and experiments that support Einstein's theory of relativity must resort to the optical observation agent OA(c).

As the theory of OR repeatedly emphasizes, Einstein's theory of relativity is that of optical observation, in Hawking's words [31], a partial theory, only valid under the optical observation agent OA(c).

Restricted by the perspective of the optical observation agent OA(c), Einstein believed, and even today's mainstream school of physics still believe, that relativistic phenomena are the essential characteristics of inertial spacetime and inertial motion, and rooted from the motion of matter.

7.2.2 OR's View based on the IOR Factor

The observation agent of OR theory is the general observation agent OA(η). In theory, the observation medium of OA(η) can be any form of matter motion, and the information-wave speed η of OA(η) can be any speed value.

The transformation of IOR spacetime has the broad perspective of the general observation agent OA(η), and therefore, the IOR factor of spacetime transformation has revealed the root and essence of inertial relativistic phenomena.

According to the theory of inertially observational relativity (IOR):

The IOR factor Γ of spacetime transformation is $\Gamma=\Gamma(\eta,v)=\dfrac{1}{\sqrt{1-v^2/\eta^2}}$,

where η is the information-wave speed of the general observation agent OA(η), the IOR factor $\Gamma=\Gamma(\eta,v)$ is a function of both the information-wave speed η and the inertial speed v of the observed object P, depends on both v and η.

Actually, as far as the essence, relativistic effects or relativistic phenomena are rooted in the observational locality ($\eta<\infty$) of OA(η), relying on the information-wave speed η rather than the speed v of the observed object P.

According to the transformation of IOR spacetime (Eqs. (4.16) and (4.18)):

$$\mathrm{OA}(\eta):\quad \Gamma=\Gamma(\eta,v)= 1\Big/\sqrt{1-v^2/\eta^2}$$

$$\begin{cases} \mathrm{OA}(c):\quad \Gamma(c,v)=\lim\limits_{\eta\to c}\Gamma(\eta,v)=1\Big/\sqrt{1-v^2/c^2}=\gamma \\ \mathrm{OA}_\infty:\quad \Gamma(\infty,v)=\lim\limits_{\eta\to\infty}\Gamma(\eta,v)=\lim\limits_{\eta\to\infty}1\Big/\sqrt{1-v^2/\eta^2}=1=\Gamma_\infty \end{cases} \tag{7.1}$$

Equation (7.1) suggests that:

(i) the IOR factor $\Gamma=\Gamma(\eta,v)$ of the general observation agent OA(η) generalizes the Lorentz factor $\gamma=\Gamma(c,v)$ of the optical agent OA(c); the Lorentz factor γ is only a special case of the IOR factor, characterizing the relativistic effects of OA(c). The physical quantities observed with OA(c) are not entirely objective or real, which contains the observational effects of OA(c) and the apparent phenomena of optical observation.

(ii) the IOR factor $\Gamma=\Gamma(\eta,v)$ of the general observation agent OA(η) generalizes the Galilean factor $\Gamma_\infty\equiv 1$ of the idealized agent OA_∞; the Galilean factor is also a special case of the IOR factor, characterizing the nonrelativistic effects of OA_∞. The physical quantities observed with OA_∞ has no observational effects and apparent phenomena, which are the objectively and real physical quantities.

(iii) For the observed object P moving at the same identical speed v, a specific observation agent OA(η) has a specific IOR factor $\Gamma=\Gamma(\eta,v)$ of spacetime transformation. So, under different observation agents, the inertial object P exhibits different degrees of relativistic effects.

It is thus clear that the so-called relativistic effects depend on observation and observation agents. Therefore, the relativistic effects or phenomena that the inertial object P presents under a specific observation agent OA(η) (for example, the optical agent OA(c)) is not the intrinsic attribute or essential feature of spacetime and matter motion, but rather observational effects and apparent phenomena.

According to Eq. (7.1), the higher the information-wave speed η of OA(η), the smaller the IOR factor $\Gamma=\Gamma(\eta,v)$. In particular, as $\eta\to\infty$, the IOR factor $\Gamma=\Gamma(\eta,v)$ converges to the Galilean factor Γ_∞, and the observational relativistic effects of OA(η) would disappear accordingly.

This indicates that the essence of relativistic effects or relativistic phenomena is a class of observational effects or apparent phenomena rooted in the observational locality of observation agents.

7.2.3 Physical Quantities Observed: Objective or Observational?

According to Eq. (7.1), as depicted in Tab. 1.1, different observation agents have different information-wave speeds, and therefore, have different degrees of observational locality: for the observed object P moving at the inertial speed v, a specific observation agent OA(η) have its own specific IOR factor $\Gamma=\Gamma(\eta,v)$. Let OA(η_1) and OA(η_2) be two different observation agents, then $\Gamma(\eta_2,v)<\Gamma(\eta_1,v)$ if $\eta_2>\eta_1$. This suggests that the relativistic effects or relativistic phenomena that the observed object P present depend on observation agents: the physical quantities of P observed with different observation agents have different observed values, and so, contain different degrees of observational effects and apparent phenomena.

In the IOR factor $\Gamma=\Gamma(\eta,v)$, the objectively real component is the Galilean factor $\Gamma_\infty\equiv 1$, while the rest $\Delta\Gamma=\Gamma(\eta,v)-\Gamma_\infty$ represents relativistic effects, which are purely observational effects and apparent phenomena.

The IOR factor $\Gamma=\Gamma(\eta,v)=1/\sqrt{(1-v^2/\eta^2)}$ $(v<\eta)$ in Eq. (7.1) can be decomposed in terms of Taylor series:

$$\Gamma(\eta)=\frac{1}{\sqrt{1-v^2/\eta^2}}=1+\frac{1}{2}\frac{v^2}{\eta^2}+\frac{1\cdot 3}{2\cdot 4}\frac{v^4}{\eta^4}+\frac{1\cdot 3\cdot 5}{2\cdot 4\cdot 6}\frac{v^6}{\eta^6}+\cdots=\Gamma_\infty+\Delta\Gamma(\eta)$$

$$\begin{cases}\Gamma_\infty=\lim\limits_{\eta\to\infty}\Gamma(\eta)=1\\ \Delta\Gamma(\eta)=\dfrac{1}{2}\dfrac{v^2}{\eta^2}+\dfrac{1\cdot 3}{2\cdot 4}\dfrac{v^4}{\eta^4}+\dfrac{1\cdot 3\cdot 5}{2\cdot 4\cdot 6}\dfrac{v^6}{\eta^6}+\cdots\end{cases}\tag{7.2}$$

where $\Gamma_\infty=\Gamma(\infty)\equiv 1$ is the Galilean factor that is independent of observation and has no observational effects, representing the objectively physical existence; $\Delta\Gamma(\eta)$ can be called **the observational-effect factor**, relying on the observation agent OA(η), representing the observational effects and apparent phenomena rooted in the observational locality ($\eta<\infty$) of OA(η).

It is worth noting that: in the Taylor series of the IOR factor $\Gamma(\eta,v)$, only the first item, that is, the Galilean factor $\Gamma_\infty\equiv 1$, is independent of observation; while the other items all depend on the observation agent OA(η), or in other words, depend on the information-wave speed η of OA(η).

So, in the IOR factor $\Gamma(\eta)=\Gamma_\infty+\Delta\Gamma(\eta)$, the Galilean factor $\Gamma_\infty\equiv 1$ represents the objectively physical reality; while the observational-effect factor $\Delta\Gamma=\Gamma(\eta,v)-\Gamma_\infty$ represents purely observational effects and apparent phenomena.

Obviously, $\Delta\Gamma(\eta)>0$ if $0<v<\eta<\infty$, and therefore, the relativistic effects of inertial spacetime and inertial motion lead to the dilation of the IOR factor of spacetime transformation: $\Gamma(\eta,v)=1/\sqrt{(1-v^2/\eta^2)}>\Gamma_\infty$.

Equation (7.2) suggests that: for the observed object P moving at the inertial speed v, the higher the information-wave speed η of the observation agent OA(η), the closer the IOR factor is to the Galilean factor Γ_∞, the smaller the observational-effect factor $\Delta\Gamma(\eta)$, and the weaker the observational effects; in particular, if $\eta\to\infty$, then $\Delta\Gamma(\eta)\to 0$, all relativistic phenomena of P observed with OA(η) would disappear, and the observational spacetime $X^{4d}(\eta)$ would be exactly the Cartesian spacetime X^{4d}_∞, that is, the real face of the objective world.

Different observation agents have different degrees of observation locality, and therefore, lead to different degrees of relativistic effects. This indicates that relativistic phenomena rely on observation, and belong to observational effects.

So, the IOR factor $\Gamma(\eta)=\Gamma_\infty+\Delta\Gamma(\eta)$ of spacetime transformation mean that

(i) Our observation contains the real information about the objectively physical world that is represented by the Galilean factors Γ_∞, and meanwhile, contains the observational effects and apparent phenomena that are represented by the observational-effect factors $\Delta\Gamma(\eta)$;

(ii) Relativistic phenomena are rooted in the observational locality of observation agents, not the intrinsic attribute or essential property of inertial spacetime and inertial motion.

As stated in Chapter 5, based on the IOR factor $\Gamma(\eta)=\Gamma_\infty+\Delta\Gamma(\eta)$ of spacetime transformation, the theory of OR has clarified that: the OR observational mass $m=m(\eta,v)$ contains both the objectively real mass m_∞ of the observed object P, i.e. the intrinsic mass m_o of P, and the observational effect $\Delta m(\eta,v)$ of the observational agent OA(η); the OR observational momentum $p=p(\eta,v)$ contains both the objectively real momentum p_∞ of P and the observational effect $\Delta p(\eta,v)$ of OA(η); the OR observational kinetic energy $K=K(\eta,v)$ contains both the objectively real kinetic energy K_∞ of P and the observational effect $\Delta K(\eta,v)$ of OA(η).

Likewise, based on the IOR factor $\Gamma(\eta)=\Gamma_\infty+\Delta\Gamma(\eta)$, the theory of OR will clarify that all relativistic effects under the general observation agent OA(η) (including the optical agent OA(c)) are observational effects or apparent phenomena; an observed (observational) physical quantity of OA(η) or OA(c), not only contains the objectively real information of the observed object P, but also contains the observational effect of observation agent.

7.3 The Relativistic Effects of Spacetime

The relativistic effects or relativistic phenomena of spacetime stem from our observation of time and space, depend on our detection and measurement of time and space, involving the interrelationship between time and space. In Einstein's theory of special relativity, the famous relativistic effect of **time dilation and length contraction** exactly refers to the interrelationship between time and space.

According to the theory of OR, the objectively real spacetime is exactly what Galileo and Newton described for us, that is, the observational spacetime $X^{4d}{}_\infty$ of the idealized observation agent OA$_\infty$. However, restricted by observation, restricted by the observational locality ($\eta<\infty$) of the general observation agent OA(η), the observational spacetime $X^{4d}(\eta)$ of the observer O armed with OA(η) is not equivalent to the objectively real spacetime $X^{4d}{}_\infty$.

As far as inertial spacetime, in the Taylor series expansion of Eq. (7.2), the IOR factor $\Gamma(\eta)=\Gamma_\infty+\Delta\Gamma(\eta)$ of spacetime transformation reflects the observational relativistic-effects of inertial spacetime. Based on the IOR factor $\Gamma(\eta)=\Gamma_\infty+\Delta\Gamma(\eta)$ in Eq. (7.2), the theory of IOR can analyze the relativistic effects of inertial spacetime and reveal the root and essence of the relativistic effects of Einstein's special theory of relativity.

In this section, we take **the dilation of time**, **the contraction of length**, and **the relativity of simultaneity** as the examples of relativistic effects or relativistic phenomena for expounding the root and essence of the relativistic effects or relativistic phenomena in inertial spacetime. Meanwhile, based on the theory of IOR, we can foresee the root and essence of the phenomenon of **spacetime curvature** in gravitational spacetime.

7.3.1 The Dilation of Time

Time is the most fundamental attribute of spacetime.

The dilation of time is the most basic relativistic effect of spacetime.

In a sense, it is the dilation of observed (observational) time that leads to all observed (observational) physical quantities, including spacetime and matter, either to **dilate** or to **contract**. For the observational physical quantities in the theory of OR, no matter dilation or contraction, is only the observational dilation or the observational contraction, being observational effects or apparent phenomena.

The view of **time dilation** originated from Lorenz. In order to explain the Michelson-Morley experiment, Lorenz proposed a hypothesis that time might dilate by the factor of $1/\sqrt{(1-v^2/c^2)}$ while the observed object P was moving [4-6].

Einstein's Dilation of Time

Time dilation and length contraction are the most classic relativistic-effects, that never fail to fascinate, in which the dilation of time is the most basic.

According to Einstein's special theory of relativity and the agreements of Sec. 1.1.1 in Chapter 1, suppose that two events occur at different times t_1' and t_2' at the same spatial location $x_1'=x_2'$ in the reference frame O'. In the view of the observer O', the time interval is $\Delta T'=|t_2'-t_1'|$; while, in the reference frame O, or in the view of the observer O, the occurrence times of these two events are t_1 and t_2 respectively, and the time interval is $\Delta T=|t_2-t_1|$.

According to the Lorentz transformation (Eq. (4.12)), we have that

$$\begin{aligned}\Delta T=|t_2-t_1|&=\frac{\left|(t_2'-t_1')+(x_2'-x_1')v/c^2\right|}{\sqrt{1-v^2/c^2}}\\&=\frac{|t_2'-t_1'|}{\sqrt{1-v^2/c^2}}=\frac{\Delta T'}{\sqrt{1-v^2/c^2}}>\Delta T'\quad(|v|>0)\end{aligned}\tag{7.3}$$

This is namely Einstein's dilation of time in inertial spacetime: $\Delta T>\Delta T'$.

The c in the Lorentz factor, i.e., the speed of light in vacuum, is a cosmic constant, which is invariant and the same relative to all inertial observers. Therefore, Einstein's dilation of time $\Delta T>\Delta T'$ requires the observed object P to be in motion: $v\neq 0$. Accordingly, Einstein believed that the dilation of time is the essential characteristic of spacetime and matter motion, and rooted from matter motion.

Actually, Einstein's dilation of time is only a special case of IOR's dilation of time. Einstein's dilation of time is the dilation of observational time t under the optical agent OA(c), rather than the dilation of the objectively real proper-time τ.

IOR's Dilation of Time

Time would also dilate in the inertial spacetime of IOR theory.

However, the theory of OR discovers that: the objectively real time (proper time) dτ does not dilate; the so-called time dilation is actually the dilation of observational time dt=d$t(\eta)$, which is the observational effect of the observation agent OA(η).

According to the transformation of IOR spacetime (Eq. (4.18), i.e., so-called the general Lorentz transformation), under the general observation agent OA(η), Einstein's dilation of time (Eq. (7.3)) should be rewritten as:

$$\Delta T(\eta)=\left|t_2(\eta)-t_1(\eta)\right|=\frac{\left|\left(t_2'(\eta)-t_1'(\eta)\right)+\left(x_2'(\eta)-x_1'(\eta)\right)v/\eta^2\right|}{\sqrt{1-v^2/\eta^2}}$$
$$=\frac{\left|t_2'(\eta)-t_1'(\eta)\right|}{\sqrt{1-v^2/\eta^2}}=\frac{\Delta T'(\eta)}{\sqrt{1-v^2/\eta^2}}>\Delta T'(\eta)\quad\left(|v|>0\right) \tag{7.4}$$

This is namely IOR's dilation of time in inertial spacetime: $\Delta T(\eta)>\Delta T'(\eta)$.

Equation (7.4) shows that IOR's dilation of time is the dilation of observational time in the inertial observational spacetime of the general observation agent OA(η), which depends on OA(η). In essence, it does not depend on the speed v of matter motion, but depends on the information-wave speed η of OA(η).

According to the agreements of Sec. 1.1.1 in Chapter 1, suppose that the clock T_P is at rest in the reference frame O' or relative to the observer O', then, according to Def. 1.2 in Chapter 1, the time $\Delta T'$ that T_P presents to O' is the objectively real proper-time $\Delta\tau$: $\Delta T'=\Delta\tau$; while the time ΔT that T_P presents to the observer O is the observational time Δt under the observation agent OA(η), which is the dilative time: $\Delta t>\Delta\tau$. So, the so-called time dilation is not the dilation of objectively real proper-time $\Delta\tau$, but the dilation of observational time Δt. Moreover, the dilation of observational time $\Delta t=\Delta t(\eta)$ depends on observation agent OA(η): with different observation agents, the observational time would have different degrees of dilation in observational spacetime.

Actually, as a sort of relativistic effect, the dilation of time in the theory of OR originally has been reflected in the IOR factor $\Gamma(\eta)$=d$t(\eta)$/dτ (Eqs. (7.1-2)):

$$\begin{aligned}\mathrm{d}t(\eta)&=\Gamma(\eta)\,\mathrm{d}\tau=\frac{\mathrm{d}\tau}{\sqrt{1-v^2/\eta^2}}=\left(\Gamma_\infty+\Delta\Gamma(\eta)\right)\mathrm{d}\tau\\&=\mathrm{d}\tau+\Delta\mathrm{d}t(\eta)\geq\mathrm{d}\tau\quad\left(\Gamma_\infty\equiv1,\ \Delta\Gamma(\eta)\geq0,\ \Delta\mathrm{d}t(\eta)\geq0\right)\end{aligned} \tag{7.5}$$

where dτ is the objectively real intrinsic time, dt=d$t(\eta)$ is the observational (observed) time of the observer O under the observation agent OA(η), and Δdt=Δd$t(\eta)$ is the dilative part of observational time dt.

This is namely IOR's dilation of time in inertial spacetime: d$t(\eta)\geq$dτ.

In Eq. (7.5), the dilative part of observational time dt is: Δdt=$\Delta\Gamma(\eta)$dτ.

According to the Taylor-series decomposition of IOR factor in Eq. (7.2), the observational-effect factor $\Delta\Gamma(\eta)$ represents purely observational effects or apparent phenomena. Therefore, the dilative part Δdt of IOR's observational time is the dilative part, or more exactly, the unreal part of the observational time dt of the observation agent OA(η):

$$\begin{aligned}\Delta \mathrm{d}t(\eta) &= \Delta\Gamma(\eta)\,\mathrm{d}\tau \\ &= \left(\Gamma(\eta)-\Gamma_\infty\right)\mathrm{d}\tau = \mathrm{d}t(\eta)-\mathrm{d}\tau \end{aligned} \tag{7.6}$$

So, IOR's dilation of time is the dilation of observational time or observational time-element dt, not the dilation of objectively real proper-time dτ. The dilative part Δdt=Δdt(η) of time depends on the observation agent OA(η): different observation agents lead to different degrees of dilation of the observational time dt(η), and therefore, have different Δdt(η).

This indicates that the so-called time dilation depends on observation and observation agents, being a sort of observation effect or apparent phenomenon.

According to Eq. (7.5), for the clock T_P moving at the inertial speed v (>0) relative the observer O armed with the observation agent OA(η), the lower the information-wave speed η of OA(η), the more significant the dilation of the observational time dt, and the larger the dilative part Δdt of time.

Under the optical observation agent OA(c), as $\eta\to c$,

$$\mathrm{d}t_c = \lim_{\eta\to c}\mathrm{d}t(\eta) = \lim_{\eta\to c}\frac{\mathrm{d}\tau}{\sqrt{1-v^2/\eta^2}} = \frac{\mathrm{d}\tau}{\sqrt{1-v^2/c^2}} = \mathrm{d}t(c)\ge \mathrm{d}\tau \quad (v>0) \tag{7.7}$$

This is namely the dilation of the observational time-element dt(c) under the optical agent OA(c), i.e., the dilation of time in Einstein's special relativity. It is thus clear that Einstein's dilation of time dt(c) is only a special case of IOR's dilation of time dt(η) of the general observation agent OA(η).

Equation (7.7) shows that Einstein's time-element dt_c, as the observational time-element dt(c) of the optical agent OA(c), contains the time-dilation effect of optical observation: dt_c=dt(c)>dτ, that is not the objectively real proper-time dτ.

In particular, under the idealized observation agent OA$_\infty$, as $\eta\to\infty$,

$$\mathrm{d}t_\infty = \lim_{\eta\to\infty}\mathrm{d}t(\eta) = \lim_{\eta\to\infty}\frac{\mathrm{d}\tau}{\sqrt{1-v^2/\eta^2}} = \mathrm{d}\tau \tag{7.8}$$

This is namely the time-element dt(∞) under the idealized agent OA$_\infty$, that is, the time-element dt_∞ of Newton's classical mechanics, which is objective and real time with on time-dilation effect.

Equation (7.8) shows that Newton's time-element dt_∞, as the observational time-element dt(∞) of the idealized agent OA$_\infty$, represents the objectively real proper-time: dt_∞=dt(∞)=dτ.

In summary, no matter Einstein's dilation of time or IOR's dilation of time, in essence, is a sort of observational effect, and rooted in the observational locality (c<∞ or η<∞) of the observation agent OA(c) or OA(η).

The objectively real proper-time does not dilate.

7.3.2 The Contraction of Length

The contraction of length means the contraction of space.

In China, it is customary to translate **the contraction of length** into **the contraction of ruler**, and translate **time dilation and length contraction** into **time dilation and ruler contraction**. Another expression of length contraction is **FitzGerald-Lorentz contract**. At first, in order to explain the Michelson-Morley experiment, Fitzgerald proposed a hypothesis that all objects might physically contract by a factor of $\sqrt{(1-v^2/c^2)}$ along the line of motion [3].

According to the theory of OR, as a relativistic effect, no matter Einstein's contraction of length or IOR's contraction of length, in essence, it is a sort of observational effect, that is, the observational contraction of space.

Einstein's Contraction of Length

According to Einstein's special theory of relativity and the agreements of Sec. 1.1.1 in Chapter 1, suppose that there two different special points x_1' and x_2' with the distance or length $\Delta X'=|x_2'-x_1'|$ in the reference frame O'; in the reference frame O or in the view of the observer O, at the same time $t_1=t_2$, x_1' and x_2' locate at the spatial points x_1 and x_2 of O, respectively, with the distance or length $\Delta X=|x_2-x_1|$.

According to the Lorentz transformation (Eq. (4.12)), we have that

$$\Delta X' = |x_2' - x_1'| = \frac{|(x_2 - x_1) - v(t_2 - t_1)|}{\sqrt{1 - v^2/c^2}} = \frac{|x_2 - x_1|}{\sqrt{1 - v^2/c^2}} = \frac{\Delta X}{\sqrt{1 - v^2/c^2}} \tag{7.9}$$

That is, $$\Delta X = \Delta X' \sqrt{1 - v^2/c^2} < \Delta X' \quad (|v| > 0) \tag{7.10}$$

This is namely Einstein's contraction of length in inertial spacetime: $\Delta X < \Delta X'$.

The c in the Lorentz factor, i.e., the speed of light in vacuum, is a cosmic constant, which is invariant and the same relative to all inertial observers. Therefore, Einstein's contraction $\Delta X < \Delta X'$ of length requires the observed object P to be in motion: $v \neq 0$. Accordingly, Einstein believed that the contraction of length is the essential characteristic of spacetime and matter motion, and rooted from matter motion ($v \neq 0$).

Actually, Einstein's contraction of length is only a special case of IOR's contraction of length. Einstein's contraction of length is the contraction of observational length or observational space under the optical agent OA(c), rather than the contraction of the objectively real length or space.

IOR's Contraction of Length

Length or space would also contraction in the inertial spacetime of IOR theory.

However, the theory of OR discovers that: the objectively real space or the intrinsic length of space (including that of the ruler) does not contract; the so-called length contraction is actually the contraction of observed spatial length, which is the observational effect of the observation agent OA(η).

According to the transformation of IOR spacetime (Eq. (4.18), i.e., so-called the general Lorentz transformation), under the general observation agent OA(η), Einstein's contraction of length (Eq. (7.9)) should be rewritten as:

$$\Delta X'(\eta)=\left|x_2'(\eta)-x_1'(\eta)\right|=\frac{\left|\left(x_2(\eta)-x_1(\eta)\right)-v\left(t_2(\eta)-t_1(\eta)\right)\right|}{\sqrt{1-v^2/\eta^2}}$$

$$=\frac{\left|x_2(\eta)-x_1(\eta)\right|}{\sqrt{1-v^2/\eta^2}}=\frac{\Delta X(\eta)}{\sqrt{1-v^2/\eta^2}} \tag{7.11}$$

That is, $\Delta X(\eta)=\Delta X'(\eta)\sqrt{1-v^2/\eta^2}<\Delta X'(\eta)\quad(|v|>0)$ (7.12)

This is namely IOR's contraction of length: $\Delta X(\eta)<\Delta X'(\eta)$.

Equations (7.11-12) show that IOR's contraction of length is the contraction of observational length in the observational spacetime under the general observation agent OA(η), which depends on OA(η). In essence, it does not depend on the speed v of matter motion, but depends on the information-wave speed η of OA(η).

Suppose that $L_o=\Delta X'=|x_2'-x_1'|$ is a ruler, and at rest in the reference frame O' or relative to the observer O', then, according to Def. 1.2 in Chapter 1, the length $\Delta X'$ is the objectively real intrinsic-length of the ruler L_o, independent of the observation agent OA(η); while ΔX is the observational length L of the ruler L_o under the observation agent OA(η), which is the contractive length: $L=\Delta X(\eta)<\Delta X'(\eta)=L_o$. So, the so-called length contraction is not the contraction of objectively real intrinsic-length of the ruler L_o, but the contraction of observational length. Moreover, the contraction of observational length $\Delta X=\Delta X(\eta)$ depends on the observation agent OA(η): with different observation agents, inertial spacetime and the ruler L_o would have different degrees of contraction.

This indicates that the so-called length contraction depends on observation and observation agents, being a sort of observation effect or apparent phenomenon.

According to Eqs. (7.11-12), for the ruler L_o moving at the inertial speed v (>0) relative the observer O armed with the observation agent OA(η), the lower the information-wave speed η of OA(η), the more significant the contraction of the observational length ΔX.

Under the optical observation agent OA(c), as $\eta\to c$,

$$\Delta X_c=\lim_{\eta\to c}\Delta X(\eta)$$

$$=\lim_{\eta\to c}L_o\sqrt{1-v^2/\eta^2}=L_o\sqrt{1-v^2/c^2}=\Delta X(c)<L_o \tag{7.13}$$

This is namely the contraction of the observational length $\Delta X(c)$ under the optical agent OA(c), i.e., the contraction of observational length ΔX_c in Einstein's special relativity. It is thus clear that Einstein's contraction of observational length ΔX_c is only a special case of IOR's contraction of observational length $\Delta X(\eta)$ of the general observation agent OA(η).

Equation (7.13) shows that Einstein's ruler L_o contracts under the optical agent

OA(c), contains the length-contraction effect of optical observation: $\Delta X_c = \Delta X(c) < L_o$, that is not the objectively real length of the ruler L_o.

In particular, under the idealized observation agent OA_∞, as $\eta \to \infty$,

$$\Delta X_\infty = \lim_{\eta\to\infty} \Delta X(\eta) = \lim_{\eta\to\infty} L_o \sqrt{1 - v^2/\eta^2} = L_o \tag{7.14}$$

This is namely the length $\Delta X(\infty)$ of the ruler L_o under the idealized agent OA_∞, that is, the length ΔX_∞ of the ruler L_o in Newton's classical mechanics, which has no length-contraction effect, and is the objectively real intrinsic-length of the ruler L_o.

Equation (7.14) shows that Newton's ruler-length ΔX_∞, i.e., the observational length $\Delta X(\infty)$ under the idealized agent OA_∞, represents the objectively real ruler-length: $\Delta X_\infty = \Delta X(\infty) = L_o$.

In summary, no matter Einstein's contraction of length or IOR's contraction of length, in essence, is a sort of observational effect, and rooted in the observational locality ($c<\infty$ or $\eta<\infty$) of the observation agent OA(c) or OA(η).

The objectively real ruler-length does not contract.

7.3.3 The Relativity of Simultaneity

In a sense, the problem of simultaneity is a philosophical one.

No matter based on the plain view of nature or based on our reason or logicality, simultaneity is absolute: arbitrary two events are either simultaneous or not.

According to his special theory of relativity, however, Einstein claimed that simultaneity was relative or relativistic.

Einstein's View on Simultaneity

According to Einstein's special theory of relativity, simultaneity is relative, or in another word, relativistic: different observers have different views of simultaneity. Moreover, in Einstein's view, such relativity of simultaneity is the essential characteristic of spacetime, the essential characteristic of the natural world, and like time dilation and length contraction, rooted from matter motion.

According to the agreements of Sec. 1.1.1 in Chapter 1, suppose that there are two inertial reference frames (or observers) O and O' as depicted in Fig. 1.1, and two events A and B occur in spacetime: (i) in the reference frame O', the event A is at the location x_A' at the time t_A', the event B at the location x_B' at the time t_B'; (ii) in the reference frame of O, the event A is at the location x_A at the time t_A, the event B at the location x_B at the time t_B. Let $t_A'=t_B'$, that is, the events A and B are simultaneous in the reference frame O' or in the view of the observer O'. Then, in the reference frame O or in the view of the observer O, are the two events A and B also simultaneous? Or rather, $t_A=t_B$?

According to Einstein's special theory of relativity, in the reference frame O, or in the view of the observer O, the event A and the event B may not necessarily be simultaneous. Since the event A and the event B occur simultaneously in the reference frame O', then $t_A'=t_B'$. According to the Lorentz transformation (the $O' \to O$ in Eq. (4.12)), if $x_A' \neq x_B'$, then we have that

$$\left|t_{\mathrm{B}}-t_{\mathrm{A}}\right|=\frac{\left|\left(t'_{\mathrm{B}}-t'_{\mathrm{A}}\right)+\left(x'_{\mathrm{B}}-x'_{\mathrm{A}}\right)v/c^{2}\right|}{\sqrt{1-v^{2}/c^{2}}}=\frac{\left|x'_{\mathrm{B}}-x'_{\mathrm{A}}\right|}{\sqrt{1-v^{2}/c^{2}}}\frac{|v|}{c^{2}}\neq 0\quad(|v|>0)\tag{7.15}$$

This seems to mean that: if the event A and the event B occur at different locations ($x_A'\neq x_B'$) in the reference frame O', then the event A and the event B, that occur simultaneously in the view of the observer O', are not simultaneous in the reference frame O or in the view of the observer O: $t_B\neq t_A$.

