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Enter by the Narrow Gate, for Getting New Perspective to Bring Modern Technology Into Order

Kayoko Awaya
Japan Association for Philosophy of Science, Japan

Abstract: One of the main causes of issues about the today's situation of technology comes from a big mismatch between the new technology based on quantum mechanics (laws the micro world) and the old perspective (mechanistic and reductionistic viewpoint in the macro world) for almost half century. I explain this circumstance and show how to settle this problem by solving the so-called measurement problem of quantum mechanics. These give us a new perspective which unify the laws of macro and micro worlds and bring modern technology into order. To go this way would be to enter by the narrow gate.

Key words: new technology, old mechanistic viewpoint, measurement problem of quantum mechanics, complementarity between macro and micro worlds, new world view

1. Introduction

People today seem to get lost in a big jungle of highly advanced industrial technology especially developed after World War II (WWII), such as nuclear development, information technology, biotechnology, nanotechnology, artificial intelligence (AI) etc. Some people describe our future as rose-colored with self-driving car, wearable products, gene therapy, genome editing, internet of things, smart city etc. Others think these technologies bring about the nightmare such as climate crisis, nuclear war, collapse of life order by genetic engineering, domination by AI, surveillance society etc.

In any case, almost all people use today's individual technology with vague anxiety, because they don't have any idea or enough time to decide about right or wrong. Where on earth are we going toward? Is there anyone who knows the right direction? Moreover, such kind of chaos shakes people more violently and rapidly under the accelerating computing power and the pressure of global market, so that we seem to be more losing the power to see into the future.

I think that one of the main causes of this chaotic situation is the mismatch between new technology and old perspective. That is, we introduce the new technology obtained in the micro world after WWII, although we still have the old perspective, i.e., mechanistic and reductionistic viewpoint with classical physics of 19th century in our usual macro world. In fact, we have no idea about a new world view by unifying the laws describing the behaviors of the macro and micro worlds, which should be obtained by properly solving the measurement problem of quantum mechanics.

I'll investigate these circumstances around quantum mechanics and show a hopeful indication that the obtained new perspective may lead us to an ordered new world view.

2. Difficult Delivery of Quantum Mechanics and Thereafter

The Industrial Revolution (IR) took place first in England. Since then we had the 1st IR (1760s-1840s), the 2nd IR (late 19th century-early 20th century) and

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Corresponding author: Kayoko Awaya, Ph.D., research areas: philosophy of science, environment issues. E-mail: kaako1945@gmail.com.

the 3rd IR (1960s~) which is also known as the computer revolution or the digital revolution. Now it is said that we are at the entrance of the 4th IR [1]. At first glance, this looks like a simple series of progress. However we have to pay attention to the difference between IRs before and after WWII, because after WWII technology began to use ingredients in the micro world and the application of quantum mechanics grew explosively. “Quantum mechanics” seems to be named according to the tradition since Newtonian mechanics like “mechanics in the field of quantum phenomena in the micro world” such as rigid body mechanics and fluid mechanics. However the situation seemed to be completely different as follows.

In early 20th century, the great turbulence occurred at the field of physics, the base of science. Until end of 19th century, we could correctly explain the behaviors of almost all macro objects — usually enough to be seen with the naked eye — by the so-called classical physics including Newtonian mechanics, Maxwell’s electromagnetism, thermal statistical mechanics, etc. More strictly speaking, we can define the macro object by saying that it can be described by classical physics.

However at the beginning of 20th century, the situation changed drastically when we stepped into the micro world — the objects are molecule, atom, nucleus, electron etc. At first, physicists thought that micro objects also obeyed the same laws of classical physics just as celestial and terrestrial bodies obey the same Newtonian mechanics. But physicists have realized that micro objects can not be described by classical physics, and to make matters worse they even contradict the concepts of classical physics, and therefore the ideas used in our daily lives. For example, to be a wave or to be a particle are never compatible with each other for any macro object in classical physics and also our common sense, while any micro object can behave as a wave as well as a particle depending on experimental situations.

In our real macro world, almost all objects are considered to have definite values for physical quantities such as mass, position, velocity, momentum, etc., at any time, whether they are measuring or not. Then for example, you can describe the orbit of a thrown ball. If you know the values of position and velocity of the ball at a certain time, you can calculate the whole orbit by Newton’s law of motion under the gravity. Of course you can have an image of parabola, so you can also play catch even if you do not know Newton’s law — your body had already learned the law. Anyway in an abstract sense, the concept of our physical macro world is composed of definite values of all observables which are defined as physical quantities to be able to be measured. Therefore you can draw an image of the (macro) world and well behave.

Whereas, in quantum mechanics treating micro objects, the basic laws themselves include the part which cannot describe without the term of “measurement”. Therefore the measurement problem becomes primary for quantum mechanics, and the interpretation problem is also involved in it.

