Global Approximation Interpretation of Quantum Mechanics (Standard Interpretation)*

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Abstract

The interpretation of quantum mechanics (QM) has been being fiercely debated ever since its early times. We have made much progress in understanding the basic interactions and elementary particles a few decades after. However, this progress has never been incorporated into QM, even though it supposes to deal with the microscopic world. To fill the discrepancy, we adopt the advances of the more fundamental theories, i.e., Standard Model (SM) and its peers, together with some extended reasoning, and elaborated the global approximation feature of the Schrödinger equation and its physical implications, and interpret QM with no extra assumption. To our surprise, our approach seems to lead to intuitive understandings of all formerly puzzled QM concepts and phenomena. Global Approximation Interpretation (GAI) of QM can explain the physical meaning of Schrödinger equation and wave function, the origin of probability interpretation of wave function, the role of coherence, the boundary between classical and quantum world, the origin of quantization, the properties and the physical pictures of elementary particles, quantum entanglement, quantum eraser experiment, etc. Philosophically, GAI can reconcile opposing cognition theories, such as reductionism and holism, idealism and materialism, determinism and indeterminism. We also find the reality is relative.

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1 Introduction

In 1900, to solve the problem of blackbody radiation, Planck suggested that energy can only appear in quantized amounts [1]. In 1913, to explain the Rydberg formula of atomic spectral lines, Bohr suggested that electrons can only be located on the "quantized" orbits of atoms and only absorb or release "quantized" energy [2]. In 1923, De Broglie proposed the concept of matter wave [3]. In 1926, Schrödinger wrote down the Schrödinger equation from the concept of matter waves, [4] explained the spectral lines and covalent bonds of hydrogen atoms. In 1927, Bohr and Heisenberg formulated the Copenhagen interpretation (CI) of quantum mechanics [5, 6] to explain the wave function. Since then, quantum mechanics on the microcosm has been established. The interpretation of the Copenhagen School is still the orthodox theory today [7].

The main principles of CI are: wave-particle duality, all properties of a quantum are embedded in its wave function. The wave function is probabilistic, and measurement causes it to collapse. The wave-particle duality satisfies the principle of complementarity, and the correspondence to classical physics is the principle of correspondence [8]. Some related physical properties obey the Heisenberg uncertainty principle.

The rise of the CI of quantum mechanics shocked the scientific community at the time and was very successful, but it also met with fierce criticism. Einstein, Schrödinger, and others are firm opponents of some of these concepts, such as probability and wave function collapse.

Although many other interpretations have appeared in the past hundred years, the pilot wave theory [9], the multiverse theory [10], etc., CI has always been dominant.

With the progress of Bell experiments in the 1980s, the recognition of CI reached the highest level. In the following decades, although the recognition has declined [11], it remains as the basic interpretation taught in textbooks. Theoretical physicists, such as Feynman [12], Smolin [13], t'Hooft [14], Weinberg [15], etc., have all expressed their concerns on quantum mechanics and CI.

Quantum mechanics does not answer questions such as "what are elementary particles?" and "what is the interaction?" These issues are the frontiers of subsequent research. The progress of these studies has greatly improved our understanding of the world. Although we cannot say that these theories are final, we should put these understandings into quantum mechanics to solve the problems such as "no one understands quantum mechanics" [12].

We will re-examine the physical implications of the Schrödinger equation and its solution (wave function) based on the pictures of elementary particles and interactions and try to establish a quantum mechanics interpretation based on these basic theories.

Many concepts and phenomena in quantum mechanics are quite confusing, and we will list some here. Some of them have been heatedly debated [16–18], and some are newly proposed in this paper:

1. Wave-particle duality Is "particle" a wave or a particle? What is meant by "sometimes behave like a wave and sometimes a particle"? Waves are distributed in a space-time continuum, and particles generally have definite sizes and positions.

2. Measurement problem Before and after the CI measurement, the process is discontinuous, and the transition occurs instantaneously and randomly, which can cause all physical quantities to be discontinuous. In particular, if you are in the superposition of several energy eigenstates before the measurement, only certain energy can be obtained after the measurement, and the energy is not conserved before and after the measurement. Angular momentum has the same problem. These quantities should be conservative in principle. In the classic system, the measurement does not affect the state of the system. In the quantum system, measurement causes a sudden, irreversible change of the system [19].

3. Uncertainty principle In classical physics, the properties that particles can have at the same time, such as position and speed, are in principle impossible to measure simultaneously in quantum mechanics. The more accurate one quantity is, the more uncertain the other quantity must be.

4. The puzzling properties of the elementary particles For a classic object, we can measure its various physical properties. These properties are self-consistent, with clear physical meaning, understand-

able, such as size, momentum, mass, angular momentum, etc. However, in quantum mechanics, the basic properties of elementary particles can only be artificially defined, and they are regarded as the intrinsic properties of particles. They are hard to understand, and there is no physical picture. For example, how big is an electron? If it is measured or classically defined as large, the spin cannot be the measured value because it must rotate faster than the speed of light [20]. Another example is the photon, which has no rest mass, but does have momentum, and can also have angular momentum.

5. Reality If you don't measure a quantum object, you cannot know its properties, but measurement changes it. Then, before the measurement, does it have an objective state [21]? Einstein thought there was, Bohr thought there was no, or it is impossible to know. "If I don't look at the moon, will it not exist?" This is the magnification of this argument.

6. Quantum entanglement (nonlocality) Two entangled particles can affect each other instantaneously, even if they are very far apart. This image violates the principle of locality [22], but supporters claim that countless experiments have irrefutably proved this phenomenon [23, 24].

7. Determinism Classical physics is deterministic in principle. That is, the physical state of the past completely determines the future. In quantum mechanics, all futures are possibilities. Quantum mechanics cannot tell which possibility to develop in the future. It can only give the possibility of each branch. Of course, there are some other interpretations, such as multi-universe interpretation [10].

8. Delayed choice experiment Quantum interference experiments are confusing enough. Delayed choice experiment [25], that is, it seems that future choices can change the past paths of the particles. The experiments seem to support the idea of changing the past in the future.

9. Photon problem As a special case where the properties of elementary particles are hard to understand, photons are especially incomprehensible and even theoretically not self-consistent. For example, does a photon have a certain energy or not? Each answer has its agreements and contradictions with experiments.

It seems that GAI (SI) can provide a physical picture consistent with cognitive intuition for all the above annoying concepts and give self-consistent interpretations.

2 Standard worldview

2.1 Elementary theories of the physical world

How does everything work? After thousands of years of hard work by countless thinkers and scientists, we should have almost figured out the basic laws of interactions between objects.

Our current most recognized theory about elementary interactions is the Standard Model (SM) [26]. It describes the three basic interactions in the universe, namely electromagnetic interaction, weak interaction, and strong interaction, excluding gravity. These three kinds of interactions can be integrated together, called Grand Unification Theory (GUT) [27]. If gravity is also integrated, it is called Theory of Everything (ToE) [28].

We will not go to the details of these theories, but they have been rigorously tested by numerous experiments and reasoning. We do not have the final theory yet, and the current one does not necessarily be right in every detail. They may subject to change in the future. However, we can still draw some basic lines of these basic laws that govern the physical world. That is, what should our worldview look like under the SM, or GUT?

Contrary to our general concept of succinct and graceful physical laws, real-world interactions are extremely complicated and trivial. We can look at a simplified version of the Lagrangian of the SM of particle physics [26]:

$$
\begin{aligned}
L = & -\frac{1}{4}B_{\mu\nu}B^{\mu\nu} - \frac{1}{8}tr(W_{\mu\nu}W^{\mu\nu}) - \frac{1}{2}tr(G_{\mu\nu}G^{\mu\nu}) \qquad (U(1), SU(2)\ \text{and}\ SU(3)\ \text{term}) \\
& + (\bar{\nu}_L, \bar{e}_L)\bar{\sigma}^{\mu}_{i}D_{\mu}\begin{pmatrix}\nu_L \\ e_L\end{pmatrix} + \bar{e}_R\sigma^{\mu}{}_{i}D_{\mu}e_R + \bar{\nu}_R\sigma^{\mu}_{i}D_{\mu}\nu_R + (h.c.) \qquad (\ \text{lepton dynamial term}) \\
& - \frac{\sqrt{2}}{\nu}[(\bar{\nu}_L, \bar{e}_L)\phi M^e e_R + \bar{e}_R\bar{M}^e\bar{\phi}\begin{pmatrix}\nu_L \\ e_L\end{pmatrix}] \qquad (\ \text{electron,muon,tauon mass term}) \\
& - \frac{\sqrt{2}}{\nu}[(-\bar{e}_L, \bar{\nu}_L)\phi^* M^{\nu}\nu_R + \bar{\nu}_R\bar{M}^{\nu}\phi^T\begin{pmatrix}-e_L \\ \nu_L\end{pmatrix}] \qquad (\ \text{neutrino mass term}) \\
& + (\bar{u}_L, \bar{d}_L)\bar{\sigma}^{\mu}_{i}D_{\mu}\begin{pmatrix}u_L \\ d_L\end{pmatrix} + \bar{u}_R\sigma^{\mu}{}_{i}D_{\mu}u_R + \bar{d}_R\sigma^{\mu}{}_{i}D_{\mu}d_R + (h.c.) \qquad (\text{quark dynamial term}) \\
& - \frac{\sqrt{2}}{\nu}[(\bar{u}_L, \bar{d}_L)\phi M^d d_R + \bar{d}_R\bar{M}^d\bar{\phi}\begin{pmatrix}u_L \\ d_L\end{pmatrix}] \qquad (\text{down, strange, bottom mass term}) \\
& - \frac{\sqrt{2}}{\nu}[(-\bar{d}_L, \bar{u}_L)\phi^* M^u u_R + \bar{u}_R\bar{M}^u\phi^T\begin{pmatrix}-d_L \\ u_L\end{pmatrix}] \qquad (\text{up, charmed, top mass term}) \\
& + \overline{(D_{\mu}\phi)}D^{\mu}\phi - m_h^2[\bar{\phi}\phi - v^2/2]^2/2v^2 \qquad (\text{Higges dynamical and mass term})
\end{aligned}
\tag{1}
$$

The Lagrangian in quantum field theory represents the dynamics and kinematics properties of the system. It can also be considered as the number of degrees of freedom in the system, as well as the energy distribution and transition rules in and between each degree of freedom. Each particle is a dynamic field distributed in time and space.

The space-time of quantum field theory is a covariant space-time that obeys the special relativity, so all the basic interactions of the SM satisfy the principle of locality [29], that is, the propagation of any interaction cannot exceed the speed of light.

When calculating the realistic physical processes, Feynman's rule of path integral is also applied. Even for the simplest single particle case, in principle, there an infinite number of orders. Every next order is much more complicated than the previous one.

Lagrangian, or the terms in the field equations, contain various differential operators. For the differential operator to be valid, the function must be continuous. That is, all quantities in various degrees of freedom in the field equation should be continuous. This implies that all physical world quantities must be continuous, from a microscopic point of view.

The Feynman rule (Feynman diagram) of quantum field theory calculations [30] gives the contribution of various possible particle interaction processes to a specified process, generally only when the perturbation assumption holds, that is, the higher-order contribution is negligible. In most cases, the perturbation assumption is invalid. Even if the perturbation assumption holds, the high-order processes that need to be considered may be too complicated to calculate.

The formulation, implication, and calculation rules of the standard model of field theory all show that our physical world is a very complex, intertwined, and nonlinear one [31]. Any elementary process is nonlinear, and even the vacuum itself is infinitely complex and nonlinear.

As for the GUT that we hope to establish, and the TOE, although we still don't know its specific form, they must include all interactions, and all matter must participate in all basic interactions, and they are all coupled together. Their formulation and implications might even be more complicated than the above.

We can give a simple example to illustrate the complexity of interactions between matter, even if only classical electromagnetic interaction is considered. All matter participates in electromagnetic interactions. Even no charge is involved, there is always a spin and magnetic moment. An electron has an infinite range of action, so any charged object will inevitably influence infinity. If it is neutralized, such as hydrogen atoms, will the affected range be very small? No, its range of influence is still infinite because it has a magnetic moment. According to its internal energy level, there are higher-order electrical multipole momentums, and the range of action of these momentums is also infinite. If you consider the changes over time, the changes caused by changes, and the actual complexity of the physical world, any precise calculation or measurement will be impossible.

2.2 Summation

The physical picture of the objective world based on the standard model can be called the standard worldview.

Whether starting from elementary physical theory or our common sense, we can see that the physical world is extremely complex, multi-degree-of-freedom, nonlinear, and possesses infinite objects. Any seemingly simple process is complicated.

Some observations:

- All basic interactions obey the principle of locality, and there is no superluminal interaction.
- The mathematical formulation should be conceptually separated from the actual physical world. The physical world is inherently complex, and mathematical formulation can only be the approximation from a certain direction to a certain extent.
- The equivalence between matter and energy has profound significance. In the current theoretical framework, matter or energy is the basis for the existence, or observability, of the physical world.
- Lagrangian, or the laws of physics, are the same for any space-time point. Every point in space-time is equally complex. As long as the conditions are the same, such as energy density or other degrees of freedom, the physical processes are the same.

3 The physical meaning of Schrödinger equation

How did the Schrödinger equation come about? According to Feynman, “It is not possible to derive it from anything you know. It came out of the mind of Schrödinger.” [32]

However, there is a widely circulated “derivation of Schrödinger equation”, which is written on some quantum mechanics textbooks [33].