The c in the Lorentz transformation, i.e., the speed of light in vacuum, is a cosmic constant, which is invariant and the same relative to all inertial observers. Therefore, the non-simultaneity ($t_B\neq t_A$) in O requires the observed object P to be in motion: $v\neq 0$. Accordingly, Einstein believed that simultaneity is relative or relativistic, the relativity of simultaneity is the essential characteristic of spacetime and matter motion, and rooted from matter motion ($v\neq 0$).

Actually, Einstein's relativity of simultaneity is only a special case of IOR's relativity of simultaneity, which is the observational effect of the optical agent OA(c) and not the objectively physical reality.

IOR's View on Simultaneity

In the theory of IOR, there is also the problem of simultaneity.

However, the theory of OR discovers that: the relativity of simultaneity is a sort of observational effect or apparent phenomenon.

According to the transformation of IOR spacetime (Eq. (4.18), i.e., so-called the general Lorentz transformation), under the general observation agent OA(η), Einstein's relativity of simultaneity (Eq. (7.15)) should be rewritten as:

$$\begin{aligned}\left|t_{\mathrm{B}}(\eta)-t_{\mathrm{A}}(\eta)\right|&=\frac{\left|\left(t'_{\mathrm{B}}(\eta)-t'_{\mathrm{A}}(\eta)\right)+\left(x'_{\mathrm{B}}(\eta)-x'_{\mathrm{A}}(\eta)\right)v/\eta^{2}\right|}{\sqrt{1-v^{2}/\eta^{2}}}\\&=\frac{\left|x'_{\mathrm{B}}(\eta)-x'_{\mathrm{A}}(\eta)\right|}{\sqrt{1-v^{2}/\eta^{2}}}\frac{|v|}{\eta^{2}}\neq 0\quad(|v|>0)\end{aligned}\tag{7.16}$$

Therefore, like in the case of optical observation, under the general observation agent OA(η), if the event A and the event B occur at different locations ($x_A'(\eta)\neq x_B'(\eta)$) in the reference frame O', then the event A and the event B, that occur simultaneously in the view of the observer O', are not simultaneous in the reference frame O or in the view of the observer O: $t_B(\eta)\neq t_A(\eta)$.

However, Eq. (7.16) shows that IOR's relativity of simultaneity is that of the general observation agent OA(η), which depends on OA(η). In essence, it does not depend on the speed v of matter motion, but depends on the information-wave speed η of OA(η): different observation agents exhibit different degrees of observational relativity of simultaneity.

This indicates that the so-called relativity of simultaneity depends on observation and observation agents, being a sort of observation effect.

According to Eq. (7.16), for the observed object P moving at the inertial speed v

(>0) relative the observer O armed with the observation agent OA(η), the higher the information-wave speed η of OA(η), the smaller the time interval $|t_B(\eta)-t_A(\eta)|$, and the more the events A and B tend to be simultaneous.

Under the optical observation agent OA(c), as $\eta\to c$,

$$\Delta T_{AB}(c)=\lim_{\eta\to c}\left|t_B(\eta)-t_A(\eta)\right|$$
$$=\lim_{\eta\to c}\frac{\left|x'_B(\eta)-x'_A(\eta)\right|}{\sqrt{1-v^2/\eta^2}}\frac{|v|}{\eta^2}=\frac{\left|x'_B(c)-x'_A(c)\right|}{\sqrt{1-v^2/c^2}}\frac{|v|}{c^2}\neq 0\quad(|v|>0) \tag{7.17}$$

This is namely the relativity of simultaneity under the optical agent OA(c), i.e., the relativity of simultaneity in Einstein's special relativity. It is thus clear that Einstein's relativity of simultaneity is only a special case of IOR's relativity of simultaneity of the general observation agent OA(η).

In particular, under the idealized observation agent OA_∞, as $\eta\to\infty$,

$$\Delta T_{AB}(\infty)=\lim_{\eta\to\infty}\left|t_B(\eta)-t_A(\eta)\right|=\lim_{\eta\to\infty}\frac{\left|x'_B(\eta)-x'_A(\eta)\right|}{\sqrt{1-v^2/\eta^2}}\frac{|v|}{\eta^2}=0 \tag{7.18}$$

Equation (7.18) shows that, under the idealized agent OA_∞, if the event A and the event B occur at the same time ($t_A'(\infty)=t_B'(\infty)$) in the reference frame O', then in the view of the observer O, regardless of whether the event A and the event B occur at the same location in O', the event A and the event B must be simultaneous in the reference frame O: $t_B(\infty)=t_A(\infty)$.

This is namely the simultaneity under the idealized agent OA_∞, that is, the simultaneity in Newton's classical mechanics, which has no the effect of relativistic simultaneity, and represents the objectively real simultaneity.

So, simultaneity is absolute.

7.3.4 Spacetime Curvature

Spacetime curvature is not the relativistic nature of inertial spacetime, but rather the relativistic nature of gravitational spacetime. The relativistic problem of gravitational spacetime will be discussed in **the 2nd volume of OR: Gravitationally Observational Relativity** (GOR), i.e., the theory of GOR.

However, based on the theory of IOR, i.e., **the 1st volume of OR: Inertially Observational Relativity** (IOR), we can not only reveal the essence of the relativistic phenomena of inertial spacetime and inertial motion, but also foresee the essence of relativistic phenomena of gravitational spacetime and matter interactions.

Based on the theory of IOR, we first make predictions about the most puzzling relativistic phenomenon of the curvature of gravitational spacetime [26-28]: in essence, **spacetime curvature** is just an observational effect or an apparent phenomenon.

Einstein's Curvature of Spacetime

For simplicity, we make use of the Schwarzschild metric to examine the **curvature** of gravitational spacetime in Einstein's general theory of relativity.

In 1915, Einstein established his general theory of relativity [8], in which Einstein's field equation is a set of nonlinear partial differential equations with difficulty to solve. At first, Einstein only obtained an approximate solution to his field equations. In 1916, Schwarzschild, a German physicist, obtained the first exact solution to Einstein's field equation, known as the Schwarzschild solution [80].

Schwarzschild set the gravitational scene as a **binary system** $\{M,m\}$: M is a sphere (celestial body) with the radius R, with the centrosymmetric distribution of matter or mass, forming a static spherically-symmetric gravitational field; m is a matter object ($<<M$) moving in the gravitational field of M. According to Newton's law of universal gravitation, the gravitational potential $\chi=-GM/r$, where r ($\geq R$) is the distance of m away from M.

The Schwarzschild solution is the external vacuum solution for the static spherically-symmetric gravitational field of the celestial body M, where the coordinates of spacetime (x^0,x^1,x^2,x^3) is in the form of spherical coordinates: $(x^0,x^1,x^2,x^3)=(ct,r,\theta,\varphi)$, rather than in the form of Cartesian coordinates (ct,x,y,z).

The spacetime line-element ds in the Schwarzschild solution is

$$\begin{aligned} \mathrm{d}s^2 &= g_{\eta\nu}\mathrm{d}x^\mu\mathrm{d}x^\nu \\ &= \left(1+\frac{2\chi}{c^2}\right)c^2\mathrm{d}t^2 - \left(1+\frac{2\chi}{c^2}\right)^{-1}\mathrm{d}r^2 - r^2\mathrm{d}\theta^2 - r^2\sin^2\theta\mathrm{d}\varphi^2 \end{aligned} \tag{7.19}$$

where G is Newton's gravitational constant, χ is Newton's gravitational potential, and $g_{\mu\nu}$ is the Schwarzschild metric:

$$\left(g_{\mu\nu}\right) = \mathrm{diag}\left(\left(1+\frac{2\chi}{c^2}\right), -\left(1+\frac{2\chi}{c^2}\right)^{-1}, -r^2, -r^2\sin^2\theta\right) \tag{7.20}$$

Equation (7.20) shows that the Schwarzschild metric $g_{\mu\nu}=g_{\mu\nu}(\chi)$ depends on the gravitational potential $\chi=-GM/r$, so the external spacetime of the celestial body M is curved in the Schwarzschild gravitational scene.

In the spacetime line-element ds and the spacetime metric $g_{\mu\nu}$ of the Schwarzschild solution, the speed c of light is a cosmic constant, and therefore, the curvature of spacetime requires the existence of gravitational potential: $\chi\neq 0$. Accordingly, confined to the perspective of the optical observation agent OA(c) and adhering to his consistent logic, Einstein believed that **spacetime curvature** is the essential characteristic of gravitational spacetime, and rooted in the existence of the matter M or the gravitational potential χ.

According to his general theory of relativity [8], Einstein believed that the existence of matter or energy leads to the curvature of spacetime: the greater the density of matter or energy, the greater the curvature of gravitational spacetime.

So, is the spacetime that accumulates matter or energy, such as gravitational spacetime, really curved?

In OR's View of Curvature of Spacetime

Actually, the Schwarzschild metric $g_{\mu\nu}$ is not only related to the gravitational potential χ, but also to the speed c of light in vacuum: $g_{\mu\nu}=g_{\mu\nu}(c,\chi)$. Naturally, the speed c of light in the Schwarzschild metric $g_{\mu\nu}$ is rooted from the principle of the invariance of the speed of light, which is employed as the axiom or logical premise of Einstein's theory of relativity, including the special and the general.

Like Einstein's special theory of relativity, Einstein's general theory of relativity is also the theory of optical observation, or the theory of the optical observation agent OA(c), in which light plays the role of the observation medium or the information wave, and the speed light c is the information-wave speed. Naturally, the light speed c in the Schwarzschild metric $g_{\mu\nu}$ represents the information-wave speed of the optical agent OA(c).

Logically, taking the advantage of the general observation agent OA(η), by substituting the information-wave speed η of OA(η) for the speed light c of the optical observation agent OA(c), the Schwarzschild line-element ds of Eq. (7.19) can be generalized as

$$\begin{aligned} \mathrm{d}s^2 &= g_{\eta\nu}(\eta,\chi)\mathrm{d}x^\mu \mathrm{d}x^\nu \\ &= \left(1+\frac{2\chi}{\eta^2}\right)\eta^2\mathrm{d}t^2 - \left(1+\frac{2\chi}{\eta^2}\right)^{-1}\mathrm{d}r^2 - r^2\mathrm{d}\theta^2 - r^2\sin^2\theta\mathrm{d}\varphi^2 \end{aligned} \tag{7.21}$$

and the Schwarzschild metric $g_{\mu\nu}=g_{\mu\nu}(c,\chi)$ of Eq. (7.20) can be generalized as $g_{\mu\nu}=g_{\mu\nu}(\eta,\chi)$ of the general observation agent OA(η):

$$\left(g_{\mu\nu}(\eta,\chi)\right) = \mathrm{diag}\left(\left(1+\frac{2\chi}{\eta^2}\right), -\left(1+\frac{2\chi}{\eta^2}\right)^{-1}, -r^2, -r^2\sin^2\theta\right) \tag{7.22}$$

where $(x^0,x^1,x^2,x^3)=(\eta t, r, \theta, \varphi)$ is the spacetime coordinates of OA(η), η is information-wave speed of OA(η), $g_{\mu\nu}(\eta,\chi)$ is the gravitational metric of the observational spacetime $X^{4\mathrm{d}}(\eta)$ of OA(η).

Equation (7.22) shows that, for the observational spacetime $X^{4\mathrm{d}}(\eta)$ of the general observation agent OA(η), the gravitational metric $g_{\mu\nu}=g_{\mu\nu}(\eta,\chi)$ also depends on Newton's gravitational potential $\chi=-GM/r$. Therefore, under the general observation agent OA(η), observationally, the gravitational spacetime $X^{4\mathrm{d}}(\eta)$ of OA(η) is also curved.

However, the so-called curvature of the gravitational spacetime $X^{4\mathrm{d}}(\eta)$ of the general observation agent OA(η), in essence, does not depend on gravitational interaction or Newton's gravitational potential χ, but depends on the information-wave speed η of the observation agent OA(η): under different observation agents, the identical gravitational spacetime observationally exhibits different degrees of curvature.

This suggests that the so-called spacetime curvature relies on observation and observation agents, being an observational effect and an apparent phenomenon.

Under the optical observation agent OA(c), as $\eta\to c$,

$$g_{\mu\nu}(c,\chi) = \lim_{\eta\to c} g_{\mu\nu}(\eta,\chi)$$
$$= \mathrm{diag}\left(\left(1+\frac{2\chi}{c^2}\right), -\left(1+\frac{2\chi}{c^2}\right)^{-1}, -r^2, -r^2\sin^2\theta\right) \tag{7.23}$$

This is namely the Schwarzschild metric under the optical agent OA(c), i.e., the gravitational metric $g_{\mu\nu}(c,\chi)$ of Einstein's general theory of relativity. It is thus clear that the Schwarzschild metric is only a special case of the gravitational metric $g_{\mu\nu}(\eta,\chi)$ under the general observation agent OA(η).

In particular, under the idealized observation agent OA_∞, as $\eta\to\infty$,

$$g_{\mu\nu}(\infty,\chi) = \lim_{\eta\to\infty} g_{\mu\nu}(\eta,\chi)$$
$$= \lim_{\eta\to\infty}\mathrm{diag}\left(\left(1+\frac{2\chi}{\eta^2}\right), -\left(1+\frac{2\chi}{\eta^2}\right)^{-1}, -r^2, -r^2\sin^2\theta\right)$$
$$= \mathrm{diag}\left(1,-1,-r^2,-r^2\sin^2\theta\right) \tag{7.24}$$

This is namely the gravitational metric under the idealized agent OA_∞, that is, the gravitational metric $g_{\mu\nu}(\infty,\chi)$ in Newton's classical mechanics, representing the objective and real gravitational spacetime.

It is worth noting that the gravitational metric $g_{\mu\nu}$=diag(+1,–1,$-r^2$,$-r^2\sin^2\theta$) in Eq. (7.24) is exactly the Minkowski metric in the form of spherical coordinates, representing flat spacetime rather than curved spacetime.

Equation (7.24) indicates that the idealized observation agent OA_∞ has no observational locality, no observational effects, and therefore, presents us with the objectively real spacetime: flat rather than curved. It turns out that, regardless of whether there are gravitational fields or gravitational potentials, the objectively real spacetime must be flat rather than curved.

So, there is no so-called curved spacetime in the university.

It can be seen that, in essence, the so-called spacetime curvature in Einstein's general theory of relativity is the observational effect and apparent phenomenon of the optical observation agent OA(c), rather than the existence of the matter M or the gravitational potential χ in spacetime, and rooted in the observational locality ($c<\infty$) of the optical observation agent OA(c).

The spacetime curvature in Einstein's general theory of relativity is just an optical illusion. The optical agent OA(c) has the observational locality ($c<\infty$), which, like a wide-angle lens, makes gravitational spacetime appear somewhat curved or deformed.

However, the objectively real spacetime, regardless of the existence of matter or energy, regardless of observation, must be flat rather than curved.

7.4 The Relativistic Effects of Matter Motion

Based on his special theory of relativity, Einstein believed that the relativistic effects or relativistic phenomena of inertial spacetime and inertial motion are the essential characteristics of spacetime, and rooted in the motion of matter.

According to Einstein's special theory of relativity, the value of a physical quantity of the same observed object P in motion ($v \neq 0$) are different from that of P at rest ($v=0$). The physical quantities of matter in motion are called relativistic or moving physical quantities, such as relativistic mass, relativistic momentum, and relativistic energy. Moreover, Einstein regarded the relativistic physical quantities as the objective and real physical existence.

Motion is relative. According to the agreements of Sec. 1.1.1 in Chapter 1, suppose that there are two inertial reference frames (or observers) O and O' as depicted in Fig. 1.1: let the observed object P at rest in O', then the mass of P is the rest mass m_o in the frame O' or in the view of the observer O'; let the frame O' be moving at the inertial speed v relative to the frame O, then, according to Einstein's special theory of relativity, the mass of P is the relativistic mass m in the frame O or in the view of the observer O, which is greater than the rest mass m_o, and the higher the v, the greater the m is.

Mass is the intrinsic attribute of matter. The different observers, O and O', observe the same object P, why do they have different views of the mass of P as well as the gravitational effects of M exerting on P?

Logically, this seems quite absurd.

According to the theory of OR, the objectively real mass of an object P is Newton's classical mass $m_\infty = m_o$, which is the mass observed and measured by the idealized observation agent OA_∞. However, restricted by observation, restricted by the observational locality ($\eta < \infty$) of the observation agent $\mathrm{OA}(\eta)$, the mass m of P observed by the observer O armed with the observation agent $\mathrm{OA}(\eta)$ is not equivalent to the objectively real mass m_o of P.

Actually, restricted by the observational locality of observation agents, all the observed (or observational) physical quantities are not equivalent to the objectively and real physical quantities.

As far as inertial spacetime, according to the Taylor-series decomposition in Eq. (7.2), the IOR factor $\Gamma(\eta) = \Gamma_\infty + \Delta\Gamma(\eta)$ of inertial spacetime reflects the observed (or observational) relativistic-effects of inertial spacetime and inertial motion. So, based on the IOR factor $\Gamma(\eta) = \Gamma_\infty + \Delta\Gamma(\eta)$, the theory of IOR can examine the relativistic physical quantities of inertial spacetime, and reveal the root and essence of the relativistic effects of matter motion.

In this section, we take **the relativistic mass**, **the relativistic momentum**, and **the relativistic kinetic-energy** as the examples of relativistic physical quantities for expounding the root and essence of the relativistic effects or relativistic phenomena of matter motion in inertial spacetime.

7.4.1 Observational Mass vs Relativistic Mass

Mass is the most basic attribute of a material object. **Relativistic mass** is the most basic relativistic physical quantity of matter motion.

Einstein believed that the relativistic mass of matter is the objectively physical existence. However, the theory of OR discovers that the so-called relativistic mass is actually the observed (or observational) mass, not entirely objective or real.

Einstein's Relativistic Mass

In Einstein's special relativity, time dilates and mass also dilates.

According to the mass-speed relation (Eq. (5.1)) in Einstein's special relativity:

$$m(v)=\gamma(v)m_o=\frac{m_o}{\sqrt{1-v^2/c^2}}>m_o \quad (|v|>0) \tag{7.25}$$

where m_o is the rest mass of the observed object P, and m is Einstein's relativistic mass of P, or called moving mass.

Equation (7.25) means that the mass of P dilates with P's moving: $m>m_o$ ($v\neq 0$).

The c in the mass-speed relation (Eq. (7.25)), i.e., the speed of light in vacuum, is a cosmic constant, which is invariant and the same relative to all inertial observers. Therefore, the dilation of mass ($m>m_o$) requires the observed object P to be in motion: $v\neq 0$. Accordingly, Einstein believed that the relativistic effect of mass is the essential characteristic of the physical world, and rooted from matter motion ($v\neq 0$).

Actually, the dilation of mass in Einstein's special theory of relativity is only a special case of IOR's mass dilation, which is the dilation of the observational (or observed) mass under the optical agent OA(c), not the objectively real mass.

IOR's Observational Mass

In the theory of OR or IOR, mass dilates too.

However, the theory of OR discovers that the objectively real mass $m_\infty=m_o$ does not dilate; the so-called **relativistic mass** m is actually the **observational mass** $m=m(\eta)$, depending on the observational agent OA(η) and containing the observational effect of OA(η).

As stated in Chapter 5, according to the IOR mass-speed relation (Eq. (5.5)), as well as the Taylor-series decomposition of the IOR factor (Eq. (7.2)) or the Taylor-series decomposition of the IOR mass (Eq. (5.6)), under the general observation agent OA(η), the observational mass in IOR theory is:

$$\begin{aligned} m(\eta,v)&=\Gamma(\eta,v)m_o=\frac{m_o}{\sqrt{1-v^2/\eta^2}}=\left(\Gamma_\infty+\Delta\Gamma(\eta,v)\right)m_o \\ &=m_o+\Delta m(\eta,v)\geq m_o \quad \left(\Gamma_\infty\equiv 1, \Delta m(\eta,v)=\Delta\Gamma(\eta,v)m_o\right) \end{aligned} \tag{7.26}$$

where m_o is the rest mass of the observed object P; $m=m(\eta,v)$ is the relativistic mass of P, i.e., the observed (or observational) mass of OA(η) in IOR theory; $\Delta m=\Delta m(\eta,v)$ is the dilative part of the observed mass of OA(η), not the objectively physical existence.

Equation (7.26) means that the IOR mass of P dilates too: $m(\eta,v)>m_o$.

However, the IOR observational mass $m=m(\eta,v)$ is that of the general observation agent OA(η), depending on observation or observation agents. In essence, the so-called mass dilation does not depend on the speed v of matter motion, but on the information-wave speed η of the observation agent OA(η): under different observation agents, the same object P (with the same inertial speed v) exhibits different observational masses.

It is thus clear that the so-called relativistic mass depends on observation and contains observational effects or apparent phenomena.

According to Eq. (7.26), for the observed object P moving at the inertial speed v, under the observation agent OA(η), the lower the information-wave speed η of OA(η), the more significant the dilative effect of the observational mass m, and the larger the dilative part Δm of mass is.

Under the optical observation agent OA(c), as $\eta \to c$,

$$\begin{aligned} m_c &= \lim_{\eta\to c} m(\eta,v) = \lim_{\eta\to c} \Gamma(\eta,v) m_o = \lim_{\eta\to c} \frac{m_o}{\sqrt{1-v^2/\eta^2}} = \frac{m_o}{\sqrt{1-v^2/c^2}} \\ &= \left(\Gamma_\infty + \Delta\Gamma(c,v)\right) m_o = m_o + \Delta m(c,v) \ge m_o \qquad (7.27) \\ &\left(\Gamma_\infty \equiv 1,\ \Delta m(c,v) = \Delta\Gamma(c,v) m_o\right) \end{aligned}$$

This is namely the dilation of the observational mass $m(c)$ under the optical agent OA(c), i.e., the dilation of the relativistic mass m_c of Einstein's special theory of relativity. It is thus clear that Einstein's relativistic mass m_c is only a special case of the observational mass $m(\eta)$ of the general observation agent OA(η).

Equation (7.27) shows that Einstein's relativistic mass m_c, as the observational mass $m(c)$ of the optical agent OA(c), contains the effect of optical observation: $m_c=m(c)\ge m_o$, and is not the objective real mass m_o of the observed object P.

In particular, under the idealized observation agent OA_∞, as $\eta\to\infty$,

$$m_\infty = \lim_{\eta\to\infty} m(\eta,v) = \lim_{\eta\to\infty} \Gamma(\eta,v) m_o = \lim_{\eta\to\infty} \frac{m_o}{\sqrt{1-v^2/\eta^2}} = m_o \qquad (7.28)$$

This is namely the observational mass $m(\infty)$ under the idealized agent OA_∞, i.e., the classical mass m_∞ of Newton's mechanics, with no observational effect and no mass dilation, representing the objectively real mass m_o of the observer object P.

Equation (7.28) shows that Newton's classical mass m_∞, as the observational mass $m(\infty)$ of the idealized agent OA_∞, is exactly the objective real mass: $m_\infty=m_o$.

In summary, no matter Einstein's relativistic mass or IOR's observational mass, in essence, the dilation of mass is a sort of observational effect, and rooted in the observational locality ($c<\infty$ or $\eta<\infty$) of the observation agent OA(c) or OA(η).

The objectively real mass $m_\infty=m_o$ of matter never dilates.

7.4.2 Observational Momentum vs Relativistic Momentum

If mass is relativistic, then naturally, momentum is also relativistic. If the relativistic mass of matter objectively exists, then the relativistic momentum of matter also objectively exists, as Einstein advocated.

However, the theory of OR discovers that the so-called relativistic momentum is the observed (or observational) momentum, not entirely objective or real.

Einstein's Relativistic Momentum

In Einstein's special relativity, mass dilates and momentum also dilates.

According to the definition (Eq. (5.11)) of relativistic momentum in Einstein's special relativity:

$$p = mv = \gamma m_o v = \frac{m_o v}{\sqrt{1-v^2/c^2}} > p_o = m_o v \quad (|v|>0) \tag{7.29}$$

where $p_o=m_o v$ ($p_o=p_\infty$ and $m_o=m_\infty$) is the classical momentum of the observed object P, i.e., the momentum produced by the classical mass m_∞; and $p=mv$ is Einstein's relativistic momentum, i.e., the momentum produced by the relativistic mass m.

Equation (7.29) means that the momentum of P dilates: $p>p_o$ ($v\neq 0$).

Einstein believed that the relativistic effect of mass is the essential characteristic of the physical world; Likewise, Einstein believed that the relativistic effect of momentum is also the essential characteristic of the physical world.

Actually, the dilation of momentum in Einstein's special relativity is only a special case of IOR's momentum dilation, which is the dilation of the observational momentum under the optical agent OA(c), not the objectively real momentum.

IOR's Observational Momentum

In the theory of OR or IOR, momentum dilates too.

However, the theory of OR discovers that the so-called **relativistic momentum** p is actually the **observational momentum** $p=p(\eta)$, depending on the observation agent OA(η), containing the observational effect of OA(η).

As stated in Chapter 5, according to the definition of the IOR momentum (Eq. (5.12)), as well as the Taylor-series decomposition of the IOR factor (Eq. (7.2)) or the Taylor-series decomposition (Eq. (5.13)) of the IOR momentum, under the general observation agent OA(η), the observational momentum in IOR theory is:

$$\begin{aligned} p(\eta,v) &= m(\eta,v)v = \Gamma(\eta,v) m_o v \\ &= \frac{m_o v}{\sqrt{1-v^2/\eta^2}} = \left(\Gamma_\infty + \Delta\Gamma(\eta,v)\right) p_o = p_o + \Delta p(\eta,v) \geq p_o = m_o v \\ &\left(\Gamma_\infty \equiv 1, \Delta p(\eta,v) = \Delta\Gamma(\eta,v)\, p_o\right) \end{aligned} \tag{7.30}$$

where $p_o=m_o v$ ($p_o=p_\infty$ and $m_o=m_\infty$) is the classical momentum of the observed object P, i.e., the momentum produced by the classical mass m_∞; $p=p(\eta,v)=m(\eta,v)v$ is IOR's observational momentum, i.e., the momentum produced by the observational mass $m(\eta,v)$; $\Delta p=\Delta p(\eta,v)$ is the dilative part of the observational momentum, not the objectively physical existence.

Equation (7.30) means that the IOR momentum of P dilates too: $p(\eta,v)>p_o$.

However, the IOR observational momentum $p=p(\eta,v)$ is that of the general observation agent OA(η), depending on observation or observation agents: under different observation agents, the same object P (with the same inertial speed v) exhibits different observational momentums.

It is thus clear that the so-called relativistic momentum depends on observation and contains observational effects or apparent phenomena.

According to Eq. (7.30), the observational momentum $p=p(\eta,v)$ of the observed object P moving at the speed v dilates with the dilation of P's observational mass $m=m(\eta,v)$: under the observation agent OA(η), the lower the information-wave speed η of OA(η), the more significant the dilative effect of the observational mass m, the larger the dilative part Δm of P's observational mass m, and therefore, the larger the dilative part $\Delta p=\Delta mv$ of P's observational momentum $p=p(\eta,v)$ is.

Under the optical observation agent OA(c), as $\eta\to c$,

$$\begin{aligned} p_c &= \lim_{\eta\to c} p(\eta,v) = \lim_{\eta\to c}\frac{m_o v}{\sqrt{1-v^2/\eta^2}} = \frac{m_o v}{\sqrt{1-v^2/c^2}} \\ &= \big(\varGamma_\infty + \Delta\varGamma(c,v)\big)\,p_o = p_o + \Delta p(c,v) \geq p_o = m_o v \qquad (7.31) \\ &\big(\varGamma_\infty \equiv 1,\ \Delta p(c,v) = \Delta\varGamma(c,v)\,p_o\big) \end{aligned}$$

This is namely the dilation of the observational momentum $p(c)$ under the optical agent OA(c), i.e., the dilation of the relativistic momentum p_c of Einstein's special theory of relativity. It is thus clear that Einstein's relativistic momentum p_c is only a special case of the observational momentum $p(\eta)$ of the general observation agent OA(η).

Equation (7.31) shows that Einstein's relativistic momentum p_c, as the observational momentum $p(c)$ of the optical agent OA(c), contains the effect of optical observation: $p_c=p(c)\geq p_o$, and the dilative momentum $p_c=p(c)$ is not the objective real momentum $p_o=m_ov$ of the observed object P.

In particular, under the idealized observation agent OA$_\infty$, as $\eta\to\infty$,

$$p_\infty = \lim_{\eta\to\infty} p(\eta,v) = \lim_{\eta\to\infty}\frac{m_o v}{\sqrt{1-v^2/\eta^2}} = m_o v = p_o \qquad (7.32)$$

This is namely the observational momentum $p(\infty)$ under the idealized agent OA$_\infty$, i.e., the classical momentum p_∞ of Newton's mechanics, with no observational effect and no momentum dilation, representing the objectively real momentum $p_\infty=p_o$ of the observer object P.

Equation (7.32) shows that Newton's classical momentum p_∞, as the observational momentum $p(\infty)$ of the idealized agent OA$_\infty$, is exactly the objectively real momentum: $p_\infty=p_o$.

In summary, no matter Einstein's relativistic momentum or IOR's observational momentum, in essence, the dilation of momentum is only a sort of observational effect, and rooted in the observational locality ($c<\infty$ or $\eta<\infty$) of the observation agent OA(c) or OA(η).

The objectively real momentum $p_\infty=p_o$ of matter never dilates.

7.4.3 Observational Kinetic Energy vs Relativistic Kinetic Energy

In Newton's mechanics, the inertial moving object P, as a matter particle (mass point), has only kinetic energy K. However, in Einstein's special theory of relativity, P, as an inertial matter particle, not only has kinetic energy but also has rest energy, and moreover, energy and mass can be transformed into each other.