More than half a century after the formulation of quantum mechanics, there were proposed various kinds of models and serious discussions about the interpretation problem including measurement. However no winner has been exactly decided and any theory has been regarded as a matter of taste by others. Even the so-called standard interpretation, i.e., Copenhagen interpretation led by Bohr, has some pragmatic and positivist feature, so that various applications of quantum mechanics can get results without being bothered with severe problems of measurement and interpretation. Thus the discussion about the interpretation problem including measurement gradually declined and such a tendency becomes stronger under the computer revolution.

Therefore *technically* we have marched forward on seemingly fertile grounds in areas such as electronics, the chemical industry, computer science, gene technology, etc., resulting in the 3rd IR, while *theoretically* we have to continued to move with uncertainty. For example, R.P.Feynman, one of the best physicists in 20th century, said frankly in 1982 [2]:

> ...we always have had (secret, secret, close the doors!) we always have had a great deal of difficulty in understanding the world view that quantum mechanics represents... It has not yet become obvious to me that there's no real problem. I cannot define the real problem, therefore I suspect there's no real problem, but I'm not sure there's no real problem.

I would venture to say that a great change of world view is required by accepting quantum mechanics. So at first, let me introduce the problem of quantum mechanics.

3. The Problem of Quantum Mechanics and Neuman's Discussion about the Measuring Process

In any physical theory, we usually use three fundamental concepts of physical system, state and physical quantity, so that we can understand a physical situation, i.e., approach the physical reality; the state corresponds to certain experimental procedures to prepare a system, and the physical quantities correspond to the properties that we can observe. In classical physics, a state is clearly specified by some values of the physical quantities — usually the position and the momentum in the case of single particle system — so that they can be regarded to directly show the physical reality. How about the situation in quantum physics?

3.1 The Scheme of Quantum Mechanics

In quantum mechanics, a value obtained from a measurement is contingent, meaning that the same measurements of a physical quantity in the same experimental conditions do not necessarily the same result. So the concept of the state branches from the concept of physical quantity and their relation is more indirect. In fact, we can see that the state is concerned with a kind of latent possibility resulting in that the meaning of the concepts such as physical system, physical quantity and the state are more delicate than in classical physics.

(1) Introduction of Hilbert Space

The standard mathematical form of quantum mechanics was established by J. von Neuman [3]. He introduced an abstract Hilbert space to describe the unprecedented behavior of quantum objects, by unifying the matrix mechanics (given by Heizenberg; particle image) and the wave mechanics (given by Shroedinger; wave image) in more abstract space. The essential character different from our 3- or 4-dimensional spaces of the backgrounds of Newtonian mechanics or theory of relativity, is that it is directly connected with the measurement of the system.

The prescription of Hilbert space for quantum mechanics is as follows. One physical system (object) corresponds to one Hilbert space $\mathscr{H}$ which is a complex linear vector space. Any possible state of this system is described by the vector (Ψ, φ, etc.) in $\mathscr{H}$. We call it state vector, state function or probability function, etc. Any physical quantity of this system corresponds to a linear operator (A, B, etc.) in $\mathscr{H}$. Any measured value is one of the eigenvalues of the linear operator corresponding to the physical quantity that we measure. Namely this Hilbert space is composed by a set of eigenvectors corresponding to the measured values (eigenvalues) of a physical quantity which we want to measure.

The superposition principle, one of the most peculiar properties of quantum mechanics, is ensured by the state described as a vector Ψ in $\mathscr{H}$. Namely, if Ψ_1 and Ψ_2 are different states in the same $\mathscr{H}$, then the superposition of them ($\Psi_1+\Psi_2$) is also a possible state in $\mathscr{H}$. If we carelessly apply this principle to the macro world, we shall find the grotesque depiction such as the famous Schrodinger's cat which may be regarded as a superposition of "living cat" and "dead cat" [4]. Refer [3] for the terminology and more detail mathematical treatment of the abstract Hilbert space.

(2) Two Laws of Quantum Mechanics

Now I introduce the essence of two laws in quantum mechanics necessary for the later discussions.

Law 1:

If we measure a physical quantity *A* with an object (state Ψ), then we get one of the eigenvalues of *A*, and never two or more values at the same time.

In general, we cannot predict the measuring value itself, but there is a probability law (Born rule) which gives a unique probability distribution for the same repeated measurements obtained from Ψ just before the measurement. Namely, We get the average value of $A = \langle\Psi|A|\Psi\rangle$ where we use the Dirac's bra and ket notations [5].

Law 2:

Between measurements, a state Ψ of any quantum object obeys the Schrodinger equation which is causal and deterministic time development just like Newton's equation of motion in classical physics.

3.2 The Problem and Theory of Measurement by Neuman

At first glance, there seems to be no practical problem in the above two laws. However strictly speaking, there is a simple logical defect. We do not know theoretically the (quantum mechanical) definition of measurement itself, by which we should apply the Law 1 or Law 2. In fact, J. S. Bell said "On this list of bad words from good books, the worst of all is measurement" [6]. This is one of the paraphrases of the very origin of the measurement problem including the so-called reduction of the state vector.