We write down the one-dimensional stationary Schrödinger equation,

$$E(x,t) = \frac{-\hbar^2}{2m}\frac{\partial^2\psi}{\partial x^2} + V(x)\psi(x,t) \tag{2}$$

And the one-dimensional time-dependent Schrödinger equation:

$$i\hbar\frac{\partial\psi}{\partial t} = \frac{-\hbar^2}{2m}\frac{\partial^2\psi}{\partial x^2} + V(x)\psi(x,t) \tag{3}$$

Generally, we say that Schrödinger equation is a wave equation, but the wave equation should look this (one-dimensional):

$$\frac{\partial^2 u}{\partial t^2} = c^2\frac{\partial^2 u}{\partial x^2} \tag{4}$$

u is the wave function, and c is the propagation speed of the wave.

If we throw away the item with V, just as in free space, the forms of Schrödinger equation (3) and wave equation (4) are not the same because Schrödinger equation has only one-order time differentiation of the wave function, and the wave equation has second-order time differentiation. That is to say, Schrödinger equation is not a wave equation.

In fact, the form of Schrödinger equation is a diffusion equation (one-dimensional constant coefficient diffusion equation):

$$\frac{\partial\phi(x,t)}{\partial t} = D\frac{\partial^2\phi(x,t)}{\partial x^2} \tag{5}$$

D is the diffusion coefficient.

That means, from the perspective of mathematical equations, the physical meaning of Schrödinger equation is not a wave equation, but a diffusion equation with an imaginary diffusion coefficient of $\frac{i\hbar}{2m}$.

The physical picture of the diffusion equation is obvious. Take thermal diffusion as an example. Once a heat source appears in a medium, the heat will diffuse to the entire medium.

We know that the solution of the general stationary Schrödinger equation is a fixed probability distribution without diffusion. The time-dependent Schrödinger equation is rarely used. Even if it is used, we usually use adiabatic approximation, that is, treat it as a stationary Schrödinger equation. We can regard the stationary Schrödinger equation as a special form of the time-dependent Schrödinger equation.

And what does the imaginary diffusion coefficient mean? The presence of imaginary coefficients in a quadratic differential equation usually means fluctuations.

Combining the above two points, we can think that the Schrödinger equation is a wave diffusion equation. What is the diffusion rate? Considering that the imaginary diffusion coefficient has already been taken into account, we do not care about its value. What is the final solution of the wave function? Since its distribution remains unchanged, it can be considered the final state of the wave after sufficient diffusion. The non-relativistic nature of Schrödinger's equation means that the propagation speed of the action is infinite, that is, full diffusion does not require time.

Therefore, we can assume that the solution to Schrödinger's equation is the final stable state reached by the sufficiently diffused waves. How about the initial waves? It can be assumed of all frequencies (full spectrum).

We know waves are coherent, and coherent waves interfere. If waves are sufficiently diffused, only those with favorable coherent (interference) conditions will remain.

Therefore, the solution of Schrödinger equation is the set of all coherent favorable waves in this system, namely, eigenstates, or the favorable vibration modes. They must reflect all the spatial properties of the system, such as boundary conditions, the nature of the potential, etc.

Note that we are guessing the physical meaning of Schrödinger's equation. The above statements are speculations, not proofs.

However, even if we completely discard the above discussion, the conclusion that the solution of Schrödinger's equation is an intrinsic wave solution that reflects the properties of all space and the potential—that is, the global property—is still valid. Wave property is provided by the definition of Schrödinger wave function, or comes from the assumption of matter wave. The above conjectures and analogies are just for a more intuitive understanding of the physical meaning of the Schrödinger equation.

Due to the equivalence of matrix mechanics and wave dynamics [34], we can also infer that all quantum states are global states, non-relativistic, and have an infinitely fast propagation speed. However, these are only mathematical properties implied by the theory formulation, not actual physical properties.

We should also note that the above discussion refers to ideal conditions. All solutions are distributed in the full space (except for infinitely deep potential wells, which actually do not exist).

To sum up, we can conclude that the solution of Schrödinger's equation is a wave system (matter wave), ideal, global, non-relativistic, eigensolution set.

Since Schrödinger's equation is an equation describing quantum, the above properties are also the properties of quantum under the theoretical framework. In other words, every quantum described by quantum mechanics is a set of matter waves (eigenstates), ideal, global, and non-relativistic.

For comparison, we can discuss the general solutions of time-dependent differential equations. We need initial conditions, corresponding boundary conditions, and the solution is a set of equations that vary with time. Under normal circumstances, there are almost no real systems that can be analytically solved, so we use numerical methods, such as fluids, plasmas, electromagnetic fields, etc. We also have to know the initial states of the system, boundary conditions, to calculate the properties of the system evolving over time. We hardly use numerical methods to solve Schrödinger's equation, because, in physics, the problem to be solved is not an initial value problem. Moreover, the numerical method of dividing time and space into grids is in principle a local algorithm, because the value of each grid point at the next moment depends only on the value of a certain number of surrounding grids at the previous moment (not including implicit methods). Therefore, the numerical method for the eigenvalue problem of differential equations is very unreliable. In fact, we usually use the matrix method to solve the eigenvalue problem of quantum mechanics [35].

In principle, to calculate the behavior of any single particle or multiple particles of a real quantum system, the Schrödinger equation requires the state of the entire universe to be known, because the state of the entire universe is part of the potential. If the identicalness of the particles is taken into consideration, a non-relativistic, many-body, real system is impossible to calculate.

Quantum is not equal to the particle. In fact, whether it is Schrödinger's equation or matrix mechanics, quanta have no direct relationship with particles. Particle properties are questions that need to be answered when it comes to measurement.

Due to the complexity of the real physical system discussed in the previous section, we can also say that the solution of the Schrödinger equation is the non-relativistic ideal limit solution of the system.

4 Quantization as Emergence

The basic definition of quantum is similar to the concept of atom in ancient Greece, which is the smallest unit of a certain type of matter or quantity. Quantization refers to the phenomenon that physical quantities that should be continuous in a classical case can only take certain discrete values. For example, the electrical charge is composed of basic unit charges.

In nature, quantization is actually a common concept, such as individual people, data in information (bits), molecules, atoms, and so on. However, some basic physical quantities, such as energy, momentum, angular momentum, heat, etc., at least in classical situations, we believe that they should change continuously. However, in the microscopic world, we find that it may not be true. Plank [1] assumed the discontinuous change of energy (radiation) in 1900 to solve the problem of black body radiation ultraviolet divergence that plagued physics at that time and won the Nobel Prize in 1918.

With the success of Bohr's atomic model and a large number of experiments on the microcosm, people believe that quantization is the norm, and even the only principle. Charge, angular momentum, energy level, ..., etc., are all quantized.

However, as for Planck's original hypothesis, the definition of energy quantization is not clear. In 1905, Einstein believed that light is composed of light quantum (Lichtquanta), explained the photoelectric effect [36] and won the Nobel Prize. However, Planck does not believe that photons are what he calls the quanta of energy. Is there a quantum of energy that changes in energy, like in electric charge? Although we thought that photons were quantized in later theories, we did not think that energy was quantized. Energy quantization only means energy level discontinuity, rather than any energy change with a minimum energy unit.

In other words, energy is not quantized. So how did the energy level quantization [18] appear?

As we know, the electron energy level quantization in the Bohr model is a natural result of the Schrödinger equation in the Coulomb potential. That is to say, as long as the electron behaves like a matter wave, in the Coulomb potential, it satisfies the global conditions such as the periodicity of the central potential and being zero at infinity, the energy level discretization is inevitable. In fact, all discrete energy levels of bound states come from the same reason.

Therefore, we do not need energy quantization assumptions. Energy is not quantized. The quantization of the energy level is due to the fact that in the atomic bound state, the electron material wave can only have some discrete eigenstates.

Angular momentum is the same.

In the bound state, the discrete eigenstates of the quantum wave also have discrete angular momentum, and the smallest unit of change is the angular momentum of the lightest charged particle—the electron, $\hbar/2$. Note that this does not mean that the angular momentum of the electron has to changes in that unit. It is just the property of the eigenstate.

If the emergence of energy quantization is understandable, the quantization of angular momentum is not convincing. We can understand that angular momentum is discrete in discrete energy levels. However, energy can change continuously, so why cannot the angular momentum act alike? Why does it have one smallest unit?

Considering that eigenstates can be superimposed, even in a bound state with discrete energy levels, the energy of a particle is not exactly discrete. It can change continuously because the portion (probability magnitude) of any eigenstates is continuous. The same is true for angular momentum. Discrete energy level or angular momentum is only the dominant vibrational state (eigenstate). So it is not true that angular momentum must change one minimum unit at a time.

So, why do we feel that the angular momentum is quantized? That is because we usually discuss eigenstates. In eigenstates, energy and angular momentum are both discrete. However, the particles need not be in a single eigenstate. The spectral lines of discrete states that we see are the results of the resonances between the eigenstates of different atoms, and in fact, all energy radiation is present.

However, the electric charge is quantized. Whether it is an integer (electron) or a fraction (quark), it is still quantized, isn't it? Also, why is the angular momentum of elementary particles, such as electrons, quantized? We will answer these questions in the next section, "What are elementary particles?"

In the understanding of GAI, all basic physical quantities are continuous, and quantizations are all emergences [37], which is the discrete manifestation of wave vibration under the combined action of potential and space topology. Just like the frequencies of an instrument are some discrete values.

Are the degrees of freedom quantized, or is there a fixed number of degrees of freedom? Is there a correlation between degrees of freedom? Non-relativistic quantum mechanics cannot answer such questions.

There are also phenomena similar to angular momentum quantization in the macroscopic world, such as orbital resonance between stars. The wave eigenstate (dominant vibration) that reflects energy quantization is even more ubiquitous, such as the resonance of musical instruments, buildings, vehicles, and rockets, etc.

Note: Emergence refers to a phenomenon or law that occurs when a simple system grows to a certain extent in terms of scale and quantity, but not in the original system.

5 What are elementary particles?

In section 2, we discussed what the real physical world looks like. The basic conclusion is: the interaction of the physical world is complex, many-body, and nonlinear. It is the same for a single particle, even a vacuum.

In a classical picture, the particle we define is generally a point, or to avoid infinity, we imagine the particle as a small ball (there is no reason to imagine any other geometric shapes), for example, like a glass ball, a grain of sand, or smaller particles. Obviously, this image is unreasonable because if it is a small ball, what is the material of the ball? Are the materials of different particles the same? What are the physical properties of the material? None of these questions can be answered.

If it is a point particle, the problem of materials can be avoided, but there is a problem of infinity, whether charged or uncharged, because it also has spin and mass.

So the classical point particle picture is unacceptable.

What should elementary particles look like, or what should they be?

Let us return to the standard model Lagrangian in section 2. The Lagrangian already includes all interactions except gravity, and of course, it must also include all elementary particles except gravitons. Lagrangian exists or acts on every point in space-time. In other words, at any point in space-time, there are all types of interactions at the same time. We can also say that all particles exist. So what conditions determine a certain point, or what particles appear in a small region? It depends on how much energy there is in the region and some other basic properties, such as which degrees of freedom the energy is distributed to, what symmetry is present, and so on. However, in principle, every point, or the region near this point, has all basic interactions, or all kinds of elementary particles, as long as the conditions are right.

Which specific particle appears depends on the energy and other physical properties of the perturbation mode of the space-time point. Some perturbation modes are unstable and will spread out or become other more stable modes, i.e., decay. Some perturbation modes are stable, such as electrons, neutrinos, etc. Some compound modes are stable, such as protons and neutrons, and the components (quarks) are inseparable [38]. If you must input enough energy to tear them apart, you can only get more particles that can exist alone.

Every point in time and space in our world has complex interactions. Some interaction patterns are stable and appear as stable particles, and some are unstable and appear as particles that are easy to decay. The translation of these particles in space can be understood as the mode disappearing in one place and then appearing in a nearby place, just like the propagation of a stable wave crest on a rope. The source of these interactions or disturbance to space-time is energy. The higher the energy density, the more degrees of freedom that can be excited, and the more stable or unstable interaction patterns that may appear, that is, the more types of particles.

Therefore, elementary particles are the stable, or a relatively stable disturbance mode, of space with a certain density and total energy. Generally, there is a relatively limited spatial range, or the main disturbance range (locality).

Although the elementary particles behave as specific types of particles, they still contain all the interactions defined in the Lagrangian. It is just that some interactions have a large contribution, and some small, because different interaction has a different energy range. For low-energy electrons and photons, we only need to calculate the contribution of electromagnetic force (quantum electrodynamics, QED).

Even so, from the perspective of quantum field theory, each electron is still an extremely complex existence, because it will affect every space-time point near it and excite an infinite number of "virtual photons". Only when these virtual photons are taken into account can quantum electrodynamics correctly calculate the properties of electrons. In other words, these "virtual photons" have real contributions and cannot be separated from the electrons. They are actually part of the electrons [30]. From this perspective, these virtual photons are real.

From a classic point of view, just like the example we gave in section 2, every electron is infinite because its range of influence is infinite. In fact, all particles participating in electromagnetic interaction have this property.

It is impossible to separate the field from the particle. The field is a part of it, so it is natural to include the reaction of other matter to the field and the influence of other matter (fields), because the influence of other matter (fields) cannot be separated either.

Let us look at the “intrinsic properties” of elementary particles. Every elementary particle should have a mass, which is the energy required by the perturbation to produce it. Generally, we only consider its rest mass. There are two other basic properties: spin and charge. Electric charge is an electrostatic one, with discrete values (absolute values) such as 1/3, 2/3, and 1, which are all properties of the particle, or space-time perturbation. For a specific particle, the static mass and charge are constant, which is easy to understand.

Spin is a bit different. Although we say that the total spin of a particle is also constant, different values will appear in the measurement. Take the electron as an example. When we measure its spin, sometimes it is 1/2, sometimes it is -1/2. If it has not been measured, it is unpredictable. Photon is even stranger. Photons can be polarized, and the spin is any value between -1 and 1. In fact, photons are even stranger, and we will discuss them in a dedicated chapter later.