In Sec. 5.3 **IOR mass-energy relation** of Chapter 5, it has been clarified that the objectively real energy of an inertial matter particle follows the laws of Newton's mechanics: the inertial moving object P only has the kinetic energy K. In the inertial theory of relativity, including Einstein's special theory of relativity and the theory of IOR, the so-called **rest energy** $E_o=m_oc^2$ or $E_o=m_o\eta^2$ is not the objectively physical existence; in the so-called **mass energy** $E=mc^2$ or $E=m\eta^2$ ($E=K+E_o$), the part that really has physical significance is only the kinetic energy K.

Einstein's Relativistic Kinetic Energy

In Einstein's special relativity, mass dilates and kinetic energy also dilates.

According to the formula (Eq. (5.17)) of the relativistic kinetic energy in Einstein's special relativity:

$$\begin{aligned} K &= E - E_o = mc^2 - m_oc^2 = (\gamma - 1)m_oc^2 \\ &= \left(\frac{1}{\sqrt{1-v^2/c^2}} - 1\right)m_oc^2 \quad \left(E_o = m_oc^2,\, E = mc^2\right) \end{aligned} \tag{7.33}$$

where E is Einstein's mass energy, i.e., the total energy of the inertial matter particle P, E_o is the rest energy of P, K is the kinetic energy, depending on the Lorentz factor γ, naturally, being relativistic.

In Eq. (7.33), $E=mc^2$ is namely the famous Einstein formula, or referred to as **Einstein's mass-energy relation**.

Expand the Lorentz factor γ as Taylor series, then

$$\begin{aligned} K &= (\gamma - 1)m_oc^2 \\ &= \left(\frac{1}{2}\frac{v^2}{c^2} + \frac{1\cdot 3}{2\cdot 4}\frac{v^4}{c^4} + \frac{1\cdot 3\cdot 5}{2\cdot 4\cdot 6}\frac{v^6}{c^6} + \cdots\right)m_oc^2 = K_o + \Delta K \\ &\begin{cases} K_o = \dfrac{1}{2}m_ov^2 = K_\infty \\ \Delta K = \left(\dfrac{1\cdot 3}{2\cdot 4}\dfrac{v^4}{c^4} + \dfrac{1\cdot 3\cdot 5}{2\cdot 4\cdot 6}\dfrac{v^6}{c^6} + \cdots\right)m_oc^2 \end{cases} \end{aligned} \tag{7.34}$$

where K_o is exactly Newton's classical kinetic energy K_∞, while ΔK is the dilative part of Einstein's relativistic kinetic energy.

Equation (7.34) means that the relativistic kinetic energy K of the observed object P dilates with the mass dilation of P: $K>K_o$.

Einstein believed that the relativistic effect of mass is the essential characteristic of the physical world; Likewise, Einstein believed that the relativistic effect of kinetic energy is also the essential characteristic of the physical world.

Actually, the dilation of kinetic energy in Einstein's special relativity is only a special case of IOR's kinetic-energy dilation, i.e., is the dilation of the observational kinetic energy under the optical agent OA(c), not the objectively real kinetic energy.

IOR's Observational Kinetic Energy

In the theory of OR or IOR, kinetic energy dilates too.

However, the theory of OR discovers that the so-called **relativistic kinetic energy** K is actually the **observational kinetic energy** $K=K(\eta)$, depending on the observation agent OA(η), containing the observational effect of OA(η).

As stated in Chapter 5, in the theory of IOR, the observationally relativistic kinetic-energy formula (Eq. (5.21)) holds true as follows:

$$\begin{aligned} K(\eta,v) &= E(\eta,v)-E_o(\eta) = m(\eta,v)\eta^2 - m_o\eta^2 = \left(\Gamma(\eta,v)-1\right)m_o\eta^2 \\ &= \left(\frac{m_o v}{\sqrt{1-v^2/\eta^2}}-1\right)m_o\eta^2 \quad \left(E_o = m_o\eta^2,\, E=m\eta^2\right) \end{aligned} \tag{7.35}$$

where $E=E(\eta,v)$ is the IOR mass energy, i.e., the total energy of the inertial matter particle P under the general observation agent OA(η), $E_o(\eta)=E(\eta,0)$ is the IOR rest energy of P, $K(\eta,v)$ is the IOR kinetic energy of P, depending on the IOR factor $\Gamma(\eta,v)$, naturally, also being relativistic.

In Eq. (7.35), $E=m\eta^2$ is the IOR mass-energy relation, or referred to as **the general Einstein formula**.

Expand the IOR factor $\Gamma(\eta,v)$ as Taylor series, then

$$\begin{aligned} K(\eta,v) &= \left(\Gamma(\eta,v)-1\right)m_o\eta^2 \\ &= \left(\frac{1}{2}\frac{v^2}{\eta^2}+\frac{1\cdot 3}{2\cdot 4}\frac{v^4}{\eta^4}+\frac{1\cdot 3\cdot 5}{2\cdot 4\cdot 6}\frac{v^6}{\eta^6}+\cdots\right)m_o\eta^2 = K_o + \Delta K(\eta,v) \\ & \begin{cases} K_o = \dfrac{1}{2}m_o v^2 \\ \Delta K(\eta,v) = \left(\dfrac{1\cdot 3}{2\cdot 4}\dfrac{v^4}{\eta^4}+\dfrac{1\cdot 3\cdot 5}{2\cdot 4\cdot 6}\dfrac{v^6}{\eta^6}+\cdots\right)m_o\eta^2 \end{cases} \end{aligned} \tag{7.36}$$

where K_o is exactly Newton's classical kinetic energy K_∞, while $\Delta K=\Delta K(\eta,v)$ is the dilative part of IOR's observationally relativistic kinetic energy, not the objectively physical existence.

Equation (7.36) means that the IOR kinetic energy of the observed object P dilates with the mass dilation of P under OA(η): $K(\eta,v)>K_o$.

However, the IOR observational kinetic energy $K=K(\eta,v)$ is that of the general observation agent OA(η), depending on observation or observation agents: under different observation agents, the same object P (with the same inertial speed v) exhibits different observational kinetic energy.

It is thus clear that the so-called relativistic kinetic energy depends on observation and contains observational effects or apparent phenomena.

According to Eq. (7.36), the observational kinetic energy $K=K(\eta,v)$ of the observed object P moving at the speed v dilates with the dilation of P's observational mass $m=m(\eta,v)$: under the observation agent OA(η), the lower the information-wave speed η of OA(η), the more significant the dilative effect of the observational mass m, the larger the dilative part Δm of P's observational mass m, and therefore, the larger the dilative part $\Delta K=\Delta K(\eta,v)$ of P's observational kinetic energy $K=K(\eta,v)$ is.

Under the optical observation agent OA(c), as $\eta\to c$,

$$\begin{aligned} K_c &= \lim_{\eta\to c} K(\eta,v) = \lim_{\eta\to c}\left(\Gamma(\eta,v)-1\right)m_o\eta^2 \\ &= \lim_{\eta\to c}\left(\frac{1}{\sqrt{1-v^2/\eta^2}}-1\right)m_o\eta^2 = \left(\frac{1}{\sqrt{1-v^2/\eta^2\, c}}-1\right)m_o c^2 \\ &= K(c,v) = K_o + \Delta K(c,v) \ge K_o = \frac{1}{2}m_o v^2 \end{aligned} \tag{7.37}$$

This is namely the dilation of the observational kinetic energy $K(c)$ under the optical agent OA(c), i.e., the dilation of the relativistic kinetic energy K_c of Einstein's special theory of relativity. It is thus clear that Einstein's relativistic kinetic energy K_c is only a special case of the observational kinetic energy $K(\eta)$ of the general observation agent OA(η).

Equation (7.37) shows that Einstein's relativistic kinetic energy K_c, as the observational kinetic energy $K(c)$ of the optical agent OA(c), contains the effect of optical observation: $K_c=K(c)\ge K_o$, and the dilative kinetic energy $K_c=K(c)$ is not the objective real kinetic energy $K_o=m_o v^2/2$ of the observed object P.

In particular, under the idealized observation agent OA_∞, as $\eta\to\infty$,

$$\begin{aligned} K_\infty &= \lim_{\eta\to\infty} K(\eta,v) = \lim_{\eta\to\infty}\left(\Gamma(\eta,v)-1\right)m_o\eta^2 \\ &= \lim_{\eta\to\infty}\left(\frac{1}{\sqrt{1-v^2/\eta^2}}-1\right)m_o\eta^2 = \frac{1}{2}m_o\eta^2 = \frac{1}{2}m_\infty\eta^2 \end{aligned} \tag{7.38}$$

This is namely the observational kinetic energy $K(\infty)$ under the idealized agent OA_∞, i.e., the classical kinetic energy K_∞ of Newton's mechanics, with no observational effect and no kinetic-energy dilation, representing the objectively real kinetic energy $K_\infty= m_\infty v^2/2$ of the observer object P.

Equation (7.38) shows that Newton's classical kinetic energy K_∞, as the observational kinetic energy $K(\infty)$ of the idealized agent OA_∞, is exactly the objectively real kinetic energy: $K_\infty=K_o$.

In summary, no matter Einstein's relativistic kinetic energy or IOR's observational kinetic energy, in essence, the dilation of kinetic energy is only a sort of observational effect, and rooted in the observational locality ($c<\infty$ or $\eta<\infty$) of the observation agent OA(c) or OA(η).

The objectively real kinetic energy $K_\infty=K_o$ of matter never dilates.

8 The Unity of Newton and Einstein in IOR

Both Newton's classical mechanics and Einstein's relativity theory are only the partial theories of physics in Hawking's words [31], and as a matter of fact, both are the partial theories of OR theory. The unity of the partial theories of physics is not the mechanical or formal reproduction or repetition of old theories, but the progress and even leap in human beings' cognition of the objective world, which is a major step in tracing the logical origin of the theoretical systems of physics.

Beyond doubt, it is of great significance to unify Newton's classical mechanics and Einstein's relativity theory, two great theoretical systems in physics, into the same theoretical system under the same axiom system.

One physical world, one logical system.

Only if the causal chains of physics start from the most basic logical premises, can we truly recognize and understand the essence of the physical world, generalize and unify the partial theories of physics.

The theory of IOR is built up on the basis of the more basic axiom system than the axiom system of Einstein's theory of relativity, starting from the most basic logical premise: the definition of time, and therefore, possesses the high degree of generality and unity. The theory of IOR has generalized and unified the Galilean transformation and the Lorentz transformation, and generalized and unified Newton's inertial mechanics and Einstein's special relativity, infusing new ideas and insights into both classical physics and modern physics.

Tab. 8.1 is a list for the analogy of the theory of IOR and Einstein's special relativity as well as Galilean-Newtonian inertial mechanics, demonstrating the unification of Newton and Einstein in the theory of IOR.

Now, the theory of Inertially Observational Relativity (IOR), or the theory of IOR for short, has been established on the basis of the OR axiom system. Newton's theory of inertial mechanics and Einstein's theory of special relativity have been generalized and unified into **the 1st volume of OR: Inertially Observational Relativity** (IOR); while Newton's theory of universal gravitation and Einstein's theory of general relativity, the two great gravitational theories in physics, will be generalized and unified into **the 2nd volume of OR: Gravitationally Observational Relativity** (GOR).

Perhaps, as Hawking said [31]: "Then we should know the mind of God."

8.1 The Unity of the Coordinate Systems of Inertial Spacetime

The theory of IOR is the theoretical system of the general observation agent OA(η). Galilean-Newtonian inertial mechanics is the theory of the idealized observation agent OA_∞; while Einstein's special theory of relativity is the theory of the optical observation agent OA(c). As the IOR basic formulae shown in Tab. 8.1, if OA(η) is the optical agent OA(c), then the theory of IOR strictly converges to

Einstein's special relativity, while if OA(η) is the idealized agent OA_∞, then the theory of IOR strictly converges to Galilean-Newtonian inertial mechanics.

Tab. 8.1 takes the basic formulae of IOR theory as examples to demonstrate the generality and unity of IOR theory.

According to the theory of OR, the spacetime of a specific theoretical system in physics is the observational spacetime of a specific observation agent OA(η), which is different from the objectively real spacetime. Following Minkowski's logic, chapter 1 in **the 1st volume of OR: Inertially Observational Relativity** (IOR) defines the concept of **Observation Agent**, and meanwhile, defines **the coordinate framework of 4d inertial spacetime** for the observational spacetime $X^{4d}(\eta)$ of the general observation agent OA(η).

This section analyzes the generality and unity of the IOR observation agent OA(η) and the coordinate framework of IOR spacetime $X^{4d}(\eta)$.

8.1.1 Cartesian Spacetime vs Minkowski Spacetime

According to the agreements of Sec. 1.1.1 in Chapter 1, there can be different formalization methods for the inertial spacetimes O and O', including different observation agents and different coordinate frameworks.

Cartesian Coordinate System

We know that Galileo and Newton hold the absolutist view of spacetime: space and time are independent of each other; space is just space and time is just time. Such absolutist view of spacetime is reflected in Galileo's doctrine and Newton's theory. Therefore, in Galilean-Newtonian classical mechanics, there is no concept of **spacetime**, only the mutually independent **space** and **time**.

In order to describe space and time in formalization, Descartes invented **Cartesian coordinates** or **Cartesian coordinate system**, which can be referred to as the coordinate framework of Cartesian spacetime: in the O and O' of Cartesian coordinates, the spatial location of the observed object P can be represented by different coordinates (x,y,z) and (x′,y′,z′) respectively, while the time t of O and the t' of O' are the same ($t=t'$), or the rate time flowing dt and dt' are the same (dt=dt').

Actually, as stated in Sec. 1.4.3 Idealized Observation Agent of Chapter 1, Cartesian coordinate system represents the idealized observation system, that is, the idealized observation agent OA_∞, in which the of information-waves speed is infinite, and information takes no time to cross space.

It is shown in Eq. (1.4) of Chapter 1 that

$$\text{Cartesian Spacetime } \mathrm{OA}_\infty \triangleq \left\{ \begin{array}{l} X^{4\mathrm{d}}{}_\infty : \left\{ \begin{array}{l} x^0 = \eta t \ \ (\eta \to \infty); \\ x^1 = x, x^2 = y, x^3 = z \end{array} \right\} \\ \mathrm{d}t = \mathrm{d}\tau \\ \mathrm{d}l^2 = \mathrm{d}x^2 + \mathrm{d}y^2 + \mathrm{d}z^2 \end{array} \right\},$$

where OA_∞ is the idealized observation agent, $X^{4d}{}_\infty$ is the idealized observational spacetime of OA_∞; dt is the idealized observational time-element, dτ is the objectively real time-element (**proper time**), i.e., the **mathematical time** in Newton's words; dl is the line-element of Cartesian 3d space (x,y,z), the time axis x^0 has no physical significance as $\eta\rightarrow\infty$.

Cartesian spacetime or the coordinate framework of Cartesian spacetime (3d space independent 1d time) reflects the absolutist view of spacetime.

The Coordinate Framework of Minkowski Spacetime

Mach and Einstein hold the relativist view of spacetime: space and time are dependent of each other; space is time and time is also space. Such relativist view of spacetime is reflected in Einstein's theory of relativity, and whereupon, there is the concept of **Spacetime**.

Minkowski discovered that Einstein's special theory of relativity could be more formally described in a coordinate framework of 4d spacetime, and then, there is the concept of **Minkowski spacetime** (Eq. (1.1)) [50,51].

Actually, Minkowski spacetime represents the optical observation system, that is, the optical observation agent OA(c), in which the observation medium is light, and the transmission speed of observed information is the speed of light in vacuum, and is limited ($c<\infty$): it takes time for information to cross space.

So, the optical observation agent OA(c) has its observational locality.

It is shown in Eq. (1.1) of Chapter 1 that

$$\text{Minkowski Spacetime }\ \mathrm{OA}(c) \triangleq \left\{ \begin{array}{l} X^{4\mathrm{d}}(c):\left\{x^0 = ct;\ \ x^1 = x,\, x^2 = y,\, x^3 = z\right\} \\ \mathrm{d}s^2 = c^2\mathrm{d}t^2 - \mathrm{d}x^2 - \mathrm{d}y^2 - \mathrm{d}z^2 \end{array} \right\},$$

where OA(c) is the optical observation agent, $X^{4\mathrm{d}}(c)$ is the optical observational spacetime of OA(c); dt is the optical observational time-element, ds is the line-element of Minkowski 4d spacetime (x^0,x^1,x^2,x^3), the space coordinates (x^1,x^2,x^3) may be Cartesian coordinates (x,y,z).

Minkowski Spacetime or the coordinate framework of Minkowski spacetime (3d space dependent of 1d time) reflects the relativist view of spacetime.

8.1.2 IOR Inertial Spacetime

The theory of OR has already clarified [26-30]: all the theories of physics depend on observation and are restricted by observation; in theory, all the forms of matter motion can be employed as observation media to transmit the information of observed objects to observers.

In the 1st volume of OR, Chapter 1 defines the concept of **Observation Agent** in Sec. 1.4.2, denotes the general observation agent as OA(η), in which, the observation medium $M(\eta)$ can be any form of matter motion or any matter wave, and the information-wave speed η of OA(η) or $M(\eta)$ can be arbitrary speed.

According to Def. 1.1 in Chapter 1, the general observation agent OA(η) and its inertial spacetime $X^{4\mathrm{d}}(\eta)$ can be formalized as

IOR's Inertial Spacetime $\mathrm{OA}(\eta) \triangleq \left\{ \begin{array}{l} X^{4\mathrm{d}}(\eta): \left\{ \begin{array}{l} x^0 = \eta t; \\ x^1 = x,\, x^2 = y,\, x^3 = z \end{array} \right\} \\ \mathrm{d}s^2 = \eta^2 \mathrm{d}t^2 - \mathrm{d}x^2 - \mathrm{d}y^2 - \mathrm{d}z^2 \end{array} \right\},$

where OA(η) is the general observation agent, $X^{4\mathrm{d}}(\eta)$ is the observational spacetime of OA(η); dt is the observational time-element of OA(η), ds is the line-element of 4d observational spacetime $X^{4\mathrm{d}}(\eta)=(\mathrm{x}^0,\mathrm{x}^1,\mathrm{x}^2,\mathrm{x}^3)$, the space coordinates $(\mathrm{x}^1,\mathrm{x}^2,\mathrm{x}^3)$ may be Cartesian coordinates (x,y,z).

It should be pointed out that no matter Def. 1.1 of the general observation agent OA(η) or Eq. (1.2) is not the logical premise presupposed by the theory of OR, but the logical consequence derived by the theory of IOR following and analogizing Minkowski's logic and method [50,51].

Thus, the general observation agent OA(η) becomes the formalized coordinate framework of 4d spacetime in the theory of IOR.

8.1.3 The Unity of Descartes and Minkowski

The Cartesian coordinate system is the coordinate framework of 3d space that can be employed to serve Newton's inertial mechanics; while Minkowski spacetime is the coordinate framework of 4d spacetime specially designed by Minkowski for Einstein's special relativity.

Obviously, Minkowski spacetime is a special case of IOR spacetime: the coordinate framework of Minkowski 4d spacetime is the optical observation agent OA(c); while the coordinate framework of IOR 4d spacetime is the general observation agent OA(η). There is the strictly corresponding relationship of isomorphic consistency between OA(c) and OA(η).

One does not believe that there is any link between Descartes and Minkowski.

However, in the theory of OR or IOR, Cartesian coordinate system is also a coordinate framework of 4d spacetime, or a special case of the coordinate framework of 4d spacetime, referred to as **the idealized observation agent** by the theory of OR, and denoted as **OA$_\infty$**. Likewise, there is the strictly corresponding relationship of isomorphic consistency between the idealized agent OA$_\infty$ and the general observation agent OA(η).

Perhaps, you can foresee that the general observation agent OA(η) generalizes Minkowski's optical agent OA(c), but you may not necessarily foresee that the general observation agent OA(η) generalizes Descartes's idealized agent OA$_\infty$.

As shown in Tab. 8.1, in theory of IOR, the general observation agent OA(η) and the coordinate framework of 4d spacetime $X^{4\mathrm{d}}(\eta)$ generalize and unify the idealized observation agent OA$_\infty$ and the optical observation agent OA(c), or in other words, generalize and unify Cartesian coordinate system and the coordinate framework of Minkowski 4d spacetime.

Naturally, as $\eta \to c$, the general observation agent OA(η) strictly converges to Minkowski's optical observation agent OA(c):

$$
\lim_{\eta\to c}\mathrm{OA}(\eta)=\lim_{\eta\to c}\left\{\begin{array}{l} X^{4\mathrm{d}}(\eta):\left\{\begin{array}{l}x^0=\eta t\\ x^1=x\\ x^2=y\\ x^3=z\end{array}\right\} \\ \mathrm{d}s^2=\eta^2\mathrm{d}t^2 \\ \qquad -\mathrm{d}x^2-\mathrm{d}y^2-\mathrm{d}z^2\end{array}\right\}=\left\{\begin{array}{l} X^{4\mathrm{d}}(c):\left\{\begin{array}{l}x^0=ct\\ x^1=x\\ x^2=y\\ x^3=z\end{array}\right\} \\ \mathrm{d}s^2=c^2\mathrm{d}t^2 \\ \qquad -\mathrm{d}x^2-\mathrm{d}y^2-\mathrm{d}z^2\end{array}\right\}=\mathrm{OA}(c) \tag{8.1}
$$

In particular, as shown in Eq. (1.3), as $\eta\to\infty$, the 4d spacetime line-element ds of the observational spacetime $X^{4\mathrm{d}}(\eta)$ of OA(η) is split into independent time-element dt of 1d time (x^0) and independent line-element dl of 3d space (x,y,z):

$$
\mathrm{d}\tau^2=\frac{\mathrm{d}s^2}{\eta^2}=\mathrm{d}t^2-\frac{\mathrm{d}l^2}{\eta^2}\quad\left\{\begin{array}{l}\mathrm{d}\tau^2=\lim\limits_{\eta\to\infty}\dfrac{\mathrm{d}s^2}{\eta^2}=\lim\limits_{\eta\to\infty}\left(\mathrm{d}t^2-\dfrac{\mathrm{d}l^2}{\eta^2}\right)=\mathrm{d}t^2\\ \mathrm{d}l^2=\mathrm{d}x^2+\mathrm{d}y^2+\mathrm{d}z^2\end{array}\right. \tag{8.2}
$$

where $\mathrm{d}\tau$ is the objectively real time (proper time).

Thus, as shown in Eq. (1.4), the general observation agent OA(η) strictly converges to Descartes's idealized observation agent OA_∞:

$$
\lim_{\eta\to\infty}\mathrm{OA}(\eta)=\lim_{\eta\to\infty}\left\{\begin{array}{l} X^{4\mathrm{d}}(\eta):\left\{\begin{array}{l}x^0=\eta t\\ x^1=x\\ x^2=y\\ x^3=z\end{array}\right\} \\ \mathrm{d}s^2=\eta^2\mathrm{d}t^2 \\ \qquad -\mathrm{d}x^2-\mathrm{d}y^2-\mathrm{d}z^2\end{array}\right\}=\left\{\begin{array}{l} X^{4\mathrm{d}}{}_\infty:\left\{\begin{array}{l}x^0=\infty t\\ x^1=x\\ x^2=y\\ x^3=z\end{array}\right\} \\ \mathrm{d}t=\mathrm{d}\tau \\ \mathrm{d}l^2=\mathrm{d}x^2+\mathrm{d}y^2+\mathrm{d}z^2\end{array}\right\}=\mathrm{OA}_\infty \tag{8.3}
$$

So, as shown in the row 8.1-1 of Tab. 8.1, the general observation agent OA(η) of the theory of OR or IOR has generalized and unified the optical agent OA(c) and the idealized agent OA_∞, or in other words, generalizes and unifies Cartesian coordinate system and the coordinate framework of Minkowski 4d spacetime.

8.2 The Unity of the Invariance of Light Speed and the Cartesian Invariance

Chapter 2 in **the 1st volume of OR: Inertially Observational Relativity** (IOR) has constructed the axiom system for the theory of OR, in which the most essential and indispensable logical premise is the definition of time, being regarded as the most basic logical premise for the theory of OR.

The definition of time in the theory of OR (Def. 2.2 in Chapter 2) leads to a direct inference: the invariance of time-frequency ratio.

It is based on the definition of OR time and the invariance of time-frequency ratio that chapter 3 in the 1st volume of OR has deduced and proved the most important theorem in the theory of OR or IOR: the theorem of **the invariance of information-wave speeds**.

The theorem of the invariance of information-wave speeds has revealed the essence of the phenomenon of the invariance of light speed: actually, the so-called invariance of light speed is only a special case of the invariance of information-wave speeds, that is, the invariance of the information-wave speed of the optical agent OA(c), being valid only if light is employed as the observation medium to transmit observed information for inertial observers. So, in the theory of OR, the theorem of the invariance of information-wave speeds generalizes Einstein's principle of the invariance of light speed.

Now, Einstein's invariance of light speed is no longer a **principle**.

Actually, any specific observation agent has its own specific **information-wave speed** and its own specific **invariance**:

(i) **The idealized agent**: **OA$_\infty$** with the Cartesian invariance, the speed of the information wave of OA$_\infty$ is infinite, and naturally, invariant or the same relative all inertial observers. It takes no time for information to cross Cartesian spacetime.

(ii) **The optical agent**: **OA(c)** with the invariance of light speed, the speed c of light looks or observes invariant or the same relative to all inertial observers as light acts as the information wave of OA(c).

(iii) **The general observation agent**: **OA(η)** with the invariance of information-wave speeds, the speed η of any matter wave looks or observes invariant or the same relative to all inertial observers as the matter wave acts as the information wave of OA(η).

The invariance of information-wave speeds can be formalized as:

$$\mathrm{OA}(\eta): \quad \forall v \in (-\eta, \eta) \;\; \eta \oplus v = \eta \tag{8.4}$$

where OA(η) is the general observation agent, in theory, its observation medium $M(\eta)$ can be any form of matter motion, its information-wave speed η can be any speed value; "⊕" is the operator of speed addition, and v is an inertial speed.

The Invariance of Information-Wave Speeds: As shown in Eq. (8.4), for any observation agent OA(η), the information-wave speed η of OA(η) plus an inertial speed v ($<\eta$), remains the speed η, and is observationally invariant or the same relative to all inertial observers.

Naturally, as $\eta \to c$, OA(η)→OA(c), the invariance of information-wave speeds of OR theory reduces to **Einstein's invariance of light speed**:

$$\lim_{\eta \to c} \mathrm{OA}(\eta) = \mathrm{OA}(c): \quad \forall v \in (-c, c) \;\; c \oplus v = c \tag{8.5}$$

Equation (8.5) shows that, for the optical agent OA(c), the information wave is light, the information-wave speed η is the speed c of light; if light is employed as the observation medium to transmit observed information for inertial observers, then the speed c of light plus and an inertial speed v ($<c$) remains the speed c of light.

This is Einstein's invariance of light speed.

In particular, as $\eta\to\infty$, $\mathrm{OA}(\eta)\to\mathrm{OA}_\infty$, the invariance of information-wave speeds of OR theory reduces to the Cartesian Invariance:

$$\lim_{\eta\to\infty}\mathrm{OA}(\eta)=\mathrm{OA}_\infty:\quad \forall v\in(-\infty,\infty)\ \ \infty\oplus v=\infty \tag{8.6}$$

Equation (8.6) shows that, for the idealized agent OA_∞, the information-wave speed η tends to infinite. The speed at infinity is naturally invariant.

This is namely **the Cartesian invariance**.

So, as shown in the row 8.1-2 in Tab. 8.1, the invariance of information-wave speed of the theory of OR or IOR has generalized and unified Einstein's invariance of light speed and the Cartesian invariance.

The Cartesian invariance is the nature of Cartesian spacetime, and implied in Galilean-Newtonian inertial mechanics; while the invariance of light speed is the nature of Minkowski spacetime, and presupposed by Einstein as the logical premise for his theory of special relativity. The invariance of information-wave speeds in the theory of OR is neither an implied nature nor a presupposed logical premise, but the logical consequence of OR theory. Now, the invariance of information-wave speeds of OR theory generalizes and unifies the Cartesian invariance and the invariance of light speed, and once again shows that: the theory of OR is logically self-consistent; and moreover, is logically consistent not only with Galilean-Newtonian inertial mechanics, but also with Einstein's special relativity.

It is of the symbolic significance that the invariance of information-wave speeds generalizes and unified the invariance of light speed and the Cartesian invariance, which indicates that Newton's classical mechanics (including the inertial and the gravitational) and Einstein's theory of relativity (including the special and the general) will be unified in the theory of OR.

8.3 The Unity of Spacetime Transformations

Chapter 4 in the 1st volume of OR has deduced the transformation of IOR spacetime, that is, the OR transformation relation of inertial spacetime. And in Sec. 4.4 of Chapter 4, we discuss the unification of the Galilean transformation and the Lorentz transformation, two great spacetime transformations, into the transformation of IOR spacetime. It is of the symbolic significance that the transformation of IOR spacetime, **the general Lorentz transformation**, generalizes and unifies the Galilean transformation and the Lorentz transformation, which indicates that Galilean-Newtonian inertial mechanics and Einstein's special relativity are generalized and unified into the theory of IOR.

In Sec. 4.4 of Chapter 4, we discuss the problem on the unification of spacetime transformations, involving the IOR factor of spacetime transformation, as well as the transformation of IOR spacetime and the law of IOR speed-addition.

8.3.1 The Unity of the Lorentz factor and the Galilean Factor

Before deriving the transformation of IOR spacetime, in proving the theorem of the invariance of information-wave speeds in Chapter 3, the theory of OR has derived the IOR factor Γ of spacetime transformation:

the IOR factor (Eq. (3.21)) $\Gamma(\eta)=\dfrac{\mathrm{d}t}{\mathrm{d}\tau}=\dfrac{1}{\sqrt{1-v^2/\eta^2}}$.

In this sense, the IOR factor of spacetime transformation is independent of the transformation of IOR spacetime (Eqs. (4.16) and (4.18)): its logical route is different from the Lorentz factor $\gamma=1/\sqrt{(1-v^2/c^2)}$ and the Galilean factor $\Gamma_\infty\equiv 1$.