Neuman found a peculiar dual nature of the quantum mechanical procedure which could not be satisfactorily explained. Namely, on one hand, a state Ψ is transformed into the state Ψ' by the Schroedinger equation which is purely causal (Law 2). On the other hand, the state Ψ — you may measure a quantity with distinct eigenvalues — undergoes a non-causal change (reduction) in the measurement (Law 1). Hereafter for convenience, we suppose 1st kind measurement where the same eigenvalue and eigenstate are obtained for the same successive measurements like position measurement.

Now let us see the theory of measurement by Neuman [3]. He says that we must always divide the world into two parts, the one being the observed system, the other the observer. The boundary between the two can be pushed arbitrarily deep into the interior of the body of the actual observer. Moreover he says that this is the content of the principle of the sycho-physical parallelism.

To prove this arbitrariness of the boundary position, he divide the world into three parts: I, II, III. I is the system actually observed, II the measuring instrument, and III the actual observer. Then he considers two cases where the boundary is drawn between I and II+III (case 1) or between I+II and III (case 2). For simplicity, suppose that we measure a quantity A — with the discrete eigenvalues a_1, a_2, ... and the corresponding complete orthonormal set of eigenfunctions ψ_1, ψ_2, ... — of a system with the state Ψ. Moreover he introduces the quantity B — with the discrete eigenvalues b_1, b_2, ... and the corresponding complete orthonormal set of eigenfunctions φ_1, φ_2, ...— of the measuring instrument with the state Φ. The one-to-one correspondence between $\{a_i\}$ and $\{b_i\}$ holds because of the meaning of measurement itself.

Then this measuring process (time development) is schematically shown as follows.

Case 1 (I/II+III)

$\Psi(t_1) = \Sigma c_n\psi_n(t_1)$ ➡ measurement of *A* : a_i with probability $|c_i|^2$

Case 2 (I+II/III)

$\Psi(t_1) \otimes \Phi_0(t_1) = \Sigma c_n\psi_n(t_1) \otimes \Phi_0(t_1)$ →(Schrodinger time development) →

$\Sigma c_n\psi_n(t_2) \otimes \varphi_n(t_2)$ ➡ measurement of *B*: $b_i(a_i)$ with probability $|c_i|^2$

where t_1 is the initial time and t_2 is the time after the interaction between the object and the instrument, Φ_0 is initial state of the instrument, $\otimes$ shows direct product, and Σ shows the sum over all n = 1, 2, ... of the subscript.

In fact, Neuman discusses with the statistical ensemble instead of the individual system described above. We prefer to discuss with individual system, because of the simple fact of the existence and its more elemental property, but the essences of both are the same. About the Schroeding equation in Case 2, he showed actual examples of the operator corresponding to the time development.

The conclusions are:

1) There is no contradiction between Case 1 and Case 2, i.e., the same results are obtained as long as the probability law (Law 1) is used in the measurement. So there is also no contradiction in the dual nature of the laws of quantum mechanics.

2) This seems a kind of proof of the psycho-physical parallelism. Neuman also mentioned about the abstract ego which is the part after the deepest boundary and regarded not to be material, so that it nonphysically causes the reduction of the state corresponding to the consciousness of the measuring result. This may justify the mind-body dualism.

The psycho-physical parallelism is a kind of consequence of the mind-body dualism which was advocated by Descartes at the starting point of the Science Revolution as is well known. Therefore we can say that Neuman brought back us to the point where the natural philosophy was inspired by removing the mind from the body, resulting in the domination of mechanistic and reductionistic world view (at least, view of nature) over 300 years. Then you may say that Neuman called back this mind (abstract ego) and gave it the role of the reduction (i.e., the probability law)

4. Physical Theory of Measurement

In general, we can never measure some properties of micro objects without any disturbance, and therefore we cannot reach a physical reality in quantum mechanics from the "criterion of physical reality" defined by Einstein et al. [7]. Then it is very difficult for us to have a concrete image of behaviors of micro objects like classical physics. Instead, we have to accept the very abstract Hilbert space and the state vector Ψ as described above. The only clue is the act that we prepare a state of a micro object and observe a trace left in our macro physical world. It is well known that Bohr asked the measurement for the objectivity of quantum mechanical behavior. My teacher have said "compute in the other world, experiment in this world." In the case of Neuman's discussion above, maybe the story ends when someone's abstract ego recognizes the trace. But whose abstract ego?

Here we want to investigate physically the measuring process to the end. S. Tomonaga said [8]:

> How is it that we can answer the question of what experiment should be done for measuring a physical quantity? In order to answer this question, we have to theoretically investigate the system, including the instrument, and examine the logical consequences. This king of argument is called the theory of measurement, and this is necessary for quantum mechanics to be theoretically complete. [emphasis by Tomonaga]

Then you can see that Neuman's discussion was just on this line. But why and where did he get lost in the infinite regression and mysticism of the abstract ego? There have been proposed many theories of measurement after Neuman, but even now we do not have enough consensus about authorized theory which appropriately solves the measurement problem. Actually almost all scientists can be seen to even lose interest in such a problem with the bustle of the digital revolution.