At least from a classical point of view, we generally think that a particle monopolizes a space equivalent to its size. Other particles can occupy the inextricably “influence” part.

The only elementary particle without rest mass is the photon. There is no consensus on the physical picture of the photon. Many people believe that photons, like other elementary particles, have a location and a size. As we are going to discuss photon separately, we only give our key points of view on photon: at least for low-energy photon (energy lower than X-rays, below the order of hundred electron volts), just like phonon [39], you can take them as quasi-particles, which is still a low-energy excitation within a certain range of space-time, or, a wave, i.e., an electromagnetic wave. As the frequency increases, the energy is concentrated, and the energy density increases, and the higher degrees of freedom of the space-time energy scale will be excited, such as positive-negative electron pairs, complex excitation modes with higher degrees of freedom, making the photon more like a localized elementary particle.

5.1 Summation

- Elementary particles are not point particles, and each particle has a wide range of influence that cannot be separated. If it is not truncated artificially, the influence range of every particle is infinite.

- There are no elementary particles in the classic picture. All particles are complex, with all kinds of nonlinear interactions. The different manifestation is because of the different perturbation energy. Only in low-energy situations, the participation of high energy scale degrees of freedom can be ignored.

- The particles in the elementary particle table may be excited by a single component (specific degrees of freedom), may be eigenstates, and may not exist independently. Stable or relatively stable particles in nature may be elementary particles, such as electrons, or stable combined excitation modes, such as protons (composite particles).

- For particles with rest mass, the main space range of their mass is very small, which can be estimated by the uncertainty principle. Its size is what we usually call the particle size, which can be measured. The size and location of this particle are localized.

- Low-energy photons are electromagnetic waves that are excited in a wide range. High-energy photons are more particle-like.

We can find that when all the elementary particles are listed, there is none called quantum. Although Einstein once called photon light quantum, the concept of the photon is the most controversial. So, what is quantum?

6 What is a quantum

Quantum mechanics, or quantum physics, is about how quantum works. Quantization is the inevitable result of Schrödinger's equation that must meet certain boundary conditions in certain potential, while Schrödinger's equation is an equation of ideal matter waves, and its solution is the global limit under non-relativistic conditions.

Starting from the SM, we have also concluded that elementary particles are a certain excitation mode of energy in space-time. Each particle or excitation mode is very complicated. All differential variables are continuous.

So what exactly is quantum in quantum mechanics?

According to De Broglie's original assumption, all matter is waves, described by Schrödinger's equation. In other words, all matter is quantum, including combinations of matter and even macroscopic objects. All quanta have quantum effects, such as double-slit interference. We have no reason or a limit to determine how large material will no longer cause double-slit interference, but we cannot make small enough slits.

Since all matter is quanta, how do we distinguish between quantum and classical systems? In fact, there are no boundaries. There is only one set of rules. There are only basic interactions that we have not yet completely figured out. All phenomena are continuous, complex, nonlinear, and interacting with each other, such as discontinuous spectral lines, interference, entanglement, etc., but they appear to be "quantum".

To give another example, if a continuous metal plate is irradiated with X-rays of appropriate wavelengths, a large number of regular diffraction spots can appear [40,41]. These spots are discontinuous and discrete so that we can obtain the metallic lattice structure. The discreteness is the result of continuous basic interactions of certain periodicity.

As the experimental basis of quantum theory, the discreteness of the atomic spectrum, we should also notice the resonance between a large number of atoms of the same kind. The light that is just at the right frequency of the atom is easily absorbed or blocked. Resonance is formed among a large number of atoms of the same kind. If the atomic thermal motion is slow, the resonance will be particularly concentrated, and the peak will be very sharp. This is exactly what the laser or atomic clock hopes to achieve.

6.1 Quantum is wave

All "quantum properties", that is, the discreteness of some physical quantities, wave interference effects, etc., ultimately, are the properties of the wave, either restricted by the potential, boundary conditions, periodicity, and other conditions, or free. In other words, quantum is a wave. De Broglie's matter wave hypothesis is the actual theoretical basis of quantum theory, not Planck's hypothesis of discontinuity of physical quantities.

So why does matter show the properties of waves? In a system controlled by long-range forces (such as electromagnetic systems) or closely related systems (such as in a medium), waves are natural. Any change in a physical quantity in any part of the system will inevitably propagate out in the form of waves. We said that if any elementary particle is not truncated artificially, its influence is infinite. Its influence is its intrinsic properties, which cannot be stripped off. Therefore, any change in a particle must also propagate in the form of a wave.

In this case, a quantum particle is no different from a classical particle with a field, such as an electric dipole or a multipole. And we do have some phenomena that only appear under quantum conditions, such as superconductivity. With continuous physical quantity, superconductivity is still understandable, and Cooper's conception [42] is not problematic. The same is true for laser, although we generally describe it as a macroscopic quantum effect. With the understanding of continuous physical quantities, the laser is only the resonance of atomic radiation. Pumping is the drive of the resonance between specific energy levels.

The properties of waves are valid in all space, or within a certain restricted region. That is, they are global. This is the origin of quantum "non-locality". However, these global properties are just correlation, not causality.

6.2 Quantum is wave function

We now have complex interactions, physical picture of elementary particles, and waves in spacetime. The changes in basic physical quantities are continuous, and no quantum is found. Then what is quantum?

Let us look at a typical quantum description. The wave function of a photon is a plane wave. In fact, the wave function of any free particle is a plane wave, and its energy or momentum can be any positive number. In the infinitely deep square well, the wave function of any particle is also a plane wave, but the energy of the wave is "quantized". Because of the limitation of the well (boundary conditions), only certain fixed energy wave functions can exist. There is minimum energy, zero-point energy, or the energy of the ground state. Other potential wells are more complicated, but the principle is the same. The global wave function is restricted, and the energy cannot be of any value. So quantization is only caused by the potential, not by the particle.

The wave function is the basic description of a quantum. The wave function contains all information about the quantum. A quantum can be any particle or matter. Therefore, we can say that a quantum is its wave function. Whether in integral (summation) form or vector form, the wave function refers to the set of probability wave amplitudes of all possible states of the particle [5, 43]. The possible states can be the discrete eigenstates or a certain physical value (representation) selected arbitrarily, such as coordinates, momentum, energy, etc.

Therefore, quantum becomes a collection of probability. However, once it is treated as probability amplitudes, it automatically possesses some strange properties, such as superposition, entanglement, and so on. These are also the properties of waves (we will discuss the entanglement in detail in the next section).

Quantum mechanics is all about the wave function. However, the wave function is not a physically measurable quantity. Only its modulus square is a statistical distribution. Any measurement is a destruction of the wave function, and we can never obtain accurate information about the quantum. It must be assumed that there are a large number of the same quanta, and the same measurement is performed on them so that the total statistical distribution can be considered to reflect the properties of the quanta. If we do not know all the information of a certain quantum in advance, we will not be able to prepare a large number of the identical quantum (quantum no-cloning theorem) [44]. Of course, there are naturally a large number of relatively certain identical or similar quantum states, such as the energy levels of the same kind of atoms.

The wave function is the collection of the probability amplitudes of all possible measured values of a particle (or quantum).

6.3 The inherent limitations of quantum description

All quantum peculiarities, or properties that cannot be intuitively understood, are properties of waves. All wave functions are global, and it does not take time to measure or collapse. The superposition of quantum comes from the superposition of probability amplitude, which is the linear property of Schrödinger's equation. These properties are all the properties of the ideal wave. For example, in the near-ideal case, the scale is so small that the speed of interaction propagation—the speed of light—can be treated as almost infinite; or the wave itself is close to ideal, with good monochromaticity and long coherence distance. The properties of the system can be described by the non-relativistic Schrödinger equation, or as we usually say, the system is a quantum system.

Therefore, quantum mechanics is only applicable to microscopic and low-energy systems. The propagation speed of the interaction can be regarded as infinite. It should be noted that this is only an approximation, not a true description of the interaction. Its violation of the principle of locality is internal and cannot be separated, and there must be "non-locality".

On this basis, some quantum descriptions, such as the description of the second quantization of the identical particle system, the annihilation operator, the creation and annihilation operators of the discrete energy eigenvalue system, etc., are also subject to the same limitation.

We should be cautious about any nonlocal properties of a quantum system, such as quantum entanglement.

7 Quantum Entanglement

7.1 Public description of quantum entanglement

Quantum entanglement is one of the most difficult concepts in physics. What is quantum entanglement? We must mention the public description of quantum entanglement.

Why public description? Because you cannot find such a description in the research paper or a textbook. In literature, people will directly talk about Bell basis, Bell inequality, Bell experiment [45], local realism, hidden variable theory, and non-locality. However, on all public occasions, including professional research speakers, they will tell you mysteriously that quantum entanglement is two particles that are specially correlated to each other, no matter how far apart. Once you touched (measured) one of them, the other must instantaneously change accordingly. Then he will tell you that he doesn't understand what is going on, but the experiments proved this fact irrefutable.

He can also give seemingly simple but incomprehensible algebraic expressions to illustrate this entanglement relationship and prove quantum entanglement cannot transmit information.

Regarding quantum entanglement, two metaphors seem very vivid:

Uncle metaphor A man's sister gave birth to a child far away, although no one told him, he automatically became an uncle. This change is instantaneous and superluminal.

Glove metaphor A pair of gloves are randomly placed into two boxes that cannot be detected from outside and sent to two places far apart. Once you open one of the boxes, you will immediately know the left and right of the gloves in the other box, or the state of the other glove is determined.

According to the basic definition of quantum mechanics and other physical laws, we can give the following descriptions about quantum entanglement [46, 47]:

1. Quantum can be any particle or matter so that quantum entanglement can occur between any objects.

2. Quantum entanglement takes no time or happens simultaneously at both points far apart. According to the special theory of relativity, the "simultaneousness" of two events is relative. So the "simultaneousness" here violates the special theory of relativity.

3. Quantum entanglement violates the principle of locality; that is, any influence or interaction cannot exceed the speed of light.

4. Quantum entanglement cannot be any known interaction, because the Standard Model and General Relativity tell us that no known basic interaction can exceed the speed of light.

5. "When one of the entangled particle pair is touched, the other immediately changes accordingly." This is a causal description. However, all experiments can only prove the existence of correlation, but not the existence of causality.

6. If there is a causality between the changes of two events, it must be able to convey information. Quantum entanglement cannot transmit information, so there must be no causality.

7. Since quantum entanglement connection cannot be separated, you don't know whether any object in front of you is entangled with any other object anywhere in the universe. Of course, it is impossible to know whether the change that occurred on the object was caused by its entangled partner, or whether its change caused the instantaneous influence to any other objects anywhere in the universe. Such a physical world cannot be reduced or investigated.

8. If the speed of light is infinity, the principle of locality problem is gone.

The above descriptions are in contradiction with the existing theories or logically inconsistent. So the publicly described concept of quantum entanglement is wrong.

However, apart from this public statement, there is no other picture of quantum entanglement.

We should note that countless Bell experiments have only found correlations between "entangled particles", but have never proved that this correlation is causal [48]. Causality is limited by the principle of locality, but the correlation is not. Therefore, the term "caused" in the public description of quantum entanglement has no experimental evidence.

According to the understanding of Schrödinger equation and quantum provided by the GAI, quantum entanglement is a plain phenomenon.

7.2 Quantum entanglement in GAI

The wave function of any quantum is global. If we use the coordinate representation, as long as a particle is detected at any point, then we immediately know that all other points are empty. If there are only two options, or space is divided into two parts, then whether there is a particle in either of them is "entangled". Once found in one part, the other part must be empty. These two events are instantaneously correlated.

However, this is the nature of measurement in the CI. If we call it entanglement, then any wave function is entangled, and a single particle is also self-entangled (between different measured values or eigenstates) [49].

In other words, entanglement is a measurement property and nothing new. The description of wave function collapse, in the CI, is inherently timeless and occurs instantaneously in all space. That is, any measurement is a global event, or "non-local" event.

The quantum in quantum mechanics can be any object, as long as it can be described by Schrödinger equation, and it is not limited to a single particle. In the case of multiple particles, if there is an interaction, it should be described by many-body theory. If there is no interaction, it can be described by identical particle theory. It is strange that in the analysis of quantum entanglement, neither of the two descriptions are used, but a Bell inequality description that can prove that the two events of the measurement are correlated.

All quanta are waves, and there is a correlation between any two points in any waves. Coherence is the basic property of waves. The definition of coherence is that the values are always correlated, usually differ only by a phase shift.

Therefore, the Bell inequality experiment just proved the most elementary assumption of quantum mechanics: quantum is a matter wave, and the measurement statistics between different points are correlated. Correlation is established at any time in the full space, and there is no information other than the wave itself.

It also implies an experimental method that distinguishes between the interpretation of wave and the interpretation of entanglement. In the interpretation of wave, all measurement statistics satisfy the same correlation of the wave, and the description of entanglement believes that only two particles that are entangled are correlated. Therefore, if there is a time difference in the experiment and the setting is unchanged, that is, two particles are definitely not a pair, should also be correlated, which would support wave interpretation, and make entanglement description unnecessary. The existing Bell experiments deliberately exclude the measurement results at different times. We should simply reverse the data collection logic. If the correlation still exists, then it is proof of a common quantum matter wave.

The GAI does not propose any new assumptions, but points out the complex nature of elementary particles and interactions, clarifies the physical meaning of Schrödinger's equation and the approximate nature of the theoretical framework. From the perspective of GAI, quantum entanglement is not a new phenomenon, but a basic property of matter waves. Whether it is called non-locality or remote instant correlation, it is the basic nature of matter waves.

So how to understand the numerous quantum entanglement experiments? Or, what is their true nature?