The theory of OR has already clarified that the factors of inertial spacetime transformation, including the IOR factor Γ of spacetime transformation, as well as the Lorentz factor γ and the Galilean factor Γ_∞, are important representations of the relativistic effects of inertial spacetime.

Naturally, as $\eta\to c$, the IOR factor $\Gamma(\eta)$ of spacetime transformation strictly converges to the Lorentz factor $\gamma=\Gamma(c)$:

$$\mathrm{OA}(c):\ \gamma=\lim_{\eta\to c}\frac{1}{\sqrt{1-v^2/\eta^2}}=\frac{1}{\sqrt{1-v^2/c^2}} \tag{8.7}$$

In particular, as $\eta\to\infty$, the IOR factor $\Gamma(\eta)$ of spacetime transformation strictly converges to the Galilean factor $\Gamma_\infty=\Gamma(\infty)$:

$$\mathrm{OA}_\infty:\ \Gamma_\infty=\lim_{\eta\to\infty}\frac{1}{\sqrt{1-v^2/\eta^2}}=1 \tag{8.8}$$

So, as shown in the row 8.1-3 in Tab. 8.1, the IOR factor $\Gamma(\eta)$ of spacetime transformation has generalized and unified the Lorentz factor γ of the Lorentz transformation and the Galilean factor Γ_∞ of the Galilean transformation. No matter the Lorentz factor γ or the Galilean factor Γ_∞ is the special case of the IOR factor $\Gamma(\eta)$: the Lorentz factor $\gamma=\Gamma(c)$ belongs to the optical agent OA(c); while the Galilean factor $\Gamma_\infty=\Gamma(\infty)$ belongs to the idealized agent OA_∞.

8.3.2 The Unity of the Lorentz Transformation and the Galilean Transformation

The Lorentz transformation and the Galilean transformation are two great relations of spacetime transformation in physics. Originally, they were regarded as two separate and even opposite relations of spacetime transformation.

On the basis of the demonstration of the invariance of information-wave speeds, Chapter 4 in the 1st volume of OR has deduced the transformation of IOR spacetime in differential form (Eq. (4.16)), and then, has derived the transformation of IOR spacetime in algebraic form (Eq. (4.18)):

$$\begin{array}{ll} O'\to O: & O\to O': \\ x=\Gamma(x'+vt') & x'=\Gamma(x-vt) \\ y=y' & y'=y \\ z=z' & z'=z \\ t=\Gamma\left(t'+\dfrac{vx'}{\eta^2}\right) & t'=\Gamma\left(t-\dfrac{vx}{\eta^2}\right) \end{array} \qquad \left(\Gamma=\Gamma(\eta)=1\big/\sqrt{1-v^2/\eta^2}\right).$$

The transformation of IOR spacetime in algebraic form is isomorphically consistent with the Lorentz transformation, and therefore, it is referred to in the theory of OR or IOR as **the general Lorentz transformation**.

According to Eq. (4.20) in Chapter 4, as $\eta \to c$, the transformation of IOR spacetime or the general Lorentz transformation (Eq. (4.18)) strictly converges to the Lorentz transformation (Eq. (4.12)):

$$
\begin{array}{ccc}
O'(\eta) \to O(\eta): & & O'(c) \to O(c): \\
\lim\limits_{\eta \to c} \begin{cases} x = \Gamma(x' + vt') \\ y = y' \\ z = z' \\ t = \Gamma\left(t' + \dfrac{vx'}{\eta^2}\right) \end{cases} & = & \begin{cases} x = \gamma(x' + vt') \\ y = y' \\ z = z' \\ t = \gamma\left(t' + \dfrac{vx'}{c^2}\right) \end{cases}
\end{array}
\tag{8.9}
$$

According to Eq. (4.22) in Chapter 4, as $\eta \to \infty$, the transformation of IOR spacetime or the general Lorentz transformation (Eq. (4.18)) strictly converges to the Galilean transformation (Eq. (4.4)):

$$
\begin{array}{ccc}
O'(\eta) \to O(\eta): & & O'_\infty \to O_\infty: \\
\lim\limits_{\eta \to \infty} \begin{cases} x = \Gamma(x' + vt') \\ y = y' \\ z = z' \\ t = \Gamma\left(t' + vx'/\eta^2\right) \end{cases} & = & \begin{cases} x = x' + vt' \\ y = y' \\ z = z' \\ t = t' \end{cases}
\end{array}
\tag{8.10}
$$

So, as shown in the row 8.1-4 in Tab. 8.1, the general Lorentz transformation (Eq. (4.18)) has generalized and unified the Lorentz transformation (Eq. (4.12)) and the Galilean transformation (Eq. (4.4)).

Both the Lorentz transformation and the Galilean transformation are special cases of the transformation of IOR spacetime: the Lorentz transformation belongs to the optical observation agent OA(c); the Galilean transformation belongs to the idealized observation agent OA_∞.

Now, the Lorentz transformation of the optical agent and the Galilean transformation of the idealized agent, two great transformations of inertial spacetime in physics, have finally been unified into the theory of OR or IOR.

8.3.3 The Unity of the Laws of Speed Addition

Originally, physics believed in the law of Galileo’s speed-addition.

The law of Galileo’s speed-addition is in line with both our intuition and our reason. However, after the birth of Einstein’s special theory of relativity, physics turns to believe in the law of Einstein’s speed-addition (that is, the speed-addition law based on the Lorentz transformation), and regards the law of Galileo’s speed-addition as the approximate law being valid only in the situation of macroscopic low-speed.

The law of Galileo’s speed-addition (Eq. (4.5)) is the most direct logical inference of the Galilean transformation; the law of Einstein's speed-addition (Eq. (4.13)) is the most direct logical inference of the Lorentz transformation.

On the basis of the transformation of IOR spacetime in differential form (Eq. (4.16)), Chapter 4 in the 1st volume of OR has directly derived the law of IOR speed-addition (Eq. (4.17):

$$\begin{array}{ll} O' \to O: & O \to O': \\ u_x = \dfrac{\mathrm{d}x}{\mathrm{d}t} = \dfrac{\mathrm{d}x' + v\mathrm{d}t'}{\mathrm{d}t' + v\mathrm{d}x'/\eta^2} = \dfrac{u'_x + v}{1 + vu'_x/\eta^2} & u'_x = \dfrac{\mathrm{d}x'}{\mathrm{d}t'} = \dfrac{u_x - v}{1 - vu_x/\eta^2} \\ u_y = \dfrac{\mathrm{d}y}{\mathrm{d}t} = \dfrac{\mathrm{d}y'}{\Gamma\left(\mathrm{d}t' + v\mathrm{d}x'/\eta^2\right)} = \dfrac{u'_y\sqrt{1 - v^2/\eta^2}}{1 + vu'/\eta^2} & u'_y = \dfrac{\mathrm{d}y'}{\mathrm{d}t'} = \dfrac{u_y\sqrt{1 - v^2/\eta^2}}{1 - vu_x/\eta^2} \\ u_z = \dfrac{\mathrm{d}z}{\mathrm{d}t} = \dfrac{\mathrm{d}z'}{\Gamma\left(\mathrm{d}t' + v\mathrm{d}x'/\eta^2\right)} = \dfrac{u'_z\sqrt{1 - v^2/\eta^2}}{1 + vu'/\eta^2} & u'_z = \dfrac{\mathrm{d}z'}{\mathrm{d}t'} = \dfrac{u_z\sqrt{1 - v^2/\eta^2}}{1 - vu_x/\eta^2} \end{array}$$

The law of IOR speed-addition (Eq. (4.17)) is isomorphically consistent with both the law of Einstein's speed-addition (Eq. (4.13)) and the law of Galileo's speed-addition (Eq. (4.5)).

According to Eq. (4.19) in Chapter 4, as $\eta \to c$, the law of IOR speed-addition (Eq. (4.17)) strictly converges to the law of Einstein's speed-addition (Eq. (4.13)):

$$\begin{array}{ccc} & O'(\eta) \to O(\eta): & O'(c) \to O(c): \\ \lim\limits_{\eta \to c} & \begin{cases} u_x = \dfrac{u'_x + v}{1 + vu'_x/\eta^2} \\ u_y = \dfrac{u'_y\sqrt{1 - v^2/\eta^2}}{1 + vu'/\eta^2} \\ u_z = \dfrac{u'_z\sqrt{1 - v^2/\eta^2}}{1 + vu'/\eta^2} \end{cases} = & \begin{cases} u_x = \dfrac{u'_x + v}{1 + vu'_x/c^2} \\ u_y = \dfrac{u'_y\sqrt{1 - v^2/c^2}}{1 + vu'/c^2} \\ u_z = \dfrac{u'_z\sqrt{1 - v^2/c^2}}{1 + vu'/c^2} \end{cases} \end{array} \tag{8.11}$$

According to Eq. (4.21) in Chapter 4, as $\eta \to \infty$, the law of IOR speed-addition (Eq. (4.17)) strictly converges to the law of Galileo's speed-addition (Eq. (4.5)):

$$\begin{array}{ccc} & O'(\eta) \to O(\eta): & O'_\infty \to O_\infty: \\ \lim\limits_{\eta \to \infty} & \begin{cases} u_x = \left(u'_x + v\right)/\left(1 + vu'_x/\eta^2\right) \\ u_y = u'_y\sqrt{1 - v^2/\eta^2}\,/\left(1 + vu'/\eta^2\right) \\ u_z = u'_z\sqrt{1 - v^2/\eta^2}\,/\left(1 + vu'/\eta^2\right) \end{cases} = & \begin{cases} u_x = u'_x + v \\ u_y = u'_y \\ u_z = u'_z \end{cases} \end{array} \tag{8.12}$$

So, as shown in the row 8.1-5 in Tab. 8.1, the law of IOR speed-addition (Eq. (4.17)) has generalized and unified the law of Einstein's speed-addition (Eq. (4.13)) and the law of Galileo's speed-addition (Eq. (4.5)). No matter the law of Einstein's speed-addition or the law of Galileo's speed-addition is only the special case of the law of IOR speed-addition: the law of Einstein's speed-addition belongs to the optical observation agent OA(c); while the law of Galileo's speed-addition belongs to the idealized observation agent OA_∞.

Now, the theory of IOR has clarified that: the law of Galileo's speed-addition under the idealized agent OA_∞ is the objective law of nature; the law of Einstein's speed-addition under the optical agent OA(c) is not the objective law of nature, but the phenomenon of optical observation.

8.4 The Unity of Matter-Motion Formulae

Following the theorem of the invariance of information-wave speeds in Chapter 3 as well as the transformation of IOR spacetime and the law of IOR speed-addition in Chapter 4, Chapter 5 in **the 1st volume of OR: Inertially Observational Relativity** (IOR) further has deduced the basic formulae or relationships of IOR theory. Naturally, on the basis of the invariance of information-wave speeds or the general Lorentz transformation, following the logic of Einstein's special theory of relativity, the theory of OR has established the whole theoretical system of IOR theory which is isomorphically consistent with Einstein's special theory of relativity. Chapter 5 mainly deals with the motion of inertial objects, including the problems of the mass, momentum and energy of inertial objects, derives the relationships or models of inertial matter motion, including the IOR mass-speed relation, the IOR formula of relativistic momentum, and the IOR mass-energy relation.

Like all the formulae or relationships in theory of IOR, the fundamental relationships of IOR matter motion also present the high degree of generality and unity of the theory of OR or IOR.

8.4.1 The Unity of Mass-Speed Relations

The problem of the mass of matter is one of the most basic problems in Newton's theory of classical mechanics.

Newton's mechanics never stopped discussing whether there is a difference between the **Inertial Mass** m_I and the **Gravitational Mass** m_G.

The so-called mass, in short, refers to the amount of matter contained in an object, which can be denoted as m_o. According to Def. 1.2 in Chapter 1, the theory of OR refers to m_o as the intrinsic mass of matter or an object. For an object, no matter its inertial force F_I or its gravitational force F_G must be directly proportional to its amount of matter contained in the object, that is, directly proportional to its intrinsic mass m_o. Therefore, by appropriately setting the ratio of inertial force F_I or gravitational force F_G, or by properly calibrating the gravitational constant G, the intrinsic mass m_o can be employed to characterize both the inertial mass m_I and the gravitational mass m_G. In this way, there is no need for the concepts of inertial mass and gravitational mass.

Likewise, the problem of the mass of matter is also one of the most basic problems in Einstein's theory of relativity.

In his theory of relativity, Einstein removed the concepts of inertial mass and gravitational mass, but introduced the concepts of **relativistic mass** (**moving mass**) and **rest mass**. According to Einstein's special theory of relativity, the mass m of an inertial moving object P is related to its inertial speed v:

Einstein's mass-speed relation (Eq. ((5.1)) $m=\gamma(v)m_o=\dfrac{m_o}{\sqrt{1-v^2/c^2}}$,

where m=$m(v)$ is the relativistic mass of the observed object P, depending on the inertial speed v of P; m_o=$m(0)$ is the rest mass of P.

Actually, based on the definition of intrinsic physical quantities in Def. 1.2 of Chapter 1, Einstein's concept of rest mass is equivalent to the concept of **the intrinsic mass** in the theory of OR.

By analogizing and following the logic of Einstein's special theory of relativity, Chapter 5 in the 1st volume of OR has derived

The IOR mass-speed relation (Eq. ((5.2)) $m=\Gamma(\eta,v)m_o=\dfrac{m_o}{\sqrt{1-v^2/\eta^2}}$,

where m_o is the objective and real intrinsic mass of the observed object P, m=$m(\eta,v)$ is the observational mass of P observed with the observation agent OA(η), relying more on the information-wave speed η of OA(η) than on the speed v of P.

According to Eq. (5.7) in Chapter 5, as $\eta\to c$, the observational mass $m(\eta,v)$ of the general observation agent OA(η) strictly converges to Einstein's relativistic mass m_c, that is, the observational mass $m(c,v)$ of the optical observation agent OA(c). In particular, according to Eq. (5.8) in Chapter 5, as $\eta\to\infty$, the observational mass $m(\eta,v)$ of the general observation agent OA(η) strictly converges to Newton's classical mass m_∞, that is, the observational mass $m(\infty,v)$ of the idealized observation agent OA_∞, or, the intrinsic mass m_o of the observed object P.

Such isomorphic-consistency relationship can be stated as follows:

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

$$\begin{cases}\mathrm{OA}(c):\quad m_c=m(\eta,v)=\lim\limits_{\eta\to c}\dfrac{m_o}{\sqrt{1-v^2/\eta^2}}=\dfrac{m_o}{\sqrt{1-v^2/c^2}}\\[2ex] \mathrm{OA}_\infty:\quad m_\infty=m(\infty,v)=\lim\limits_{\eta\to\infty}\dfrac{m_o}{\sqrt{1-v^2/\eta^2}}=m_o\end{cases}\tag{8.13}$$

So, as shown in the row 8.1-6 in Tab. 8.1, the IOR mass-speed has generalized and unified Einstein's relativistic mass-speed relation (m_c=$m_o/\surd(1-v^2/c^2)$) and Newton's classical mass-speed relation (m_∞=m_o), has generalized and unified the concept of Einstein's relativistic mass and the concept of Newton's classical mass.

Both Einstein's relativistic mass m_c and Newton's classical mass m_∞ are special cases of the observational mass of IOR theory: Einstein's relativistic mass m_c is the observational mass $m(c,v)$ of the optical agent OA(c); Newton's classical mass m_∞ is the observational mass $m(\infty,v)$ of the idealized agent OA_∞.

In particular, as shown in Eq. (8.13), Newton's classical mass m_∞=m_o, which suggests that Newton's classical mass m_∞ represents the objectively real mass m_o, that is, the intrinsic mass m_o of matter.

8.4.2 The Unity of Momentum Concepts

In Newton's theory of classical mechanics, the classical momentum p_∞ of the inertial moving object P is the product of the classical mass m_∞ of P and the inertial moving speed v of P: $p_\infty = m_\infty v$ ($\mathbf{p}_\infty = m_\infty \mathbf{v}$ in vector form).

In Einstein's theory of special relativity, the momentum $p=mv$ of the inertial moving object P is relativistic, in which the mass m naturally adopts relativistic mass: $m=m_o/\sqrt{(1-v^2/c^2)}$, and therefore, momentum is defined as

Einstein's relativistic momentum (Eq. ((5.11)) $p = mv = \gamma m_o v = \dfrac{m_o v}{\sqrt{1-v^2/c^2}}$.

In Sec. 5.2 of Chapter 5, by analogizing and following the logic of Einstein's special theory of relativity, the theory of IOR defines the observational momentum of the general observation agent OA(η) as

IOR momentum (Eq. (5.12)) $p(\eta,v) = m(\eta,v)v = \Gamma(\eta,v)m_o v = \dfrac{m_o v}{\sqrt{1-v^2/\eta^2}}$.

According to Eq. (5.14) in Chapter 5, as $\eta \to c$, the observational momentum $p=p(\eta,v)$ of the general observation agent OA(η) strictly converges to Einstein's relativistic momentum p_c, that is, the observational momentum $p_c=p(c,v)$ of the optical observation agent OA(c). In particular, according to Eq. (5.15) in Chapter 5, as $\eta \to \infty$, the observational momentum $p=p(\eta,v)$ of the general observation agent OA(η) strictly converges to Newton's classical momentum p_∞, that is, the observational momentum $p_\infty=p(\infty,v)$ of the idealized observation agent OA_∞.

Such isomorphic-consistency relationship can be stated as follows:

$$\mathrm{OA}(\eta): \quad p = p(\eta,v) = \frac{m_o v}{\sqrt{1-v^2/\eta^2}}$$

$$\begin{cases} \mathrm{OA}(c): \quad p_c = p(\eta,v) = \lim\limits_{\eta \to c} \dfrac{m_o v}{\sqrt{1-v^2/\eta^2}} = \dfrac{m_o v}{\sqrt{1-v^2/c^2}} \\ \mathrm{OA}_\infty: \quad p_\infty = p(\infty,v) = \lim\limits_{\eta \to \infty} \dfrac{m_o v}{\sqrt{1-v^2/\eta^2}} = m_o v = p_o \end{cases} \tag{8.14}$$

So, as shown in the row 8.1-7 in Tab. 8.1, the formula of IOR observational momentum has generalized and unified Einstein's formula of relativistic momentum and Newton's formula of classical momentum; in other words, the concept of IOR observational momentum has generalized and unified the concept of Einstein's relativistic momentum and the concept of Newton's classical momentum.

Both Einstein's relativistic momentum p_c and Newton's classical momentum p_∞ are special cases of the observational momentum of IOR theory: Einstein's relativistic momentum p_c is the observational momentum $p(c,v)$ of the optical agent

OA(c); Newton's classical momentum p_∞ is the observational momentum $p(\infty,v)$ of the idealized agent OA_∞.

In particular, as shown in Eq. (8.14), Newton's classical momentum $p_\infty=p_o$, which suggests that Newton's classical momentum $p_\infty=m_\infty v$ represents the objectively real momentum $p_o=m_o v$ of matter or an object.

8.4.3 The Unity of Mass-Energy Relations

There is no so-called mass-energy relation in Newton's theory of classical mechanics. In Newton's mechanics, there is no concept of **mass energy** E and **rest energy** E_o, an inertial moving object has only one kind of energy, that is, kinetic energy in the classical sense: $K_\infty=m_\infty v^2/2$.

Einstein formula $E=mc^2$ is the most famous physical equation in Einstein's special theory of relativity, also known as

Einstein's mass-energy relation: $$\begin{cases} E = K + E_o = \gamma m_o c^2 = \dfrac{m_o c^2}{\sqrt{1-v^2/c^2}} = mc^2 \\ \begin{cases} E_o = m_o c^2 \\ K = (\gamma - 1) m_o c^2 \end{cases} \end{cases},$$

where E is the so-called **mass-energy**, i.e., the total energy of the observed inertial object of P, including the relativistic kinetic energy K and rest energy E_o; m_o and m are respectively the rest mass and moving (relativistic) mass of P.

In Sec. 5.3 of Chapter 5, by analogizing and following the logic of Einstein's special theory of relativity, the theory of IOR has derived Eq. (5.12):

IOR's mass-energy relation: $$\begin{cases} E = K + E_o = \Gamma m_o \eta^2 = \dfrac{m_o \eta^2}{\sqrt{1-v^2/\eta^2}} = m\eta^2 \\ \begin{cases} E_o = m_o \eta^2 \\ K = E - E_o = \left(\Gamma(\eta, v) - 1\right) m_o \eta^2 \end{cases} \end{cases},$$

where η is the information-wave speed of the general observation agent OA(η).

The Generality and Unity of Mass-Energy Relations

Obviously, as shown in the row 8.1-8 in Tab. 8.1, as $\eta\to c$, the IOR mass-energy relation $E=m\eta^2$ strictly converges to Einstein's mass-energy relation $E=mc^2$; as $\eta\to\infty$, the IOR mass-energy $E=m\eta^2$ tends to infinite. It is thus clear that the IOR mass-energy $E=m\eta^2$, including Einstein's mass-energy $E=mc^2$, has no the objectively physical significance. This is consistent with Newton's theory and logical thought of classical mechanics.

The Generality and Unity of Rest-Energy Formulae

Obviously, as shown in the row 8.1-9 in Tab. 8.1, as $\eta\to c$, the IOR rest energy $E_o=m_o\eta^2$ contained in the IOR mass-energy relation $E=m\eta^2$ strictly converges to the rest energy $E_o=m_oc^2$ contained in Einstein's mass-energy relation $E=mc^2$; as $\eta\to\infty$, the IOR rest energy $E_o=m_o\eta^2$ contained in the IOR **mass-energy** $E=m\eta^2$ tends to infinite. It is thus clear that the IOR rest-energy $E_o=m_o\eta^2$, including Einstein's rest-energy $E_o=m_oc^2$, has no the objectively physical significance. Likewise, this is consistent with Newton's theory and logical thought of classical mechanics.

The Generality and Unity of Kinetic-Energy Formulae

According to Eq. (5.25) in Chapter 5, as $\eta\to c$, the IOR observational kinetic-energy formula $K_\eta=K(\eta,v)$ strictly converges to Einstein's relativistic kinetic-energy formula $K_c=K(c,v)$. In particular, according to Eq. (5.26) in Chapter 5, as $\eta\to\infty$, the IOR observational kinetic-energy formula $K_\eta=K(\eta,v)$ strictly converges to Newton's classical kinetic-energy formula $K_\infty=K(\infty,v)$.

Such isomorphic-consistency relationship can be stated as follows:

$$\mathrm{OA}(\eta):\quad K_\eta=K(\eta,v)=\left(\frac{1}{\sqrt{1-v^2/\eta^2}}-1\right)m_o\eta^2$$

$$\begin{cases}\mathrm{OA}(c):\quad K_c=K(\eta,v)=\lim\limits_{\eta\to c}\left(\dfrac{1}{\sqrt{1-v^2/\eta^2}}-1\right)m_o\eta^2=\left(\dfrac{1}{\sqrt{1-v^2/c^2}}-1\right)m_oc^2\\ \mathrm{OA}_\infty:\quad K_\infty=K(\infty,v)=\lim\limits_{\eta\to\infty}\left(\dfrac{1}{\sqrt{1-v^2/\eta^2}}-1\right)m_o\eta^2=\dfrac{1}{2}m_ov^2=K_o\end{cases}$$

(8.15)

So, as shown in the row 8.1-10 in Tab. 8.1, the formula of IOR observational kinetic-energy has generalized and unified Einstein's formula of relativistic kinetic-energy and Newton's formula of classical kinetic-energy; in other words, the concept of IOR observational kinetic-energy has generalized and unified the concept of Einstein's relativistic kinetic-energy and the concept of Newton's classical kinetic-energy.

Both Einstein's relativistic kinetic-energy K_c and Newton's classical kinetic-energy K_∞ are special cases of the observational kinetic-energy of IOR theory: Einstein's relativistic kinetic-energy K_c is the observational kinetic-energy $K(c,v)$ of the optical agent OA(c); Newton's classical kinetic-energy K_∞ is the observational kinetic-energy $K(\infty,v)$ of the idealized agent OA_∞.

In particular, as shown in Eq. (8.15), Newton's classical kinetic-energy $K_\infty=K_o$, which suggests that Newton's classical kinetic-energy $K_\infty=m_\infty v^2/2$ represents the objectively real kinetic-energy $K_o=m_ov^2/2$ of matter or an object.

Table 8.1. The Generality and Unity of Newton and Einstein in the theory of IOR

	The Theory of IOR (the general observation agent OA(η))	Einstein's Special Relativity (the optical agent OA(c): $\eta\to c$)	Galilean-Newtonian Inertial Mechanics (the idealized agent OA_∞: $\eta\to\infty$)
8.1-1	OA(η) and IOR spacetime $X^{4d}(\eta)$: $$\mathrm{OA}(\eta)=\left\{\begin{array}{l} X^{4d}(\eta):\left\{\begin{array}{l} x^0=\eta t \\ x^1=x, x^2=y, x^3=z \end{array}\right\} \\ \mathrm{d}s^2=\eta^2\mathrm{d}t^2-\mathrm{d}x^2-\mathrm{d}y^2-\mathrm{d}z^2 \end{array}\right\}$$	OA(c) and Minkowski spacetime $X^{4d}(c)$: $$\mathrm{OA}(c)=\left\{\begin{array}{l} X^{4d}(c):\left\{\begin{array}{l} x^0=ct \\ x^1=x, x^2=y, x^3=z \end{array}\right\} \\ \mathrm{d}s^2=c^2\mathrm{d}t^2-\mathrm{d}x^2-\mathrm{d}y^2-\mathrm{d}z^2 \end{array}\right\}$$	OA_∞ and Cartesian spacetime $X^{4d}{}_\infty$: $$\mathrm{OA}_\infty=\left\{\begin{array}{l} X^{4d}{}_\infty:\left\{\begin{array}{l} x^0=\infty t \\ x^1=x, x^2=y, x^3=z \end{array}\right\} \\ \mathrm{d}t=\mathrm{d}\tau \\ \mathrm{d}l=\sqrt{\mathrm{d}x^2+\mathrm{d}y^2+\mathrm{d}z^2} \end{array}\right\}$$
8.1-2	IOR' invariance of information-wave speeds: $$\mathrm{OA}(\eta):\ \forall v\in(-\eta,\eta)\ \ \eta\oplus v=\eta$$ The information-wave speed η of OA(η) is observationally invariant.	Einstein's invariance of light speed: $$\mathrm{OA}(c):\ \forall v\in(-c,c)\ \ c\oplus v=c$$ If OA(η) is the optical agent OA(c), then the speed c of light is observationally invariant.	Cartesian invariance: $$\mathrm{OA}_\infty:\ \forall v\in(-\infty,\infty)\ \ \infty\oplus v=\infty$$ The information-wave speed of the idealized agent OA_∞ is infinite, naturally, invariant.
8.1-3	The IOR factor: $\Gamma=\Gamma(\eta)$ $$\Gamma=\Gamma(\eta)=\frac{1}{\sqrt{1-v^2/\eta^2}}$$	The Lorentz factor: $\gamma=\Gamma(c)$ $$\gamma=\Gamma(c)=\lim_{\eta\to c}\Gamma(\eta)=\frac{1}{\sqrt{1-v^2/c^2}}$$	The Galilean factor: Γ_∞ $$\Gamma_\infty=\lim_{\eta\to\infty}\Gamma(\eta)=\lim_{\eta\to\infty}\frac{1}{\sqrt{1-v^2/\eta^2}}=1$$

8.1-4	The general Lorentz transformation: $O'(\eta)\to O(\eta)$: $\begin{cases} x=\Gamma(\eta)(x'+vt') \\ y=y' \\ z=z' \\ t=\Gamma(\eta)\left(t'+\dfrac{vx'}{\eta^2}\right) \end{cases}$	The Lorentz transformation $O'(\eta)\to O(\eta)$: $O'(c)\to O(c)$: $\lim\limits_{\eta\to c}\begin{cases} x=\Gamma(\eta)(x'+vt') \\ y=y' \\ z=z' \\ t=\Gamma(\eta)\left(t'+\dfrac{vx'}{\eta^2}\right) \end{cases} = \begin{cases} x=\gamma(x'+vt') \\ y=y' \\ z=z' \\ t=\gamma\left(t'+\dfrac{vx'}{c^2}\right) \end{cases}$	The Galilean transformation: $O'(\eta)\to O(\eta)$: $O'_\infty\to O_\infty$: $\lim\limits_{\eta\to\infty}\begin{cases} x=\Gamma(\eta)(x'+vt') \\ y=y' \\ z=z' \\ t=\Gamma(\eta)\left(t'+\dfrac{vx'}{\eta^2}\right) \end{cases} = \begin{cases} x=x'+vt' \\ y=y' \\ z=z' \\ t=t' \end{cases}$
8.1-5	The law of IOR speed-addition: $u(\eta)=\dfrac{u'+v}{1+\dfrac{u'v}{\eta^2}}$	The law of Einstein's speed-addition: $u(c)=\lim\limits_{\eta\to c}\dfrac{u'+v}{1+\dfrac{u'v}{\eta^2}}=\dfrac{u'+v}{1+\dfrac{u'v}{c^2}}$	The law of Galileo's speed-addition: $u_\infty=\lim\limits_{\eta\to\infty}\dfrac{u'+v}{1+\dfrac{u'v}{\eta^2}}=u'+v$
8.1-6	IOR's observational mass: $m=m(\eta)$ $m=m(\eta)=\dfrac{m_o}{\sqrt{1-v^2/\eta^2}}$	Einstein's relativistic mass: $m(c)$ $m(c)=\lim\limits_{\eta\to c}\dfrac{m_o}{\sqrt{1-v^2/\eta^2}}=\dfrac{m_o}{\sqrt{1-v^2/c^2}}$	Newton's classical mass: m_∞ $m_\infty=\lim\limits_{\eta\to\infty}\dfrac{m_o}{\sqrt{1-v^2/\eta^2}}=m_o$
8.1-7	IOR's observational momentum: $p=p(\eta)$ $p=p(\eta)=m(\eta)v=\dfrac{m_o v}{\sqrt{1-v^2/\eta^2}}$	Einstein's relativistic momentum: $p(c)$ $p(c)=\lim\limits_{\eta\to c}\dfrac{m_o v}{\sqrt{1-v^2/\eta^2}}=\dfrac{m_o v}{\sqrt{1-v^2/c^2}}$	Newton's classical momentum: p_∞ $p_\infty=\lim\limits_{\eta\to\infty}\dfrac{m_o v}{\sqrt{1-v^2/\eta^2}}=m_o v=m_\infty v$
8.1-8	IOR's mass-energy relation: $E=E(\eta)$ $E=E(\eta)=m\eta^2=\dfrac{m_o\eta^2}{\sqrt{1-v^2/\eta^2}}$	Einstein's mass-energy relation: $E(c)$ $E(c)=\lim\limits_{\eta\to c}\dfrac{m_o\eta^2}{\sqrt{1-v^2/\eta^2}}=\dfrac{m_o c^2}{\sqrt{1-v^2/c^2}}=mc^2$	Newton's mass-energy relation: E_∞ $E_\infty=\lim\limits_{\eta\to\infty}E(\eta)=\lim\limits_{\eta\to\infty}\dfrac{m_o\eta^2}{\sqrt{1-v^2/\eta^2}}=\infty$

8.1-9	IOR's rest energy: $E_o=E_o(\eta)$ $$E_o=E_o(\eta)=m_o\eta^2$$	Einstein's rest energy: $E_o(c)$ $$E(c)=\lim_{\eta\to c}E(\eta)=\lim_{\eta\to c}m_o\eta^2=m_oc^2$$	Newton's rest energy: $E_{o\infty}$ $$E_{o\infty}=\lim_{\eta\to\infty}E_o(\eta)=\lim_{\eta\to\infty}m_o\eta^2=\infty$$
8.1-10	IOR's observational kinetic energy: $K=K(\eta)$ $$K=K(\eta)=E(\eta)-E_o(\eta)$$ $$=(\varGamma(\eta)-1)m_o\eta^2$$	Einstein's relativistic kinetic energy: $K(c)$ $$K(c)=\lim_{\eta\to c}K(\eta)=\lim_{\eta\to c}(E(\eta)-E_o(\eta))$$ $$=(\varGamma(c)-1)m_oc^2=(\gamma-1)m_oc^2$$	Newton's classical kinetic energy: K_∞ $$K_\infty=\lim_{\eta\to\infty}K(\eta)=\lim_{\eta\to\infty}(E(\eta)-E_o(\eta))$$ $$=\lim_{\eta\to\infty}(\varGamma(\eta)-1)m_o\eta^2=\frac{1}{2}m_\infty v^2$$

Notes: The theory of IOR has generalized and unified Einstein's theory of special relativity and Galilean-Newtonian theory of Inertial Mechanics. All formulae or relationships in the theory of IOR, as $\eta\to c$, strictly converge to that of Einstein's special relativity; $\eta\to\infty$, strictly converge to that of Galilean-Newtonian inertial mechanics. It is thus clear that the theory of IOR is logically consistent not only with Einstein's special relativity, but also with Galileo's doctrine and Newton's theory. Moreover, such strict corresponding relationship between different theoretical systems, from one aspect, confirms the logical self-consistency and theoretical validity of the theory of IOR and even OR.