T. Takabayashi who is one of the best historians of quantum physics, proposed a physical theory of measurement [9]. He started to follow the Neuman's theory, but more carefully examined the stage of micro-macro transition in the measuring process, where a trace appears as an irreversible classical event meaning that it is not affected by its reading, etc. and of course independent of the abstract ego. It is wanted to establish based on quantum mechanics (including the probability rule) that a measurement finally results in a classical trace by the reduction of the state because of the macro property of the detector. At that time, we need not request the existence of classical macro materials from the beginning such as Copenhagen interpretation.

In order to investigate the essential parts of the measuring process, it is enough to consider the three fundamental stages: Preparation, Spectral Decomposition and Detection. For example, Fig. 1 schematically shows a spin measurement of an electron.

The 1st stage is the incident electron with the state vector Ψ from the left (Preparation). Usually Ψ is a superposed state of spin up Ψ_+ and down Ψ_-: $\Psi = \Psi_+ + \Psi_-$. The 2nd stage is made of the spectral decomposition (S.D.) of Ψ, corresponding to the division into the spin up and down macroscopically separated each other in our real space, under an appropriate magnetic field. The 3rd stage is the contact of the system to the detectors D_+ and D_-, corresponding to the spin up and down respectively, detection, which is just essential for all measurement. In fact, there are often measurements only this stage, i.e., position (orbit) measurements of cosmic rays by bubble chambers or cloud chambers.

Now let us focus on the detection. This is the very point where the reduction may happen and Neuman escaped to the abstract ego. Detector is a system which causes a micro-macro transition by a huge number N of freedom in the quantum mechanical treatment. About the interaction between the detector and the system by quantum mechanics (Schroedinger time development), Takabayashi considers the detector as a set of small detectors — he names them "cells" — and writes a "non-neutral (exited) state" of n-th cell as Φ_n. That is, the observable (physical quantity) of the detector, say $\boldsymbol{Q}$, is a macro-observable corresponding to a kind of collective coordinate. The state where $\boldsymbol{Q}$ has an eigenvalue q_n, actually includes states with many degenerate quantum numbers and has a corresponding subspace (sector), one of the states is written as Φ_n.

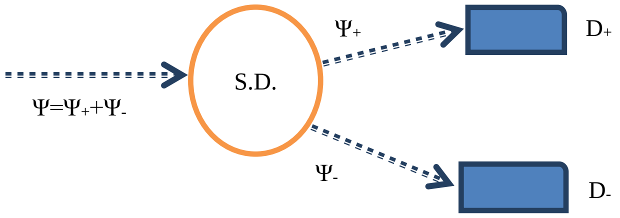

Fig. 1 Conceptual Diagram of Spin Measurement of an Electron With a Superposed State Ψ of Spin Up Ψ+ and Down Ψ-.

Then, these Φ_n show distinguished macro states of the detector, and the overlaps of state functions between them in the configuration space can be neglected as long as the detector works well—they are actually mutual incoherent. Namely for N→∞,

$$\langle \Phi_n | \mathbf{Q} | \Phi_m \rangle \simeq 0 \qquad (n \neq m)$$

Here if we write the initial neutral state of the detector system as Φ_0, then the time development (by quantum mechanics) of the combined system with the detector is as follows

$\Psi\Phi_0 = \Sigma c_n \Psi_n \otimes \Phi_0 \rightarrow$ (Schroedinger time development) $\rightarrow \Sigma c_n \Psi_n \otimes \Phi_n$.

The observable of the combined system is $A \otimes \boldsymbol{Q}$, and the expectation value (for N→∞) is

$$\Sigma\Sigma c^*_n c_m \langle \Psi_n | A | \Psi_m \rangle \langle \Phi_n | \mathbf{Q} | \Phi_m \rangle$$
$$\simeq \Sigma |c_n|^2 \langle \Psi_n | A | \Psi_n \rangle \langle \Phi_n | \mathbf{Q} | \Phi_n \rangle,$$

disappearing the interference term with the reduction of the state function, i.e., the final state is actually one of the eigenstates. That is the essence of his basic idea about the measuring process — see Ref. [9] for the detail discussion and several examples.

He took a step ahead of Neuman. He showed the reduction of the state by the quantum mechanical interaction itself between a system and the detector which has an enormous number of freedom N. Of course, this is approximate and true only if N→∞. However just this enables us to avoid Neuman's mysticism — the infinite regression of the boundary between the observed system and the observer, and the abstract ego — and physically investigate the condition of occurrence of detection, i.e., realization of the reduction. This is the very physical theory of measurement. He himself said “Our physical theory of measurement is expected to be the most reasonable and incorporated into physics in this way though it is quite qualitative yet” [9].