For the polarized light entanglement experiment, the laser irradiates the crystal in the middle to produce a pair of "entangled" photons. The polarization direction of the "entangled" photons are measured on both sides. It is found that each photon seems to know the polarization of the photon on the opposite side and aligns with it. Entanglement interpretation put the experiment in a time orderly sequence: the photon pair is generated; photons move to both ends like particles; both trigger the recording equipment. In this case, the measurements on both sides should be independent, so it is impossible to understand the correlation. No matter how the direction of the measurement polarizer is changed, the other side seems always to know it. The understanding of the GAI is that the polarizers are involved in the generation of photon pairs, because they are in the coherence range of the laser, or the effective range of the global wave mode. The photon pair is produced according to the state of the measurement. We do not have *three* separate events as understood by entanglement interpretation, but *one* "entangled" global event. When down-converting photon pairs create, the polarization direction of one end of the polarizer is preferentially selected, because photons are detected behind the polarizer and must pass through one of the polarizers. The two ends are symmetrical. No matter which end is selected, the correlation is still there.

For atom entanglement experiments, such as the "loophole-free" experiment [50–52], the "entangling" operation actually makes two atoms resonate, and the resonant atoms are of course in phase or correlated at all times. Resonance is a basic property of the wave.

An "entangled state" is *one* state that collapses after measurement. Generally, a quantum state can only be measured once, but because the entangled state involves two photons, two measurement events can be triggered, but the two measurements must be correlated, and the second measurement has no additional information. Treating the two measurements as two independent events is the key to the previous misinterpretation.

7.3 The problem with the metaphors

The concept of quantum entanglement is unnecessary. The causality added in the public statement does not exist. There is no experimental proof, and it is not logically valid, so it is wrong.

What are the problems with the metaphors of the uncle and the gloves?

Uncle metaphor In verbal expression, the relationship between someone and his sister is global, independent of time, and does not require information transmission. This relationship has no physical connection. In other words, from a physical point of view, they have nothing to do with each other. The kinship or "of someone" in the language is not a physical connection. A man becomes an uncle is not a physical change at all, but an event that cannot be defined physically.

Give another example. I can think that my lucky star is North Star. Anything that happens on "my star" does not affect me. If I care about it, my observation of it must be restricted by the laws of physics, which is the principle of locality. Anything that is happening on the North Star now, I can use words to describe it as "My North Star has a flare", "My North Star..." If it is actually observed, it must be an event that happened many years ago. And what is happening now, I can only know after many years. In other words, the non-local connection between me and "my star" is non-physical and cannot cause a physical influence.

There is no restriction on this kind of "of", or related. I can turn anything in the universe into "mine". For example, the galaxy I called M87, the person I like, ... If "of" is a substantial entanglement relationship, then any two objects in the universe are essentially instantaneous entangled. Actually, this is exactly the description of the full-space potential and boundary conditions required by the Schrödinger equation in the "fundamental" non-relativistic quantum mechanics.

Therefore, the problem with this metaphor is to treat such a non-physical relationship as kinship as a physical one.

Glove metaphor The "undetectable assumption" in the glove metaphor is the same as the paradox with Schrödinger's cat, as in all quantum measurements. The collapse occurs globally, but this is an approximate description of the wave function.

Which glove is in the box? We cannot answer this question because we do not know. We did not detect, and the hypothetical premise forbids you to detect. If you accept the undetectable assumption, you return to the Schrödinger cat paradox. We do not have to accept it, because macroscopically, it can always be traced back to the moment when the glove was put in the box, such as asking the executor or recording a video.

Even if we cannot detect or trace, we still know which glove is in the box is certain. Opening any box can neither change the state of the glove in this box nor the other one. In other words, this is a situation with pre-determined hidden variables. After the boxes are packed, the left and right sides of the gloves of each box are determined.

In fact, there is no difference in mathematics between the "left or right" of a glove and the "present or not" of a particle. So the glove problem is the measurement problem. The example of dividing a particle's space into two parts is equivalent to the "left or right" of the gloves.

The measurement of any wave function can only be done once, because it collapses globally after one measurement, and the next measurement is about another system. One measurement can only get one state, and one state has no information. Therefore, neither gloves nor quantum entanglement can transmit information, because the system has only one state and cannot encode any information at all.

Therefore, the glove metaphor is a simple measurement problem. The measured non-local "entanglement" property comes from the global nature of the wave function.

7.4 Summation

The nonlocality of quantum entanglement is an illusion of the global property of the quantum state. It violates the principle of locality unless the speed of light is infinity. We can design an experiment to distinguish entanglement interpretation and global quantum state interpretation of Bell experiments.

8 What is a photon?

8.1 Photon problem

> All the fifty years of conscious brooding have brought me no closer to answer the question, “What are light quanta?” Of course today every rascal thinks he knows the answer, but he is deluding himself. —— Albert Einstein,(1951). [53]

In his later years, Einstein was still confused about the concept of photons, which is why he has the famous saying above. Unfortunately, not many people know it. In one of the most popular optical textbook in the world, “Optics” by Eugene Hecht [54], when discussing the definition of the photon, he used the above quotation.

In the interpretation of many experiments, such as delayed-choice experiments (quantum eraser) [7, 55], photon entanglement experiments, etc., researchers often understand photons as some kind of point particles.

What is a photon? This question remains unanswered up to date.

Photon is one of the most basic quantum or particle. In the definition, it is as an elementary particle with its spin being 1, there is no static mass, and its energy is Planck’s constant h multiplied by its frequency, and then no more other information. However, in reality, we have more complicated photons.

The properties of photons are fundamental when we try to understand some quantum mechanics experiments. We need a correct picture of a photon, not like defining a virtual object in a computer language with only one or two data types. The physical picture of photons is the key to understanding most quantum features.

Let us first list some of the characteristics and problems of photons:

1. Let us not consider the gravitational effect. The photon is not charged and moves at the speed of light, so it is uncontainable.

2. In quantum mechanics, photons are free, and the wave function is a plane wave, which extends the entire space. The probability of finding the photon in the entire space is the same. In fact, it is all zero. This is far from our general understanding of photons. For example, they can be produced from a certain atom and then absorbed by another; or, we can see the trail of a high-energy photon in a cloud chamber.

3. Unlike other elementary particles, which have definite spins, a real photon can have spin in various superimposed states. It is generally believed that it can have any value between -1 and $+1$, corresponding to various polarization states, including circular (± 1), elliptical, linear (0), etc. In fact, we are afraid it is even more complicated, and its spin may exceed 1.

4. From the perspective of electromagnetic radiation, the only difference between high-energy photons and low-energy ones is their frequency. However, the classic electromagnetic radiation pattern is much more complicated than the general concept of polarized photons, mainly due to the existence of various multipole radiation and the interaction of complex electromagnetic fields and matter.

   Electromagnetic radiation generally diffuses and propagates in the entire space. However, photons, especially high-energy photons, seem to move like particles in one direction at the speed of light, without diffusion.

5. According to the definition of the photon, the energy of a photon should be a fixed single value, and there should not be a distribution, but the photon emitted by an atom has an intrinsic bandwidth. The intrinsic energy bandwidth of different atoms and different levels varies, reflecting the large differences in energy level half-life (energy-halflife uncertainty relationship [56]). The energy distribution of a single photon is hard to understand because we can use prisms to divide photons into different energies. This is in contradiction with the inseparability property of elementary particles (not including high-energy processes).

6. In some experiments, the angular momentum of the photon seems to be greater than 1, which is difficult to understand. This kind of phenomenon is generally explained as photon orbital angular momentum [57]. However, photons cannot be constrained. From the perspective of photons, the concept of orbital angular momentum is incomprehensible. In the orbital angular momentum theory of light, the images with orbital angular momentum ±1 and spin ±1 are the same. That is to say, if the theory of orbital angular momentum holds, the spin concept is not needed. In other words, the wavefront of light has a degree of freedom of helicity, whether it is called spin or orbital angular momentum, but it should have only one name, not necessarily quantized, and can be greater than 1.

7. The atomic energy-level transition is understood as the generation or absorption of photons. Since the photon spin is 1, the angular momentum difference between the two energy levels must be 1. If the angular momentum difference is not 1, it is considered that the transition will not occur, and it is a forbidden transition [58]. However, forbidden transitions do happen. If we check the photon energy, there is just one single process. This means that the photon's spin is not 1, it can be 2, 3, or even greater. In the classical picture, it is not difficult to understand, which is a multipole radiation, such as electric quadrupole radiation, magnetic dipole radiation, or higher order ones. However, it is impossible to understand from the definition of the elementary particle of the photon, because the maximum spin of photons is 1, and it is impossible to take away more than 1 unit of angular momentum from the atom.

8. Is a photon a point in space or a certain range of distribution? If it is a point, its coherence is difficult to understand. If it is a certain range of distribution, how large is it? What kind of distribution? If different photons have different distributions, the identical particle concept is in danger.

9. Considering the lifetime of atomic energy levels (a few nanoseconds to hundreds of milliseconds), the distribution range of a photon is very large, from a few meters to tens of thousands of kilometers. Even if the shortest distance of a few meters is far more than tens of billions of times the size of an atom, how does it interact with atoms? In particular, how does the photoelectric effect occur?

Note that the above problems about spin do not exist in classical electromagnetic theory. In the classical case, we do not require the rotation speed of the electromagnetic vector (wavefront helicity) to be some discrete value. It is not required that the orbital angular momentum (or spin) be ±1 or other integers.

Regarding the energy level lifetime or the half-life of a transition, there are two understandings. One is the probabilistic lifetime, such as the γ decay of the nucleus. For each decayed nucleus, a γ photon is decayed at a certain time, and it happens instantaneously. The half-life only reflects the intensity of the decay. We can track every photon that decays; the other is the time required for energy level transitions, that is, the duration of each transition. For atomic energy level transitions, the resonance between atoms of the same species cannot be ignored, because they inevitably influence each other. The results we observe are the result of mutual influences. So atoms have stimulated radiation, but usually, nuclear decay does not.

8.2 Photon in GAI

In section 2, we said that there is no single standalone "clean" elementary particle. All elementary particles cannot be stripped of their influence on the surrounding space-time. All particles and all interactions are complicated. The same is true for photons, which are the result of all basic interactions specified by an infinite number of space-time points in SM.

Photon has no rest mass, so it is pure energy. According to the standard model, energy scale, or energy density, determines the importance of different physical interactions. For high-energy photons (γ rays), due to the high energy concentration in a small space-time range, other more localized degrees of freedom in SM, such as electron-positron pairs, other high-order interactions, appear. Their contribution is so significant that the high-energy photon is more like a localized particle. High-energy photons do not diffuse or lose energy only through interaction with other particles. Low-energy photons (the energy is much lower than the mass of the electron, 511 keV, photons in optical phenomena are low-energy ones). Considering its wide spatial distribution, the energy density in any part is very low. Except for electromagnetic interaction, all other degrees of freedom are frozen and cannot be excited. Therefore, low-energy photons appear as pure electromagnetic radiation, described by classical electromagnetic radiation theory. In fact, Maxwell's equation is a simplified electromagnetic interaction of SM. The other interactions and degrees of freedom still exist at each space-time point, but the contribution is too small and can be ignored. Therefore, low-energy photons are classical electromagnetic waves that can be described by Maxwell's equations.

So how to understand the quantum nature of photons? That is, the relationship between the energy of the photon and the Planck's constant and frequency, or in other words, why does the atomic energy level transition always emit a photon? Instead of lower energy photons? This concerns the property of the eigenstate, which is the allowed solution to Schrödinger's equation. Eigenstate is the dominant mode. As we said above, the range of a photon far exceeds that of an atom and is hundreds of millions of times of the atomic radius. For atoms, this intrinsic oscillation frequency is obviously the preferred frequency. We should also note that in optical experiments, such as line spectral measurement, there are always a large number of the same atoms involved, and there are resonances among atoms. It is the dominant mode (eigenmode) that releases or absorbs all energy at once. The dominant radiation or absorption line is a manifestation of the combined effect of a large number of atoms of the same species.

To put it objectively about the atomic spectrum, we only see some resonance peaks with relatively concentrated radiant energy frequencies. We did not see how atoms emit or absorb photons.

In the GAI, all photons are complex and in principle nonlinear, but low-energy photons are linear classical electromagnetic waves, with all the properties, such as superposition and coherence, and can be linearly decomposed. The spiral nature of the electromagnetic component of the wavefront, namely the spin, is determined by the radiation source.

As the energy increases, the physical composition of the photon is constantly changing. For high-energy γ photons, weak force and strong force comes into play. The effective range of these two interactions is very short. As the photon moves at the speed of light, there is no decay, and it can only lose energy by interacting with other particles.

The photons emitted by atomic electron energy level transitions only involves electromagnetic interaction, while the photons produced by nuclear processes involve higher energy scale interactions.

Except for gravity, electromagnetic interaction is the only long-range low-energy interaction in physics. Therefore, it is natural that electromagnetic processes dominate our daily world. If one calls the energy change process of an atom the generation or absorption of a photon, of course, it can be defined that way, but there are too many kinds of photons like this, and a simple mathematical definition may not be enough.

8.3 Another wave-particle duality

The dispute between the wave and particle nature of photons lasted for centuries. Later, it was believed that the wave-particle duality explained by quantum mechanics ended the dispute. However, Einstein's doubts make us feel that the problem is not so simple [59]. First of all, the behavior of "sometimes like waves and sometimes like particles" described in the wave-particle duality is not well-defined. Secondly, experiments to prove the particle nature of photons are not convincing. It is not so much the particle nature of photons as the particle nature of the detection method. The particle nature of low-energy photons is an observable effect. A widely distributed wave with the right frequency can sure excite a localized atom.

Simply treat all particles as a "pure matter wave" model can explain all the properties of photons and particles with rest mass [60]. The particle-like behaviors of electrons and photons come from quantization and eigenstates, and all particles are only waves.