9 IOR and the Big Puzzles in Physics

Innate curiosity prompts human beings to explore nature constantly.

Mysteries or puzzles are the product of wisdom. As intelligent life, the mankind, since the moment when they had self-awareness, have been having the fundamental mysteries or puzzles: who are we, where are we, and where do we come from? These are indeed big puzzles. Up till today, we are still not very clear about who we are, where we are, or where we come from.

Table 9.1 OR and the 15 Big Puzzles in Physics

Serial Number	Big Puzzles in Physics
BP-01	Why is the Speed of Light Invariant?
BP-02	The Problem of Photon Mass
BP-03	The Essence of Relativistic Effects
BP-04	The Mysterious Planck Constant
BP-05	The Essence of Quantum Effects
BP-06	Heisenberg's Uncertainty Principle
BP-07	De Broglie Wave
BP-08	The Mystery of Electronic Double-Slit Experiment
BP-09	Why is Spacetime Curved?
BP-10	The Precession of the Perihelion of the Orbit of Mercury
BP-11	The Gravitational Deflection of Light
BP-12	The Gravitational Redshift of Light
BP-13	Gravitational Waves
BP-14	Black Holes
BP-15	The Big Bang

Notes: Perhaps, there are many other physical puzzles that can be interpreted by the theory of observational relativity (OR). Table 9.1 looks forward to listing up more big puzzles of physics. OR's interpretation of the big puzzles listed in Tab. 9.1 may not necessarily be accurate, but only for readers and physicists to examine and criticize so as to promote our understanding of such big puzzles in physics field.

The mankind has constantly been exploring nature.

Now, we have at least realized that: human beings are intelligent life on an ordinary planet (we call it **the earth**) in the solar system; we are not living on the back of a giant turtle; the earth is a ball rather than a flat earth; the earth is not the center of the universe, and the sun is not either.

With the progress and development of science, human understanding of the objective world was constantly enriched and deepened, and the sky of physics seemed to be becoming increasingly clear. We once thought that there were only two dark clouds left in the clear sky of physics: one is **the ethereal catastrophe** of Michelson-Morley experiment [2]; the other is **the ultraviolet catastrophe** of blackbody-radiation experiment [11-13]. However, it was just **the ethereal dark-cloud** and **the ultraviolet dark-cloud** that had been transformed into downpours, leading to more mysteries and puzzles for physics.

The old puzzles have not been solved yet, but new mysteries have been emerging constantly: does the universe have a center, if so where is it, why does the sun rise in the east and set in the west, is the earth's rotation around the sun due to gravity or spacetime curvature, why is the speed of light invariant, why is spacetime curved, is the motion of matter or the evolution of the universe certain or uncertain, how black is a black hole, and was there really the Big Bang in the early universe?

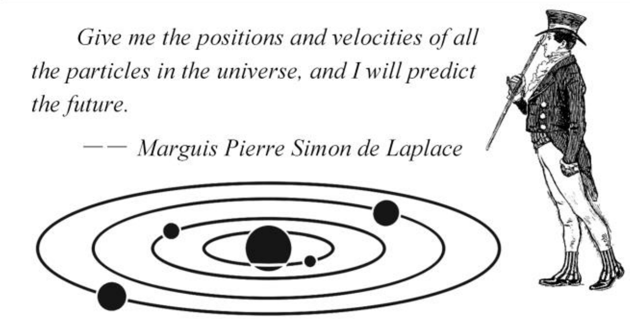

Figure 9.1 Laplace's Famous Quote.

Newton established the law of universal gravitation [81], telling us that the earth is subjected to the gravitational force of the sun, so that the earth goes around the sun; while Einstein established the theory of general relativity [8], telling us that the surrounding spacetime of the sun is curved by the mass or energy of the sun, and the curved spacetime makes the earth go around the sun. Galileo established the Galilean transformation, telling us that the motion of matter follows the law of Galileo's speed-addition; while Einstein established the theory of special relativity [7], which was originated from the **ethereal catastrophe**, telling us that the motion of matter follows the Lorentz transformation and the law of Einstein's relativistic speed-addition: the speed of light is invariant and has no the effect of speed addition. Classical mechanics tells us that the motion of matter or even the evolution of the universe has its intrinsic laws, just as Laplace's famous quote: "Give me the positions and velocities of all the particles in the universe, and I will predict the future."; while quantum mechanics tells us that the motion of matter and the evolution of the universe follows the principle of uncertainty: Laplace could not accurately determine the position and speed of a matter particle simultaneously [78].

So, the mankind is very confused.

Is the speed of light invariant or not? Is the motion of matter or the evolution of the universe certain or uncertain? Does gravitation exist or not? Is spacetime curved or not? Is the earth's moving around the sun due to the gravitational interaction between matter and matter or due to the spacetime curved by the sun?

Relativity theory is the product of the ethereal catastrophe; quantum theory is a product of the ultraviolet catastrophe. The big mysteries or big puzzles of contemporary physics are almost related to both the ethereal catastrophe and the ultraviolet catastrophe, or in other words, related to both relativity theory and quantum theory. Naturally, the big puzzles listed in Tab. 9.1 are also related to the theory of OR, including the theory of IOR and the theory of GOR.

What are listed in Tab. 9.1 are 15 big puzzles of contemporary physics. One is familiar with the interpretations for those puzzles made by the mainstream school of physics. Of course, such interpretations are most based on the perspective of the optical observation agent OA(c).

Now, based on the theory of OR, we can take a broader perspective, that is, from the perspective of the general observation agent OA(η), to reexamine those big puzzles of physics. Perhaps, we will make new discoveries and get new insights.

In **the 1st volume of OR: Inertially Observational Relativity** (IOR), Chapters 3-5 have established the theory of inertially observational relativity, i.e., the theory of IOR; Chapter 6 has established the theory of OR matter waves. The theory of IOR and the theory of OR matter waves can or have already interpreted several big puzzles in Tab. 9.1. The big puzzles from BP-01 to BP-08 listed in Tab. 9.1 mainly involve Einstein's theory of special relativity and de Broglie's theory of matter waves as well as quantum mechanics, which can be interpreted based on the theory of IOR and the theory of OR matter waves. The big puzzles from BP-09 to BP-15 listed in Tab. 9.1 mainly involve Einstein's theory of general relativity, left for the theory of GOR in **the 2nd volume of OR: Gravitationally Observational Relativity** (GOR) to interpret.

BP-01 Why is the Speed of Light Invariant?

BP-01.1 The Statement of the Problem

The Invariance of Light Speed (Einstein's original intention): The speed of light in vacuum is the ultimate speed of the universe and cannot be exceeded; the speed of light in vacuum or in **the free spacetime** has no the effect of speed addition, and so, is invariant or the same relative to all inertial observers.

The principle of invariance of light speed was proposed by Einstein.

In 1905, based on the principle of the invariance of light speed, Einstein established his theory of special relativity [7]. It has been more than a hundred years by now. However, we still cannot understand why the speed of light is invariant.

So, is the speed of light invariant or not, or why is the speed of light invariant?

This is the big puzzle marked as BP-01 in the theory of OR.

BP-01.2 The Mainstream View

The mainstream school of physics believe that:

(i) There must be an upper limit to the speed, so-called **the ultimate speed** of the universe; the ultimate speed must be invariant, that is, the same relative to all inertial observers.

(ii) The speed of light in vacuum is exactly the ultimate speed of the universe, and therefore, the speed of light in vacuum is invariant.

According to the logic argued in a circle by the mainstream school of physics: the speed of light is invariant, so the speed of light is the ultimate speed of the universe and cannot be exceeded; the speed of light is the ultimate speed of the universe and cannot be exceeded, so the speed of light is invariant.

Nowadays, the principle of invariance of light speed has become the **faith** of physicists and the mainstream school of physics.

BP-01.3 The View of IOR Theory

In the axiom system of OR theory (see Chapter 2 or Refs. [26,27]), there is a fundamental principle: the principle of physical observability (PO), or the principle of PO for short: all observable physical quantities must be finite. The principle of PO is evident or self-evident, and consistent with the principle of locality. Actually, the principle of locality is only a logical consequence of the principle of PO. According to the principle of PO, the speeds of all forms of matter motion in the universe, including the speeds of light, gravitational waves, and quantum entanglement, must be finite or limited. So, there must be a certain form of matter motion with the highest intrinsic speed among all forms of matter motion. However, this does not mean that the speed of such a form of matter motion is invariant.

Actually, the principle of the invariance of light speed is only a hypothesis. As the logical premise of Einstein's theory of relativity, the invariance of light speed cannot be proved by Einstein's theory of relativity to be true or to be false.

The theory of OR Starts from the most basic logical premises, derives the invariance of time-frequency ratio from the definition of time (Def. 2.2), deduces the general Lorentz transformation that is isomorphically consistent with the Lorentz transformation, and finally, establishes the whole theoretical system of IOR. In the process of logical deduction, the theory of IOR has proven an important theorem: **the invariance of information-wave speeds** (see Chapter 3 or Refs. [26,27]).

As stated in Chapter 3, the theorem of the invariance of information-wave speeds is supported not only by logical deduction but also by observation and experiment. So, as the logical consequence of OR theory, the invariance of information-wave speeds is of both theoretical basis and empirical basis.

Thus, the theory of OR discovers that the speed of light is not really invariant, and moreover, light may not necessarily be the fastest form of matter motion.

It turns out that Einstein's invariance of light speed is only a special case of the invariance of information-wave speeds. The hypothesis of the invariance of light speed can hold true or be valid only if the observation agent OA(η) is the optical agent OA(c). Actually, whether light is the fastest form of matter motion in the universe or not does not mean that the speed of light is invariant.

As stated in Sec. **7.1 The Essence of the Invariance of Light Speed** of Chapter 7: Einstein's theory of relativity is the theoretical model of optical observation; in essence, Einstein's invariance of light speed is just an observation effect or apparent phenomenon when light is employed as the observation medium to transmit the information on observed objects to inertial observers, which is rooted from the observational locality ($c<\infty$) of the optical observation agent OA(c).

So, there is no form of matter motion with invariant speed in the universe!

BP-02 The Problem of Photon Mass

BP-02.1 The Statement of the Problem

The Problem of Photon Mass: According to the relativistic mass-speed relation $m=m_o/\sqrt{(1-v^2/c^2)}$ in Einstein's special theory of relativity [7], photons, and even all matter particles moving at the speed of light, have no the rest mass m_o, otherwise, their moving mass or relativistic mass m would be infinite.

However, due to the inherent view of nature, people are subconsciously unwilling to accept Einstein's inference of photon zero-mass. The efforts of physicists to detect the rest mass of photons have never stopped [32-37,82-85]. Some great physicists, such as de Broglie [32,33], Schrödinger [34,35], and Feynman [36], ever made efforts to detect the rest mass of photons.

So, does a photon have the rest mass of its own or not; and if the answer is yes, then how much is the rest mass of a photon?

This is the big puzzle marked as BP-02 in the theory of OR.

BP-02.2 The Mainstream View

The mainstream school of physics believe in Einstein's theory: a photon only possesses the moving mass m but has no the rest mass m_o.

Most physicists do not seem to doubt Einstein's doctrine of moving mass. But, subconsciously, they believe that the rest mass is the real mass of matter or objects, and that a photon should have the rest mass of its own.

Proca even prepared an amendment scheme of massive photon for the Maxwell's electromagnetic-field equations [86]. He proposed a relativistic massive wave equation for a vector field, in which a photon has the rest mass of its own. Physicists cherish the hope of finding the rest mass of photons beyond their moving mass. However, all attempts to detect the rest mass of photons have failed, only left a string of the upper bounds of photon rest-mass that gradually approach zero [37,82-84]. In 2014, the upper bound of photon rest-mass recommended by the Particle Data Group (PDG) was 1.5×10^{-54} kg [85], which was made by Ryutov in 2007 through analyzing the properties of the solar wind at Pluto's orbit [83].

Accordingly, the mainstream school of physics believe Einstein was right.

BP-02.3 The View of IOR Theory

Einstein inferred from his theory of special relativity that the rest mass m_o of a photon was zero. It is worth noting that the speed $v=c$ of photons happens to be at the singularity of Einstein's mass-speed relation: $m=m_o/\sqrt{(1-v^2/c^2)}$. As Hawking ever remarked [31]: "Mathematics cannot really handle infinite numbers. At singularity, the theory itself breaks down or fails."

In theory of OR, the IOR mass-speed relation (Eq. (5.5)) is

The mass-speed of OA(η): $m=m(\eta)=\Gamma(\eta)m_o=\dfrac{m_o}{\sqrt{1-v^2/\eta^2}}$,

where OA(η) is the general observation agent, m_o is the rest mass of the observed object P, $m=m(\eta)$ is the observational mass of P observed in the observational spacetime $X^{4d}(\eta)$ of OA(η), η is the information-wave speed of OA(η), and v is the moving speed of P.

It is thus clear that the relativistic mass $m=m(\eta)$ of the observed object P depends on the information-wave speed η of OA(η), and therefore, contains the observational effect of OA(η), not exactly the objectively real mass of P.

So, the mass-speed relation $m=m_o/\sqrt{(1-v^2/c^2)}$ in Einstein's special theory of relativity is only a special case of the mass-speed relation in the theory of OR, which can hold true or be valid only if the observation agent OA(η) is the optical observation agent OA(c).

It should be pointed out that $v=\eta$ is exactly the singularity of the IOR mass-speed relation. In Hawking's words: At singularity $v=\eta$, the IOR mass-speed relation must break down or fail.

I. The Mass of Photon cannot be Detected by the Optical Agent OA(*c*).

The IOR mass-speed relation suggests that, limited or restricted by the singularity $v=\eta$ of the mass-speed relation, the observation agent OA(η) cannot detect and determine the mass of the informons of its own. Therefore, the optical observation agent OA(c) cannot detect the mass of photons which act as the informons of OA(c), just as you cannot lift yourself up.

According to the principle of physical observability (PO), the relativistic mass or moving mass $m(\eta)$ of the informons of the observation agent OA(η) must be finite: $m(\eta)<\infty$. Therefore, for all observation agents (including the optical observation agent OA(c)), their informons (including the photons of the optical observation agent OA(c)) have no the rest mass m_o:

$$m_o=\Gamma^{-1}(\eta)m(\eta)=m(\eta)\sqrt{1-\eta^2/\eta^2}=0 \tag{9.1}$$

It should be pointed out that: Eq. (9.1) does not mean that the informons of the observation agent OA(η) have no rest mass; it only means that the IOR mass-speed relation (Eq. (5.5)) breaks down or fails at the singularity $v=\eta$.

Thus, we cannot count on the observation agent OA(η) to detect the rest mass of OA(η)'s own informons; naturally, we also cannot count on the optical agent OA(c) to detect the rest mass of photons.

Restricted by the current level of human technology, our observations and experiments mostly rely on the optical agent observation OA(c). Meanwhile, our theoretical models for describing the mass and energy of photons, including Einstein's theory of relativity, Maxwell's equations, and Proca's equations, are mostly the products of the optical observation agent OA(c). Although all the present results of observations or experiments for detecting the physical effects of the photon rest-mass, such as the dispersion effect of light, the deviation of Coulomb's law in electrostatic field, the breaking of Ampere's loop law, and etc, supports Einstein's argument of photon zero-mass, they are all produced by the optical agent OA(c), contain the observational effects of OA(c), and do not represent the objectively physical reality.

The efforts to make use of the optical observation agent OA(c) to detect or determine the rest mass of photons are doomed to be futile.

II. The Rest Mass of Photon is not Zero.

The IOR mass-speed relation indicates that the rest mass of photons is not zero.

The IOR mass-speed relation (Eq. (5.5)) is the mass-speed relation of the general observation agent OA(η), which suggests that although the rest mass m_o of a photon cannot be detected or determined with the optical observation agent OA(c), it can be done with the superluminal observation agent OA(η) ($\eta > c$).

Naturally, in the observational spacetime $X^{4d}(\eta)$ of the observation agent OA(η) ($\eta \geq c$), a photon must have its own observational mass: $m(\eta) > 0$. According to the principle of PO, the observational mass $m(\eta)$ of a photon in the observational spacetime $X^{4d}(\eta)$ of OA(η) ($\eta \geq c$) must be finite: $m(\eta) < \infty$.

Therefore, according to the IOR mass-speed relation (Eq. (5.5)), once there is the technology of superluminal observation, the rest mass m_o of a photon can be detected or determined by OA(η) ($\eta > c$):

$$m_o = m(\eta)\sqrt{1 - c^2/\eta^2} > 0 \quad (\eta > c) \tag{9.2}$$

So, the rest mass of photons objectively exists independent of observation.

III. All Matter Particles have the Rest Masses of Their Own.

Actually, the IOR mass-speed relation (Eq. (5.5)) suggests that all matter particles possess the rest masses of their own. Actually, the rest mass of an object is the objectively real mass of its own.

Naturally, in the observational spacetime $X^{4d}(\eta)$ of the observation agent OA(η) ($\eta \geq v$), a particle or an object P moving at the inertial speed v must have its own observational mass: $m(\eta) > 0$. According to the principle of PO, the observational mass $m(\eta)$ of P in the observational spacetime $X^{4d}(\eta)$ of OA(η) ($\eta \geq v$) must be finite: $m(\eta) < \infty$.

Therefore, according to the IOR mass-speed relation (Eq. (5.5)), if the information-wave speed η of the observation agent OA(η) is higher than the inertial speed v of P, then the rest mass m_o of P can be determined by OA(η) ($\eta > v$):

$$m_o = m(\eta)\sqrt{1 - v^2/\eta^2} > 0 \quad (\eta > v) \tag{9.3}$$

It is thus clear that, all matter particles, including photons, neutrino, and even graviton, have the rest masses of their own, i.e., the intrinsic masses of their own.

IV. The Theoretical Predicted Value of the Rest Mass of a Photon

Then, how much does a photon weigh?

In **the 2nd volume of OR: Gravitationally Observational Relativity** (GOR), based on the analysis of the gravitational redshift of light as well as the classical kinetic energy and potential energy of photons, based on the theory of GOR gravitational redshift, the theory of GOR will theoretically calculate the rest mass of photons and make theoretical prediction for the rest mass of photons.

BP-03 The Essence of Relativistic Effects

BP-03.1 The Statement of the Problem

The Relativistic Effects: Einstein's theory of relativity, including the special and the general, reveals the relativistic effects or relativistic phenomena of spacetime as well as matter motion and matter interactions. **the 1st volume of OR: Inertially Observational Relativity** (IOR) mainly relates the relativistic effects or phenomena of inertial spacetime and inertial motion, such as the invariance of light speed, the phenomena of time dilation and length contraction, the effect of relativistic speed-addition, the relativity of simultaneity, the issue of mass dilation, and the problem of photon mass.

Einstein's special theory of relativity has been established for more than 100 years, but people still cannot understand, and physics still cannot interpret, why spacetime and matter motion exhibit relativistic effects or relativistic phenomena.

Actually, all relativistic effects or relativistic phenomena of Einstein's theory of relativity stem from Einstein's hypothesis of the invariance of light speed. The invariance of light speed itself is just a sort of relativistic phenomenon. Einstein's theory of relativity cannot explain the invariance of light speed as its logical premise, and naturally, also cannot explain the relativistic effects or relativistic phenomena as its logical consequences.

So, what is the essence of relativistic phenomena?

This is the big puzzle marked as BP-03 in the theory of OR.

BP-03.2 The Mainstream View

Based on his special theory of relativity, Einstein believed that the relativistic effects of inertial spacetime are the objectively physical reality, rooted from the motion of matter. Up to now, it has not yet been explained why spacetime and matter motion exhibit relativistic effects or relativistic phenomena, but the mainstream school of physics still insist that relativistic effects are the essential characteristics of the physical world.

For the relativistic effects or relativistic phenomena of spacetime and matter motion, the mainstream school of physics is satisfied with knowing what they are rather than why they arise. An academician of the China Academy of Sciences, who is engaged in the research of theoretical physics, commented on the theory of observational relativity (OR): "It is totally wrong to attribute relativistic phenomena to observational effects."

However, our senior academician could not explain why.

BP-03.3 The View of IOR Theory

It is the important discovery of OR theory that: **All relativistic effects are apparent phenomena**, in which the most important is that: **The speed of light is not really invariant**.

The theory of IOR has proved the theorem of **the invariance of information-wave speeds**, which suggests that so-called **the invariance of light speed** is only a special case of **the invariance of information-wave speeds** when the observation agent OA(η) is the optical agent OA(c): the speed of light is observationally invariant if and only if light acts as the observation medium for transmitting the information of observed objects to inertial observers. As a matter of fact, no matter the invariance of information-wave speeds or the invariance of light speed is only a sort of observational effect or apparent phenomenon.

All the relativistic effects or relativistic phenomena in Einstein's theory of relativity are rooted from the hypothesis of the invariance of light speed. So, we can conclude that all relativistic effects or relativistic phenomena of Einstein's theory of relativity are observational effects or apparent phenomena.

In the theory of IOR, we have repeatedly discussed the root and essence of the relativistic effects or relativistic phenomena of inertial spacetime and inertial motion. In particular, based on the theory of IOR, Chapter 7 of **the 1st volume of OR: Inertially Observational Relativity** (IOR) focuses on the root and essence of the relativistic effects or relativistic phenomena, including the phenomenon of the invariance of light speed, the relativistic effects of inertial spacetime, and the relativistic effects of inertial motion.

The theory of IOR has clarified that the relativistic effects of inertial spacetime and inertial motion depends on observation and observational agents: different observation agents present different degrees of relativistic effects. It is thus clear that all relativistic effects or relativistic phenomena of inertial spacetime and inertial motion, whether based on the theory of IOR or on Einstein's theory of special relativity, are not the objectively physical reality.

As stated in Chapter 7, all relativistic phenomena, whether based on the theory of IOR or on Einstein's theory of special relativity, in essence, are observational effects or apparent phenomena, rooted from the observational locality ($\eta<\infty$) of human observation agent OA(η), including the optical agent OA(c).

The essence of the relativistic effects of inertial spacetime and inertial motion has been clarified by the theory of IOR (see Chapter 7). The problem about the essence of the relativistic effect or relativistic phenomena of gravitational spacetime and gravitational interactions will be left for **the 2nd volume of OR: Gravitatonally Observational Relativity** (GOR) to study.

BP-04 The Mysterious Planck Constant

BP-04.1 The Statement of the Problem

Planck Constant: In 1900, Planck introduced the quantum hypothesis $E=hf$, based on which he had theoretically derived the law of blackbody radiation [14]. Planck's law of blackbody radiation was in good agreement with the experiment of blackbody radiation. More importantly, the quantum hypothesis $E=hf$, which serves as the logical premise of Planck's law of blackbody radiation, marks the birth of quantum theory [15,16], where h is the famous Planck constant.

The quantum hypothesis $E=hf$ or the hypothesis of energy quanta, where $E=hf$ is known as Planck equation, suggests that the emission or absorption of electromagnetic energy is discrete or discontinuous: a quantum is the minimal element of the energy in electromagnetic waves.

Even Planck himself did not believe the quantum hypothesis $E=hf$ is reasonable. However, he had to make such a hypothesis so that his could theoretically derive the law of blackbody radiation in line with the experiment of blackbody radiation. Just as Einstein and relativity theory could not explain Einstein's hypothesis of the invariance of light speed, Planck and quantum theory could not explain Planck's hypothesis of energy quanta, in which, of course, the most mysterious is the Planck constant h.

So, in essence, what does the Planck constant h mean?

This is the big puzzle marked as BP-04 in the theory of OR.

BP-04.2 The Mainstream View

In the dictionary of physics, the Planck constant h is a cosmic constant.

The Planck constant h multiplied by the frequency f a photon of is exactly equal to the energy E of the photon: $E=hf$.

Planck's constant h is an empirical value and must be determined by experiment. The exact value of the Planck constant h is $h=6.62607015\times^{-34}$ J·s recommended by the International System of Units (SI).

One can understand the rationality and physical significance of the speed c of light in vacuum as a cosmic constant; but one cannot quite understand why there exists such an energy-quantum constant in the universe.

In the field of physics, there are different views on the Planck constant h.

BP-04.3 The View of IOR Theory

In the theory of OR, the theory of IOR not only has generalized and unified Newton's inertial mechanics and Einstein's special relativity, but also has generalized and unified Einstein's theory of special relativity and de Broglie's theory of matter waves. So, Einstein formula $E=mc^2$ and Planck equation $E=hf$, the two great formulae in physics, have been unified in the theoretical system of OR, moving towards the unification of relativity theory and quantum theory.

Thus, we have gained new understanding and new insight into Planck equation $E=hf$ and the Planck constant h.

I. The General Planck Equation [26,27]: $E=h_\eta f$

The theory of IOR derives the invariance of time-frequency ratio from the most basic logical premise of the definition of time (Def. 2.2), and then deduces the transformation of IOR spacetime (Eq. (4.18)), so-called **the general Lorentz transformation**, in which the IOR factor $\Gamma(\eta)=dt/d\tau$ of spacetime transformation can be expressed in two forms: the wave-like form $\Gamma(\eta)=f/f_o$ (Eq (6.1)) and the particle-like form $\Gamma(\eta)=m/m_o$ (Eq. (6.2)).

As stated in Sec. 6.4 of Chapter 6: **The Theory of OR Matter Waves**, it is based on the wave-like form $\Gamma(\eta)=f/f_o$ of the IOR factor that the theory of OR matter waves has derived the general Planck equation $E=h_\eta f$ (Eq. (6.16)), which is the formula of OR energy quanta, generalizing Planck equation $E=hf$.

Thus, the theory of OR matter waves gives birth to an important formula of physics: **the general Planck equation** $E=h_\eta f$.

Now, Planck equation $E=hf$ is no longer a hypothesis, but a logical consequence of OR theory. Planck equation $E=hf$ is no longer a universal formula, but a special case of the general Planck equation $E=h_\eta f$, which holds true or is valid only if the observation agent OA(η) is the optical agent OA(c).

As stated in the theory of OR matter waves in Chapter 6, the general Planck equation $E=h_\eta f$ is the formula of the energy quanta under the general observation agent OA(η), where the so-called **energy quanta** refer to the informons of the general observation agent OA(η). The general Planck equation $E=h_\eta f$ suggests that, for a different observation agent OA(η), the energy per unit hertz of its informons is different, or in other words, the coefficient h_η of the energy-frequency ratio of its informons is different. Actually, the Planck constant h is only a special case of the general Planck constant h_η, that is, the coefficient of the energy-frequency ratio of the informons (photons) of the optical agent OA(c).

II. The GPC Identity: $h_\eta\eta=C$ ($C\equiv hc$)

Naturally, in the general Planck equation $E=h_\eta f$, the most important, or what is different from Planck equation $E=hf$, is the general Planck constant h_η.

In Chapter 6, based on Bohr's correspondence principle [71], the theory of OR matter waves built an identity for the general Planck constant h_η: $h_\eta\eta=C$ ($C\equiv hc$), **the GPC identity** for short.

