Interpretation of Quantum Mechanics in Terms of Discrete Time II

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From the perspective of discrete time, the macroscopic world and the microscopic world are divided using the Planck mass as a reference point. The microscopic world is a world where the nature of time is discrete and non-locality dominates, and the macroscopic world is a world where the nature of time is continuous and locality dominates. The macroscopic world is not reduced to the result of the order of the microscopic world, and the physical laws of both worlds are real. The differences between the two worlds lead to limitations in applying physical intuition formed in the macroscopic world to the microscopic world. As an alternative to this, a new model of the physical reality of matter in the microscopic world was proposed.

1 Boundary between the macroscopic world and the microscopic world

From a discrete time perspective, quantum waves are formed by the contributions of Δt future and past spinors, and can be expressed as follows [1]:

$$\begin{aligned} &(x^\mu + \Delta x^\mu)\,\Psi(x^\mu) - x^\mu\,\Psi(x^\mu + \Delta x^\mu) \\ &\quad = \Delta x^\mu \exp\left(-\frac{i}{\hbar}\Delta x^\alpha P_\alpha\right)\Psi(x^\mu)\ . \end{aligned} \tag{1}$$

In (1), the time component of Δx^μ is $c\Delta t$.

In order for (1) to be established, the following two assumptions are necessary:

1. $\Psi(x^\mu)$ is an analytic function.
2. $[x^\mu, P_\nu] = -i\hbar\delta^\mu_\nu$, where $P_\nu = i\hbar\frac{\partial}{\partial x^\nu}$.

Mathematically, there is no limit to the lower limit of Δx^μ, or Δt, in the Taylor expansion of $\Psi(x^\mu + \Delta x^\mu)$. However, there is a physical constraint on the lower limit of Δt. Δt is defined as the time taken for light to pass through the reduced Compton wavelength $\lambda\!\!\!^-_c$ [2]:

$$\Delta t = \frac{\lambda\!\!\!^-_c}{c} = \frac{\hbar}{mc^2}\ . \tag{2}$$

As mass increases, $\lambda\!\!\!^-_c$ decreases. However, physically, this process cannot proceed without limitations, because a black hole is formed when $\lambda\!\!\!^-_c$ becomes the Schwarzschild radius r_s. Therefore, $\lambda\!\!\!^-_c$ must satisfy the following conditions:

$$\left(\lambda\!\!\!^-_c = \frac{\hbar}{mc}\right) > \left(r_s = \frac{2Gm}{c^2}\right)\ . \tag{3}$$

Since the mass at $\lambda\!\!\!^-_{c,p}$, the lower limit of $\lambda\!\!\!^-_c$, is the Planck mass m_p, the lower limit of Δt is the Planck time t_p.

$$\begin{aligned} \lambda\!\!\!^-_{c.p} &= \frac{\hbar}{m_p c} = \frac{2Gm_p}{c^2} \\ \Delta t_{lower\ limit} &= \frac{\hbar}{m_p c^2} = \sqrt{\frac{2\hbar G}{c^5}} = t_p\ . \end{aligned} \tag{4}$$

If $\Delta t \le t_p$, the analytic expansion of $\Psi(x^\mu + \Delta x^\mu)$ is mathematically possible, but physically not possible. This means that (1) is not possible, so it can be said that plane waves as harmonic oscillations are not formed. In other words, $\Delta t = t_p$ becomes the boundary point of whether a quantum wave is formed or not. Since Δt is inversely proportional to mass, this boundary is determined only by mass. That is, the Planck mass. Using this as a reference point, the quantum world and the non-quantum world are divided.

The Planck mass is the boundary, but there is one more thing to consider. Eq. (1) is for a plane wave of a single wavelength. If the mass is close to the Planck mass (1.5×10^{-8} kg), it is of course not an elementary particle but a composite. In this case as well, for (1) to hold, the waves of all components must be in a coherent state. Therefore, the Planck mass is theoretically the maximum value of a quantum system where quantum waves can be formed. However, for actual composites in thermal equilibrium, even if the mass is less than the Planck mass, quantum waves may be canceled out and quantum phenomena may not appear. This tendency will be greater as the mass of the system or the number of components increases.