GAI understanding of photons provides another wave-particle duality. As the energy increases, or the energy density increases, the photon dominated by electromagnetic interaction gradually becomes dominated by stronger interactions and becomes more particle-like γ photon.

The SM reveals that the interaction behavior of space-time points depends on the energy density, and the wave-like property is natural, but it will be more particle-like in high energy density. We can take a basin of calm water as an example. If we drive the water surface slowly and regularly, we can get a series of smooth waves. If different water waves are driven in different directions, these waves will be superposed. In some special places, if the oscillation caused by the superposition of the waves reaches a certain frequency or amplitude, some water will be thrown out to produce water droplets. The water droplets show particle properties instead of water continuum wave. Throwing a stone into the water means that the energy is more concentrated. In addition to the spreading water ripples, some water droplets will appear. Treating the water surface on a large scale, we can write ideal continuous wave or fluid equations. However, even for water, the interaction that determines its microscopic properties is still extremely complex. At different scales, there is surface tension, van der Waals forces, hydrogen bonds, covalent bonds, oscillation, rotation, collective motion, gas-liquid balance, vortex, etc. These interactions can be ignored in large-scale wave studies. When water droplets appear, other effects such as surface tension becomes more important.

The nature of space-time and energy determines the different physical manifestations of photons in different energy density scales. The large-scale coherence and globality of photons in low-energy experiments is the behavior of waves under certain boundary conditions. At this time, they are just waves. All interference experiments can be simply explained by wave coherence. Quantum entanglement is just a special kind of coherence.

The equivalence of energy and mass can also understand the different behavior of photons in different energy scale. The lower the energy density, the less likely there will be components such as positive-negative pairs and other high-energy elementary particles within a certain spatial range. The degrees of freedom of high energy scale will not appear, and their contributions are too small. However, if the energy is more concentrated, the situation is different. The rest mass is the energy contained in a certain relatively stable perturbation mode in space-time.

The particle nature of high-energy photons can also be explained by special relativity. Suppose low-energy photons are ordinary radial electromagnetic radiation in a reference frame close to the speed of light. In that case, the photon energy will be concentrated at the point facing the direction of motion of the frame of reference. In contrast, the energy in other directions is relatively small to be negligible (Headlight effect [61]).

8.4 Summation

Photon, like other particles, is a perturbation mode of energy to space-time. The low-energy photon is a simplified electromagnetic interaction of SM, or electromagnetic waves, with no inherent quantization requirements. Whether spin or energy is quantized is determined by the source of the disturbance. High-energy photons are more like local particles due to the participation of higher energy scale degrees of freedom. The definition of the photon in the elementary particle table is a mathematical definition of a single mode, not a physical reality.

9 Reality

9.1 Debate on objective reality

The reality, or objective reality, is a philosophical concept that refers to the existence and nature of matter, or the objective world, that does not depend on human perception and knowledge. Our perception and knowledge of the matter are subjective.

In quantum mechanics, the physical system is equivalent to matter, or reality, and measurement equivalent to perception and knowledge, which is subjective. As in quantum mechanics, measurement affects the physical system being measured. That is, subjectivity affects objective reality; the independence of objective reality is questioned. That is, does objective reality really exist?

This is one of the important arguments in the early days of quantum mechanics. The belief that objective reality still exists is called realism. Einstein was a firm realist, and Bohr was firmly opposed to realism, arguing that it would be meaningless to discuss objective reality without observations [62]. The famous quotation that reflects this difference in understanding is: “If you are not looking at the moon, does it exist?”. Only at the philosophical level, there is no obvious answer to this controversy. Einstein believed that, whether you look at it or not, the moon exists. Bohr believes that if no one sees the moon, there is no point in discussing the existence of the moon. Seeing is measuring.

Specific to the measurement process of quantum mechanics, such as the spin of an electron, because a single electron is too fragile, no matter what method is used to measure it, it will definitely change its state significantly. So does it have a spin state before measurement? Is it the state we measured? There are several possible situations (assuming the measurement is correct) [21]:

1. The measurement does not change the original state of the electron and the measured value is the original value of the electron spin.
2. The measurement does not change the original state of the electron, and the measurement happens to get this value, and it can get another value.
3. The measurement changes the state of the electron and the electron turns the original spin direction to the measured value.
4. The measurement changed the state of the electron. The electron had no spin before, and the measurement caused the electron to produce the measured spin.

Unfortunately, although we all agree with the measurement results, we have no way of knowing which of the above situations actually happened.

There is also a relevant question: whether the measurement changes the object, does the object originally have a certain state? Although we would never know what the state is. Realism believes that it exists, but Bohr believes that it is meaningless to discuss the issue.

For situation 1 and 2, the measurement does not change the state of the electron, which is very unlikely. Whether the measurement is a magnetic field or an electric field, it will affect the state of the electron. It is possible that the electron does not need to be changed, but in principle, it has to interact with the measuring device because the device is much more powerful than a single electron. No-changing of the electron is also inconsistent with the CI’s understanding of measurement. Situation 2 does comply with the Copenhagen Interpretation. Measurement causes the electron to collapse, but before the collapse, the state of the electron did not change. Situation 1 is a special case of situation 2.

In situation 3, a standalone electron has a predetermined spin, although the direction is uncertain. This is the traditional view. The difference between this situation and situation 2 is that the electron state has changed during the measurement, such as it aligns with the magnetic field, and not just wave function collapse. The probabilistic collapse has a chance to collapse into another value.

Situation 4 means that in the interaction with the measurement equipment (for example, in a magnetic field), the electron’s spin degree of freedom selects a direction, or the spin (and direction) is generated during the interaction. Or, the quantization in a specific direction is generated during the interaction. It may have no spin when it exists independently, or some residual spin left over from the last interaction.

Situation 1 and 2 are probabilistic measurements, and no interaction is involved. Situation 3 and 4 consider the interaction brought about by the measurement, and the measurement readings are deterministic.

Actually, all four situations conform to realism. Before the measurement, the electron has a predetermined state (including the superposition state), although we cannot know what the state is. Bohr believes that it is meaningless to discuss the pre-measurement state, so he actually did not deny realism. He thinks that physics should be based on measurable or measured properties (instrumentalism) [63].

Another proof for the validity of realism comes from our calculation of elementary particles. According to the standard model, the calculation of some basic properties of particles, such as electrons, can be very accurate. The basis of the calculation, that is, the numerous Feynman paths cannot be measured, but they are still working. They should have been accurately described so that we can have very accurate calculation results. However, the calculation of other particles is limited due to calculation difficulties.

9.2 Answer by GAI

Purely at the philosophical level, if it is not experimentally verified, the argument is indeed meaningless. After all, the person who argues, or the scientific explorer himself, can only be subjective. Our description of any objective must go through our cognition and our measurement. If the measurement itself is not objective, objectivity does not exist. If the object is not measurable or verifiable, different viewpoints are just philosophy, not science.

However, we still want to know what happened after all. What we cannot measure right now, does not necessarily mean that we cannot in the future. We can also guess from all known facts.

GAI starts from the standard model, recognizing the interaction and the complexity of elementary particles.

Situation 1 and 2 in the previous subsection actually deny the interaction and attribute the result to the special discontinuity of the measurement. We believe that this view of measurement is a rude simplification, derived from the ideal wave limit picture of Schrödinger equation. The instantaneous change from one ideal wave to the next must be discontinuous, but this is not the real process.

In section 8, we believe that the spin of a photon is not quantized and can be any value. Whether quantized or not depends on the process of photon generation. Situation 4 is equivalent to the idea that the spin of a single standalone electron does not need to be quantized. When interacting, $\pm 1/2$ are the two eigenvalues of the electron. The spin is the emergence of the electron participating in the interaction, rather than being the "intrinsic property" of its own.

Considering the interaction between electron and measurement devices, unlike the traditional view of Situation 3, GAI favors Situation 4. The reasons are:

1. GAI believes that the global intrinsic behavior of the wave nature is the source of all quantization, so is the quantization of electron spin.
2. The physical picture of $1/2$ spin is hard to understand. For example, it changes back to the original state after two full rotations. As the eigenstate during the interaction, it can be understood similarly to orbital angular momentum quantization.
3. It is difficult to understand the spin of a single standalone electron, at least from a classical perspective.
4. At least there is no experimental evidence to disprove it because experimental evidence must be obtained through interaction or measurement, which is similar to Schrödinger's cat paradox.
5. The understanding is actually consistent with CI.

Since experiments cannot tell us what happened, we can only reason by logic and guess which one is more likely, for example, which view has fewer assumptions.

In section 4, we argued that the quantization of atomic energy levels and angular momentum are natural emergences, so why can't the quantized angular momentum of elementary particles be the same reason? After all, we believe that elementary particles are some intrinsic or stable energy excitation mode of a complex multi-body process. They do not need to have the same properties when they exist independently. For example, neutrons are unstable when they exist alone but very stable with a proton. The confinement of quarks is also an example.

In conclusion, for realism, GAI recognizes Einstein's realism, but it is not contradictory to Bohr's instrumentalism. However, due to the recognition of local interaction and complexity, we do not agree with CI's probability and wave function collapse measurement theory. As an extension of the emergent quantization concept, we believe that the spin of elementary particles is also the intrinsic mode that appears when interacting, not necessarily the property of standalone existence. Of course, it is also possible that the particle does have its spin when it is alone.

9.3 The relativity of reality

About reality, there is one more point that should be discussed. That is, whether, in the context of philosophy or science, the reality is relative. We cannot avoid discussing reality from the perspective of subjective cognition and interaction.

We cannot deny that we are the cognitive subjects and cannot rule out the influence of cognitive ability and measurement validity.

Any cognition, or measurement, of our object, is a complex interaction. Generally speaking, the more macroscopic and stable the object being measured, the closer the space-time distance, the less susceptible to the influence of observation tools, the easier it is to get repeated results, and the more reliable the measurement results are. For example, whether there is a moon or not, although many people have not seen it and have doubts in their hearts, there are still many people who have seen it. If we already have scientific tools, we cannot be affected by the climate and the location of the moon. Every one of us can check whether the moon exists; if we know that physical phenomena caused by the moon's gravity, such as tides, exist at any time, we also know where the moon is.

If the distance of time and space is far away, or the object signal is weak, or the tool is defective, or we are biased, the observation results will be less reliable. Therefore, we do not have strong confidence in some ancient historical events, the physical properties of distant celestial bodies, the properties of microscopic objects, the vague memories of witnesses,...

Conversely, is any fact absolutely credible? For example, would we believe that the moon must be there? If someone tells you that the moon is missing, or that two moons appear in the sky, should you believe him? How about another person tells the same story? Or even more people?

In physical measurement, all the values we measured have uncertainty, such as electron mass. Although it is very accurate, there is an inevitable uncertainty, that is, the width of the statistical distribution of experimental measurement.

Generally speaking, quantization means accuracy, no uncertainty, and no distribution width.

The mathematical definition is the same when we define the mass of an object as M or the speed at v, which means that these quantities are accurate, and there is no uncertainty.

Due to the complexity of the interactions in the standard worldview and the influence of external factors added at any time, it is impossible to obtain a noise-free and accurate measurement. Infinitely precise measurement is impossible.

The uncertainty of physical quantities comes from the relativity of reality. For measuring the spin direction of an unknown electron, the error is of the same magnitude as the measured value, which is very unreliable. Although we believe there is a reality, it is unknowable, which is why Bohr criticized reality.

For certain quantum concepts, such as quantum computing, the relativity of physical reality is ignored. In Shor's algorithm [64], operations like $N+1,\ N+2,\ N*M$ are required, where N is expressed by a physical quantity and is an integer of at least 1000 binary bits, or about 300 decimal digits. So far, no physical quantity has an accuracy of more than 15 decimal digits. In quantum computing, 3-digit precision is very difficult. How to correctly implement $1.01(\pm 2) \times 10^{300} + 1$? So Shor's algorithm cannot be implemented for really large numbers.

The reality based on cognition and measurement is of course relative, even if the word “reality”, you ask different people, and they will tell you a different answer. We don’t even have a unified view of what reality is, and how can anything be absolutely correct or absolutely accurate?

9.4 Summation

GAI recognizes both realism and Bohr’s instrumentalism. We believe that physical reality is valid before measurement, but due to the influence of instrumentalism, the perceived reality must be relative.

10 Determinism

10.1 Determinism and mechanical determinism

Determinism means that the state of the physical system evolving over time is predetermined.

It is generally believed that classical physics is deterministic. As long as we know the motion states of all objects at any time, we can predict all the states at any time in the future. This is the earliest Newtonian mechanical determinism.

According to the relativity of reality discussed in section 9, we know that it is impossible to know the exact physical state at any moment. Considering the complexity of multi-body interaction and nonlinearity, together with the problems of calculation methods (for example, there is no accurate calculation method in computational fluidal dynamics, CFD), and the butterfly effect, even under classical conditions, it is impossible to calculate or predict the evolution of the physical system accurately.

10.2 The probabilistic nature of quantum mechanics

In CI, quantum mechanics, including measurement, is inherently probabilistic, that is, indeterministic. In principle, the measurement result is unpredictable. If there are multiple possible outcomes, the probability of each outcome is determined by the probability amplitude of its wave function. If it is a single process and cannot be repeated, it is impossible to predict the result. For example, at which point the photons irradiated on the screen through the double slits will fall, it is impossible to predict and calculate. Although we can calculate that certain points are more likely to land, we cannot make any predictions for points with the same probability.

Researchers of quantum field theory, like t'Hooft, infer that the causality and locality of quantum phenomena close to the Planck scale can be restored through a deterministic theory [14].

In section 6, we said that quantum is the wave function, and the wave function is the probability amplitude of all possible measurements.