5. Some Comments to Get New Perspective

Nearly a century has passed since the establishment of mathematical form of quantum mechanics, and the essence has not changed. Moreover we cannot see its applicable limitation yet. Therefore we have rather a strong impression that quantum mechanics is something final. However we have not yet succeeded in incorporating quantum mechanics into our world view, but keep on still raising the old perspective of mechanistic and reductionistic view point established in the macro world resulting in some serious mismatch. That is, we use the new technology of micro world separately and near-sightly with the old perspective under the market pressures. This seems to be just a basic cause of the chaotic situation of today’s technology. Therefore it is an urgent issue for us to replace the old perspective with new one based on quantum theory. Then I’ll show some attempts to explore the new perspective as follows.

5.1 Complementarity Between Macro and Micro Worlds

First, to get an intuitive image about the relationship between macro and micro worlds, it is a good idea to sketch out the actual measuring processes for macro and micro objects. Let us suppose that we want to take a picture of a table or some macro object to record the shape. Here we need not only a camera with a film, but also plenty of photons, which are transmitted from table to the film in the camera. However, we usually do not worry if the photons disturb the table so that the picture is blurred. This is because we can neglect the extremely small action of the photons of visible light compared with the movement of the table as a whole. Thus we can get the same objective picture of the table, i.e., the same (macroscopic) image under the same conditions, no matter who takes the pictures, no matter when or where. Replacing the camera by our eyes and making many observations, we can obtain more or less an objective image of the outer world. We are now able to understand that our concepts of the objective reality of the macro world, independent of our consciousness, and also the objective laws of its behaviors, have been obtained through the very existence of micro objects (photons of visible light in the above case), although we are not usually aware of them. Under these circumstances, it is no wonder that we have no measurement problem in classical physics, except the technical one.

So what happens when we want to measure a micro object? We have the famous *gedanken* experiment of an electron’s position and momentum measurement using “Heisenberg’s γ-ray microscope” [10] — this was the staring point of the uncertainty principle. For example, at the instant when the position is determined (therefor at the instant when the photon is scattered by the electron), the electron undergoes a discontinuous change in momentum. Considering that a state of a particle is specified by a pair of values of the position and the momentum at the same time in classical physics, this experiment shows that state of the electron cannot be determined in classical meaning. Moreover in general, a micro object is discontinuously disturbed by a measurement and then we cannot predict the value of any physical quantity of a micro object in a single measurement (strictly speaking, except when the state of the object is in one of the eigenstates of the measured quantity). Quantum mechanics tells us that we can expect no more than the probability of finding a value when we bring in a macro measuring instrument. This probability can be calculated by using the state vector Ψ just before the measurement (detection). Between measurements, Ψ itself develops according to the Schroedinger equation in the Hilbert space constituted by the macro environment. Thus micro objects are to be described only with the framework of macro objects.

Combining these two kinds of measuring processes and of behaviors of macro and micro objects, we arrive at a very interesting insight: the classical idea of physical reality of a macro object was actually obtained only thanks to the existence of micro object, while our description of the behavior of a micro object is ultimately only possible within the scheme of macro objects. In other words, we may conclude that macro and micro objects are epistemologically complementary. They need to be inseparably bound up with each other for us to recognize them. That is, both classical and quantum physics join up to form one complete whole. In this meaning too, the modern science revolution is not yet finished and the latter half is left behind [11].

On the other hand, we understand that quantum theory is more universal including the classical physics. Because all macro objects are composed of (a huge number of) micro objects and their classical behaviors are ultimately driven from quantum mechanics, with the disappearance of quantum coherence by random thermal motion, the correspondence principle and the physical theory of measurement. Then we get Fig. 2 as an image based on the legend of "Sun Wo Kong" in China [12], in which all the universe is said to be in the Buddha's palm. In the figure the macro and micro worlds are epistemologically conditioned by each other, and they are contained in the palm of "Ψ". We cannot escape from our position in nature from where we have to measure the outer world. Thus for example, the smaller a micro object we try to investigate experimentally, the bigger the accelerator we need, because of the uncertainty principle of quantum mechanics. We now live in a period where we have to select which kind of, and which field of, technology should be developed with our limited resources.

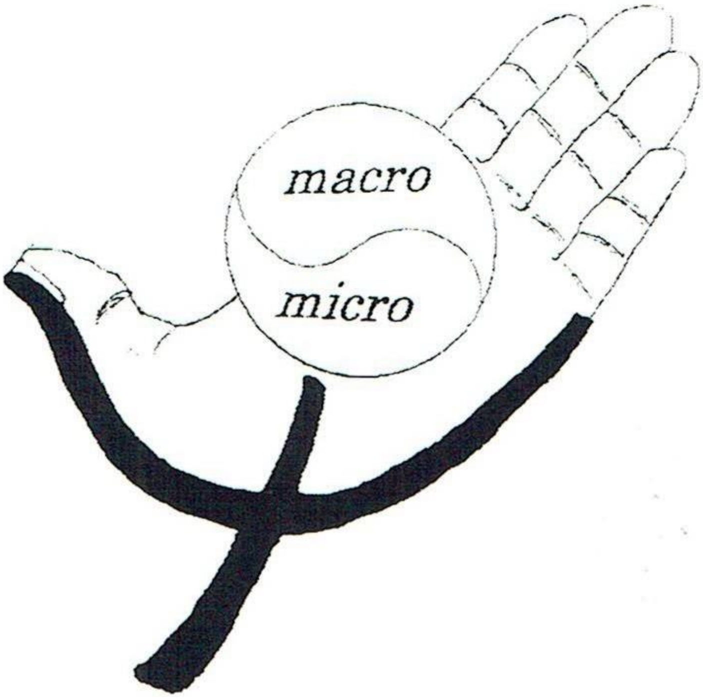

Fig. 2 Epistemological complementarity between the macro- and micro-worlds in the Palm of "Ψ".