In fact, it can be inferred from existing quantum mechanics that the Planck mass is the boundary between the quantum world and the non-quantum world. The Compton wavelength of matter is defined as the wavelength of a photon with energy equal to its rest energy. However, when the wavelength of the photon becomes the Schwarzschild radius, the photon is confined by its own gravitational field. Therefore, the Compton wavelength is limited by the Planck length, and the mass at this point is the Planck mass. This means that the Planck mass represents the limit to which the Compton wavelength, which refers to the quantum characteristics of matters, can be achieved.

Now, I will discuss the properties of time when $m \ge m_p$. In (1) and the physical constraints of Δt, it was discussed that if $m < m_p\left(\Delta t > t_p\right)$, a quantum wave is formed, and if $m \ge m_p\left(\Delta t \le t_p\right)$, a quantum wave is not formed. In the latter case, Δt is not defined by physical constraints. In other words, the concept of discrete time does not apply to the physical system. If the concept of discrete time is not applied, there is only one possibility. That is continuous time. This means that if the mass of a physical system is greater than the Planck mass, the time applied to the system must be continuous. As a result of this discussion, the following conclusions can be drawn. With the Planck mass as the reference point, elementary particles in the microscopic world have their own discrete time, while the macroscopic world has continuous time. Since the characteristics of continuous time are independent of the mass of the object, all macroscopic objects have the same continuous time in their stationary inertial frames. This is why the time we experience feels as if it is universal.

The above contents are summarized and shown in the figure below. In Fig. 1, $\Delta t = 0$ in the $m \geq m_p$ range does not mean that (1) is applied, but simply represents continuous time.

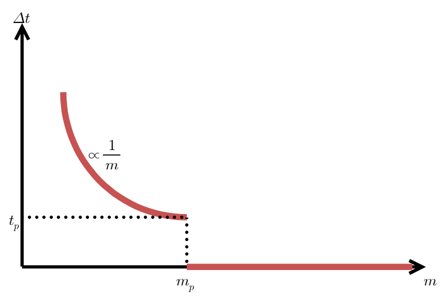

Fig. 1: $\Delta t - m$ graph

As you can see from Fig. 1, the macroscopic world is not on a continuous line with the microscopic world. In other words, the limit of any variable in the microscopic world cannot become the macroscopic world. Since the properties of time are completely different in the two worlds, the dynamical principles based on them are also bound to be different. Both the macroscopic world and the microscopic world are real worlds with their own unique characteristics. This perspective is very different from existing quantum mechanical interpretations. Most existing quantum mechanical interpretations (Copenhagen, many worlds, decoherence, etc.) view the macroscopic world as the limit of the continuum of the microscopic world.

In the microscopic world, the nature of time is discrete, and as discussed in the previous paper [4], matter in this discrete time repeats the process of wave collapse and propagation as a non-local wave. Thus, the characteristic of the microscopic world is non-locality. Meanwhile, in the macroscopic world, the nature of time is continuous. Since local principles naturally apply to fields defined in continuous time, the characteristic of the macroscopic world is locality. Naturally, the physical intuition of the world where locality applies and the world where non-locality applies is bound to be different. The physical intuition of the macroscopic world dominated by classical mechanics is clear. Things like particles, waves, and determined trajectories are concepts based on local principles. However, according to the discussion so far, the microscopic world is non-local, so intuition with concepts based on local principles is bound to have limitations. In the next section, I will present a model for a new physical intuition based on the non-locality of the microscopic world.

2 The new quantum mechanical reality of matter

As mentioned in the previous section, concepts such as particles, waves, and trajectories are concepts established in the macroscopic world where local principles are applied. They are concepts of physical reality that humans, as beings in the macroscopic world, infer from their experiences. However, there are bound to be limitations in describing the microscopic world with these concepts. One solution to this difficulty is Heisenberg's method as follows [5]:

> We can no longer speak of the behaviour of the particle independently of the process of observation. As a final consequence, the natural laws formulated mathematically in quantum theory no longer deal with the elementary particles themselves but with our knowledge of them.

But I think more can be said about reality. We may think of the microscopic world as something that cannot be directly experienced. However, in reality, all parts of our body act according to the order of the microscopic world, and the basic parts of living things experience quantum phenomena. I think that what can be experienced can be drawn.