The interpretation of quantum as the wave function, or the description of probability amplitude, has the following problems:

1. The wave function is not physical. The probability amplitude is not a physical quantity. It cannot be measured and can only be verified by large quantity statistics.
2. In the Copenhagen Interpretation, the measurement causes the wave function to collapse. The collapse of the wave function occurs instantaneously and does not require time. This process cannot be physical, because the physical quantity before and after the collapse is discontinuous, and the wave function itself is not a physical quantity.

From the probabilistic nature of quantum mechanics, we know measurement causes unpredictable discontinuous changes. Although there are some theories, such as the multi-universe theory [10, 65], that try to interpret this quantum behavior, in each universe it proposes, every measurement is still discontinuous and causes the universe to split infinitely.

Since the result of any measurement cannot be predicted, quantum mechanics is inherently probabilistic and indeterministic.

10.3 Classical probability

For a classical system with many-body interaction, nonlinearity, and rapid evolution, the long-term evolution is unpredictable. However, the system still has statistical properties that can be described by macroscopic quantities, and its microscopic composition satisfies the macroscopic statistical properties, while the specific behavior of the microscopic components is not important. This is exactly the scope of statistical physics. Statistical physics discusses probability distributions.

That is to say, for a classical system, if we cannot track its evolution, we will also describe it with probability. In other words, the classic evolution system that we cannot track seems to be probabilistic.

For example, considering the gas enclosed in a piston expands or compresses adiabatically, if the process is not recorded, we will find that the gas velocity distribution in the initial and final state is a perfect normal distribution, but the height and width of the distribution change. The velocity distribution function is global and affects every gas molecule. If the process of change is ignored, the probability distribution of each molecule has undergone a sudden change, which can also be called "collapse" (the concept of collapse here is not the same as that of quantum mechanics, which collapse to a single value). We can assume infinitely slow adiabatic changes for the classical process, and the distribution function will change continuously. If we ignore the process of change, it looks similar to quantum measurement.

The same is true for coin tossing. Suppose you ignore the movement of the coin and the influence of all variables (momentum, direction, mechanical properties of the drop point, changes in airflow, etc.), the head and tail distribution when the coin stops is a relatively stable distribution. However, if the process can be tracked, we can predict which face of the coin will land on at least shortly before it stops.

Therefore, even in a classical system, we can only describe it with probability if it is sufficiently complex. And if we can track it, the more information we can have, the more predictable it can be.

10.4 View of GAI

GAI thinks that the wave function or the solution of the Schrödinger equation is an approximation of the ideal wave limit. We did not discuss the physical meaning of the wave function. For the time being, Bohm's probability interpretation is used.

The measurement of course leads to a change of the quantum. Change to what? Another state, or another wave function. The measurement definition in quantum mechanics is actually sampling. We tend to believe that the intervention of the measuring device actually changes the state of the original wave function.

That is, the measurement changes the wave function from one stable distribution to another. Since quantum mechanics completely ignores the intermediate process of changing from one state to another and only describes the initial and final states, it is inevitable and can only be described by probability. This is the same as the classical situation.

By accepting the probability assumption of the wave function, GAI can understand the indeterminism of quantum mechanics but believes that its principle is the same as classical physics because it ignores the intermediate physical processes.

So, is the real physical process deterministic or not?

GAI recognizes physical reality but thinks that physical reality is relative and cannot be accurately described. In this case, the real physical process is deterministic, but cannot be accurately calculated or predicted because it is impossible for us to depict the original physical system accurately.

We rephrase above as follows: GAI believes that considering the relativity of reality, physical processes are deterministic but cannot be accurately predicted. The more macroscopic the system, the richer the information we can acquire, the more we can calculate and predict; the more microscopic, and the more complex the system, the more unpredictable. This is consistent with the classical view of determinism.

The future cannot be accurately predicted, but is the future of the physical world predetermined? Random? Or is it chaotic? For example, how to understand the randomness of nuclear decay?

From a physical point of view, the calculation is very difficult due to the complexity of the basic interaction and nonlinear nature. However, we just cannot calculate. Being incalculable does not mean that the micro process is inherently probabilistic. The wave function definition of quantum mechanics is a mathematical definition to describe statistical properties, not a physical definition.

As for the randomness of nuclear decay, although we cannot predict it, and it seems to be random, but we cannot prove it. It can happen deterministically but appears to be random. It's like statistical physics or tossing a coin. Of course, we cannot prove it is deterministic either.

10.5 Free will and fatalism

Although GAI cannot prove nor accurately predict, we still tend to believe that the physical process is deterministic, that is, the future has been predetermined. This of course has serious philosophical consequences, which may seriously affect people's worldviews and attitudes to life.

However, GAI's determinism is called agnostic determinism, which is different from agnosticism, determinism, and indeterminism.

If people really understand the meaning of this kind of determinism, they will not necessarily be pessimistic or fatalistic.

First of all, looking at it from a cosmic perspective, according to our current understanding of the universe, the fate of the universe is determined.

Secondly, it is impossible to verify whether the future of individuals and human society has been determined. Each of us can only experience the past and the future once. No one can go back in time and make another choice and compare. Since it cannot be changed, cannot be compared, and cannot be predicted, the future is still uncertain and should not affect anyone's free will. Even if your current free will and thinking are previously determined, you cannot change. You still have to think that way, have to decide, and bear the corresponding consequences.

Thirdly, can we think that the future has been determined anyway, and we don't have to do anything, as long as we eat and sleep and wait for the bright future to come? The problem is that the future, especially your own future, although determined, you don't know what it would be, and it may not necessarily be good. You may have a miserable future, which is determined by your doing nothing.

The more macroscopic the system, the more determined its macroscopic properties and the easier it is to predict. We hope that humanity will soon step into the next level of civilization, the stellar civilization. If no major accidents occur, it should be relatively certain, but this requires everyone's efforts. Again, this is not guaranteed. If there are more people doing nothing, human civilization may go downhill. Don't forget the "great filter".

Whether your free will is really free or random, you still have to work hard to acquire all kinds of information, think, and make decisions. You are part of the world, part of the future, and your will, decisions, and hopes are also part of the world. You can have and experience full consciousness and freedom, as well as the joy and happiness that you strive for, whether they are determined or created.

10.6 Summation

It is wrong to think that classic determinism can accurately calculate the future of the world. The relativity of reality and the complexity of calculation indicate that the future cannot be accurately calculated.

The indeterminism of quantum mechanics comes from the nature of its probabilistic formulation and is non-physical.

GAI tends to believe that the world is deterministic, but it cannot be accurately calculated or predicted. Inability to calculate accurately does not mean that it is indeterministic.

It is necessary to distinguish between agnostic determinism, agnosticism, determinism, and indeterminism.

Determinism does not necessarily mean the absence of free will or fatalism.

11 The physical meaning of wave function

As mentioned earlier, the most precise definition of quantum is its wave function, but what exactly is a wave function?

In the classic wave description, a wave, such as the electric field component (one-dimensional) of electromagnetic waves,

$$E(x,t) = E_0 e^{i(kx-\omega t)}, \tag{6}$$

is a fluctuation of some physical quantity, with dimensions, which can be field strength, pressure, position offset, etc. E_0 is the amplitude of the fluctuation. The square of the amplitude is energy density.

In CI, the amplitude of the quantum wave function is the probability amplitude of the particle's appearance. However, neither probability nor amplitude of probability is a physical quantity. In other words, the quantum wave function is not a physical description. However, this interpretation is consistent with experimental statistics and we can say it is supported by experiments. So why is this happening?

Let's first take a look at some clues and hints:

11.1 Schrödinger equation and plane waves

Let's write down the Schrödinger equation (simple form):

$$H\psi(x,t) = E\psi(x,t) = E\psi(x)e^{-iEt/\hbar} = E\psi(x)e^{-i\omega t}. \tag{7}$$

H is the Hamiltonian, and the dimension is energy, which is the same as E on the right side of the equation. E is a constant, which can be understood as similar to the amplitude E_0 in the equation (6). $\psi(x)$ is the spatial part of the stationary wave function. If it is a free particle, the solution of Schrödinger's equation is a plane wave, $\psi(x) = Ae^{-ikx}$, where A is the normalization constant, so we have:

$$\psi(x,t) = Ae^{i(kx-\omega t)}. \tag{8}$$

With the same form as (6).

From Eq. (8) we can see that for free particles, or plane waves, the form of the quantum wave function is the same as the classical wave. However, classical wave expression has a clear physical meaning, and the physical quantity of the fluctuation is simple harmonic oscillation over space and time. The quantum wave function, according to Copenhagen Interpretation, is just a probability wave. Since the plane wave extends infinitely, the probability of finding particles in any small area is almost zero. That is, the normalization constant A tends to zero. But in Eq. (6), the amplitude is an arbitrary value. This difference can be eliminated in an infinitely deep well of finite width.

In a finite-width and infinite-depth well, the quantum wave function is the same as the classical one, and both have discrete wavelengths, and both are standing waves. The difference is that the amplitude of the quantum wave function is restricted by the normalization condition, while the classical wave has no restriction. But the normalization condition is only because the number of particles is required to be 1. For a quantum wave function, the sum of the probabilities of all possible wave modes can only be equal to 1.

We regard the plane wave as a special case of the wave function and find that the quantum wave function of the photon is consistent with the classical form. However, the classical description has a clear physical meaning, but the quantum probability amplitude description needs interpretation.

In Eq. (7), if the energy E of the particle is regarded as a whole, then the square of its spatial distribution function $\psi(x)$ is the energy density distribution of the particle in space. So the wave function is the energy density distribution function.

11.2 Interactions involved in waves

We have explained earlier that only electromagnetic interaction in the standard model is the long-range, low-energy interaction that plays a role in the laboratory experiments. If we carefully analyze all classical wave phenomena, such as sound waves, electromagnetic waves, seismic waves, water waves, etc., you can find that the elementary interaction involved can only be electromagnetic interaction (water waves have gravity but are constant).

In real-life applications, the quantum phenomena described by the Schrödinger equation are all electromagnetic. Other potentials are mostly hypothetical. Nuclear physics is not discussed here, which involves strong interaction.

In other words, the various quantum phenomena we discuss in condensed matter physics, atomic and molecular physics, optics, chemistry, materials, biology, etc., are actually all electromagnetic ones.

In a physical system dominated by electromagnetic effects, waves are the most basic phenomena.

11.3 Walking droplet experiments

The walking droplet experiment refers to a small oil drop on a vibrating water surface. The vibrating water surface can produce various wave behavior. By observing the motion trajectory of the oil drop to simulate various quantum phenomena, it is also called hydrodynamic quantum analogs [66].

The walking droplet experiment can simulate double-slit interference [67], tunneling effect [68], quantized orbits [69], Zeeman effect, quantum corral [70], etc.

In the walking droplet experiment, it is actually the wave behavior of water waves. The similarity between water wave and quantum effect comes from the nature of quantum matter wave. However, the walking droplet experiment can also help us understand the particle nature and the probability amplitude because of the oil droplet tracer. Experiments have a large number of statistics on the trajectory of oil droplets. The statistical properties of the trajectory show various quantum or wave features.

11.4 The physical origin of the wave function

Quantum mechanics describes physical objects. It is the wave function that embodies all the quantum properties, but the wave function is not physical. Instead, the physical definition of a classical wave description is clear. Should the wave function have a physical origin, or that it actually happens to be the expression of certain physical property?

We know that the classical amplitude actually represents the energy density. In the standard worldview, we said that the energy density is the basis of what kind of basic interactions space-time shows. Although the range of the wave function amplitude is generally far less than what required by the activation of other degrees of freedom, the region with high energy density is more likely to cause the corresponding excitation, such as the photoelectric effect, the reduction of silver ions during film development, etc., which are completely valid. Like in the walking droplet experiment, oil droplets are more distributed in areas with large amplitude and high energy density. In this way, the quantum wave amplitude should be the amplitude of a certain physical quantity, such as the electric field strength.

In other words, the probability amplitude of the wave function is actually the amplitude of a certain physical quantity reflecting the energy density, and the wave function is that of a certain real physical quantity. When the wave function is measured using particles, for example, there are many reducible silver ions in a developing film, the areas with high wave function energy density are more likely to be developed. The probability value is energy density. The wave function becomes an energy wave.

In the standard world view, particles are inherently the perturbation mode of energy to space-time. Reflected in quantum mechanics, considering non-relativism, an abstract quantum is its low-energy part, or the electromagnetic interaction part, in the form of energy.

Note that the term probability is still used here. However, it is already what we discussed in section 10, that is, it is the physical process that determines the occurrence of an event, but there is no good way to calculate it.

11.5 Summation

The Schrödinger equation is the diffusion equation of matter waves, and electromagnetic interaction is the interaction carrier of matter waves. The similarity between photon wave function and classical electromagnetic radiation wave function implies that quantum wave function is energy wave. We can understand the particle nature of quantum waves from walking droplet experiments. The probability amplitude description should have a physical origin. The quantum wave function is also its energy density distribution function, and the energy density determines the action probability of particle properties. The probability concept in CI just happens to depict the energy density characteristics of matter waves.

12 Boundary between quantum and classical world

It is generally believed that the quantum world is different from the classical world, and there are essential differences. The microscopic world is controlled by quantum theory, while the classical world can be explained by classical Newtonian theory. However, there is only one world, and the laws are different. How should they be connected?

Traditionally, Bohr's correspondence principle [8] and H. Dieter Zeh's quantum decoherence theory [71] to try to answer this question. We discuss them below and put forward the viewpoint of GAI.

12.1 correspondence principle

Bohr described the corresponding principle in 1920 [8, 72], but as early as 1913 when he proposed the atomic Bohr model, he had already used this principle. Correspondence principle refers to: In the limit of the large quantum number, the description of the physical system by quantum theory should conform to that of the classical one.