The GPC identity $h_\eta\eta=hc$ is the formalization of Bohr's correspondence principle, elucidating the corresponding relationship between the general Planck constant h_η and Planck equation $E=hf$ of the optical agent OA(c), as well as the corresponding relationship between the general Planck constant h_η and Newton's classical model of the idealized agent OA_∞. In particular, the GPC identity $h_\eta\eta=hc$ suggests that different observation agents have different Planck constants.

According to the GPC identity $h_\eta\eta=hc$: $h_\eta\to h_c=h$ as $\eta\to c$, conforming to Planck equation $E=hf$ under the optical agent OA(c); $h_\eta\to h_\infty=0$ as $\eta\to\infty$, conforming to Newton's classical model under the idealized agent OA_∞. In other words, the GPC identity $h_\eta\eta=hc$ is logically consistent with Bohr's correspondence principle [71].

It is thus clear that the Planck constant h is not a cosmic constant, but a coefficient of optical observation, that is, the parameter of the optical observation agent OA(c), which is only applicable to the optical observation system.

As stated in the theory of OR matter waves in Chapter 6, Planck equation E=hf was originally Planck's hypothesis of energy quanta, and the Planck constant h is the the energy-frequency ratio of energy quanta. It is worth noting that Planck's energy quanta are photons, that is, the informons of the optical agent OA(c). Actually, the Planck constant h is only the energy-frequency ratio of the informons (photons) of the optical observation agent OA(c).

So, the general Planck constant h_η is the energy-frequency ratio of the informons of the general observation agent OA(η): the informons of different observation agents have different coefficients of energy-frequency ratio.

III. The Essence of the Planck Constant *h*

According to the general Planck equation E=$h_\eta f$ and the GPC identity $h_\eta\eta$=hc of the theory of OR matter waves, we can conclude that, in essence, the Planck constant h is the energy-frequency ratio of photons and even all electromagnetic matter particles, and also the energy-frequency ratio of the informons (photons) of the optical observation agent OA(c). Therefore, as an observation coefficient, the Planck constant h plays an important role in the optical observation system.

Our observation and experiment mostly rely on the optical observation agent OA(c), which is the main reason why the Planck constant h or Planck equation E=hf have been playing the important role in our physics.

As stated before, in the theory of OR, the IOR factor $\Gamma(\eta)$ of spacetime transformation has two forms: the wave-like form (Eq. (6.1)) and the particle-like form (Eq. (6.2)), which conforms to the wave-particle duality of matter or matter motion: the particle-like form represents the form of matter existence; the wave-like form represents the form of matter motion.

At the beginning, in order to derive the law of blackbody radiation, Planck was "forced" to propose the hypothesis of energy quanta, at that time, even he himself had ever thought it were contrary to common sense.

However, on the contrary, continuous energy or the continuity of energy could only exist in the idealized theories or the idealized models. In the objectively physical world, the mass and energy of matter must be discrete and discontinuous, which reflects the particle-like nature of matter. Actually, continuous mass or continuous energy is unrealistic and unimaginable.

In the terms of light, light is composed of photons, in other words, light waves are the collective effect of photons. Each photon has the energy E of its own, which is proportional to the frequency f of a photon: $E\propto f$, and the proportional coefficient of E to f is the energy-frequency ratio of photons as stated in Sec. 6.3 of Chapter 6, that is, the Planck constant h, experimentally measured as h=6.62607015$\times^{-34}$ J·s.

Originally, the energy quanta in Planck equation E=hf is the photons of blackbody radiation, and the Planck constant h is the energy-frequency ratio of photons. However, in quantum mechanics, the Planck constant h has gained the universal significance and has been extended to all matter particles or to all forms of matter motion.

Then, the question arises: is the Planck constant h really a universal constant, or in other words, are the energy-frequency ratios of all matter particles in the universe the same as the Planck constant h?

According to the theory of OR matter waves, according to the general Planck equation $E=h_\eta f$ and the GPC identity $h_\eta \eta=hc$, different observation agents have different Planck constants, or in other words, different informons have different energy-frequency ratios. In particular, the GPC identity $h_\eta \eta=hc$ suggest that: under the optical agent OA(c), $h_\eta \to h$ as $\eta \to c$, conforming to quantum models and Planck equation $E=hf$; under the idealized agent OA_∞, $h_\eta \to 0$ as $\eta \to \infty$, conforming to classical models and Bohr's correspondence principle.

In theory, any matter particle can serve as an informon of a specific observation agent to transmit the information of observed objects to observers. Different matter particles may have different energy-frequency ratios: the Planck constant h is only the energy-frequency ratio of photons. So, the Planck constant h is only applicable to light or electromagnetic waves rather than other matter waves, only applicable to the optical observation agent OA(c) rather than other observation agents, just as the speed c of light in vacuum is only the speed of light or electromagnetic waves rather than the speed of other matter waves.

In summary, the Planck constant h, which is in essence the energy-frequency ratio of photons, only represents electromagnetic particles, and in particular, represents the informons (photons) of the optical observation agent OA(c). Like the speed c of light, the Planck constant h can be regarded as an observation coefficient of the optical agent OA(c): the speed c of light in vacuum characterizes the speed the information wave of OA(c); the Planck constant h characterizes the energy of the informons of OA(c).

However, different observation agents (OA(η) ($\eta \in (0,+\infty)$)) have different information-wave speeds (η) and different general Planck constants (h_η).

Perhaps, experimental physicists can detect and determine the energy-frequency ratios of different matter particles or different matter waves with different speeds, for example, the electrons with various speeds, and then, verify the GPC identity in the theory of OR matter waves: $h_\eta \eta=C$ ($C \equiv hc$), and alternatively, verify Bohr's correspondence principle: $h_\eta \to h$ as $\eta \to c$; $h_\eta \to 0$ as $\eta \to \infty$.

BP-05 The Essence of Quantum Effects

BP-05.1 The Statement of the Problem

Quantum Effects: According to quantum mechanics, the motion of matter presents quantum effects or the phenomenon of uncertainty in the microscopic world or microscopic spacetime. Quantum theory tells us that, in regard to the microscopic particles in the microscopic spacetime, their energies are discrete rather than continuous, their spatial positions are probabilistic rather than deterministic; they behave like both particles as well as waves, and therefore, can be described by the wave function of probability statistics.

Matter particles in the microscopic world seemingly behave more like waves.

In quantum mechanics, the behavior or state of a microscopic particle P can be described by the wave function $\Psi(x,t)$, i.e., Schrodinger equation [20]:

$$\mathrm{i}\hbar\frac{\partial\Psi(x,t)}{\partial t}=-\frac{\hbar^2}{2m}\frac{\partial^2\Psi(x,t)}{\partial x^2}+V\Psi(x,t) \tag{9.4}$$

At the beginning, the implication of the wave function $\Psi(x,t)$ in Schrodinger equation (Eq. (9.4)) was not very clear, and Schrodinger himself also could not interpret it. So, there were many different interpretations for Schrodinger's wave function. In the end, Born's interpretation was recognized and accepted by the mainstream school of physics:

$$\int_a^b\left|\Psi(x,t)\right|^2\mathrm{d}x=\int_a^b\Psi^*(x,t)\Psi(x,t)\mathrm{d}x=p_{ab}(t) \tag{9.5}$$

where $p_{ab}(t)$ is the probability of finding the particle at time t between a and b.

Born's interpretation is a sort of statistical interpretation for Schrodinger's wave function $\Psi(x,t)$, which introduces the uncertainty of matter and matter motion to quantum mechanics [21]. Interestingly, Schrodinger himself did not quite agree with such an interpretation.

Born's statistical interpretation represents the claims of the orthodox school of quantum mechanics, i.e., the Copenhagen School, that: the behaviors of microscopic matter particles are random or probabilistic; the uncertainty of microscopic particles is the essential characteristic of spacetime and matter motion.

Einstein on behalf of the realism school advocated: "God doesn't play the dice."

Quantum mechanics has been around for over 100 years. On one hand, quantum mechanics can in most cases accurately describe the probabilistic and statistical characteristics of the energies and physical states of microscopic particles; On the other hand, just as Einstein's theory of relativity cannot explain relativistic effects, quantum mechanics cannot explain quantum effects. Thus, quantum mechanics is permeated with a strong mysterious flavor, leading to many myths.

So, what is the essence of quantum phenomena?

As for the essence of quantum phenomena, there is a test for quantum effects spread in quantum mechanics: **the QE test** or **the QE thought experiment** [22].

The Test of Quantum Effects (QE thought experiment): For the observed object P, no matter a macroscopic object or a microscopic particle, you could not determine where it was before it was measured; suppose that you made an observation of P and determined that, at the time $t=t_0$, P was located at the spatial point $x=x_0$, then just before the measurement, that is, at that moment before the time t_0: $t\in[t_0^-,t_0)$, where was P?

This is the big puzzle marked as BP-05 in the theory of OR.

BP-05.2 The Mainstream View

On quantum mechanics, the views of the mainstream school of physics do not seem to be as consistent and unified as those on Einstein's theory of relativity.

Einstein himself did not seem to believe quantum mechanics was right [45,46].

In the terms of the QE test or the QE thought experiment, different schools have different views no the essence of quantum effects or quantum phenomena [22].

Different Schools' Answers to the QE Test:

The Realism School: P was located at x_0.

The Agnosticism School: Refuse to answer, or not sure where P was.

The Copenhagen School: When you measured and had observed P located at x_0 at the time t_0, the wave function $\Psi(x,t)$ collapsed, and the particle P was forced to appear at the spatial position x_0; while at the time t_0^-, P might existed at different locations with different probabilities.

The view of the orthodox school (i.e., the Copenhagen school) is known as the Copenhagen interpretation [23].

The view of the realism school should be represented by Einstein: **God does not play the dice with the universe**. As d' Espagnat said [25]: "The position of the particle was never indeterminate, but was merely unknown to the experimenter." The view of the realism school seems to be more in line with materialism or materialist view of nature. A physicist should be a materialist. However, the view of the realism school is gradually being abandoned by the mainstream school of contemporary physics.

As Griffiths said [22]: "Until fairly recently, all three positions (realist, orthodox, and agnostic) had their partisans." However, the Copenhagen interpretation has gradually become the dominant ideology of quantum mechanics.

BP-05.3 The View of IOR Theory

The theory of OR matter waves provides us with a new and broader perspective to reexamine quantum theory and the essence of quantum effects.

From the perspectives of different observation agents (OA(η) ($\eta\in(0,+\infty)$)), including the idealized agent OA_∞ and the optical agent OA(c), the theory of OR redesigns the QE test or the QE thought experiment, reexamines the essence of quantum effects or quantum phenomena, and provides the new interpretations for quantum effect or quantum phenomena. As stated in Sec. 6.10 of Chapter 6: **All quantum phenomena are observational effects**.

I. New Interpretations for Different Schools' Views

The theory of OR matter waves has discovered that quantum behaviors, i.e., the probabilistic and statistical behaviors of microscopic particles, are also observational effects. So, the views of different schools should be reinterpreted.

As stated in the theory of OR matter waves in Chapter 6, based on the wave-like form of the IOR factor $\Gamma(\eta)$ of spacetime transformation: $\Gamma(\eta)=f/f_o$, the theory of OR matter waves not only derives the general Planck equation $E=h_\eta f$, generalizing Planck equation $E=hf$, but also deduces de Broglie relation $\lambda=h_\eta/p$, generalizing de Broglie relation $\lambda=h/p$ [26,27]. According to the general Planck equation $E=h_\eta f$ and the general de Broglie relation $\lambda=h_\eta/p$, the frequency $f_\eta=f_\eta(\eta)$ and wavelength $\lambda_\eta=\lambda_\eta(\eta)$ of the observed matter particle (or matter wave) P depend on the observation agent OA(η). This suggests that quantum effects, like relativistic effects, are also observational effects.

The observed object P, no matter whether it is a macroscopic object or a microscopic particle, the observer O must rely on a certain observation agent OA(η), and employ the information wave or informons of OA(η) as the medium to transmit the information of P for O, so that, O can perceive or observe P. The theory of OR stressed repeatedly that Einstein's relativity theory and Newton's classical mechanics belong to different observation agents: Einstein's relativity theory, both the special and the general, is the theory of the optical agent OA(c), which observes the objective world through light; Newton's classical mechanics is the theory of the idealized agent OA(η).

Likewise, different schools, including the realist, the agnostic, and the orthodox, also belong to or represent different observation agents.

In the terms of the QE test or the QE thought experiment, from the perspective of OR theory, that is, the perspective of the general observation agent OA(η), there is no definite boundary or irreconcilable contradictions between the views or the interpretations of different schools.

Realism School: from the perspective the idealized agent OA_∞.

The idealized agent OA_∞ has no observational locality: the information-wave speed of OA_∞ is idealized as infinite. And moreover, the idealized agent OA_∞ has no observational perturbation: according to the GPC identity $h_\eta\eta=hc$, $h_\infty=0$, the momentum of the informons of OA_∞ is idealized as infinitesimal.

So, before and after observation, the motion trajectory of the observed object P is not affected by the observation activity of OA_∞. Therefore, from the perspective of the idealized agent OA_∞, the realism school believe that, if you see or observe the particle P located at the spatial point $x=x_0$ at the time $t=t_0$, then naturally, at the time t_0 or t_0^-, the particle P is still located at the spatial point x_0 or x_0^-.

However, there is no the idealized observation agent in the reality world.

The idealized observation agent could only exist in human reason.

Copenhagen School: from the perspective of the optical agent OA(c).

The speed c of light, as the information-wave speed of OA(c), is finite, and therefore, the optical agent OA(c) has the observational locality ($c<\infty$). According to the GPC identity $h_\eta\eta=hc$, $p_c=h_c/\lambda_c>0$: the photons as the informons of OA(c) have the momentum p_c (>0) of their own, and therefore, the optical agent OA(c) has the effect of observational perturbation.

So, the observed object P would be perturbed by the informons (photons) of OA(c), so that the motion trajectory of P would naturally exhibits certain quantum effects and uncertainty.

Such quantum effects are in essence the effects of observational perturbation.

Therefore, from the perspective of the optical agent OA(c), the Copenhagen school believe that, if you see or observe the particle P located at the spatial point $x=x_0$ at the time $t=t_0$, then naturally, the spatial position of P at the time t_0^-, i.e. before the informons (photons) of OA(c) collide with P, was indeed uncertain, and it could only be determined that, at the time t_0^-, P was located at different spatial points with different probabilities. If you did not make observation on P and there were no the informons (photons) of OA(c) colliding with P, then P would not have appeared at the spatial point $x=x_0$ at the time $t=t_0$.

It is thus clear that, even from the perspective of the Copenhagen School or the optical observation agent OA(c), quantum effects are only observational effects, or so-called **the effects of observational perturbation**.

Agnosticism School: from the perspective of no observation agent.

In the view of the agnosticism school, all observation agents are invalid: OA(η) ($\eta<v$ or $p_\eta>p$), in which ether the information-wave speed η is lower than the speed v of P or the informon momentum p_η is greater than the momentum p of P.

So, the agnosticism school refuse to accept any observation conclusion: no matter before observation or after observation, one could not really know where the observed object or particle P was. In the terms of the QE test, one could not really determine where, at the time t_0^-, P was.

Thus it can be seen from the perspective of the general observation agent OA(η) that, in the terms of the QE test or the QE thought experiment, there are two extremes in the interpretations of different schools:

(i) Observationism: the realism school believe in that what is seen or observed is objective and realistic, as a Chinese proverb goes: “Seeing is believing”;

(ii) Agnosticism: on the contrary, the agnosticism school believe in that no matter what is seen or observed is not objective and not realistic.

So, it seems reasonable that the mainstream school of physics tend to support the Copenhagen interpretation of the QE test or the QE thought experiment.

II. OE Thought Experiment: the Test of Observational Effects

The QE test particularly emphasizes that moment before P was measured and had just been observed, which seems to intentionally mislead the testees, and intends to draw off the doctrine of **wave function collapse**. Perhaps, this is related to the widely circulated Mermin’s **Is the Moon There When Nobody Looks?** [24].

Naturally, where the moon is regardless of whether you look at it.

But, why would anyone believe that, if no one looked at it, then no one could determine where the moon was or whether the moon existed, and the moon would appear only if you look at it?

Such cognition stems from subjective idealism.

As early as the 17-18$^{\text{th}}$ century, the representative figure of subjective idealism, Anglo-Irish Anglican bishop, George Berkeley, put forward the same proposition (paraphrasing): This table exists when I look at it; when I am outside this room, I cannot see it, then this table does not exist. Naturally, such Berkeley’s argument about the presence of the moon is absurd, and hardly has a room for its survival in macroscopic physics. However, quantum physicists believe that the microscopic world is different from the macroscopic world; such absurdity in the macroscopic world could become the objectively physical reality in the microscopic world.

Before observation, one naturally does not know where the moon is, and so, the position of the moon is indeed uncertain. Originally, such uncertainty is only the subjective uncertainty of the observer, but not the objective uncertainty of the moon. Now, based on Born's statistical interpretation of the wave function in Schrodinger equation, quantum, the orthodox school of quantum mechanics believe that: in the microscopic world, the observed particle P could be both here and there at the same time; P could move from the spatial point A to B by both this path and that path at the same time. Just as Erwin Schrodinger's cat [87], it could be both alive and dead at the same time.

However, the theory of OR believe that: **One world, one logic**.

There is no the definite boundary between the macroscopic world and the microscopic world. The unity and identity of the macroscopic world and the microscopic world have been clearly interpreted by or reflected in Bohr's correspondence principle [71]. No one could draw a boundary or set a threshold to determine that the observed particle P was so small that it would exhibit the weird quantum phenomena.

According to the theory of OR, d' Espagnat's view remains valid [25]: "The position of the particle was never indeterminate, but was merely unknown to the experimenter." Without observation, one would never know where the particle P or the moon is. However, this does not mean that the position or spacetime states of the particle P or the moon is objectively uncertain, let alone that the particle P or the moon does not exist.

In order to clarify the essence of quantum effects as well as relativistic effects, the theory of OR redefines the quantum effect (QE) test as the following observational effect (OE) test, or the OE thought experiment.

The Test of Observational Effects (OE thought experiment): For the observed object P, no matter a macroscopic object or a microscopic particle, you could not determine where it was before it was measured; suppose that you made an observation of P and determined that, at the time $t=t_0$, P was located at the spatial point $x=x_0$, then, at the time t_0, was P really located at the spatial point x_0?

The OE thought experiment, or the OE test, can be used to test the essence of quantum effects as well as the essence of relativistic effects. Naturally, where the observed object P was at the time t_0 does not depend on the schools of thought, but depends on observation, depends on observation agents: different observation agents must have had different observation conclusions.

Different Observation Agents' Answers to the OE Test:

The Idealized Observation Agent OA$_\infty$ ($\eta\to\infty$ and $h_\eta\to 0$): At that moment of the time t_0, the observed object P was exactly located at the spatial point x_0.

Actually, what is observed by the idealized observation agent OA$_\infty$ is objective and real. The idealized observation agent OA$_\infty$ can be referred to as **God's Agent**, that is, **God's Perspective**.

As stated in Sec. 6.7 of Chapter 6, according to the GPC identity $h_\eta\eta=hc$ in the theory of OR matter waves, for the idealized agent OA_∞: $\eta\to\infty$ and $h_\eta\to 0$.

The information-wave speed of the idealized agent OA_∞ is infinite ($\eta\to\infty$), which suggest that OA_∞ has no observational locality, the spacetime information transmitted by OA_∞ has no delay in time, and therefore, the observed object P would not exhibit the relativistic effects in the observational spacetime $X^{4d}{}_\infty$ of OA_∞. Meanwhile, the energy-frequency ratio of the informons of OA_∞ is infinitesimal ($h_\eta\to 0$), which suggests that the informons momentum of OA_∞ is infinitesimal ($p_\eta=h_\eta/\lambda_\eta\to 0$), OA_∞ has no the observational perturbation, and therefore, the observed object P would not be exhibit the quantum effects and uncertainty in the observational spacetime $X^{4d}{}_\infty$ of OA_∞.

So, whether in the macroscopic spacetime or in the microscopic spacetime, whether the observed object P is a macroscopic object or a microscopic particle, whether P is the moon or an electron, whether P is at rest or is moving, if at the time $t=t_0$ the idealized observation agent OA_∞ observed that P was located at the spatial point $x=x_0$, then, at the time t_0, P was really located at the spatial point x_0.

From **God's perspective**, or, under the idealized agent OA_∞, there are neither relativistic effects nor quantum effects in the objective world. The observational spacetime $X^{4d}{}_\infty$ of the idealized agent OA_∞ represents the objectively physical world. This suggests that relativistic effects are not the intrinsic physical property of spacetime and matter, but the observational effects caused by the observational locality ($\eta<\infty$) of realistic observation agents; quantum effects are also not the intrinsic physical property of spacetime and matter, but the observational effects caused by the observational perturbation ($h_\eta>0$) of realistic observation agents.

As Einstein remarked: "**God doesn't play the dice.**"

The Realistic Observation Agent OA(η) ($\eta<\infty$ and $h_\eta>0$): At that moment of the time t_0, the observed object P was with a certain probability located in the neighborhood of x_0 (just like Born's statistical interpretation (Eq. (9.5)): P is located at time t between a and b with the probability of $p_{ab}(t)$).

Anyway, due to the observational locality ($\eta<\infty$) and the observational perturbation ($h_\eta>0$), what are observed by means of the realistic observation agent OA(η) ($\eta<\infty$ and $h_\eta>0$) are not completely objective and completely real, and do not represent the objectively physical reality.

Naturally, the realistic observation agent OA(η) ($\eta<\infty$ and $h_\eta>0$) includes the optical observation agent OA(c). Born's statistical interpretation (Eq. (9.5)) is from the perspective of the realistic observation agent OA(η) ($\eta<\infty$ and $h_\eta>0$), and represents the view of the optical agent OA(c).

For the realistic observation agent OA(η) ($\eta<\infty$ and $h_\eta>0$), including the optical agent OA(c), the information-wave speed η is finite, and therefore, OA(η) has the observational locality ($\eta<\infty$): the spacetime information of the observed object P at the spatial point x_0 is emitted from P at the time $t_0-\Delta t$, and reaches the observer O at the time t_0 after the delay Δt (>0) in time; moreover, the informon momentum $p_\eta=h_\eta/\lambda_\eta$ is not zero, and therefore, OA(η) has the observational perturbation

(h_η>0): in theory, whether P is the moon or an electron will be perturbed by the informons of OA(η). Therefore, regardless of whether P was at rest at the spatial point x_0 at the time t_0–Δt, theoretically, P would no longer be located at the spatial point x_0 at the time t_0.

Actually, quantum effects are not unique to the microscopic spacetime.

In theory, whether in the macroscopic spacetime or in the microscopic spacetime, whether the observed object P is a macroscopic object or a microscopic particle, whether P is the moon or an electron, whether P is at rest or is moving, the informons of the realistic observation agent OA(η) ($\eta<\infty$ and $h_\eta>0$) would perturb P, making it exhibit a certain degree of quantum effects and uncertainty.

As stated in Sec. 6.7 of Chapter 6 based on the principle of physical observability (PO) and the GPC identity $h_\eta\eta=hc$, for a realistic observation agent OA(η): $\eta<\infty$ and $h_\eta>0$.

This is the human observation agent, that is, the mankind's perspective.

The mankind's perspective has the observational locality ($\eta<\infty$) and the observational perturbation ($h_\eta>0$): $\eta<\infty$ leads to relativistic effects; $h_\eta>0$ leads to quantum effects. This suggest that, in reality, each observation system or each observation agent OA(η) ($\eta<\infty$ and $h_\eta>0$)) would make observed objects exhibit both relativistic effects and quantum effects in the realistic observational spacetime.

So, both relativistic effects and quantum effects are observational effects.

The Autonomous Observation Agent OA(η) ($\eta=v$ and $h_\eta=\lambda p$): At that moment of the time t_0, the observed object P was really located at x_0.

The so-called **autonomous observation agent** OA(η) ($\eta=v$ and $h_\eta=\lambda p$) means that the spacetime information of the observed object P is carried and transmitted to the observer O by P itself: P is both the observed object of OA(η) and one of the informons of OA(η), where v is both the motion speed of P and the information-wave speed η of OA(η), p is both the momentum of P and the informon momentum p_η of OA(η), λ is both the matter-wave wavelength of P and the information-wave wavelength λ_η of OA(η).

For the autonomous agent OA(η) ($\eta=v$ and $h_\eta=\lambda p$), it should be pointed out:

(i) Autonomous agents could only determine the spacetime point of the observed object P when it reaches observers (such as the retina of human eye or an observation screen), and could not provide the information about the spacetime trajectory of P.

(ii) Naturally, an autonomous agent would not perturb the observed object P as the informon, however, P as one of the informons of the autonomous agent might be perturbed by the matter or energy of spacetime environment, for example, electromagnetic field, gravitational field, or other microscopic particles, making it exhibit quantum effects or uncertainty. (It is worth noting that such quantum effects or uncertainty are not included in quantum models such as Schrodinger equation.)

In theory, any observed object P can be an autonomous observation agent.

If the observed object P is light or a photon, then it is required that the information-wave speed η of the observation agent OA(η) is greater than or equal to the speed c of light: $\eta \geq c$, and that the informon momentum p_η of the observation agent OA(η) is smaller than or equal to the momentum p of P (photon): $p_\eta \leq p$. Therefore, the observation agent OA(η) must be either superluminal ($\eta > c$) or autonomous ($\eta = c$). Restricted by the current level of human technology, we could only rely on the optical observation agents OA(c): either to sacrifice the positioning accuracy of P and choose a softer optical agent whose the information wave has a longer wavelength or lower frequency; or to sacrifice the information about the motion trajectory of P and employ the observed light or photon P as the autonomous observation agent.

As a matter of fact, some famous observations or experiments adopted and even had to depend on the autonomous observation agent OA(η) ($\eta = v$ and $h_\eta = \lambda p$).

In the Michelson-Morley experiment [2], the observation agent adopted by Michelson and Morley was just the autonomous agent OA(η) ($\eta = c$ and $h_\eta = h$), which can be referred to as the autonomous optical agent OA(c). In the Michelson-Morley experiment, light or photons was both the observed object P of OA(c) and the information-wave or informons of OA(c) that transmitted the information about P. As depicted in Fig. 3.3, by the autonomous OA(c), Michelson and Morley could only observe the patterns of light or photons on the screen of the detector DS, but could not observe the motion trajectory of the light or photons.

In order to verify the gravitational deflection of light predicted by Einstein's general theory of relativity, in 1919, Eddington had observed the deflection of light by the sun's gravitational field through solar eclipse [88]. Naturally, Eddington's observation agent for observing the solar eclipse was the optical autonomous agent OA(c): the starlight skimming the surface of the sun was both the observed object P of OA(c) and the information wave or informons of OA(c). The autonomous OA(c) could not provide the information on the motion trajectory of starlight, but could only determine the time t_0 and the spatial point x_0 of the starlight on the observation screen when the starlight reached, and infer that the trajectory of starlight was the straight line connecting the sun and the earth.

In Young's double-slit experiment of light [89], the observation agent OA(η) is also the optical autonomous agent OA(c), where the light or photons was both the observed object P of OA(c) and the information wave or informons of OA(c). Young could not determine whether a specific photon passed through the left slit or the right slit, but could only measure the time t_0 and the spatial point x_0 of the photon on the interference screen when the photon reached. In Johansson's double-slit experiment of electrons [90,91], the observation agent OA(η) was the electronic autonomous agent OA(v_e), where the electronic wave or an electron was both the observed object P of OA(v_e) and the information wave or informons of OA(v_e), the electron speed v_e was the information-wave speed of OA(v_e). Likewise, Johansson could not determine whether a specific electron passed through the left slit or the right slit, but could only measure the time t_0 and the spatial point x_0 of the electron on the interference screen when the electron reached.

It is thus clear that although the observed values (t_0,x_0) of the autonomous agent

OA(η) (η=v and p_η=p) are the objectively real information of the observed object P, the spatial position x_0 is limited to the retina of the human eye or the observation screen of the observer.

So, the autonomous observation agent OA(η) (η=v and p_η=p) is just as a tactile sensor at rest: only when the observed object P reaches the observation screen can the spacetime information (t_0,x_0) of the observed object P be recorded.

III. Quantum Effects are the Observational Perturbation Effects

By summing up the analysis in both I and II, according to the tests of both the QE thought experiment and the OE thought experiment, as well as the statement in Sec. 6.10 of Chapter 6, the theory of OR matter waves has the following conclusions about the essence of quantum effects.

The Conclusions of the OE Test

The OE thought experiment or the OE test demonstrate that:

(i) The idealized observation agent OA_∞ ($\eta\to\infty$ and $h_\eta\to 0$) represents the objectively physical reality. The information-wave speed of OA_∞ is infinite ($\eta\to\infty$): without the observational locality, so there is no relativistic effect exhibited in the observational spacetime X^{4d}_∞ of OA_∞; the energy-frequency ratio of the informons of OA_∞ is infinitesimal ($h_\eta\to 0$): without the observational perturbation, so there is no quantum effect exhibited in the observational spacetime X^{4d}_∞ of OA_∞.

(ii) The realistic observation agent OA(η) ($\eta<\infty$ and $h_\eta>0$), including the optical agent OA(c), does not represent the objectively physical reality. According to the principle of physical observability (PO), the information-wave speed of OA(η) is finite ($\eta<\infty$): with the observational locality, so there are relativistic effects exhibited in the observational spacetime $X^{4d}(\eta)$ of the realistic agent OA(η); the energy-frequency ratio of the informons of OA(η) is not zero ($h_\eta>0$): with the observational perturbation, so there are quantum effects exhibited in the observational spacetime $X^{4d}(\eta)$ of the realistic agent OA(η).

Of course, there is no the idealized agent OA_∞ in the objectively physical world. The mankind would never be able to uncover the last veil of the objective truth or the objective world. But we would approach it slowly, and closer and closer.

The objective and real physical world could only be existed in our rationality, for example, in the OE thought experiment.