5.2 "Ψ" and the Physical Reality in Quantum Theory

Various attitudes toward physical reality in quantum mechanics branch to many groups of different interpretations of quantum mechanics [9]. Roughly speaking, one of the most serious conflict was brought about between Bohr and Einstein. Their debate never came to a settlement for the rest of their lives. Einstein's well-known saying "God doesn't play dice" is against the so-called Copenhagen interpretation. In 1949, looking back upon his hard debate with Einstein, Bohr said [13]:

> ...from the very beginning the main point under debate has been the attitude to take to the departures from customary principles of natural philosophy characteristic of the novel developments of physics initiated in the first year of this century by Planck's discovery of the universal quantum action.

Here, "customary principles of natural philosophy" corresponds to the old perspective.

This viewpoint rests on the classical idea of physical reality (classical realism), the main postulates of which can be said as follows:

[R1] There exist physical objects independent of our consciousness.

[R2] Their behaviors can be described independently of our measurement of them (whether we measure them or not).

[R3] All interactions between them including interactions with measuring instruments satisfy locality (local interaction).

Thus the world that is composed of these physical objects is considered to exist objectively, i.e., independently of human beings. And the total architecture of classical physics is built on the laws that explain the behaviors of physical objects existing objectively and independently of our measurements. In this framework Einstein and others criticized the quantum mechanical description for not being complete [7].

Now, is there any physical reality in the world of quantum mechanics (quantum world)? If there be so, how is it different from classical realism? In 2000, C. A. Fuchs and A. Peres published an opinion "Quantum Theory Needs No Interpretation", against the rush of articles in *Physics Today* promoting various interpretations of quantum mechanics. They said [14]

> Quantum theory does not describe physical reality, What it does is provide an algorithm for computing probabilities for the macro events ("detector clicks") that are the consequences of our experimental interventions. This strict definition of the scope of quantum theory is the only interpretation ever needed, whether by experimenters or theorists...

On the other hand, there appeared many theories with hidden variables with desire to revive the classical realism. Then a famous inequality (Bell Inequality) to be able to experimentally check them was proposed by S. Bell [15]. After a series of the papers and experiments, the conclusion is that quantum mechanics contradicts the hidden variable theories with classical realism in a certain range, and the experiments are rather consistent with quantum mechanics [16, 17].

Then, what should we do? Must we abandon the concept "physical reality" itself, as said above by Fucks and Peres? Namely, should we exclude the idea that the world is made up of objects whose existence is independent of human consciousness? If so, this seems tantamount to saying that we should also abandon science itself, which we have assiduously built up and confirmed on the idea of physical reality.

Returning to the postulates of classical realism, we find that [R1] can be saved by the very physical theory of measurement as described above. [R2] is generally not true in the micro objects, and more detailed investigation shows that [R3] needs to be modified in quantum world, because the non-local effects seems to appear only at the reduction of the state vector [16].

Therefore you could say that we have arrived at a kind of non-local realism, where the non-locality comes from the structure of the state vector "Ψ" itself in the Hilbert space. That is, using the coordinate representation, the state Ψ for one particle system becomes $\Psi(\mathbf{x})$ which behaves like a wave function extended over our 3-dimentional space, and $|\Psi(\mathbf{x})|^2$ corresponds the probability of finding the particle at the point $\mathbf{x}$. But this extended wave collapses at the moment when it is founded at some point $\mathbf{x}'$ (the reduction of the state), and the wave seems to suddenly converges on $\mathbf{x}'$. Is this incompatible with the special theory of relativity? But you need not necessarily draw such a picture. Because Ψ is still vector in the Hilbert space which is constructed by the supposed measurement and then disappears at the same time of the reduction.

However you may suspect if the effect of measurement at **x** can really reach to wide area of **x’** where $\Psi(\mathbf{x'}) \neq 0$ or not. Actually the discussion of Bell inequality is about the correlation between the measured values of the two-particle system which is enough separated to be able to neglect the two particle’s interaction (though they were correlated in the past). Such correlated state of two or more objects is said entanglement, very unlikely in classical physics and our usual sense. For example, suppose that the two-particle system is a singlet state composed of two electrons with spin up and down. Quantum mechanics says that if one of the electrons is found spin up, then the other spin must be down at the same time and vice versa, even if the distance between them are enough long each other to break the special theory of relativity — but this kind of non-locality (superluminal communication) seems not to be available, because of the passive character of the measurement [16].