Bohr's corresponding principle argues that quantization is the essence and is correct. The classical theory is only the behavior of quantum theory in the limit of large quantum numbers. The effect of quantization can be ignored because the unit is too small. The analysis of some typical systems, such as hydrogen atoms and harmonic oscillators, can prove that the corresponding principle is valid.

It is also believed that Planck first proposed the corresponding principle. Planck states that when the Planck constant approaches zero, quantum theory returns to classical theory [73].

Facing the legitimacy of the quantization hypothesis, Bohr or Planck's corresponding principle tries to answer, why is the physical world at the micro level quantized, but not in the classical macro world? They both believe that quantization is the basic principle, but quanta are too small to be observable in classical conditions. They cannot answer why the microscopic world is quantized but take it as a basic assumption.

It should be noted that Bohr and Planck proposed corresponding principles before the De Broglie matter wave hypothesis and the Schrödinger equation. They put forward the quantization hypothesis based only on the existing phenomenon. To solve the contradiction between quantization and classical continuous quantity, they have to reconcile to the corresponding principle.

12.2 Decoherence theory

The basic characteristic of the wave is coherence. The change of value or amplitude is within the range of oscillation, and there is a fixed phase difference between any two points.

As mentioned earlier, the quanta in quantum mechanics are all ideal waves, that is, ideal coherent in the whole space. The mathematical treatment adds a wave term containing energy to the wave function after solving the spatial part of the Schrödinger equation. The oscillating term is equal everywhere in the whole space ($e^{-iEt/\hbar}$).

Such treatment will inevitably lead to idea coherence of the wave function in the whole space. However, this is not the case experimentally. The quantum coherence has certain space-time limits.

To solve this problem, in the 1970s and 1980s, H. Dieter Zeh proposed the quantum decoherence theory [71, 74, 75], which believed that the interaction between environment and the quantum system led to the loss of quantum coherence. In mathematical formulation, the environment is often regarded as a heat bath. Although the initial decoherence theory tried to explain the measurement problem, it did not succeed [76].

The decoherence theory does not clearly define the environment and gives too much choice to the environment. In principle, one can blame the environment for any unanswerable question.

In non-relativistic quantum mechanics, since the environment is always known, or defined, embodied in the uniqueness of the potential and the boundary conditions, the Schrödinger equation always has solutions, whether are eigenstates or not. . The solution must have a certain energy, and thus also a certain oscillating term. The oscillating term is equal everywhere in the whole space or being ideal coherent.

If the environment is set as unknown, the problem is unsolvable. The discussion is meaningless.

Therefore, the disappearance of coherence should not exist with the assumption of ideal wave and Schrödinger equation. We can always specify the environmental conditions, add them to the potential or boundary conditions to obtain new solutions, and establish new ideal coherence.

12.3 View by GAI

GAI is based on the standard worldview, in which the concept of particles is different from the classical ones. However, the concept of particles is not a choice, but can only be based on particle and interaction concepts of SM established by countless theories and experiments. The classic particle concept cannot be used as a theoretical basis. In other words, the classic particle image is another kind of extreme idealization, that is, extreme localization: all the properties of particles exist on an infinitesimal point, and the interaction passes through an extra, a priori, phenomenological potential field to describe.

If standard particles and interaction pictures are used, there is no difference between the classical and quantum worlds. In the standard particle picture, each particle is a complex energy perturbation mode that fills the entire space. Some modes have more concentrated energy and can be excited with higher degrees of freedom, or have a significant contribution. Some particles are excited only with low energy degrees of freedom. The Newtonian worldview and the quantum worldview are two extreme descriptions of the same world. The Newtonian worldview is extremely local, and the quantum mechanics worldview is extremely global and ideally wave-like, but they are both low-energy, low-speed, and non-relativistic.

Low-energy photons are similar to phonons. Their energy is low, and a large range of space-time points and matter contribute.

GAI has explained the natural causes of quantization, so there is no need to distinguish between quantum systems and classical systems. Matter wave comes from the only low-energy long-range interaction in the standard model that works in laboratory space-time and energy scale. Even the phenomenon seemly participated by only one particle needs to consider the particle interaction with all surrounding electromagnetic objects, that is, the global influence, such as the double-slit condition, the influence of the measuring device, and so on.

Comparing with decoherence theory, GAI believes that quantum waves are no different from classical waves. The effective range of a particular wave depends on its temporal and spatial coherence range. The coherence range cannot be unlimited. Decoherence is not discussed in CI, but natural in GAI, as in the classical world.

12.4 Real quantum wave

Classical waves are generally not ideal, with diffusion, attenuation, dispersion, and a lifetime, unless there is an external drive.

In principle, quantum waves should be the same. Considering the complexity, many-body, and nonlinearity of interactions, ideal waves do not exist. This is also why atomic spectrum lines have intrinsic widths.

For the classical wave in a medium, due to the huge number of participating objects and numerous dissipation modes, it is bound to dissipate and decay gradually. In a vacuum, due to the lack of a dissipation mechanism, electromagnetic waves do not attenuate to travel very far. This is why we can see the end of the observable universe. They are just waves, not particles, which is why we can focus, magnify, and image with telescopes.

GAI seamlessly connects classical and quantum theory. Based on SM, the quantum theory is viewed from a more classical perspective, and the classical world is also viewed from a more wave-like (quantum) perspective. The standard worldview elaborated by GAI provides a full range of understanding of the world from microscopic to cosmic scale.

12.5 Coherence range

For the quantum properties to be significant, the system must be in the coherence range of the characteristic oscillation of the quantum matter wave, or the space-time range while the wave's energy is not significantly dissipated by the external participating objects yet. Coherence, monochromaticity, signal strength, signal-to-noise ratio, etc., are all descriptions of the soundness of the wave. In microscopic conditions, it is the valid space-time range of quantum properties.

Therefore, for any quantum phenomenon, such as interference, delayed-choice experiment, entanglement, and quantum teleportation, it must be limited by the quantum coherence range [77]. In macroscopic conditions, the spatio-temporal coherence range can be controlled to a certain extent, thus verifying the influence of coherence on quantum properties, such as entanglement. This can also prove that all quantum properties are the behavior of matter wave under certain conditions.

12.6 Generalized quantization

In the standard world view, we have explained that basic physical quantities, such as space-time, energy, angular momentum, etc., are continuous. Quantization is emergence.

Like our previous description of water waves and droplets, quantization is also ubiquitous in the macro world, or the classical world. For example, when we talk about a person, a person can only be an entire one. A grain of sand, a cell, an atom, a molecule, a crystal lattice, a snowflake, a day, a week, a dynasty, a star, a star system, a galaxy,... are all discrete, quantum concepts, but we don't feel that classical physics is discontinuous.

A person is a complex biochemical dissipation mode that has gradually evolved from molecules to cells, to multicellular organisms, but it must exist in the form of a complete life body. There are many life forms. Life is also an emergence, resulting from the self-organization of complex chemical and energy dissipation structures, and then continuous interaction and evolution with the environment and ecosystem. If we reduce people to organs, tissues, cells, mitochondria, DNA, genes,..., we will find that the basic biochemical processes that control all life are the same. The basic units are the same until they continue to reduce to atoms, nuclei, elementary particles.

However, atoms and elementary particles, like molecules and DNA, are also composite modes. Only the components that make up them are no longer familiar to us, but space-time and energy.

Even in a very macroscopic scale, we can still find some quantum properties or wave ones, such as the periodicity of the orbit, the geomagnetic reversal, ice age period, orbital resonance between different planets or satellites, the resonance of Mercury's rotation and revolution, and so on, and resonance is a typical wave property.

So quantization is not unique to the microscopic world but is widespread at all scales.

12.7 Summation

Quantum property is manifested as the discreteness of physical quantities and the coherence of waves. The traditional correspondence principle thinks that the world is discrete. The decoherence theory believes that the environment will destroy quantum coherence. GAI believes that quantization is a natural emergence; coherence destruction results from dissipation and weakening of relative influence, as in the classical world. As a special form of the wave, quantization naturally exists at all scales.

13 Origin of quantum probability

13.1 Causality and logic

Our incomprehension of quantum phenomena comes from the fact that they do not conform to our daily cognition convention and logic. For example, they have contradictory properties (wave-particle duality), non-physical (wave functions), cannot be fully understood (uncertainty principle), non-objective (reality), unpredictable (probabilistic), superluminal action (nonlocality [78]), causality problem (delayed choice experiment, future changes the past), etc.

The difference between causality in quantum mechanics and common sense or the definition in the special theory of relativity is the root of the difficulty in understanding various quantum phenomena, including wave-particle duality, nonlocality, delayed-choice experiment, probability, etc.

The physical definition of causality, or the law of causality, is that the consequence of an event cannot be earlier than its cause. In Einstein's special theory of relativity, the consequence cannot be located in front of the light cone of the cause (future). That is, the influence of an event on the surrounding cannot exceed the speed of light. This is another statement of the principle of locality [79].

The law of causality has philosophical and logical connotations and is a basic logical principle. The law of physical causality conforms to logical causality and is also the logical basis for our understanding of the physical world. If an event violates the law of causality, it will cause our logical cognitive problems. Apparently, many quantum phenomena violate the law of causality. Therefore, von Neumann et al. [80] believe that quantum events cannot be understood by classical logic, but should use another formal logic system—quantum logic—to understand. Quantum logic has developed in logic, philosophy, and mathematics [81].

However, in GAI, we do not need another system of logic, nor does it violate the law of causality. However, due to the approximation of quantum theory, causality has been changed into another form.

From the perspective of GAI, quantum properties are the final global state of the system. The system has to reside in the effective range of wave function description and within the range of instantaneous coherence. All objects, including the final potential and boundary conditions after self-consistent evolution, are the final states of the interaction of all iterations, but the intermediate stages are ignored.

Let us first look at the process of eigenstate establishment.

13.2 Establishment of the eigenstates

In quantum theory, there is no discussion about the establishment of the eigenstates, which are mathematical solutions. In classical systems, eigenstates are common, such as the resonance frequencies of architectural structures and musical notes. In the case of broad-spectrum driving, the establishment of eigenmodes needs some time to develop, as the energy concentrates on the eigenmodes. Take playing the flute for an example. When we switch the position of the hole, the original note fades rapidly because it is no longer in the eigenmode, and the driving energy of blowing is quickly concentrated to the new eigenmode, which is the new note. There is a short time for mode switching and energy reconcentration. The driving frequency of blowing is broad-spectrum, but the vibration mode of non-notes fades rapidly, while the designated mode of the note is strengthened. The eigenstate establishment time is approximately the length of the flute air column divided by the speed of sound, which is in the order of milliseconds. Considering the general pitch range is less than 1000 Hz, only one or two oscillation cycles are needed to complete the transition, and is neglected by human hearing.

Other eigenmodes or eigenstates can be understood in the same way. In the quantum realm, in most cases, because the scale is small, such as the atomic scale, and the speed of light (corresponding to the speed of sound of a flute) is large, the time needed to establish the eigenstate is very short ($\sim 10^{-18}$ seconds), so it can be ignored. The physical process with such a short time cannot be diagnosed at present. Though in the flute case, it is indeed possible to analyze the transition between notes through high time resolution audio analysis technology.

As long as the basic physical interactions are those we know, i. e., the electromagnetic, weak, and strong forces defined in SM, in the atom scale, there are only electromagnetic interactions left.

The propagation speed of electromagnetic interaction is tremendous, and the establishment of the global eigenmode is almost instant. We can not, and usually not necessary to, study the eigenstate switching, so we only deal with the conversion probabilities between the initial and final states. Since the intermediate processes cannot be tracked, the probability is the only valid mathematic method, just like a coin toss.

The speed of light is large, and the scale is small, so the speed of light can be approximated as infinity. This is exactly the non-relativistic approximation Schrödinger's equation needs.

In the process of establishing a global eigenmode, the law of causality is always in effect. However, If we drop all intermediate stages, causality is lost. For example, usually, we cannot predict the outcome of a coin toss. We can predict before the final landing if we keep tracking the coin states with a high-speed camera. There is no difficulty in understanding the whole process. We can find the cause for each rollover, the law of causality is always working, and there is no need for randomness or probability to step in.

This is the origin of quantum probability, as GAI understands. The negligence of the intermediate processes leads to the loss of the causality, hence the probability description.

From the perspective of Schrödinger's equation, the potential and the boundary conditions work together to get the final eigenstate. It is the final result of all micro-interactions and co-evolutions that do obey the law of causality. When the boundary conditions are changed or be measured, the initial state to the new state is also the result of the co-evolution of all micro-effects that keep causality.

The self-consistent field methods, random vector iterative method, and variational method used to solve some problems include or imply the complex processes of reaching the final state.

Some classical processes can be used to understand the establishment of a global mode. For example, if you turn on the light in a room, the room will light up immediately, but there is a process from dark to bright. The light starts to work, and it takes a certain time to reach the rated power; the light emitted by the light source will be absorbed or reflected on surfaces; there is a certain brightness in places where the light cannot directly illuminate; the final state we see is a stable state of absorption and balance with the light source after multiple complex reflections. Even though this process is very complicated, with many iterations, reaching the equilibrium is still very fast due to the high speed of light and impossible for the human eye to notice.

As another example, in a room with mirrors on all sides, we can see ourselves reflected many times in the mirror. It seems that there should be an infinite number of us, and all the copies seem to be in the mirror the moment we enter the room, which takes no time. If we move, the infinite number of our copies in the mirror also move synchronously and "instantly". Similarly, this is because the speed of light is too fast. In a room of a size of a few meters, even if the light is reflected hundreds of times, it only takes a few microseconds, and our eyes cannot notice. Usually, we can only see dozens of images in the mirror. No matter how many reflections there are, the light will attenuate, and the angle will be too small, making it difficult to discern too many images.