The Essence of Quantum Effects: Observational Effects

As shown in Tab. 6.1 of Chapter 6, for all relationships in the theory of OR matter waves, including that in de Broglie's theory of matter waves and even the most basic relationships in quantum mechanics, such as Planck equation, de Broglie relation, Schrodinger equation, and Heisenberg's uncertainty principle, all quantum physical quantities U=U(η,v) are observed or observational physical quantities, depending on the observation agent OA(η). Under different observation agents, the same moving object or observed object P would exhibit different degrees of quantum effects and uncertainty.

It is thus clear that, like the relativistic effects in relativity theory, all the quantum effects in the theoretical models of quantum mechanics are in essence observational effects, rather than the intrinsic nature of spacetime and matter.

The Root of Quantum Effects: Observational Perturbation

The root of the relativistic effects lies in the observational locality of the realistic observation agent OA(η): $\eta<\infty$, the information-wave speed η of OA(η) is limited, and therefore, it takes time for the observed information to cross space.

However, the root of quantum effects is different from relativistic effects.

The root of the quantum effects lies in the effect of observational perturbation of the realistic observation agent OA(η): $h_\eta>0$, the informon momentum η of OA(η) is not zero: $p_\eta=h_\eta/\lambda_\eta>0$. Therefore, in theory, the informons of the realistic agent OA(η) must inevitably perturb the observed object P.

So, quantum effects are **the effects of observational perturbation**.

Quantum Effects: both Observational and Realistic

According to the theory of OR, both relativistic effects and quantum effects are observational effects.

As stated in Sec. 6.10 of Chapter 6, relativistic effects are apparent phenomena and do not mean that the motion state of the observed object P has been changed by the observation of a certain observation agent. However, quantum effects are the effects of observational perturbation, not apparent phenomena. During the observation process, the observed object P has been perturbed by the informons of a certain observation agent, and the change of the motion state of the observed particle P is objective and real.

In this regard, quantum effects, or the effects of observational perturbation, are both observational and realistic.

Quantum Effects: both Phenomenal and Essential

As stated in Sec. 6.10 of Chapter 6, the quantum effects and uncertainty in the theoretical models of quantum mechanics are rooted from and caused by the observational perturbation effects of observation agents, that is, the effects of observational perturbation.

So, the behaviors of the observed particle P would be different before and after being measured or observed.

Anyway, the idealized agent OA_∞ is unrealistic. For the realistic observation agent OA(η) ($\eta<\infty$ and $h_\eta>0$), the information-wave speed η of OA(η) could never be infinite: $\eta<\infty$; the energy-frequency ratio h_η of the informons of OA(η) could never be infinitesimal: $h_\eta>0$. The realistic physical world is not a vacuum or the free spacetime. In addition to the informons of observation agents, the observed object P would also be perturbed by other electromagnetic fields (photons) or gravitational field (gravitons), exhibiting additional quantum effects and uncertainty. It is worth noting that such quantum effects or uncertainty are not included in the theoretical models of quantum mechanics, for example, Schrodinger equation.

In this regard, quantum effects and certainty are the natural property of the realistic physical world. In other world, quantum effects and uncertainty are both observational and realistic.

BP-06 Heisenberg's Uncertainty Principle

BP-06.1 The Statement of the Problem

The Principle of Uncertainty: For an observed object P, the observer O could not at the same time accurately determine both the spatial position x of P and the momentum p of P; such uncertainty can be quantitatively formalized as: $\sigma_x\sigma_p \geq \hbar/2$ (Eq. (6.40)), where σ_x is the standard deviation of the position x of P, σ_p is the standard deviation of the momentum p of P, h is the Planck constant, and $\hbar=h/2\pi$ is the reduced Planck constant.

The Principle of uncertainty was proposed by Heisenberg in 1927 [78]. The principle of uncertainty had sparked people's thinking about quantum mechanics and even the whole field of physics. The core problem was that: is the uncertainty in Heisenberg's uncertainty principle the essential characteristic of the objectively physical world or the effects of observation and measurement?

The mainstream school of physics believe that Heisenberg's uncertainty is the essential characteristic of the objectively physical world: the objective and real physical world is essentially uncertain. So, God is indeed playing the dice.

However, in terms of Heisenberg's uncertainty principle, the uncertainty of spacetime and matter motion refers to the uncertainty of observation or measurement, belonging to observational effects. At the beginning, Chinese physicists once translated Heisenberg's uncertainty principle as the principle of the uncertainty in measurement (i.e., 测不准原理 in Chinese), which implied that Heisenberg's uncertainty was not the objective uncertainty but that in measurement.

Actually, about Heisenberg's uncertainty principle, there is always the claim of **observer effect** in the field of physics.

So, what is the essence of Heisenberg's uncertainty?

This is the big puzzle marked as BP-06 in the theory of OR.

BP-06.2 The Mainstream View

The orthodox school of quantum mechanics, the Copenhagen School, advocates that the states of spacetime and matter motion of are in essence uncertain.

The view of the Copenhagen school or the mainstream school of physics is based on Born's interpretation, that is, Born's statistical interpretation of the wave function in Schrodinger equation [21]:

(i) The uncertainty in Heisenberg's uncertainty principle is consistent with that in Born's statistical interpretation.

(ii) Born's interpretation means that the spacetime trajectories of microscopic particles are in essence uncertain or probabilistic. At a moment, the object or particle P could be both here and there, but it was forced to show up somewhere just because you had observed or looked at it, which could be interpreted by the doctrine of wave function collapse.

(iii) Based on Born's interpretation, quantum mechanics could accurately describe the probabilistic and Statistical properties of microscopic spacetime and microscopic matter motion.

So, in the view of the orthodox school of quantum mechanics or in the view of the mainstream school of physics, the essence of the uncertainty in Heisenberg's uncertainty principle and the essence of the uncertainty in Born's statistical interpretation are originally the essence of the same thing.

BP-06.3 The View of IOR Theory

The theory of OR does not deny the intrinsic uncertainty of spacetime and matter motion in the natural world or in the objectively physical world. As stated in the big puzzle BP-05, quantum effects, including uncertainty, are both observational and realistic, both phenomenal and essential.

However, based on the broader perspective of the general observation agent OA(η) (including the idealized agent OA_∞ and the optical agent OA(c)), the theory of OR discovers that the uncertainty in Heisenberg's uncertainty principle is not the intrinsic uncertainty of the objectively physical world, but the uncertainty in observation or in measurement.

I. The Uncertainty of Schrodinger's Cat

Schrodinger himself did not agree with Born's statistical interpretation of the wave function in Schrodinger equation. So, Schrodinger conceived the famous thought experiment: **Schrodinger's cat** [87].

This is a well-known story, which can be roughly described as follows.

Erwin Schrodinger's Cat: Suppose that there is a cat, confined in a light-proof cage with a small amount of radioactive substances and cyanide in it, so that the radioactive substance would with a probability of 50% decay and release toxic gas to kill the cat; with a probability of 50% not decay and release toxic gas to kill the cat. So, at a specific moment, is Schrodinger's cat dead or alive?

Commonsense tells us: at any moment, Schrodinger's cat is either dead or alive.

However, quantum mechanics tells us: based on Born's statistical interpretation, in the quantum world, the life-death state of Schrodinger's cat is uncertain, i.e., the so-called **quantum superposition state**: at any moment, Schrodinger's cat are in different life-death states with different probabilities; or in other words, at any moment, Schrodinger's cat is both dead and alive. If you did not open the cage and observe the cat, Schrodinger's cat would always be half dead and half alive. Only if you opened the cage and observe the cat, the wave function in Schrodinger equation would collapse, and you would get a definite observation conclusion about whether Schrodinger's cat was dead or alive.

That is ridiculous. It is exactly the meaning Schrodinger intended to convey.

Schrodinger's thought experiment is philosophy-oriented and rich in philosophy.

As the commonsense, whether Schrodinger's cat is **dead** or **alive** has nothing to do with whether you **open** or **do not open** the cage, and has nothing to do with whether the wave function in Schrodinger equation **collapses** or **does not collapse**. Schrodinger equation is only a dynamic model of microscopic matter particles. For Bohn's statistical interpretation of Schrodinger's wave function, no matter how well it conformed to the physical reality, it could not represent the objective and real physical reality. One could not take the so-called collapse of the wave function in Schrodinger equation as the objective and real physical behavior of microscopic matter particles. To paraphrase d' Espagnat [25]: The life-death state of Schrodinger's cat was never indeterminate, but was merely unknown to the experimenter.

The orthodox school of quantum mechanics believe that the microscopic world and the macroscopic world are fundamentally different: different logics, different causal laws, and therefore, different evolution rules. However, according to the theory of OR: one world, one logic. There is no the definite boundary between the macroscopic world and the microscopic world.

BP-05 specifically states: "No one could draw a boundary or set a threshold to determine that the observed particle *P* was so small that it would exhibit the weird quantum phenomena."

Perhaps, this is the significance of Schrodinger's thought experiment.

II. The Principle of General Uncertainty

According to the theory of OR, the inequality (Eq. (6.40)) in Heisenberg's uncertainty principle is only an uncertainty inequality for the optical observation agent OA(c), and is a special case of the principle of general uncertainty in the theory of OR matter waves.

According to Sec. 6.9 in Chapter 6, analogizing Heisenberg's uncertainty principle, the principle of general uncertainty can be stated as follows.

The Principle of General Uncertainty: Let P be the observed object, OA(η) be the general observation agent ($\eta<\infty$), then the observer O with OA(η) could not at the same time accurately determine both the spatial position x of P and the momentum p of P; such uncertainty can be quantitatively formalized as: $\sigma_x\sigma_p\geq \hbar_\eta/2$ (Eq. (6.41)), where σ_x is the standard deviation of the position x of P observed with OA(η), σ_p is the standard deviation of the momentum p of P observed with OA(η), h_η is the general Planck constant, and $\hbar_\eta=h_\eta/2\pi$ is the reduced general Planck constant.

Based on the GPC identity $h_\eta\eta=hc$ (Eq. (6.29)), the principle of general uncertainty can be formulized as

$$\sigma_x(\eta)\sigma_p(\eta)\geq\frac{\hbar_\eta}{2}=\frac{h_\eta}{4\pi}=\frac{h}{4\pi}\frac{c}{\eta} \tag{9.6}$$

where the standard deviations $\sigma_x=\sigma_x(\eta)$ and $\sigma_p=\sigma_p(\eta)$ depend on observation, i.e., on the observation agent OA(η).

This is the uncertainty inequality of the general observation agent OA(η).

Naturally, Heisenberg's uncertainty principle, belonging to the optical agent OA(c), is only a special case of the principle of general uncertainty.

According to the principle of general uncertainty, the so-called uncertainty, including Heisenberg's uncertainty, depends on the observation agent OA(η) and is the effect of observational perturbation: different observation agents present different degrees of uncertainty; the lower the information-wave speed η of OA(η) or the greater the informon momentum p_η ($\propto h_\eta$) of OA(η), the more significant the uncertainty or the effect of observational perturbation is.

In particular, if $\eta \to \infty$, then OA(η)$\to$OA$_\infty$ and $h_\eta = hc/\eta \to 0$. This suggests that the idealized observation agent OA$_\infty$ has no the effect of observational perturbation, or in other words, has no observational uncertainty.

Thus it follows that, whether the principle of general uncertainty in the theory of OR matter waves or Heisenberg's uncertainty principle in quantum mechanics, whether the uncertainty in the principle of general uncertainty or the uncertainty in Heisenberg's uncertainty principle, is only the observational uncertainty of observation agents, does not represent the essential or intrinsic uncertainty of the objectively physical world.

III. The Tests for Uncertainty

Ozawa's Inequality and Ozawz's Experiment [92-94]

In 2003, professor Ozawa of Nagoya University in Japan claimed that the uncertainty inequality in Heisenberg's uncertainty principle might be defective, and proposed the following Ozawa inequality [92,93]:

$$\sigma_x \sigma_p + \sigma_x \Delta p + \Delta x \sigma_p \geq \frac{h}{4\pi} \tag{9.7}$$

where σ_x and σ_p are the standard deviations of the position x and momentum p of the observed object P before measurement, respectively; Δx and Δp are the fluctuations of position x and momentum p of P before measurement, respectively.

In 2012, Ozawa collaborated with the research team of Hasegawa at the Vienna University of Technology in Austria and found through experiments that [94] the experimental accuracy could indeed exceed the uncertainty limit set by Heisenberg's inequality (Eq. (6.40)): $h/4\pi$.

From the perspective of observation and experiment, Ozawa's experiment is of great significance. As elucidated by the theory of OR matter waves, Ozawa's experiment means that Heisenberg's uncertainty is not the intrinsic uncertainty of quantum systems or the physical world, but the observational uncertainty.

Ozawa's experiment provides an evidence for the principle of general uncertainty in the theory of OR matter waves.

Weak Measurement [95]

In 2012, Rozema et al from the University of Toronto in Canada reported in the journal **Physical Review Letters** that they designed and developed a physical measuring instrument, that is, the so-called **Weak Measurement** technology [95].

Rozema et al specifically mentioned that: the uncertainty in Heisenberg's uncertainty principle was originally considered the intrinsic property of all quantum systems but it had not been strictly demonstrated in experiment; the experiment conducted by Rozeman and the research team had observed the phenomena that contradicted Heisenberg's uncertainty principle and Heisenberg's inequalities.

Rozema and the team expected that the weak-measurement technology could improve the accuracy and reduce the uncertainty of quantum measurement. To test the weak-measurement technology, first of all, they made weak measurement on each photon before entering the measuring device, trying to avoid the perturbation of observation or measurement on the photons; and then, they made usual measurement on the photons; finally, they compared the two kinds of measurements. The results showed that, similar to Ozawa's experiment, the uncertainty of observation or measurement was not as large as Heisenberg's uncertainty.

According to the resolution inequality (Eq. (6.40)) of the optical observation agent OA(c), in order to reduce the observational perturbation, the experimenter can select such an optical agent OA(c) with softer informons (photons), so that the informons (photons) have smaller momentum. Perhaps this is exactly what the Rozema team mean by **weak measurement**. Rozema team's experiment tests and verifies **the effect of observational perturbation** of the optical agent OA(c), which has been predicted and interpreted in the theory of OR matter waves.

After Ozawa's experiment, Rozema team's weak-measurement experiment once again verifies that, as interpreted by the theory of OR matter waves, the uncertainty in Heisenberg's uncertainty principle is the observational uncertainty, rather than the intrinsic uncertainty of quantum systems or the physical world.

In a sense, Rozema team's experiment or weak measurement, from one aspect, confirms the principle of general uncertainty in the theory of OR matter waves.

IV. Quantum Uncertainty: the Effect of Observational Perturbation

In summary, with regard to Heisenberg's uncertainty principle, the theory of OR or the theory of OR matter waves has such a conclusion: **Heisenberg's uncertainty, in essence, is the effect of observational perturbation**.

As clarified by the theory of OR matter waves and the principle of general uncertainty, all the realistic observational agents OA(η) ($\eta<\infty$ and $h_\eta>0$), including the optical agent OA(c) ($\eta=c$ and $h_\eta=h$), have the observational uncertainty, rooted from the effect of observational perturbation. The uncertainty stated in Heisenberg's uncertainty principle is only a special case of the principle of general uncertainty, that is, the uncertainty of the optical observation agent OA(c), rather than the intrinsic uncertainty of the objectively physical world.

BP-07 de Broglie wave

BP-07.1 The Statement of the Problem

De Broglie Wave: Originally, Planck equation $E=hf$ was the relationship between the photon energy E and the photon frequency f. De Broglie speculated that all matter particles had wave-like behavior [17-19], so he extended Planck equation to all matter particles, and derived de Broglie relation $\lambda=h/p$, that is, the relationship between the particle momentum p and the particle wavelength λ, thus forming the concept of **Matter Wave**, and being known as **de Broglie wave**.

According to de Broglie's theory of matter waves, as a sort of matter wave, a matter particle has the frequency f and wavelength λ of its own:

$$\lambda = \frac{h}{p} \quad \text{and} \quad f = \frac{E}{h} \tag{9.8}$$

This is de Broglie relation, in which matter particles could be arbitrary matter particles, not just photons. In de Broglie's view, all matter is matter wave, that is, **de Broglie wave**.

De Broglie wave inherits the characteristics of light waves and has the speed relationships of light waves or photons:

$$\begin{cases} v_\mathrm{g} = v \quad \text{and} \quad v_\mathrm{p} = c^2 / v_\mathrm{g} \\ v_\mathrm{g} v_\mathrm{p} = c^2 \quad \text{and} \quad f\lambda = c \end{cases} \tag{9.9}$$

where v is the particle speed of the observed object P as a matter particle, v_g and v_p are respectively the group speed and phase speed of P as a matter wave, and c is the speed of light in vacuum.

For a general macroscopic matter system, the energy and momentum are much greater than those of a photon. Therefore, for the corresponding matter wave calculated according to de Broglie relation (Eqs. (9.8-9)), the frequency was so high and the wavelength was so short, that one could not observe and detect the de Broglie wave of a macroscopic object.

This means that the objectivity or beingness of de Broglie wave is questionable.

So, does de Broglie wave really exist? Even if matter is matter wave, does a matter wave really follows de Broglie relation?

This is the big puzzle marked as BP-07 in the theory of OR.

BP-07.2 The Mainstream View

The double-slit interference experiment shows that matter particles, including photons, electrons, neutrons and protons, atoms and molecules, and even the large molecule C_{60}, all have the wave-particle duality: all the observation screens exhibit the interference fringes unique to waves, which seems to be consistent with de Broglie's speculation about material waves. Early experiments mostly claimed that the interference fringes follow de Broglie relation; but now, more and more experiments claim that the interference fringes follow Born's interpretation.

The mainstream school of physics generally recognize de Broglie's theory of matter waves. However, in the view of mainstream school of physics, de Broglie's theory of matter waves belongs to the old quantum theory. Now, the mainstream school of physics seem to be more inclined towards the modern quantum mechanics based on Born's statistical interpretation.

BP-07.3 The View of IOR Theory

Based on more basic logical premises, the theory of IOR not only generalizes and develops Einstein's special theory of relativity, but also establishes the theory of

OR matter waves, generalizing and developing de Broglie's theory of matter waves, providing us with new insights into de Broglie wave.

I. The Theory of OR Matter Waves [26,27]

As stated in Chapters 5 and 6, based on the particle-like form $\Gamma(\eta)=m/m_o$ and the wave-like form $\Gamma(\eta)=f/f_o$ of the IOR factor $\Gamma(\eta)$ of spacetime transformation, the theory of OR has respectively derived the general Einstein formula $E=m\eta^2$ (Eq. (5.22)) and the general Planck equation $E=h_\eta f$ (Eq. (6.16)), and moreover, has deduced the general de Broglie relation $\lambda=h_\eta/p$ (Eq. (6.19), generalizing de Broglie relation and establishing the theory of OR matter waves.

As stated in Sec. 6.4 and Sec. 6.5 of Chapter 6, the general Planck equation $E=h_\eta f$ (Eq. (6.16)) and the general de Broglie relation $\lambda=h_\eta/p$ (Eq. (6.19) are the most fundamental relationships in the theory of OR matter waves:

$$f(\eta,v)=\frac{E(\eta,v)}{h_\eta} \quad \text{and} \quad \lambda(\eta,v)=\frac{h_\eta}{p(\eta,v)} \tag{9.10}$$

According to the theory of OR matter waves, all matter particles act as waves, which can also be called matter waves. However, different from de Broglie' waves, OR's matter waves have the following speed relationships:

$$\begin{cases} v_{\mathrm{g}}=v \quad \text{and} \quad v_{\mathrm{p}}=\eta^2/v_{\mathrm{g}} \\ v_{\mathrm{g}}v_{\mathrm{p}}=\eta^2 \quad \text{and} \quad f(\eta,v)\lambda(\eta,v)=\eta \end{cases} \tag{9.11}$$

where v is the particle speed of the observed object P as a matter particle, v_{g} and v_{p} are respectively the group speed and phase speed of P as a matter wave, and η is the information-wave speed of the general observation agent OA(η).

Equations (9.10-11) are the core relationships of the theory of OR matter wave.

II. OR's Matter Waves: The Information Wave of the General Observation Agent OA(η) ($\eta<\infty$)

It is worth noting that the phase speed $v_P=v_P(\eta)$ of the theory of OR matter waves, as well as the frequency $f=f(\eta)$ and wavelength $\lambda=\lambda(\eta)$ of OR's matter waves, depend on the general observation agent OA(η) ($\eta<\infty$), or in other word, depend on the information-wave speed η of OA(η).

This indicates that the same matter particle, in the observational spacetimes different observation agents, exhibits different matter waves: different frequencies, different wavelengths, and different phase speeds.

Equation (9.11) suggests that, for the same matter particle P with the particle speed v, in the view of different observation agents OA(η_1) and OA(η_2) ($\eta_2\neq\eta_1$), the group speeds v_{g1} and v_{g2} of P are the same: $v_{\mathrm{g1}}=v_{\mathrm{g2}}=v$; but the phase speeds v_{p1} and v_{p2} are different: $v_{\mathrm{p1}}=\eta_1^2/v$, $v_{\mathrm{p2}}=\eta_2^2/v$.

This means that, according to the theory of OR matter waves, the so-called matter waves are not the intrinsic matter waves of matter particles.

Equation (9.11) suggests that matter waves are actually the information waves of observation agents, which are the carrier waves loaded with the spacetime information and physical information of observed matter particles.

Thus, the physical quantities in the formulae or relationships of the theory of OR matter waves, such as the particle speed v, the group speed v_g and phase speed v_p, the wavelength λ and frequency f in the speed relationships (Eq. (9.11)) of matter waves, as well as, the energy $E(\eta,v)$ in the general Planck equation $E=h_\eta f$ (Eq. (6.16)) and the momentum $p(\eta,v)$ in the general de Broglie relation $p=h_\eta/\lambda$ (Eq. (6.19)), are actually the information of the observed object P loaded and carried by the information wave of the observation agent OA(η).

So, the theory of OR matter waves offers new insight into de Broglie wave.

III. De Broglie Wave: The Information Wave of the Optical Observation Agent OA(*c*)

Obviously, the theory of OR matter waves (Eqs. (9.10-11)) generalizes de Broglie's theory of matter waves (Eqs. (9.8-9)): as $\eta\to c$, OA(η)$\to$OA(c), and then OR's matter wave converges to de Broglie wave.

It is thus clear that de Broglie wave is only a special case of OR's matter waves, i.e., the case when the observation agent OA(η) is the optical agent OA(c). Actually, the so-called de Broglie wave is not the intrinsic wave of matter, but the information wave of the optical observation agent OA(c).

So, the so-called de Broglie wave is actually the light wave that loads and carries the information about observed objects.

BP-08 The Mystery of Electronic Double-Slit Experiment

BP-08.1 The Statement of the Problem

The Mystery of Electronic Double-Slit Experiment: The electronic double slit experiment presents confusing and even weird phenomena, that is,

(i) The phenomenon of electron self-coherence: electrons seem to have separation technique. A single electron could simultaneously pass through the left slit and the right slit of the double slits, and then, interfere with itself, leaving the interference fringes on the interference screen.

(ii) The phenomenon of electrons decoherence: electrons seemed to have stealth technique. If you tried to pry their whereabouts, electrons would hide and the interference fringes would disappear from the interference screen, if you stopped prying, the interference fringes would reappear on the interference screen.

The discussion here is about the phenomena of quantum coherence or quantum interference. (We regard coherence and interference as the same concept.)

In 1803, Thomas Young designed the double-slit experiment (depicted in Fig. 9.2), and Young's double-slit interference experiment of light showed that light had wave characteristics [89]. In 1907, Taylor repeated Young's double-slit experiment [96]. The difference was that Taylor added smoked glass to the light source to weaken the light, hence it was called the **weak-light** interference experiment. Taylor made the light weak enough so that the light source had become the emitter of single photon: photons can pass through the double slits, left slit or right slit, one by one at regular intervals. In this way, the interference experiment of weak light became the interference experiment of individual photons. Taylor originally thought that a single photon could not produce the effect of interference and the interference screen would not have interference fringes. However, surprisingly, the interference fringes like in Young's double-slit experiment were left on Taylor's interference screen.

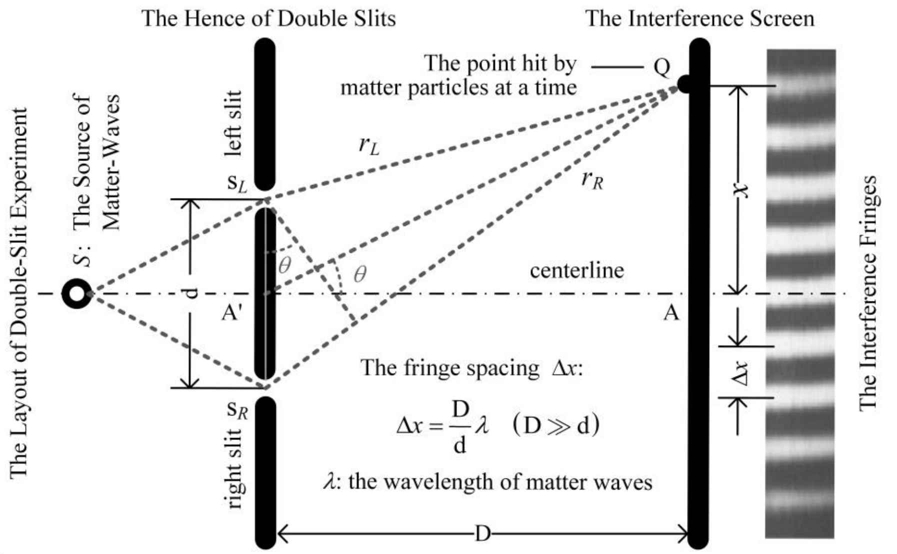

Figure 9.2 The Layout of Double-Slit Experiment: Based on Huygens principle, matter waves, including light waves and electronic waves, would be diffracted at the double slits s_L and s_R to form two wavelets (coherent waves) with the same frequency and constant phase difference; if the two wavelets simultaneously reached the same point on the interference screen (as shown in the point Q in Fig. 9.2), the interference fringes would occur and be left on the interference screen.

In 1961, Jönsson became the first person to conduct the double-slit interference experiment of electrons, verifying that electrons also had wave characteristics [90,91]. Afterwards, double-slit experiments also verified that larger particles of matter, such as protons and molecules, and even fullerene C_{60}, would also exhibit wave-like behaviors [97-99]. It seems that, as de Broglie speculated, all particles of matter were matter waves, had wave characteristics, and could exhibit wave-like behaviors.

Perhaps, inspired by Taylor's experiment and Jönsson's experiment, in 1961, Feynman conceived the thought experiment of the double-slit experiment of individual electrons [100]: (self-coherence) if an electron gun emitted electrons one by one at regular intervals, then after passing through the double slits, each electron would interfere with itself, and some interference stripes would be left on the interference screen; (decoherence) if an observer was installed at the double slits to observe which slit electrons passed through, then the interference fringes would disappear. We are confused, and wonder on what basis Mr. Feynman foresaw such phenomena of self-coherence and decoherence of electrons.

In the double-slit interference experiment of electrons, as predicted by Feynman, electrons would indeed exhibit the phenomena of self-coherence and decoherence [101,102]. People still do not fully understand the phenomena of the self-coherence and decoherence of electrons in the double slit experiment.

So, why do electrons have the behaviors of self-coherence and decoherence?

This is the big puzzle marked as BP-08 in the theory of OR.

BP-08.2 The Mainstream View

The phenomena of self-coherence and decoherence of electrons exhibited in the double-slit interference experiment of electrons indeed appear strange, are somewhat incredible and difficult to understand, which has led to many equally strange interpretations.

People believe that the interference of waves must be the interaction between different wavelets: a train of wavelet could not interfere with itself to form interference fringes, let alone individual electrons. For the phenomenon of electron self-coherence, a still popular myth is that each single electron simultaneously passed through both the left slit and the right slit, and then the left part and the right part of the same electron would interfere with each other to form the interference fringes on the background screen. The thought that electrons have separation technique is somewhat weird and not in line with commonsense. However, Mr. Feynman supported such thought, who believed that: the micro world had the significant difference from the macro world; in the micro world, electrons could be neither particles nor waves, and their behaviors were naturally unimaginable or unpredictable. Perhaps, it is based on the thought like Feynman's that the mainstream school of physics are increasingly inclined to interpret the phenomenon of electron self-coherence based on Born's statistical interpretation and the quantum superposition state of probability waves.

Compared with the self-coherence of electrons, the decoherence of electrons in the double-slit interference experiment of electrons seems even more incredible, to which there has not yet been a satisfactory explanation so far. Some people even believe that electrons have souls and are controlled by consciousness.

With the advancement of experimental technology, people are beginning to realize that the decoherence of electrons may be the effect of observational perturbation. The double-slit experiment by Mittelstaedt et al [103] and Greenberger et al [104] showed that, by reducing the observational-perturbation effect on electrons, or by sacrificing the positioning accuracy of electrons, one could obtain the interference fringes of electrons while detecting the whereabouts of electrons. The double-slit experiment by Frabboni et al [105] in 2012 was regarded as the first real implementation of Feynman's thought experiment, which not only detected the trajectories of electrons but also obtained the interference fringes of electrons. The double-slit experiment by Bach et al [106] in 2013 also implemented Feynman's thought experiment, which recorded the whole process of electrons arriving at the interference screen one by one and clearly demonstrating the classical particle characteristics of electrons.

BP-08.3 The View of IOR Theory

According to the theory of OR and the GPC identity $h_\eta\eta=hc$ (Eq. (6.29)) in the theory of OR matter waves, there is no definite boundary between the macroscopic world and the microscopic world: the macro and the micro follow the same logic and the same evolution rules; no matter in the macro or in the micro, particles are just particles that have neither separation technique nor stealth technique.

All matter in the objectively physical world exists in the form of particles and moves in the form of waves.

For a long time, the phenomena of electron self-coherence and decoherence in the double-slit interference experiments of electrons has puzzled physicists, which however are natural and easy to understand in the view of the theory of OR or the theory of OR matter waves.