All these lead us to the conclusion that the state vector Ψ in the Hilbert space is still considered to represent some sort of quantum mechanical reality, because the state Ψ takes on a mission of the identity of the system. But the meaning of identity itself is noticed to be essentially different from classical physics. Ψ should be considered for the whole system where the whole is more than the sum of the parts — e.g., entanglement state of the two electrons described above — while the whole is the sum of the parts in the old perspective of classical physics. Ψ also is not real existence in our actual space-time, but behaves like something intermediate, potential or virtual so that Ψ can have many non-classical and non-mechanical features such as superposition, entanglement, non-locality, indistinguishability of identical particles, tunnel effect, etc.

5.3 Quantum Probability and the Environment

Probability phenomena are familiar in our macro world such as the probability of a dice coming up 1, the probability of rain tomorrow, etc. These probabilities are considered to come from our insufficient knowledge. Namely, if we know more informations, then we can guess more precisely and approach 100% reliable prediction. Therefore these probabilities correspond to the degrees of the amount of our knowledge.

However, quantum probability is essentially different from these familiar ones. Quantum probability may be said finding probability, while usual (classical) one is existence probability. I explain this more concretely by the measurement of electoron’s spin shown in Fig. 1.

For convenience, we write $\Psi_+ = c_+\varphi_+, \Psi_- = c_-\varphi_-$ where φ_+ and φ_- are complete set of orthonormal eigen vector corresponding to spin up and down respectively. Now suppose that $t = t_1$ is the time just after preparation, and $t = t_2$ is the time just after the detection. Then $\Psi(t_1) = \Psi_+(t_1) + \Psi_-(t_1)$, e.g., the spin direction at $t = t_1$ is perpendicular to this sheet if $|c_+| = |c_-| = 1/\sqrt{2}$. The time development of Ψ is

$\Psi(t_1) = \Psi_+(t_1) + \Psi_-(t_1) = c_+\Phi_+(t_1) + c_-\Phi_-(t_1) \rightarrow$ (Schroedinger time development)

➡ detection by D_+ and D_- at t_2: $\varphi_+(t_2)$ or $\varphi_-(t_2)$.

If we read the result at t_3, then at time t $(t_2 < t < t_3)$ the state is φ_+ or φ_- with probability $|c_+|^2$ or $|c_-|^2$ respectively. In this time interval $(t_2 < t < t_3)$, just the classical probability (existence probability) is realized.

The typical feature of quantum mechanics is given in the time $t_1 < t < t_2$, where the probabilities $|c_+|^2$ or $|c_-|^2$ are finding probability which will appear only if we bring in the detector, because if we set another apparatus instead of the detector (D_+ and D_-) we can recombine Φ_+ and Φ_- resulting in the revival of the interference term. In any way, we can simply draw neither orbit nor wave for the behavior of the electron in $t_1 < t < t_2$. The dotted lines in Fig. 1 shows only imaginary (impossible) overlapping of the two classical orbits obtained by the movements of the two electrons with spin up and down respectively from the first time t_1.

By the way, you should not misunderstand that the reduction of the state is necessarily followed by some thermal irreversible process. For example, if you remove one of the detectors (say D_+) in Fig. 1 and you find no change of D_-, then you get φ_+, i.e., the reduction of the state happens (negative result measurement) and actually these processes are used for the preparation of a system.

Now, Takabayashi took note of the fact that in general, detectors are inevitably coupled with the "outside world (environment)" as an open system. He considered the measurement in a broad sense where the couple between a system and its environment is secondary, so that the reduction of the state takes limited time and the system irreversibly dissipates. The probability rule of quantum mechanics can be interpreted to come from just this dissipation.

In actual situation, there are many cases hard to divide the degrees of freedom of the detector from the degrees of freedom of the outside world. As the outside world is for us not to be able to accurately control and reproduce, the state of the system plus instrument becomes more incoherent because of the dissipation of the information to the outside world, and the probability rule of quantum mechanics seems to be concerned with very this stage.

In any case, we cannot so precisely arrange the total system of "the outside world" or "the outside world + the instrument" as to describe the state vectors of them. Instead of them, we use the state vector Ψ of the system, meaning that we have to accept the probabilistic phenomena in compensation for using words about only the system. Of course, we know there is no complete "vacuum" as the outside world, e.g., there always exist interactions between an atom and the electromagnetic field, whether any real photon exists or not in the field which has enormous number of freedom. Thus cosmic rays in the atmosphere go through the physical measurement in a broad sense and make showers, so that we can investigate them with the concept of usual classical probability.

Furthermore, the fixity of DNA molecule or protein also are regarded as a result of continuous measurements by the surrounding environment in a broad sense. The nature itself measures and reads the results so that they can have appropriate 3-dimensional structure, and an accumulation of such "measurements" may condition the birth of life. In fact, unless the micro world is primarily ruled by quantum mechanics, any system cannot have classical aspects in the sense of effect as well as quantum mechanical aspects, and also life would not have appeared.