13.3 Interference experiments

In section 12, we said that the typical range of quantum effect, or wave effect, is its space-time coherence range. In all interference experiments, including double-slit interference, delayed-choice experiment (quantum eraser), as long as the coherence range of light covers the experiment setup, each device (splitter, mirror, slit, etc.) is part of the global condition, and all contribute to the global interference pattern. The final pattern results from continuous feedback and interaction of all devices, light paths, and light sources. The time sequence cannot be determined based on the distance between the devices in the light path and the light source because the latter devices also affect the front. It is not the future decision that affected the light path of the past, but the relevant feedback was ignored. The entire optical path is coherent, so the final interference pattern must include all the optical path information. Like the development of eigenstates, the final interference pattern is gradually developed. If you ignore the development, you cannot understand the causality. Here, the cause and the outcome are entangled, the entire light path is the cause, and the interference pattern is the outcome.

Like the high-speed camera tracking coin toss, we can use the very high time resolution photography technique [82] to investigate the light interaction between the components in the interference experiments.

13.4 Quantum entanglement

Take the entanglement experiment of photon pairs as an example: it is generally believed that the process that occurs is [83]:

1. Laser irradiates the crystal to produce entangled photon pairs;
2. The photon pairs fly to the polarizers on both sides respectively;
3. The two photons are detected separately and independently on both sides.

When detecting, it seems that each photon knows the state of the other, so a “spooky” over-distance interaction seems to exist.

GAI takes the process differently. The laser’s coherence range is large and covers the detection device, and the detection is part of the global condition. Like the delayed-choice experiment, in the range of coherence, cause and outcome are entangled, or the final state has the participation of all objects in the entire coherent range, including the polarizers used for detection. Therefore, when the “entangled” photon pair is generated, a global optimal state (similar to eigenstate) is selected, which is parallel to the direction of one of the polarizers on the two sides, and the behavior of “seems to know the state of the other” is achieved.

The difference between the two mechanisms is that the “spooky” superluminal action has nothing to do with coherence, but GAI thinks it does. We can design an experiment to find out. We can use incoherent monochromatic light as the light source or use an electronic shutter to ensure that the generation and detection of photon pairs are separated in time, to see if there is still that “spooky” correlation, to testify the two mechanisms decisively. No such experiment has been conducted yet.

13.5 Summation

GAI thinks that the solution of Schrödinger’s equation is a global approximation, which is the system’s final state. The final state’s development is the final result of complex micro-interaction processes that obey the law of causality. Eigenstates, delayed-choice experiments, quantum entanglement, etc., all have similar development mechanisms. At the quantum scale, although the process of reaching the final state is complicated, the time is short, and it is difficult to diagnose or observe. If we ignore the process, causality no longer works, and can only be described by probability. The quantum coherent evolution is integral, global, and undividable. If we divide a coherent process into separate causal sequences, we will get wrong logical reasoning and thus fail to understand the nature of the experiment.

14 Millennium quantum dispute

14.1 Atom and continuum

In 1900, Planck proposed quantum theory and solved the blackbody radiation spectrum problem. In 1913, Bohr and Rutherford assumed that the atomic angular momentum is quantized, explained the energy levels of the hydrogen atom. Since then, quantum theory has flourished and has become the basic theory that dominates the scientific community. As a result, some traditional theories, such as gravity, have not yet been successfully quantized, tormenting physicists.

The philosophical origin of quantum theory is the ancient Greek atomism. In Greek, the original meaning of "atom" means indivisible, proposed by Leucippus and Democritus. Another source of ancient philosophy, ancient India, has similar theories. Atomism believes that nature is divided into indivisible atoms and voids.

However, ancient Chinese philosophy does not believe that there is an indivisible smallest unit. Zhuangzi, who was about the same time as Leucippus, said that "a foot long whip, halving it every day, it never ends", or, things can be divided forever. This is a continuum view.

From today's point of view, the atom theory is true, because we can only decompose to the scale of atoms or elementary particles. The continuity theory cannot be considered wrong either, because atoms can still be decomposed and can be decomposed indefinitely. Only later, the energy of the decomposition action itself will produce new matter. The decomposition can continue, but no smaller results can be obtained.

14.2 Reductionism, holism, and quantization

Later on, in the development of science, the west scholars more adopted reductionism [84], which believed that complex systems, objects, and phenomena could be described as the sum of their components. At the same time, the Asian philosophers used holism more. They believed that reduction might cause the loss of important information for complex objects, and we cannot correctly understand them. Later, the emergence theory of systems science in modern science is the mend to reductionism. As the scale and the number of participants increase, new physical phenomena will emerge, so the reverse of emergence is also true in the reduction process. That is, the physical phenomena that exist only in the original scale will be lost.

Although the idea of quantum originated from reductionism, Schrödinger's equation is holistic because it requires information in the whole space. However, people still tend to discuss and understand from the perspective of reductionism.

GAI is actually trying to understand quantum theory from the perspective of holism without introducing any assumptions. The integrity and approximation of Schrödinger's equation are also widely recognized by physicists. GAI also discusses SM from the perspective of holism and reinterprets the definitions of elementary particles and interactions. GAI believes that we should use the holistic elementary particle picture. However, the elementary particle tables listed in textbooks can only be regarded as from reductionism. The definition can be understood as a certain basic state of a particle, similar to a space-time point. We use points to describe particles' position, but we know that particles cannot occupy an infinitely small point. Similarly, when we say that a photon's energy is a certain value, it cannot be that single energy value. GAI also extends the same analogy to spin, mass, and other properties, which were previously considered to be definite single values.

However, GAI has not given up on atomic theory and quantum theory. Instead, the concept of quantum has been generalized, and a large number of quantized manifestations have also been found in the macroscopic world.

GAI believes that the energy quantum proposed by Planck does not exist, and Bohr's atomic angular momentum quantization is natural emergence, not the cause. The laser is more the result of the participation of a large number of atoms, not just the nature of single atoms.

14.3 Centennial quantum feud

Einstein and Bohr's feud is a topic of great interest all these years whenever talking about quantum theory. Although it is generally believed that Einstein lost in the feud, he did not believe that quantum theory was complete until his death. He did not even accept the photon concept that was mainly proved by himself and won him the Nobel Prize.

Bohr's nihilism, or idealism, is summarized as: "The moon does not exist when I don't look at it." It has always been the object of criticism from many people.

Schrödinger and Einstein hated the probabilistic interpretation of wave function and measurement collapse. Einstein's famous saying "God does not play dice with the universe" [85] is an expression of this position. Although Bohr's answer of "Einstein, stop telling God what to do" is clever and eloquent, but it works for himself too. After all, we have no reason to believe that the world is random. Einstein should not tell God not to play dice, and Bohr can not tell God to play either.

Schrödinger's cat was originally proposed by Schrödinger to mock the concept of measuring collapse. However, many people later used it as a thought experiment to describe and prove the legitimacy of measuring collapse.

Einstein's solution to the incompleteness of quantum mechanics, including the paradox of EPR, was the theory of hidden variables, but it was falsified by the Bell experiments. The Bell experiment also makes people believe the nonlocality of quantum, and it challenges the locality principle brought by his special theory of relativity. That is to say, his persistence and challenge not only lost the debate on the completeness of EPR and quantum theory but also threatened his other important contribution-the special theory of relativity.

Einstein was also puzzled by the "Spooky action" of EPR's entangled photons, and that is why he used the word "spooky".

John Bell, based on the natural materialism instinct, or reality, was originally on Einstein's side. He believed that the experiment he proposed should prove that the hidden variable theory is correct, and there should be no other way. The results of the experiments devasted him.

Bell's confusion is not a problem of him alone, and most physicists have the same doubts. This is why Feynman said "I think I can safely say that nobody really understands quantum mechanics" [12].

It is a pity that these confused souls have passed away. If they know the explanation of GAI, I believe they will be happy that they were right. Except for Feynman, he should pay attention to the tense when he said, though he was possibly right.

In the "play dice" dispute, we conceptually stand on Einstein's side, but we tend to believe that the result of the "dice playing" is actually certain. At least God should know the outcome. Of course, Bohr's argument still stands.

As for the "Spooky action", we can tell Einstein: "It is not spooky at all, and there is no action".

14.4 Materialism and idealism

Materialism holds that matter is the fundamental substance of the world, and consciousness reflects the material world. Idealism thinks that consciousness is more important because reality is meaningless if there is no human perception. Materialism and idealism have been two opposing ideological systems, each with different schools.

For physics, physicists in the Newtonian era were more inclined to materialism, while physicists in the quantum era were confused or opposed in this matter. Bohr represents the idealist [86, 87], who believes that measurement and consciousness have a decisive influence in physics, and most physicists accept his argument. Einstein represented materialism and believed in objective reality.

In section 9 "Reality", we said that GAI accepts both materialistic and idealistic views. The materialistic part is that measurement and human consciousness also matter and interact with the material world. The idealistic part is that the knowledge of the world can only be embodied in consciousness. Without consciousness, there is no subject to discuss the world.

Our standard worldview is derived from SM. Elementary particles, or matter, are the perturbation modes of energy to space-time, so there are only energy and space-time, not matter with classical meaning. This is a new problem that materialism needs to face. If we define both energy and space-time as matter, then consciousness is also some modes and must also be matter, so the materialistic division of matter and consciousness does not exist. Of course, the same is true for idealism.

The relativity of reality can be regarded as an amendment to both materialism and idealism.

14.5 Summation

The concept of quantum originated from atomism. Ancient Oriental and Western understandings of the origin of the world are different, but they can all justify themselves. The concept of elementary particles is reductionistic, Schrödinger's equation is holistic, and reductionism and holism complement each other. Idealism and materialism are consistent in the understanding of GAI. Reality is relative. Thousands of years of debate on discreteness and continuum, reductionism and holism, materialism and idealism, may finally find peace in the global approximation interpretation, or standard interpretation, of quantum mechanics.

A Differences between GAI and the CI

- Timing

  Quantum mechanics is a theory about the microscopic world.

  When the Copenhagen Interpretation was proposed in 1927, human beings had very little understanding of the basic interactions and elementary particles, so they could only start from phenomena and put forward theories phenomenologically. Many theoretical and experimental research in particle physics and high-energy physics have much progress in the following decades. We have gained much understanding of basic interactions and elementary particles, but are not reflected in the Copenhagen interpretation. Even the essential feature of coherence is not included.

  GAI has fully considered the development of modern theories and understandings and naturally includes the discussion of coherence.

- Theory foundation

  CI: quantization assumption, matter-wave assumption, Schrodinger equation, wave function probability description, measurement collapse assumption, uncertainty principle, correspondence principle. Later decoherence theory.

  GAI: A standard worldview based on SM, including the concept of elementary particles. GAI elaborated and expanded the concept of particles in SM, elaborated and demonstrated the physical meaning of the Schrödinger equation and wave functions, and believed that matter waves do not require assumptions and are natural features of basic interactions. We made no additional assumptions. Coherence is natural and does not require additional consideration.

- Quantization

  CI: Basic assumption.

  GAI: Natural emergence.

- Schrödinger equation

  CI: the wave equation of matter waves. Implied the assumption that any quantum is an ideal matter wave.

  GAI: the diffusion equation of matter waves. The solution is global, including information in the entire space. It is the approximate equation after the interaction propagation velocity is treated as infinity. The eigen solution is generally obtained, which is the dominant vibration mode of the system.

- Wave function

  CI: probability distribution function, the square of its modulus is the probability of the specific value, that is, the number density.

  GAI: energy density, the amplitude of a certain fluctuating physical quantity, such as displacement, electric field strength, etc.

  If the quantum energy is regarded as a unity, the GAI's wave function image is compatible with the CI.

- The physical picture of the particle

  CI: point particles have inseparable wave behavior, that is, wave-particle duality.

  GAI: waves, including standing waves, energy disturbance modes in space and time. It is generally the eigenstate, that is, the dominant vibration.

- The physical picture of the photon

  CI: There is no concept of photon in the first quantization, wave-particle duality.

GAI: at low energy, it is an electromagnetic wave. At high energy, it is a particle (localized wave). This is consistent with the standard worldview, or if the energy scale is different, then the physical appearance is different.

- Measurement

  CI: probability sampling, the process is not continuous.

  GAI: It is an interaction, which usually causes a change in the state of the system and is the result of a specific interaction.

- Quantum entanglement, nonlocality

  CI: no discussion. But the solution of Schrodinger's equation is global, and all physical phenomena are naturally global, that is, non-local, including wave functions and measurements. Later, the Bell experiment proved space-like long-distance correlation and believed that quantum has non-local behavior, which violates the principle of locality.

  GAI: Space-like correlation is a normal wave coherence property, which is global and needs to be established gradually, and the establishment process does not violate the principle of locality.

  By changing the coherence of the light source, and the separation of photon generation and measurement in time, two interpretations can be testified experimentally.

- Reality

  CI: The objectivity before the measurement is meaningless and cannot be discussed.

  GAI: There is an objective reality before the measurement, but the measurement may change the system, including the measurement of the intrinsic properties of particles. Reality is relative.

  The relativity of reality is a new concept put forward by the GAI.

- Determinism

  CI: Wave function and measurement are intrinsically probabilistic, and the future of the world is probabilistic.

  GAI: The future cannot be calculated accurately, but it should be certain.

  Agnostic (uncalculable) determinism is also a new concept put forward by global interpretation.

- Delayed choice experiments CI: did not answer, believe they are mysterious; the future can change the past.

  GAI: it is a normal coherent phenomenon. As long as all components and paths contribute within the wave's coherence range, it results from all coherence components' gradual feedback. We cannot define causality according to the light path before and after.

- Philosophy system

  CI: generally considered to be idealism, agnosticism, and non-determinism. The concept of quantization comes from classical atomism.

  GAI: the standard worldview of physics. Idealism and materialism are consistent, agnostic determinism is compatible with determinism and agnosticism (non-determinism), and atomism and continuity are not contradictory, though both concepts need to be extended slightly.

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