I. The Self-Coherence of Electrons

Based on the theory of OR, electrons are just electrons, particle by particle, neither being electron clouds nor having stealth technique. This was demonstrated by the double-slit experiment by Bach et al, in which electrons reached to the background screen one by one [106].

Actually, Taylor and others' double-slit experiments of individual electrons or individual particles have demonstrated that photons, electrons, and even the C_{60} particles have self-coherent behaviors and exhibit the interference fringes of matter waves on the background screen. For **matter waves** or **matter-particle groups**, the formation process of interference fringes is that of accumulation or superposition over time. The electronic double-slit experiment by Bach et al clearly recorded the formation process [106]: electrons reached to the background screen one by one, and their interference did not require the interaction between different electrons.

In double-slit interference experiments, even if a large number of particles gush out of the double slits at the same time, the formation process of interference fringes is also the result of accumulation and superposition over time.

Suppose that microscopic matter particles indeed have separation technique, and a single particle does indeed cross both the left slit s_L and the right slit s_R of the double-slit fence shown in Fig. 9.2 simultaneously; after being separated or separating, the left and right parts of the particle have the same speed and frequency, and have the constant phase difference. Thus, the separated left and right parts of the same particle meet the coherent conditions, being two coherent waves. Even so, at any point Q (excluding A) on the background screen, due to the path difference $\Delta r=r_R-r_L$, it is impossible for the separated left and right parts of the particle to reach to the point Q simultaneously.

So, even if electrons have separation technique, it is impossible for the separated left and right parts of a single electron to merge at the Q-point, or in other words, it is impossible for the separated left and right parts of a single electron to interfere with each other or form the so-called self-coherence at the Q-point.

It is thus clear that, just as demonstrated in the experimental video made by Bach et al, the interference fringes on the background screen are not caused by the self-coherence of individual electrons, but by the accumulation and superposition of countless single electrons over time. Bach et al, based on the theory of the quantum superposition state of probability waves, interpreted the phenomenon of electron self-coherence [106]: that is just the effect of the accumulation and superposition of countless individual electrons over time.

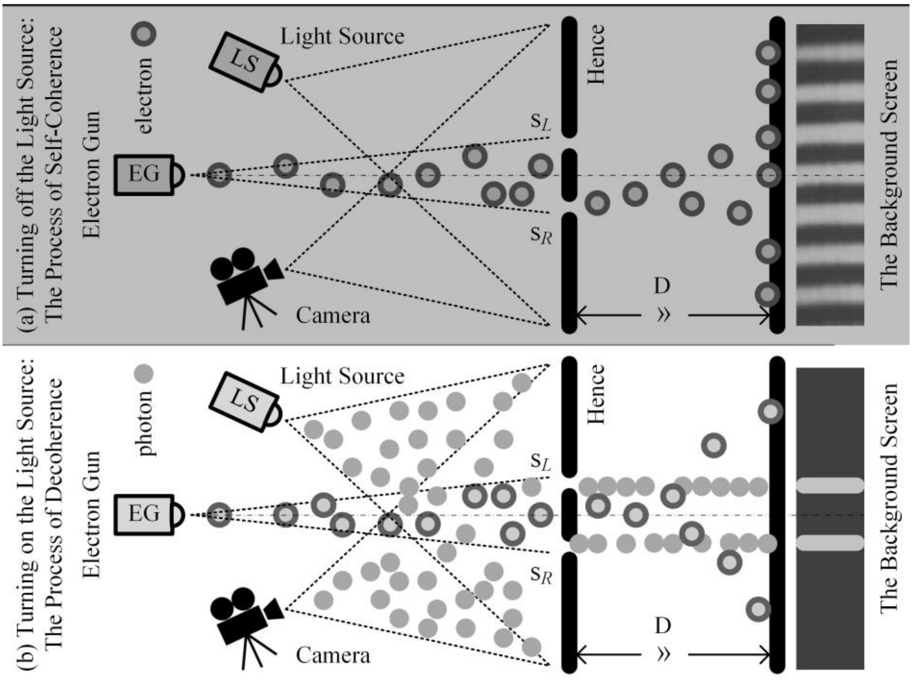

Figure 9.3 The Technological Processes for the Double-Slit Experiment of Electrons. (a) The process of electron self-coherence: Turn off the light source LS and the camera, stop recording the traces of electrons, let the electron gun EG emit electrons one by one at regular intervals, then the background screen will exhibit the interference fringes of electrons; this is the self-coherence of electrons, in which the observation agent is the electronic autonomous agent OA(v_e), the observed object P at a time is a single electron with the speed v_e, acting as one of the informons of OA(v_e). (b) The process of electron decoherence: Turn on the light source LS and the camera, record the traces of electrons, and determine whether an electron passes through the double-slit fence from the left slit s_L, the right slit s_R, or the both, at this time, electrons seems to have stealth technique: the interference fringes of electrons will disappear, and there will be only two bright fringes left on the background screen respectively corresponding to the left slit s_L and the right slit s_R; this is the decoherence of electrons, in which the observed object P at a time is still a single electron, but the observation agent is switched to the optical agent OA(c) from the electronic autonomous agent OA(v_e), and the informons of OA(c) are of course photons with the speed c of light.

II. The Decoherence of Electrons

The first double-slit interference experiment of individual electrons was conducted by Merli et al in 1974 [101,102], not only discovered the phenomenon of electron self-coherence but also the phenomenon of electron decoherence.

Compared to the self-coherence of electrons, the decoherence of electrons seems even more weird. An electron seem to have soul and consciousness, and have stealth technique: it would hide if you tried to pry its whereabouts; it would reappear if you stop prying.

As to this, Merli et al are very confused.

The phenomenon of the electron decoherence in double-slit interference experiment remains a mystery in physics to this day.

The concept of **observation agents** in the theory of OR and the theory of **the observational-perturbation effects** of observation agents provide the theoretical basis for us to examine and interpret the phenomenon of the electron decoherence in double-slit interference experiments.

Naturally, in the double-slit interference experiment of electrons, the observed object P at a time is an electron. Then, what about the observation medium or observation agent or the double-slit experiment of electrons? Who or what was transmitting the information about electrons for Merli et al?

As depicted in Fig. 9.3, Merli et al designed two technological processes for the double-slit experiment of electrons: (a) the process of electron self-coherence; (b) the process of electron decoherence.

In order to ascertain the cause of the self-coherence of individual electrons, Merli et al installed the microscopic camera near the entrance of the double slits in attempt to record the trajectories of electrons and determine whether an electron passed through the double-slit fence from the left slit s_L, the right slit s_R, or the both. Naturally, the recording or shooting the video required the light source LS. The experiment showed that: if the light source LS was turned off (the process (a)), the interference fringes of individual electrons would be left on the interference screen; if the light source LS was turned on (the process (b)), the interference fringes of electrons would disappear, and there were only two bright fringes left on the background screen respectively corresponding to the left slit s_L and the right slit s_R.

It is worth noting that, in the experiment by Merli et al, different processes mean different observation media or different observation agents: the process of electron self-coherence (a) employed the autonomous observation agent; the process of electron decoherence (b) employed the optical observation agent.

(i) The Autonomous Agent OA(v_e) and the Process of Electron Self-Coherence

The Process of Electron Self-Coherence: As depicted in Fig. 9.3(a), turn off the light source LS and the microscope camera, stop monitoring and recording the traces of electrons, and let the electron gun EG emit electrons one by one at regular intervals, then the interference fringes or self-coherent patterns of individual electrons would exhibit on the background screen.

So, it seems that a single electron could interfere with itself.

This is the so-called self-coherence phenomenon of electrons exhibited in the double-slit interference experiment of individual electrons.

It should be pointed out that, as depicted in Fig. 9.3(a), the observation agent OA(η) used for the process of electron self-coherence is the electronic agent OA(v_e)

(v_e is the speed of electrons), that is, the autonomous observation agent, in which the electron at a time is not only the observed object P of OA(v_e), but also one of the informons of OA(v_e), transmitting its own information for the observer O.

As stated in BP-05.3, the autonomous observation agent OA(η) ($\eta=v$ and $h_\eta=\lambda p$) has no the effect of observational perturbation and does not perturb the observed object P; however, the autonomous agent OA(η) ($\eta=v$ and $h_\eta=\lambda p$) could not report the information about the trajectory of the observed object P to the observer O. Only when P reaches the observation screen could the observer O determine the spacetime coordinates (t_0,x_0) on the screen.

The electrons as electronic waves emitted by the electron gun EG meet the coherence conditions: with the same speed, the same frequency or the same wavelength, and the constant phase difference. So, an electron at a time could **interfere with itself** before crossing the double-slit fence, finally reach the background screen, and leave the interference fringes or self-coherence patterns on the background screen.

Naturally, the interference fringes on the background screen are the self-coherent patterns left by electrons, or in other words, the interference fringes left by the information-wave (electronic wave acting as coherent wave) of the electronic autonomous agent OA(v_e).

(ii) The Optical Agent OA(c) and the Process of Electron Decoherence

The Process of Electron Decoherence: As depicted in Fig. 9.3(b), turn on the light source LS and the microscope camera, monitor and record the traces of electrons, and let the electron gun EG emit electrons one by one at regular intervals, then the interference fringes or self-coherent patterns of electrons would disappear from the background screen, only two bright stripes would be projected onto the background screen through the left slit s_L and the right slit s_R..

What is weird is that: once the light source LS is turned on, the double-slit interference experiment of individual electrons would be switched to the process of electron decoherence, and the interference fringes or self-coherent patterns would disappear from the background screen; once the light source LS is turned off, the double-slit interference experiment of individual electrons would be switched to the process of electron self-coherence, and the interference fringes or self-coherent patterns would reappear on the background screen.

This is the so-called decoherence phenomenon of electrons exhibited in the double-slit interference experiment of individual electrons.

Actually, the decoherence of electrons or electronic waves is owing to the switching of observation agents, and rooted from the effect of observational perturbation of observation agents, that is, the perturbation imposed on electrons by the informons of observation agents.

As depicted in Fig. 9.3(b), in the process of electron decoherence, the light source LS and the microscope camera are turned on, and the observation agent is switched from the electronic autonomous agent OA(v_e) to the optical agent OA(c). Thus, the information about the electron as the observed object P is no longer transmitted by the electron P of its own, but by the informons of OA(c): photons. At this time, like people observing the flight of birds through light, Merli et al were observing the flight of electrons through light.

Naturally, the optical agent OA(c) could provide the information about the traces of electrons to the observer O.

However, as stated in BP-05.3, the optical observation agent OA(c) has the effect of observational perturbation, whose informons have the momentum of their own and must perturb the electron as the observed object P, changing the speed or direction, the frequency or wavelength, the phase of the electron or electronic wave, and leading to the loss of the original self-coherence of the electronic wave, so that the original interference fringes or self-coherent patterns would disappear from the background screen. The double-slit experiment by Merli et al was designed for electronic interference, where the slit width δ and the distance d between the two slits are suitable for the interference of electrons or electronic waves emitted by the electron gun EG: $\delta \leq \lambda_e$. In the experiment by Merli et al, the wavelength λ_e of the electron wave is much longer than the optical wavelength λ_c of OA(c): $\lambda_e \geq \delta >> \lambda_c$. So, the background screen had only recorded the two bright stripes projected by the information wave of OA(c) through the double slits onto the background screen.

Actually, the two bright stripes on the background screen shown in Fig. 9.3(b) are that of the light wave of OA(c) through the double slits, i.e., the interference patterns left by the information wave (acting as the coherent wave) of OA(c).

It is thus clear that the phenomenon of electron decoherence in the double-slit interference experiment of individual electrons is caused by the switching of the experimental process and the effect of observational perturbation of observation agents. It is the perturbation imposed on the electrons by the informons (photons) of the optical agent OA(c) that leads to the loss of the original self-coherence of the electronic wave, and then leads to the decoherence of the electronic wave.

(iii) Quantum Eraser Experiment and Decoherence

Experimental physicists have realized that the phenomenon of the electron decoherence in the double-slit interference experiment of individual electrons is caused by the effect of observational perturbation, and have conceived and designed the quantum eraser experiment.

In 1982, Scully and Drühl proposed that the double-slit experiment might adopt the technology of quantum eraser, so that the experimenters could not only ascertain the traces of matter particles but also get the interference fringes of matter waves [107]. The quantum eraser experiment consists of three steps:

(1) To irradiate the quantum beam onto the slits of the double-slit fence of the interferometer, and confirm that the interference patterns has been exhibited on the background screen;

(2) To detect the trace of each quantum, ascertain which slit the quantum passes through (trying not to perturb the quantum during the detection), and confirm that the interference patterns has disappeared from the background screen;

(3) To erase the information of quantum path, and confirm that the interference

pattern has reappeared on the background screen.

The electrons in the experiment by Merli et al may be regarded as the entangled quantum in the quantum eraser experiment, i.e., the matter particles in the double-slit interference experiment.

The first step is similar to the process of electron self-coherence in the experiment by Merli et al, where the observation agent is the autonomous agent OA(v), the informons of OA(v) are the quantum themselves moving at the speed v, and the quantum beam is both the coherent wave and the information wave of OA(v). The second step is similar to the process of electron decoherence in the experiment by Merli et al, where the observation agent is switched to the optical agent OA(c) for detecting the traces of quanta; in order to reduce the perturbation on quanta, the informon (photon) of OA(c) needs to be sufficiently soft (with sufficient small momentum). The third step repeatedly switches observation agents between the autonomous agent OA(v) and the optical agent OA(c), observing the traces of quanta as well as the phenomena of quantum self-coherence and decoherence. Ultimately, the experimenters are able to both ascertain the trances of quanta and get the interference patterns of quanta.

In 1991, Scully et al implemented the quantum eraser experiment [108].

Actually, the quantum eraser experiment has confirmed the theory of OR and the theory of OR matter waves, verified the analysis and interpretation of OR theory about the phenomena of electron self-coherence and decoherence in the double-slit interference experiment.

(iv) Weak Measurement and Decoherence

In a sense, the technology of quantum eraser by Scully and Drühl [107] contains the idea of the weak measurement by Rozema et al [95]: the needs of both the interference patterns of quanta and the information of quantum paths require that the effect of observational perturbation from the observation agent OA(η) is as weak as possible: the informons of OA(η) should have smaller momentum to reduce the perturbation on the observed quanta.

The theory of OR has interpreted the phenomenon of electron decoherence in the double-slit interference experiment of individual electrons based on the concept of **observation agent**, and clarified that the perturbation on the electrons by the informons (photons) of the optical observation agent OA(c) is the root of the electron decoherence.

This is consistent with the logic of weak measurement [95,103,104].

The information-wave wavelength λ_η of the observation agent OA(η) can be employed as the ruler of OA(η) to measure spatial distance, the spatial resolution of which is $\lambda_\eta/2\pi$; the informon momentum of OA(η) can be employed as the scale to measure the momentum of the observed object P, the momentum resolution of which is: $p_\eta=h_\eta/\lambda_\eta$.

According to the theory of OR or the theory of OR matter waves, the observation agent OA(η) has the spatial resolution-ratio $\Delta x(\eta)$ and the momentum resolution-ratio $\Delta p(\eta)$, as well as the observational resolving-power $\Delta x(\eta)\Delta p(\eta)$, which meet the following inequality:

$$\begin{cases} \Delta x(\eta) \geq \dfrac{\lambda_\eta}{2\pi} \quad \text{and} \quad \Delta p(\eta) \geq p_\eta = \dfrac{h_\eta}{\lambda_\eta} \\ \Delta x(\eta)\Delta p(\eta) \geq \dfrac{\lambda_\eta}{2\pi}\dfrac{h_\eta}{\lambda_\eta} = \dfrac{h_\eta}{2\pi} = \hbar_\eta \quad \left(\hbar_\eta = \dfrac{h_\eta}{2\pi}\right) \end{cases} \tag{9.12}$$

where, λ_η is the information-wave wavelength of OA(η), p_η is the informon momentum of OA(η), h_η is the general Planck constant of OA(η), and $\hbar_\eta$ is the reduced value of h_η.

Logically, the observational resolving-power inequality $\Delta x(\eta)\Delta p(\eta)\geq\hbar_\eta$ (Eq. (9.12)) and the general uncertainty inequality $\sigma_x(\eta)\sigma_p(\eta)\geq\hbar_\eta/2$ (Eq. (6.41)) are consistent. Alternatively, the resolving-power inequality (Eq. (9.12)) is a new interpretation of the principle of uncertainty.

Just as Heisenberg expressed his inequality $\sigma_x\sigma_p\geq\hbar/2$ as the principle of uncertainty, the observational resolving-power inequality $\Delta x(\eta)\Delta p(\eta)\geq\hbar_\eta$ can be expressed as the following principle of uncertainty in measurement.

The Principle of Measuremental Uncertainty: Let P be the observed object, OA(η) be the general observation agent ($\eta<\infty$), which has the spatial resolution-ratio $\Delta x(\eta)$ (proportional to the information-wave wavelength λ_η: $\Delta x(\eta)\geq\lambda_\eta/2\pi$) and the momentum resolution-ratio $\Delta p(\eta)$ (inversely proportional to λ_η: $\Delta p(\eta)=h_\eta/\lambda_\eta$), then the product of $\Delta x(\eta)$ and $\Delta p(\eta)$: $\Delta x(\eta)\Delta p(\eta)\geq\hbar_\eta$, i.e. the observational resolving-power of OA(η), is fixed and intrinsic.

The Principle of Measuremental Uncertainty that

(1) Different observation agents (OA(η) ($\eta\in(0,+\infty)$)) have different resolving powers. According to the GPC identity $h_\eta\eta=hc$ (Eq. (6.29)), the larger the information-wave speed η of OA(η), the smaller the general Planck constant $\hbar_\eta$, the stronger the resolving power $\Delta x(\eta)\Delta p(\eta)$ of OA(η) is.

(2) Any realistic observation agent (OA(η) ($\eta<\infty$)) observing the observed object P could not at the same time accurately determine both the spatial position x of P and the momentum p of P, which however is only **the observational uncertainty** or **the measuremental uncertainty**.

According to the principle of measuremental uncertainty, the observational resolving-power $\Delta x(\eta)\Delta p(\eta)$ of any observation agent OA(η) is fixed and intrinsic; however, by selecting information waves with different wavelengths and the same speed η, OA(η) would have different spatial resolution-ratios $\Delta x(\eta)$ and different momentum resolution-ratios $\Delta p(\eta)$.

In the double-slit experiment, if the experimenters try to accurately locate the position x of an electron to get the information about the traces of electrons crossing through the left slit s_L or the right s_R, the information-wave wavelength λ_η of the observation agent OA(η) must be shorter. Thus, the informon momentum p_η of OA(η) must be greater: $p_\eta=h_\eta/\lambda_\eta$, leading to the stronger perturbation on electrons, and further leading to the loss of the original coherence of the electronic wave. So, the double-slit interference experiment of electrons might exhibit the phenomenon of electron decoherence.

In the double-slit interference experiment of individual electrons shown in Fig. 9.3, in order to obtain the interference fringes or coherence patterns of electrons, it is necessary to reduce the observational perturbation on electrons by the informons of the observation agent OA(η) (η<∞).

As depicted in Fig. 9.3, there are two approaches for the experimenters.

Approach 1: selecting the autonomous agent

In the double-slit experiment of individual electrons, the experimenters could adopt the electronic autonomous agent OA(v_e): the information wave of OA(v_e) is the electronic wave, in which each electron is both one of the informons of OA(v_e) and the observed object *P*. Therefore, the electron would not be perturbed the electron itself, and the electronic wave would keep the original coherence of its own. In this way, the experimenters could get the interference fringes and observe the phenomenon of electron self-coherence on the background screen.

However, the autonomous agent OA(v_e) could not provide the information about the electron's trace for the experimenters. So, the experimenters could not determine whether an electron had crossed the double-slit fence from the left slit s_L or the right slit s_R, and could only determine the coordinate position of the electron on the background screen after it reached to the screen.

Approach 2: selecting the weak agent

In terms of the current level of human science and technology, motoring or detecting the motion trajectories of electrons has to depend on the optical observation agent OA(c): the information wave of OA(c) is naturally light wave; the informons of OA(c) are naturally photons.

Photons have the momentums of their own, and therefore, would inevitably perturb the observed electrons and change the motion trajectories of electrons.

In order to reduce the perturbation on electrons by the informons (photons) of the optical agent OA(c), the experimenters have to reduce the spatial resolution-ratio $\Delta x(c)$ of OA(c), sacrifice the positioning accuracy of electrons, and select the weaker optical agent OA(c) with softer photons: the information wave (light wave) has longer wavelength λ_c and the informons (photons) have smaller momentum p_c.

This is so-called **the weak observation agent**, or **the weak agent** for short.

The effect of observational perturbation by the weak agent is weak, and might not completely change the original coherence of electrons or the electronic wave. In this way, the weak agent might not only obtain the information of the trajectories of electrons, including the information about the electrons passing through the left slit s_L or the right slit s_R, but also get the interference fringes or self-coherent patterns of the electronic wave on the background screen.

Of course, the information-wave wavelength of the weak agent is relative longer, the spatial resolution-ratio and positioning accuracy of the weak agent is relative lower, and the measurement information of the weak agent is relative weaker.

This is known as **the weak measurement technology** [95,103-106].

The experiment of weak measurement, from another aspect, has confirmed the theory of OR and the theory of OR matter waves, verified the analysis and interpretation of OR theory about the phenomena of electron self-coherence and decoherence in the double-slit interference experiment.

IOR Summary

In 1905, starting from the hypothesis of **the invariance of light speed**, based on **the principle of simplicity** and **the principle of relativity**, Einstein theoretically deduced the Lorentz transformation, established **the theory of special relativity**, and revealed the relativistic phenomenon of spacetime and matter motion.

Einstein believed that the inertial relativistic effects or phenomena were the essential characteristics of spacetime and matter motion. Einstein's theory of special relativity has been established for over 100 years. Now, the mainstream school of physics still believe that inertial relativistic phenomena are the essential characteristics of spacetime and matter motion.

In **the 1st volume of OR: Inertially Observational Relativity** (IOR), starting from the most basic logical premises, the theory of OR has derived the transformation of IOR spacetime, so-called **the generalized Lorentz transformation**, generalizing and unifying **the Galilean transformation** and **the Lorentz transformation**; on this basis, has established the theory of IOR, generalizing and unifying Newton's inertial mechanics and Einstein's special relativity, revealing the root and essence of the inertial relativistic effects or phenomena. The theory of IOR is not only the challenge to Einstein's theory of special relativity but also the development of Einstein's theory of special relativity.

Human cognition or understanding of the objective world not only depends on observation, but also is restricted by observation.

The theory of IOR has discovered that all doctrines or theories in physics are linked with their specific observation media or specific observation systems, and without exception, are branded with the marks of observation. However, since its inception, human physics has never explicitly linked its theories or spacetime models with observation, with observation media, or with the transmission of observed information.

Now, the theory of IOR has clarified the indispensable role and status of observation in the theoretical systems of physics.

The theory of IOR discovers that: the Galilean transformation is the spacetime model of idealized observation, the Lorentz transformation is the spacetime model of optical observation; Newton's inertial mechanics is the inertial theory of idealized observation, Einstein's special relativity is the inertial theory of optical observation. The Galilean transformation and Newton's inertial mechanics are the true portraits of spacetime and matter motion, while the Lorentz transformation and Einstein's special relativity are only the optical images of spacetime and matter motion.

This is the origin of the name of **Observational Relativity** (OR).

The new theory leads to the new discoveries.

The theory of IOR provides new insights into physics.

The theory of IOR has discovered that: The speed of light is not really invariant.

The theorem of **the invariance of information-wave speeds** is the most important logical consequence of IOR theory. It is the most important discovery of IOR theory that **all inertial relativistic effects are observational effects and apparent phenomena**.

The elements of IOR theory, or the contents of **the 1st volume of OR: Inertially Observational Relativity** (IOR), can be summarized as follows.

(i) The Essence of Inertial Relativistic Effects

The theory of IOR has discovered that, in essence, the inertial relativistic effects or phenomena are observational effects and apparent phenomena, but not the essential characteristics of spacetime and matter motion.

(ii) The Root of Inertial Relativistic Effects

The theory of IOR has discovered that the root of the inertial relativistic effects or phenomena lies in the observational locality − the speeds of observation media transmitting the information of observed objects to observers are all finite: it takes time for the observed information to cross space.

(iii) The Speed of Light is not Really Invariant

According to the theorem of the invariance of information-wave speeds in the theory of IOR, the speeds of observation media transmitting observed information are invariant relative to inertial observers; the invariance of light speed is only a special case of the invariance of information-wave speeds, holds true only if light acts as the observation medium to transmit observed information for inertial observers. Both the invariance of light speed and the invariance of information-wave speeds are observational effects, which are only apparent phenomena when matter particles or matter waves act as observation media.

The speed of light is not really invariant and the universe has no invariant speed. If there were an invariant speed in the universe, then it could only be the infinity!

(iv) The Problem of Photon Rest-Mass

According to Einstein's mass-speed relation in the theory of special relativity, photons have no rest mass.

However, according to the theory of IOR: the rest mass is the objectively real mass of matter with the objectively real gravitational-effect; all matter particles, including photons, have the rest mass of their own. Under the superluminal observation agent OA(η) (η>c), the rest mass of photons would present in the mass-speed relation of IOR theory. This suggests that a photon has the rest mass of its own and the rest mass of photons are observable and measurable.

In **the 2nd volume of OR: Gravitationally Observational Relativity** (GOR), the theory of GOR will provide the predicted value of photon rest-mass in theory based on the theory of GOR gravitational redshift.

(v) The Mysterious Planck Constant

According to theory of the OR matter waves, the Planck constant h is the energy-frequency ratio of photons and one of the parameters of the optical observation system or the optical observation agent OA(c). Different observation agents (OA(η) ($\eta\in(0,+\infty)$)) have different energy-frequency ratios or different

Planck constants, so-called **the general Planck constant** h_η, which follows the GPC identity: $h_\eta\eta\equiv hc$, so-called **the identity of general Planck constant**.

(vi) The Essence of Quantum Effects

According to the theory of OR matter waves: in essence, quantum effects are observational effects, rooted in the observational perturbation on observed objects by the informons of the observation agent OA(η); different observation agents (OA(η) ($\eta\in(0,+\infty)$)) present different degrees of observational perturbation or quantum effect due to different informon momentums. The general Planck constant h_∞ and the informon momentum p_∞ of the idealized agent OA_∞ tends to zero. So, there is no quantum effect or the effect of observational perturbation in spacetime and matter motion of Galileo's doctrine and Newton's inertial mechanics.

(vii) The Principle of General Uncertainty

According to the theory of OR matter waves, Heisenberg's uncertainty principle ($\sigma_x\sigma_p\geq h/4\pi$) is only a special case of the principle of general uncertainty ($\sigma_x\sigma_p\geq h_\eta/4\pi$). Heisenberg's uncertainty is only the observational uncertainty of optical observation, which holds true only if the observation agent OA(η) is the optical observation agent OA(c).

(viii) The Transformation of IOR Spacetime: Generalizing and Unifying the Galilean and Lorentz Transformations

As far as the generalization and unification of the theoretical systems or spacetime models of physics are concerned, the transformation of IOR spacetime, the so-called general Lorentz transformation, is of symbolic significance, which has generalized and unified the Galilean transformation and the Lorentz transformation, the two great spacetime models with the significant historical status.

(ix) The Theory of IOR: Generalizing and Unifying Newton's Inertial Mechanics and Einstein's Special Relativity

IOR's invariance of information-wave speeds generalizes Einstein's invariance of light speed; IOR' mass-energy relation $E=m\eta^2$ generalizes Einstein's mass-energy relation $E=mc^2$, and IOR's kinetic-energy formula $E=(\Gamma-1)m_o\eta^2$ generalizes and unifies Einstein's relativistic kinetic-energy formula $E=(\gamma-1)m_oc^2$ and Newton's classical kinetic-energy formula $E=m_\infty v^2/2$; IOR's spacetime transformation relation generalizes and unifies the Lorentz transformation and the Galilean transformation; IOR' law of speed addition generalizes and unifies Einstein's law of speed addition and Galileo's law of speed addition; and so on. Finally, in summary, the theory of IOR has generalized and unified the whole theoretical system of Einstein's special relativity and the whole theoretical system of Newton's inertial mechanics.

(x) The Theory of OR Matter Waves: Towards the Unity of Relativity Theory and Quantum Theory

The theory of OR matter waves is a component of the theory of IOR, in a sense, is the by-product of IOR theory. The theory of OR matter waves has derived the general Planck equation $E=h_\eta f$ and the general de Broglie relation $p=h_\eta/\lambda$, generalizing de Broglie' theory of matter waves. Thus, Einstein formula $E=mc^2$ and Planck equation $E=hf$, two great formulae, has been generalized by the theory of IOR under the same axiom system, and has been unified by the theory of IOR into the same theoretical system.

So, the theory of IOR has generalized both Einstein's theory of special relativity and de Broglie's theory of matter waves, marching towards the unification of relativity theory and quantum theory.

The theory of IOR, so-called **Inertially Observational Relativity**, has generalized and unified Einstein's theory of special relativity and Newton's theory of inertial mechanics. This indicates that the theory of IOR is logically consistent with both Einstein's special relativity and Newton's inertial mechanics. In particular, such logical consistency confirms the logical self-consistency of IOR theory, and moreover, confirms the logical rationality and theoretical validity of IOR theory from one aspect.

Physics is both speculative and empirical.

The theory of IOR not only has logical self-consistency and theoretical validity, but also has the support from observations and experiments. Actually, the support of observations and experiments for Einstein's special theory is the support for the theory of IOR; the support of observations and experiments for Galileo's doctrine and Newton's inertial mechanics is equally the support for the theory of IOR. In particular, the Michelson-Morley experiment is not so much a support for the invariance of light speed and Einstein's theory of special relativity, but rather a support for the invariance of information-wave speeds and the theory of IOR. As stated repeatedly by the theory of IOR, in the Michelson-Morley experiment, the invariance of light speed is only a phenomenon, while the invariance of information-wave speeds is the essence.

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