6. Concluding Remarks

One of the best contributions to our world by the West must be the rise of the scientific revolution in 17th century, because science is just universal knowledge of all humanity and enable us to see into the future of the world.

However now, as seen in today's chaotic situation of technology which comes from the mismatch between the new technology based on quantum mechanics (laws in the micro world) and the old perspective (mechanistic viewpoint in the macro world), a kind of collapse of intelligence seems to begin. The only thing we can and must do to basically get out of this situation, seems to be no choice but to enter by the narrow gate. The outline is as follows:

1) To solve the measurement problem of quantum mechanics so that we can get a new perspective of unifying the micro and macro worlds. I think the approach of "the physical theory of measurement" proposed by T. Takabayashi (see 4) is the best one so far.

2) To get an intuitive image of a new perspective based on quantum theory, it is important to know that there is an epistemological complementarity between the laws of macro and micro worlds (see 5-1) showing a consistent wholeness of understanding the lows of nature. We are always contained in the palm of "Ψ",

however far out science and technology may develop (see Fig. 2).

3) We must reflect today's usage of the new technology under the old perspective, i.e., the mechanistic and reductionistic view point. A critical field is nuclear development which is intervention in the super micro world — the size of a nucleus is about 10^{-5} of an atom. For about 4 billion years, earth ecosystem has not coexisted with nuclear reactions, which main activity stages are inside stars with no life, while we have coexisted only with chemical reactions.

We made the atomic bombs only because of the simple mechanistic reason of the huge destruction force under the pressure of WWII, and we never knew the radioactivity problem at that time. Now the radioactive contamination has been progressing over the world, which is the very quantum mechanical phenomena, and can basically uncontrollably attack DNA of any exposed organism with no sense of prevention.

4) Another prominent area is biotechnology, because as mentioned above, life appeared on the base of quantum world and the essence of life cannot be mechanistically understood. Thus the mechanistic approach to life — e.g., so-called "cutting and pasting" of DNA under neglecting the evolutionary tree of Life — may be partially and shortsightedly effective, but the influence on the wider space-time environment and later generations, is not necessarily good and is possible to destroy the order of life on the earth. This is just a human experimentation as far as we are concerned with them under the old perspective, which goal no one knows.

5) To build a new world view, it is necessary to experimentally and theoretically develop new field of quantum mechanics for enriching the image of the quantum world — recently there has been interesting progress in quantum biology [18, 19].

Furthermore, as we acquire the new world view, it would be easier to solve the today's environment issues, because quantum theory fundamentally has affinity with the environment (see 5-3), while the old mechanistic viewpoint tends to accelerate the environmental destruction under market pressures.

References

[1] K. Schwab, *The Fourth Industrial Revolution*, (World Economic Forum) 2016.

[2] R. P. Feynman, *Internat. J. Theoret. Phys*. 21 (1982) 47.

[3] J. von Neumann, *Mathematische Grundlagen der Quantenmechanik*, Springer.

[4] R. T. Beyer (Trans.), *Mathematical Foundations of Quantum Mechanics*, Prinston Univ. Press, 1955.

[5] J. Schroedinger, *Die Nturwissenchaften*, Bd. 2, 1935, pp. 807, 823, 844.

[6] P. A. M. Dirac, *The principles of Quantum Mechanics*, Oxford, 1935.

[7] J. S. Bell, *Phys. World* (August 1990) 33.

[8] A. Einstein, B. Podolsky and N. Rosen, *Phys. Rev.* 47 (1935) 777

[9] S. Tomonaga, *Quantum Mechanics*, Vol. II, Misuzu shobo, Tokyo, 1952, p. 337. (in Japanese)

[10] T. Takabayashi, *Quantum Mechanics — Measurement and interpretation problem*, (editor: K.Yasue), Kaimeisha, Tokyo, 2001. (in Japanese)

[11] W. Heisenberg, *Zeitschrift fur Physik* 43 (1927) 172-198.

[12] K. Awaya, *The Journal of Yokkaichi Univ.* 32 (1) (2019) 21-40; 32 (2) (2020) 81-97; 33 (1) (2020) 51-75; 34 (1) (2021) 29-40. (in Japanese)

[13] K. Awaya, *Physics Essays* 18 (3) (2005) 390.

[14] N. Bohr, *Albert Einstein: Philosopher-Scientist*, edited by P. A. Schipp, Library of Living Aphilosophere, Evanston, IL, 1949, p. 201.

[15] C. A. Fuchs and A. Peres, *Phys. Today* (March 2000) 70.

[16] J. S. Bell, *Physics* 1 (3) (1964) 195-200.

[17] K. Awaya, *Soryusiron Kenkyu* (Kyoto) 85 (6) (1992) 433. (in Japanese)

[18] I. Tutui, *JPSJ* 69 (12) (2014) 836-844. (in Japanese)

[19] J. McFadden, *Quantum Evolution*, Harper Collins Publishers, 2000.

[20] J. Al-Khalili and J. McFadden, *Life on the Edge: The Coming of Age of Quantum Biology*, Crown, 2015.