As can be seen in Fig. 2, the quantum mechanical reality presented here is composed of Compton sphere, spinor, and matter wave (i.e. de Broglie wave). The Compton sphere is a sphere with the reduced Compton wavelength as its radius, and as presented in the previous paper [4], it is a sphere formed by points contributing to the past and future of Δt at the center point. All points on the hemisphere are simultaneous events in discrete time Δt. Spinors contributing from the future hemisphere and spinors contributing from the past hemisphere combine at the center to form spinors at the central point. The spinors at this central point have phases according to (1), and a collection of identical phases forms a matter wave.

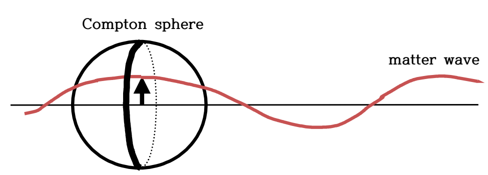

Fig. 2: The new quantum mechanical reality of matter

The wavefront of the same phase as a matter wave has the characteristics of a non-local wave. Due to their inherent characteristics, these non-local waves cause simultaneous wave collapse when they interact. (Please refer to the previous paper [4] for the process of non-local wave formation and propagation from the Compton sphere.) The start of wave propagation is the Compton sphere. While the wave is propagating, the Compton sphere no longer exists, but only a matter wave as a non-local wave. The interaction (inelastic scattering) causes an instantaneous collapse of the matter wave, and the resulting collapsed state is assumed to become a Compton sphere again. This is because the Compton sphere is the beginning of a non-local wave and can be viewed as an indecomposable elementary particle. Absorption of energy through interaction increases the frequency of the spinor phase within the Compton sphere. As a result, a matter wave as a new non-local wave with a shorter wavelength is formed and propagated. Meanwhile, electromagnetic waves are also non-local waves, but since they have no rest mass, the Compton sphere does not exist. It is assumed that the contraction of the wave due to interaction will result in only a localized electromagnetic field, the size of which will be determined by the size of the interacting matter. If there is a change in energy after interaction, it propagates as a wave with a new wavelength.

3 Conclusions

The distinction between the macroscopic world and the microscopic world has been interpreted from various perspectives since the beginning of quantum mechanics, and most perspectives have attempted to understand the macroscopic world as a continuation of the microscopic world. However, from the perspective of discrete time, the two worlds are not on a continuous line and take on completely different appearances with the Planck mass as the reference point. In the macroscopic world, the nature of time is continuous, and the principle of locality governs. In the microscopic world, the nature of time is discrete, and non-locality becomes the basic principle of existence. The macroscopic world cannot be reduced to the result of the order of the microscopic world, and the two worlds form a kind of hierarchical relationship of existence.

From the above perspective, it can be said that it is natural that concepts such as particles, waves, and trajectories, which are concepts of physical reality in the macroscopic world, that is, classical mechanics, will be difficult to apply to the microscopic world. The concept of physical reality in the microscopic world, inferred from a discrete time perspective, is quite different from that in the macroscopic world. As presented in the previous paper [4], the wave concept of the microscopic world is not a wave concept based on local principles of the macroscopic world, but a non-local wave. There are also many differences in the concept of particles. The concept of a particle in the macroscopic world is a particle without an internal structure of finite size or a point particle with no size. These particle concepts are abstracted on the basis of continuous space and time. The concept of a particle of a finite size without an internal structure still has the meaning of an internal area, and a point particle without size is premised on the meaning of an infinite division of continuous space. From a discrete time perspective, an elementary particle in the microscopic world, in the case of matter, is a Compton sphere. The size of the Compton sphere is determined by the rest mass, and although it is an elementary particle that cannot be resolved, it has an internal structure. The internal structure mentioned here does not mean a composite such as an atom. The Compton sphere consists of two hemispheres with time differences, and has an internal structure in the sense that a spinor field is formed at the center. Since the spinor formed at the center has a phase, the Compton sphere as a particle is not maintained and propagates as a matter wave over time. Due to interaction (this corresponds to the case of inelastic scattering; during elastic scattering, it maintains its wave properties without wave collapse), the matter wave collapses into a Compton sphere again. And this process repeats. This is a new physical intuition from a discrete time perspective on the microscopic world.

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